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Coal transition in
India

Assessing India's energy transition options

2018

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Climate Strategies

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Executive summary

Coal meets 30% of the world's energy needs and generates 41.1% of world's electricity (WCA, 2016). India is currently the third largest power producer using coal and third largest coal importer in the world. The Indian population is characterized by low levels of consumption of modern energy (880 KWh/capita/year) by international standards. Nevertheless sustaining one of the fastest GDP growth rates in the world currently at above 7% per annum, India is well on track to meeting and may be surpassing its NDC Paris commitments for 33-35% reduction in GHG intensity of its GDP during 2005-2030 (around 25% reduction done during 2005-2014) and 40% share of non-fossil electricity capacity by 2030 (around 30% by 2017 already). Coal, however is projected to remain the mainstay of Indian energy systems at least until 2030.

Global energy markets are experiencing a shift away from coal as a result of international agreements, national climate policies, increasing regulatory and political constraints on coal, and competitive pricing in alternative fuels. However coal transitions especially in coal dependent economy like India will be challenging, mainly due to energy security concerns and national targets (which are aligned with SDGs) on universal electricity access, housing, health, and education by 2022. Near-term transitions away from coal therefore seem difficult. However we analyse alternative decarbonization pathways and explore their impacts on energy systems, and subsequently the coal sector. Bottom-up techno-economic model, AIM/Enduse is used to conduct sectoral analysis to assess the carbon dioxide emissions, energy mix across various sectors and coal consumption under NDC and 2°C scenarios (2°C_conventional and 2°C_sustainable). Our analysis provides insights on revising the Indian NDCs to possibly raise their overall ambition levels.

The report addresses key debates on a) the future of coal in Indian energy systems, b) its influences on international coal trade, c) possibility of resultant stranded assets, and d) impact of critical natural resource such as water on coal-related assets.

Future of Coal in India and International Trade

The report derives key insights on coal demand till 2050 that need to be taken into consideration for future policies in coal, and dependent end-use sectors in the coming decade. In addition to NDCs, deep decarbonization of the economy needs to emphasize more on (according to selected pathway):

- For both 2°C scenarios
  - Increased energy efficiency in energy supply (power sector) and demand sectors (industry, transport, building and agriculture)
  - Enhanced deployments of renewables – 175 GW solar by 2030 from 70 GW (2018)
  - Demand reduction in the end-use sectors through dematerialization, recycling, reuse and changed behaviour
- For 2°C_conventional scenarios
  - Deployment of Carbon dioxide Capture Utilization and Storage (CCUS) by 2050 vis-à-vis INDC in power and industry sectors (cumulative emission reduction of 6 Gt by 2050)
- For 2°C_sustainable scenarios
  - Increase in gas power generation capacity from 24 GW in 2018 to 105 GW by 2030
  - Increase in nuclear power generation capacity from 7 GW in 2018 to 30 GW by 2030 and 50 GW by 2050
  - CCS required in industry sector (cumulative emission reduction of 2 Gt by 2050)

With limited domestic reserves of coking coal and other conventional fuels such as oil and gas in addition to resource constraints (such as water, land) and local pollution, the coal and associated businesses/infrastructure lock-ins are and will be facing challenges in the coming decades.

Implementing 2°C-compatible coal transition scenarios will require synchronised stringent actions which include: maximising the efficiency of the existing coal fleet (especially by retiring old inefficient plants and increasing the national average PLF and PAF); scaling up new and alternative fuels (renewables and storage, nuclear, gas); reducing end-use energy demands; developing a coherent strategy for the future energy systems to manage risks and avoid stranded assets; and boosting innovation and commercialisation of CCUS. **Table A** lists the possibility of revising NDC targets by raising the current GHG emission reduction targets.

Table A. Revised NDC targets

	Action Area	NDC Current targets (2005-2030)	Proposed revisions	2°C_conventional Proposed 2005-2030 revisions	2°C_sustainable Proposed 2005-2030 revisions
I	Emission Intensity to GDP	33-35%*	40-43%	45-48%	42-45%
II	Renewables - Generation Capacity	40%*	42%	40%	48%
A	MITIGATION STRATEGIES				
1	Clean Coal Policies				
a	Retiring Old inefficient power plants (GW)	25**	25	30	40
b	Add Supercritical generation (GW)	40**	40	45	60
c	Natural Gas (GW)	Not mentioned	105	135	250
d	Renewables (GW)	175*	175	150	210
e	Storage with Solar and Wind (GW)	Not mentioned	25	25	60
f	Hydro Power (GW)	Not mentioned	52	52	56
g	Nuclear Power (GW), 2030	Not mentioned	10	10	16
	Nuclear Power (GW), 2050	Not mentioned	40	30	50
h	CCUS (GW)	Not mentioned	0	200	0
2	Sectoral - Enhancing Energy Efficiency policies				
a	Industry – Decrease in Specific Energy Consumption	4-5%	4-5%	6-7%	6-7%
b	Standards and Labelling	Mandatory for 10 appliances	Mandatory for 10 appliances	Mandatory for 21 appliances	Mandatory for 21 appliances
c	Transportation – Biofuel blending Policy	5%	5%	10%	20%
B	ADAPTATION STRATEGIES				
3	Water Use Efficiency				
A	WUE in Agriculture	<20%*	20%	30%	30-35%
B	Water per unit of Power	>4m^3/MWh	4 m^3/MWh	<2 m^3/MWh	2 m^3/MWh
C	CLIMATE FINANCE POLICIES				
4	Coal Cess (INR/Ton)	200*	200	400	800
5	Reduction in fuel subsidies	Same as in current NDC	Same as in current NDC	Same as in current NDC	Same as in current NDC

*Note: * INDC 2015, ** CEA, 2017; GoI 2017a*

International Trade

On international coal trade, even if the central government retains the suggested zero-import policy for thermal coal, India will still need at least 50 Mt of steam coal imports due to demand from its import-based power plants. **Table B** presents the estimated coal production and imports under 2 C scenarios. Due to complete phase down of coal in power sector, the overall demand of steam coal reduces by 8% in 2°C_conventional and by 59% in 2°C_sustainable scenario over INDC scenario.

Stranded Assets

This report categorizes the types of stranded assets in both coal reserves and coal based power plants. Roughly one can say that nearly 220 billion tonnes of coal will remain unutilized in Indian coal mines with a notional value of roughly USD 6.7 trillion, if we take average price of coal at Rs. 2000 per tonne (~30 USD/t).

Around 222 GW out of 367 GW of total installed generation capacity is coal based as on July 31, 2018 (MoP, 2018). On the other hand, coal-based power plants closed or declared non-functional due to their

Table B. Estimated coal production and import estimates

2°C_conventional scenario

	Production		Imports	
Year	Coking*	Non-coking** (Steam coal)	Coking**	Non-coking* (Steam coal)
2020	18	684-734	62	50-100
2030	20	584-634	74	50-100
2040	23	770-820	71	50-100
2050	25	771-821	97	50-100

2°C_sustainable scenario

	Production		Imports	
Year	Coking*	Non-coking** (Steam coal)	Coking**	Non-coking* (Steam coal)
2020	18	673-723	62	50-100
2030	20	709-759	74	50-100
2040	23	376-426 #	72	0
2050	25	365-415 #	80	0

Note:
**Assumed numbers, **Estimated numbers,*

 # Domestic producers may try maintaining the current higher production levels, but export markets would be difficult to find due to climate change pressure globally on coal phase out and domestic coal demand is projected to go down in this scenario.

inefficiency and pollution amounted to 18.5 GW in 2013–2014, 23 GW in 2014–2015, 26.8 GW in 2015–2016, and 30.5 GW in 2016–2017) (MoP 2017). There are plans to shut down about 37 GW of antiquated, heavily polluting subcritical coal plants in the near future (Singh, 2016).

Since 2006, India has added 151 GW of new coal power, with about 75 percent of this capacity being subcritical (Shearer et al. 2017). These plants could be vulnerable to techno-economic-regulatory shocks due to possible coal phase down, as they are not fully depreciated and have considerable technical life remaining. The present value of these assets is around USD 100 billion. The report also discusses the possible increase of stranded assets according to selected alternative 2°C stabilization pathways in addition to physical (coal and water availability, pollution) constraints and dynamics of national and international markets.

An important facet that has not been touched upon in the current report but will play an important role is studying impacts of coal transitions at social, political and economic levels and subsequently preparing all stakeholders for a softer landing.

Impact of water resources on coal-based power plants

With growing population, urbanization, and industrialization, the demand of water will increase substantially in future. The limited supply in the availability and accessibility of fresh water at local levels, will lead to widening of the demand-supply gap across major end-use sectors in future. There has been an observed growth in competition and conflict between agriculture, which consumes around 70% of water in India, and industry especially power generation for fresh water. Power plants in likely water scarce regions are projected to face acute water challenges due to varying and uncertain weather across India that is increasingly being observed (**Table C**).

One GW of power plant shut down for a day, faces a loss of approximately INR 4-10 Crores (USD 0.6-1.5 million) in revenue (IIMA 2018, Greenpeace 2017). Our report presents methodology adopted for analysis, and discusses impact of water on a few large coal based power plants.

Table C. Generation losses – Power plant shut down due to water scarcity during 2013 -2017

Year	Number of Units	Loss of generation in Million Units*
2013-14	16	5253
2014-15	9	1258
2015-16	15	4989
April 2016 to Feb 2017	21	5870

Source: GoI (2018d)

1. Introduction

India is currently the second largest coal consumer after China, third largest power producer, third largest importer of coal and fourth largest consumer of electricity in the world; however it still has low per capita power consumption by international standards (IEA 2017). With approximately 239 million people (nearly 20% of population) still without access to electricity and given its growing population size and economic activity, India will consume more energy in coming decades to address myriad of development challenges in addition to its rising urbanization and industrialization (MoP 2017, NEP 2017). Coal remains the mainstay of Indian energy systems providing for 70% of its power generation, using more than 75% of its final energy consumption and emitting 65% of CO_2 emissions (CEA 2017). Therefore, it is currently beneficial for India because it provides: 1) Energy security—coal reserves are abundant and is the cheapest source of energy, 2) Jobs - Ten Million plus people depend on coal and associated businesses, and 3) Royalties—most of the central and eastern region states get their revenue from coal mining. Nevertheless, increased coal consumption also brings in negative production externalities such as greenhouse gas emissions and local air pollution, in addition to managing ash.

As a signatory to the Paris Climate Change Agreement (PCCA), India needs to shift to cleaner, renewable forms of energy in order to move towards a 2°C and well below 2°C world. An important aspect of this transition needs to involve reduction of coal demand across various sectors through numerous policy measures. These actions when implemented will have implications not only in the coal sector but also in the entire coal supply chain (mining, transportation, distribution, use and disposal). India has 367 GW of installed capacity, generated 1,201 billion units (BU) of electricity (power), 83% of which comes from conventional source of energy as on March 2018 (including utility and non-utility production). The installed capacity of coal power plants is 222 GW consuming 546 million tonnes (Mt) of coal. Renewable energy constituted of 69 GW of capacity generating 94 BU of electricity. The transmission and distribution (T&D) losses were at 22.77% and aggregate technical and commercial losses (AT&C) losses were at 24.62% as on 2015 (CEA 2018). India has one of the most ambitious renewable energy targets due to its commitment to Paris Climate Change Agreement (PCCA) through nationally determined contributions (NDC). It has ramped up the renewable capacity target to 175 GW of power generating capacity from 75 GW, which will increase its non-fossil fuel share to about (or more than) 40% of its installed capacity (equivalent to 26-30% generation) by 2030. Coal demand in industry such as iron and steel and cement will increase due to the rising demand in building stock. Most (~80%) of the thermal coal is produced domestically, with annual production of hard coal of around 659 Mt and lignite of around 35 Mt per year. Given the large gap between alternative fuel capacities and power demand, coal is projected to remain one of the main sources of energy due to its diverse geographical distribution, abundant availability, matured industrial base and improved technical competence (Garg *et al.,* 2017a; Vishwanathan *et al.,* 2017; IEA, 2017).

There is an observed slowing down in coal development recently due to cancellation of ultra-mega power projects (UMPP) and other power plants. As of January 2018, while 88 GW are in pipeline, 43 GW undergoing construction; about 484 GW of power plants have been cancelled and 82 GW of plants have been shelved (CoalSwarm 2018). Additionally, there is growing number of temporary shut downs due to water availability and local pollution. With decrease in anticipated demand, there has been a more than 10% decrease in coal imports for state-owned power plants (CEA, 2017; ET, 2017). The climate policies (INDC) have led to initiation of coal transitions in order to meet energy conservation (through energy efficiency) and renewable targets in the medium and long terms. Unlike the developed and transition economies, non-climate policies pertaining to efficient use of resources and local pollution are leading this transition dynamics. For example, the central government has mandated water consumption in once-through cooling systems to be within 4 litres/kWh[1] while, the consumption in newly installed pow-

1 This is equivalent to 4 cubic metres per Mega Watt-hour (m^3/MWh).

er plants should be 2 litres/kWh from January 1, 2017 (GoI, 2018d). Similarly, power plants and industries have been notified to install flue-gas desulfurization by December 31, 2020 (GoI, 2018c). This is in addition to installation of only super critical technology for all new coal based power plants; clean energy cess on coal, lignite and peat goods—since 2010; complete utilization of fly ash through fly ash management (FAM) since 1994, and reducing AT&C losses to 15% by 2022 from current around 22% (INDC 2015).

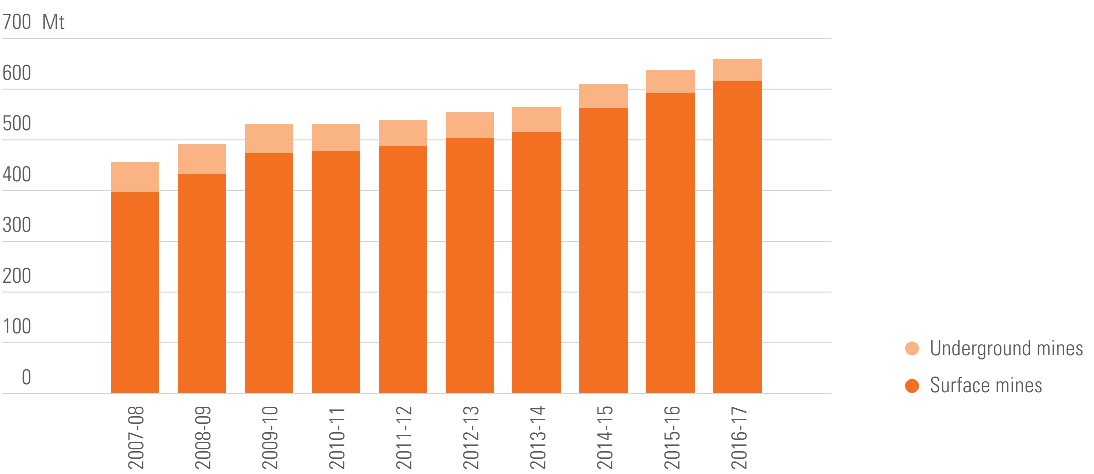
This report focuses on the national context of the coal sector and details transition pathways consistent with both national circumstances and different levels of collective climate ambition (NDC, 2°C_conventional scenario and 2°C_sustainable scenario). Section 2 presents the national context of the coal sector, from both an energy and socio-economic perspective. Section 3 proposes detailed transition pathways consistent with both national circumstances and different levels of collective climate ambition (NDC, 2°C); and discussing policy insights regarding the enabling conditions, challenges and opportunities. Section 4 discusses water-energy case study focussing on the impact of water on coal power plants in India.

2. Coal in the national context

2.1. Role of coal in the national energy system

In 2017, India contributed to around 8% of total coal production in the world. Globally, it has the third largest proved reserves which consists of anthracite, bituminous coal (92.6%), sub-bituminous and lignite (7.4 %) variety (WEC, 2017). The coal mining sector observed a growth rate of 3.7% with the number of coal producing mines increasing in 2017 over the past year, which is mainly confined to eastern and southern central parts of the country. Coal deposits occur mostly in thick seams and at shallow depths with 93% extracted from surface mines (up to a 300m depth) and remaining from underground mines as presented in **Figure 1**. Geological resources of coal in India as on April 1st, 2017 is estimated to be around 315 billion tonnes (Bt). This constitutes of coking coal (prime, medium and semi-coking) at 35 Bt and non-coking coal at 280 Bt (**Table 1**). Jharkhand (26.2%), Orissa (24.5%), Chhattisgarh (18%), West Bengal (10%), Madhya Pradesh (8.8%), Telangana (6.8%)

Figure 1. Trend in Coal production by mine type as of April 1st, 2017



Source: MoC. 2017

Table 1. Coal reserves by type as on April 1st, 2017

Type of Coal	Reserve (Quantity in Billion Tonnes)			
	Proved	Indicated	Inferred	Total
Prime Coking	4.6	0.7	0.0	5.3
Medium Coking	13.5	12.1	1.9	27.5
Blendable / Semi Coking	0.5	1.0	0.2	1.7
Non Coking (Including High Sulphur)	124.4	125.5	30.7	280.6
Total	143.1	139.3	32.8	315.1

Source: MoC. 2017

and Maharashtra (4%) account for 98% of the total reserves (GSI, 2017).

Total coal production during the year 2016-17 was 683 Mt as compared to 360 Mt during 2000 registering almost twofold increase with a growth rate of 3.7% per year during 2000-2017. Lignite production was 45 Mt in 2017 with growth of 3% over 2016. 91% of total raw coal consisted of non-coking coal. Indian coal is observed to have high ash content (15-45%) and low calorific value. Total coal[2] demand in 2016-17 was estimated to be 885 Mt, while actual supply was 842 Mt (MoC 2017, CD 2016, and CCO 2016). **Table 2** presents sector-wise breakup of actual supply of coal (2012-17) and estimated demand (2016-17). The consumption in electric power[3] sector increased to 527 Mt, while that in final energy consuming sectors (industry, building) was 165 Mt. The total projected additional demand for coal in power sector with enhanced plant load factor (PLF) and additional capacity is around 300 Mt/year resulting in the annual consumption to touch more than a billion tonne within next 3 years (MoC, 2017; Infraline, 2017). More than 90% of the coal is excavated from open cast mines, while more than 80%[4] of the production is done by Coal India Ltd. (CIL). Coal India owns 394 mines, out of which 177 are open cast, 193 are underground and 24 are mixed ones (MOC, 2018).[5] **Table 3** lists the segregation of mines by CIL's subsidiaries. CIL's provisional production in 2016-17 was 639 Mt against a target of 662 Mt and recording a growth rate of 1.9%. Of this underground mining contributed to around 31 Mt. Coal India has set a production target of 739 Mt for 2017-18 from a combination of its active and future projects. The public sector miner has identified 121 major ongoing projects expected to produce 561 Mt in 2020.

2 Coking and non-coking coal.
3 Utilities and captive.

4 Includes open cast and underground mines.
5 According to a disclosure to the BSE in April 2017.

Table 3. Number of Mines by CIL subsidiaries

Company	Open Cast	Underground	Mixed	Total
Western Coalfields Ltd	45	39	2	86
South Eastern Coalfields Ltd	22	63	1	86
Eastern Coalfields Ltd	18	60	8	86
Central Coalfields Ltd	42	21	2	65
Bharat Coking Coalfields Ltd	18	13	17	48
Mahanadi Coalfields Ltd	18	10	0	28
Northern Coalfields Ltd	10	-	0	10
North Eastern Coalfields Ltd	3	1	0	4
CIL	207	176	30	413

Source: CIL 2017

Table 2. Actual Supply (2012-17) and Estimated Demand (2016-17) in Million Tonnes

No	Sector	Actual Supply	Actual Supply	Actual Supply	Actual Supply (Provisional)	Actual Supply (Provisional)	Estimated Demand
		2012-13	2013-14	2014-15	2015-16	2016-17	2016-17
I	Coking Coal						
A	Steel – Domestic	17	15	12	12	12	13
B	Metallurgical coal Import	36	37	44	44	42	44
	Sub Total	*52*	*52*	*56*	*56*	*54*	*57*
II	Non-Coking Coal						
A	Power (Utilities)	457	439	435	446	471	599
B	Power (captive)	55	54	62	62	56	91
C	Cement	22	12	11	9	7	34
D	Sponge iron	21	18	18	8	6	24
E	Other*	108	163	240	252	99	80
	Sub Total	*663*	*687*	*766*	*777*	*639*	*828*
	TOTAL	713	739	822	832	693	885

Source: Coal Controller Organization 2017

*Note: * Other includes fertilizers, pulp and paper, other basic metal, chemicals, textiles and rayon, bricks.*

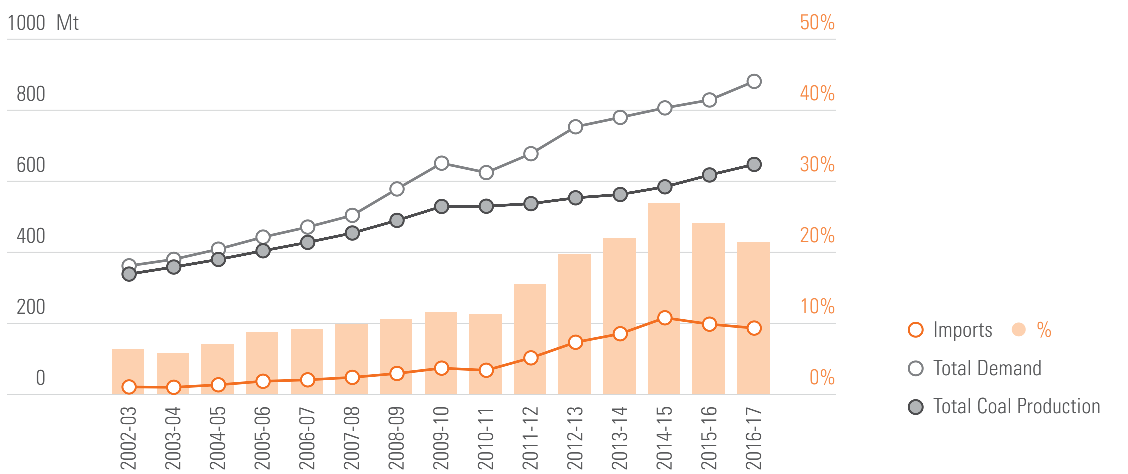
The gap between demand and supply of coal has reduced over the past couple of years, however it cannot be bridged completely due to insufficient domestic availability of coking coal and power plants designed on imported coal will continue to import coal for their production. India had cancelled 204 coal blocks allotted to various end users in 2014 by the order of apex court due to procedural anomalies. The shortfall of planned domestic production resulted in increase of imports. Indian coal and power Minister Mr. Piyush Goyal in 2015, called for zero-coal import policy by 2019. A decline of imports was observed subsequently due to improve in coal quality through third party sampling and increase in coal washeries to improve the quality of Indian coal in the last couple of years (MoP, 2017; CEA, 2017). Imports have fallen from 218 Mt in 2014-15 to 204 Mt. in 2015-16 and further to 191 Mt. in 2016-17. The trend is observed to continue in 2017-18 (PIB 2018). This has resulted in coal quality assurance resulting in substitution of nearly 11 Mt of imported coal by December 2016. Most (~90%) of imports are sourced from Indonesia (48%), South Africa (24%) and Australia (18%) (CCO, 2017). **Figure 2** presents the trend in coal demand, production and import from 2002-2017.

India, as of March 2018, has 367 GW of total power generating capacity with 222 GW of coal, 24 GW of natural gas, total renewable capacity of 121 GW (including 45 GW of large hydro, 6.78 GW of nuclear, 34 GW of wind, 21.65 GW of solar, 8.7 GW of bio-power, and 4.4 GW of small hydro). The shares in power generation from these sources are 78.5% from coal and gas, 3.1% nuclear, 10% hydro and nearly 7.8% from remaining renewable sources (CEA, 2018). The government had provided clearances for installation of additional 178.7 GW of coal based thermal power plants (TPP) in 2012 (CEA, 2017). Although, the coal thermal power plant capacity installation target was 72.3 GW during 2012-17, 91.7 GW have been installed by May 2017, of which ~39.1 GW (39 %) is super-critical technology and is operational and 48 GW is under construction (CEA, 2017; GoI, 2017a). Coal based thermal generation is critical to meet base load in order to achieve central government's 'Power for All' programme by 2019.

In 2017, coal-based generation was estimated to be 945 TWh with PLF of about 59.9% at a CAGR of 6.5% since 2002 (**Figure 3 and 4**). The factors that led to decrease in PLF include increase in coal capacity that has been built to accommodative the load for next decade, in addition to increase in natural gas and renewable share in the energy mix (GoI, 2018c). With rise in future energy demand, CEA estimates the capacity utilization to fall to as low as 48% by 2022 as addition non-thermal electricity generation capacities are installed and become operational (CEA 2017).[6] The National Electricity Plan (NEP) estimates power demand growth of 6.2% and addition of about 46 GW, between 2022 and 2027. The plan forecasts PLF to be reduced to 56.5% in 2022, on account of decommissioning of 22.7 GW by 2022 on account of age and incapability to adhere to environ-

6 https://energy.economictimes.indiatimes.com/news/power/indias-thermal-power-generation-to-reduce-by-half-in-next-five-years/57466112

Figure 2. Coal demand, production and import trend (2002-2017)



mental norms. Subsequently, PLF rises to 60.5% due to phasing out of 25.6 GW of capacity that will complete 25 years by 2027 (NEP 2017).[7]

Figure 5 maps the geographical location of coal based mines and power plants across India. Coal India Limited (CIL) has rationalized linkages for each power plant, providing more coal through fuel supply agreement (FSA). Chhattisgarh (22%), Orissa (21%), Jharkhand (19%), Madhya Pradesh (16%), Telangana (9%), Maharashtra (6%) and West Bengal (4%) accounts for 97% of the total production.

7 https://www.financialexpress.com/industry/national-electricity-plan-under-construction-power-plants-to-become-useful-after-fy22-says-central-electricity-authority/1113195/

India is the third-largest country in volume terms of CO_2 emissions in the world, behind only China and the United States. The CO_2 emissions have increased from 2000 at a rate of 5.4% per year as presented in **Figure 6**. Coal is the largest CO_2 and GHG emitting fuel source in India's energy mix. Hence, India's INDC commitments promote efficient use of coal as a strategy for national energy security and mitigating carbon emission. India's CO_2 emissions can be seen through two lenses. On per-capita basis, emissions are extremely low, however they have increased from 0.85 tCO_2/capita to 1.58 tCO_2/capita. On the other hand, per GDP basis the carbon intensity has decreased from 1.1 Mt CO_2/Billion USD to 0.9 Mt CO_2/Billion

Figure 3. Coal capacity, and generation, Plant load factor in power sector (1990-2017)

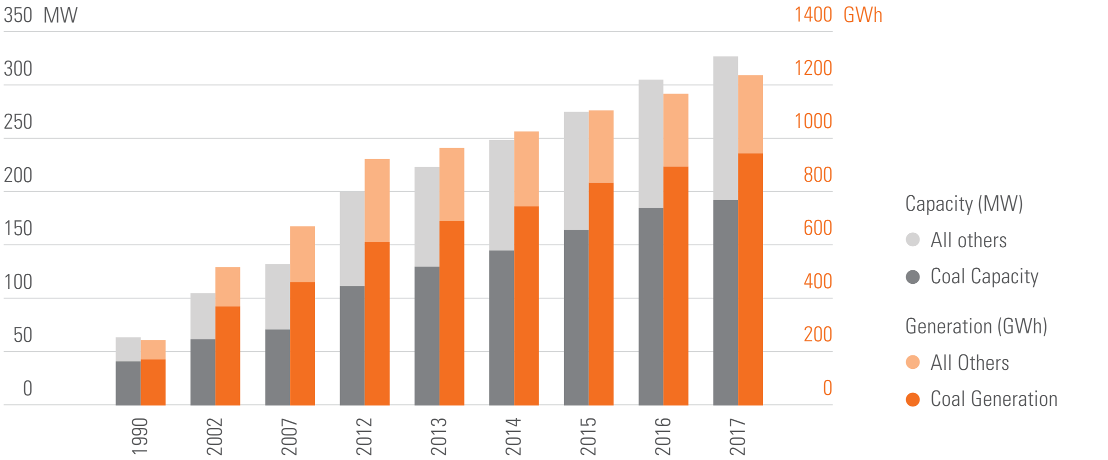
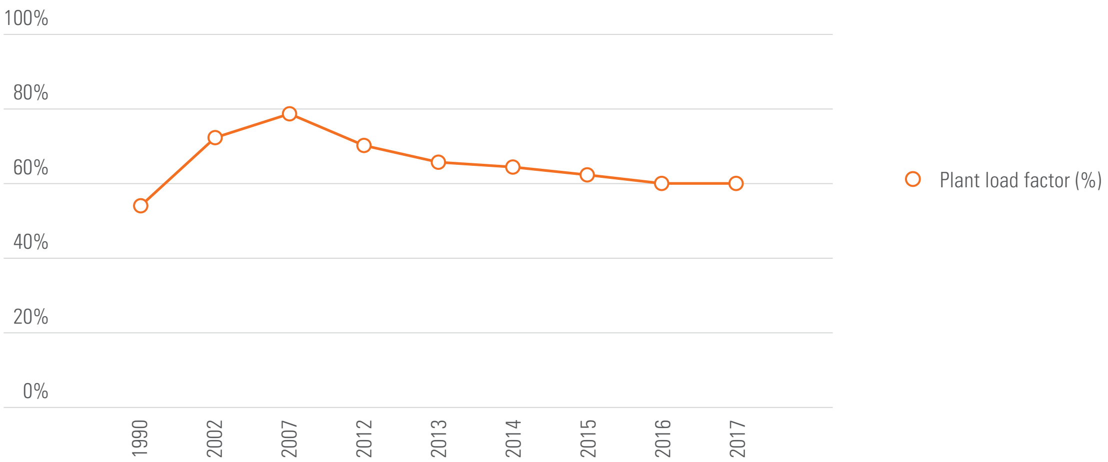


Figure 4. Plant load factor of coal power plants (1990-2017)



USD. The average electricity CO_2 emission factor is estimated at 0.732 kg-CO_2/kWh (including renewables) in the year 2015-16.

2.2 Role of coal in regional economy

With coal production primarily concentrated in the eastern half of the country, there is a geographical mismatch between the location of producers and consumers (**Figure 5**). Coal is the primary source of revenue for the states located in these regions. While there are clusters of power stations near the coal fields, other plants are scattered across the country, located closer to power demand hubs in order to save on the cost of electricity network expansion and to enhance power system relia-

Figure 6. Trend in carbon dioxide emissions in India

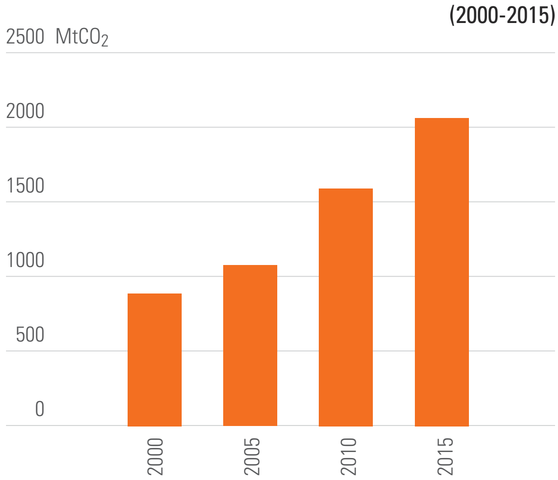
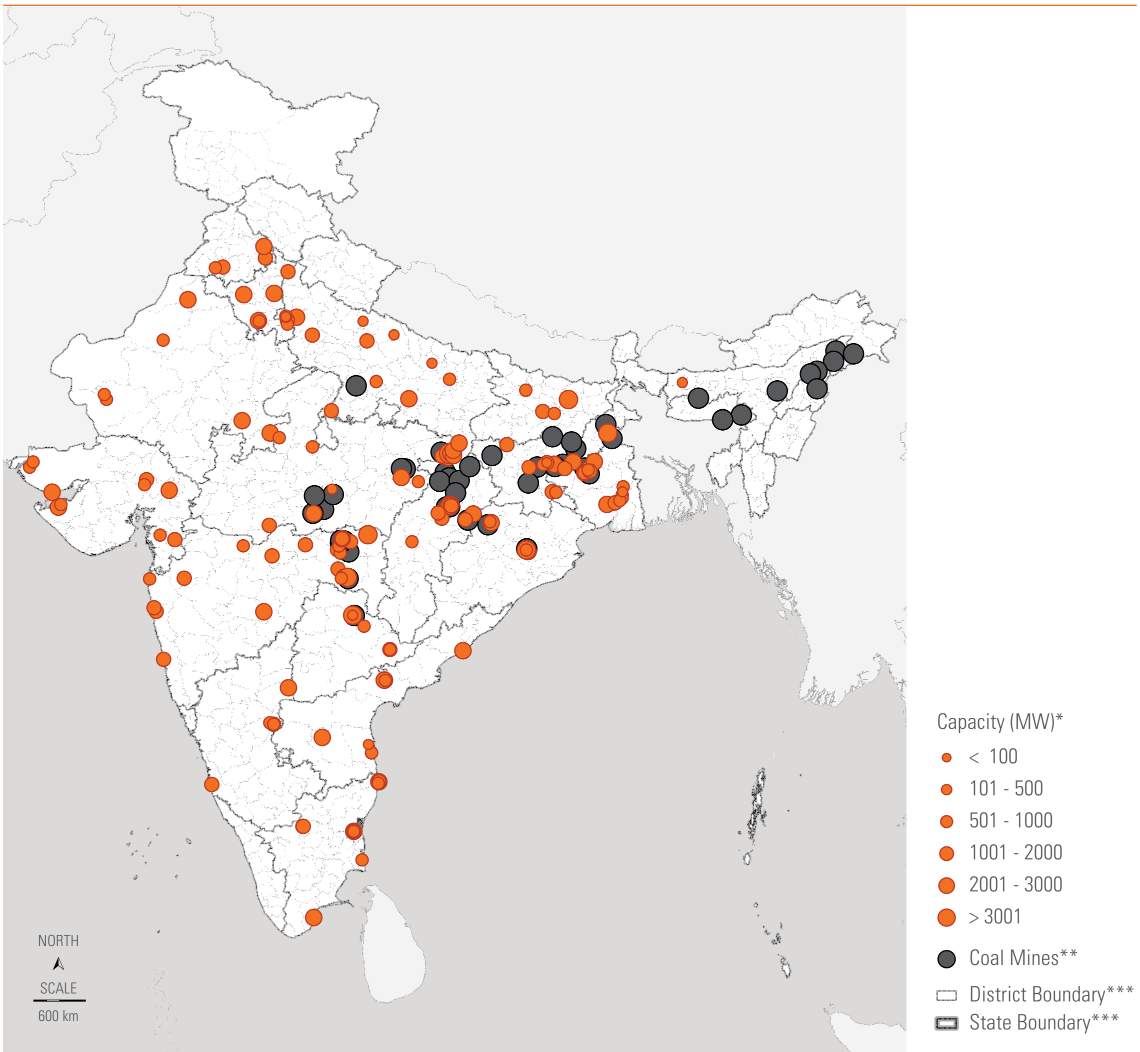


Figure 5. Geographic location – Coal-based power plants and coal mines in India



Source: Adapted from Garg et al. 2015, Central Central Electricity Authority 2011; Government of India ministry of mines Indian bureau of mines (2012)**; National Boundaries as per Gelogical Survey of India**** bility. Moreover, state-level energy policy favours a balanced distribution of power stations across the country. Consequently, large amounts of coal need to be hauled from the mines to the various end-users all over India. Coal freights apparently provide for 40% of the railways revenue (Das 2018). In order to achieve the planned production targets, CIL and SCCL have planned 515 km of railway infrastructure projects. One of the freight-specific rail line commissioned in Bihar is a 56-km stretch, is part of the eastern arm of the ambitious Rs 82,000-crore (12 billion USD) dedicated freight corridor project. This line is stated to ease coal evacuation traffic from mines in the eastern region.

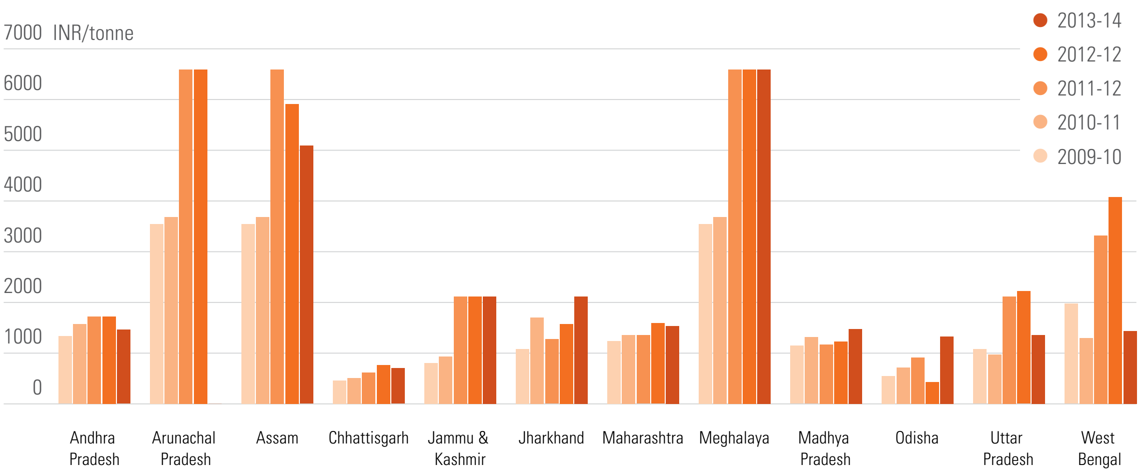
The Ministry of Coal (MoC) is responsible for managing the exploration and development of coal and lignite reserves, production, supply, distribution and prices of coal. The MoC started the allocations of coal blocks again in 2016. In India, coal allocation and pricing are influenced by the government. The state currently exercises control over more than 90% of production and full control over marketing of domestic coal. CIL has a dominant position, producing roughly 80% of India's coal. The auction and allotment proceeds from 83 coal mines allocated so far have been estimated at more than 59 billion USD over the life of the mine/lease period. The exchequer has benefitted beyond assumptions and added surplus revenue to the Government. It had also ensured commercial price discovery mechanism for the coal resource barring charges of favouritism. CIL has identified 64 future projects against 1 Bt coal production target by 2019-20. Out of this, 21 projects having capacity of 181 Mt/Year and capital expenditure of 4.5 billion USD have so far been approved. In addition to that the competitive based bidding for coal block allocations to power sector have resulted declining tariffs and consumers savings. The savings accrued from auction of 9 blocks to power sector is likely to the tune of 10 billion USD (CIL, 2015). In 2017, the NEP estimates suggest coal requirement to reach 877 Mt in 2026-27, hence CIL production may reach 1 Bt/year around 2030 (NEP, 2017).

More than 90% of the coal produced is from open cast mines (MoC, 2017). The specific energy consumption ranges from 152-207 MJ/tonne, which is 40-56% above the minimum energy consumption of open mines (90 MJ/t) (Sahoo *et al.*, 2013). State wise cost of production is presented in **Figure 7**. Prices for coal are set by CIL (and SCCL) and depend on the quality and type of coal. The average pithead price of coal produced ranges 447-3,388 INR[8] (6.6-50) per tonne according to grade and GCV bands as of January 2018 (presented in **Figure 8**). The current imported prices of coal on an average cost range from 2,800 INR (41.4 USD) per tonne to 6,200 INR (91.6 USD) per tonne, depending on grade of coal and country of origin (**Figure 9** and **Table 4**). The rent from surface mines is currently used to cross-subsidize the more expensive production of underground mines.

Path dependencies of coal use have strong socio-economic and political linkages, in addition to huge invest-

8 In this report USD = 67.68 INR

Figure 7. State wise - Cost of production



Source: CIL. 2017

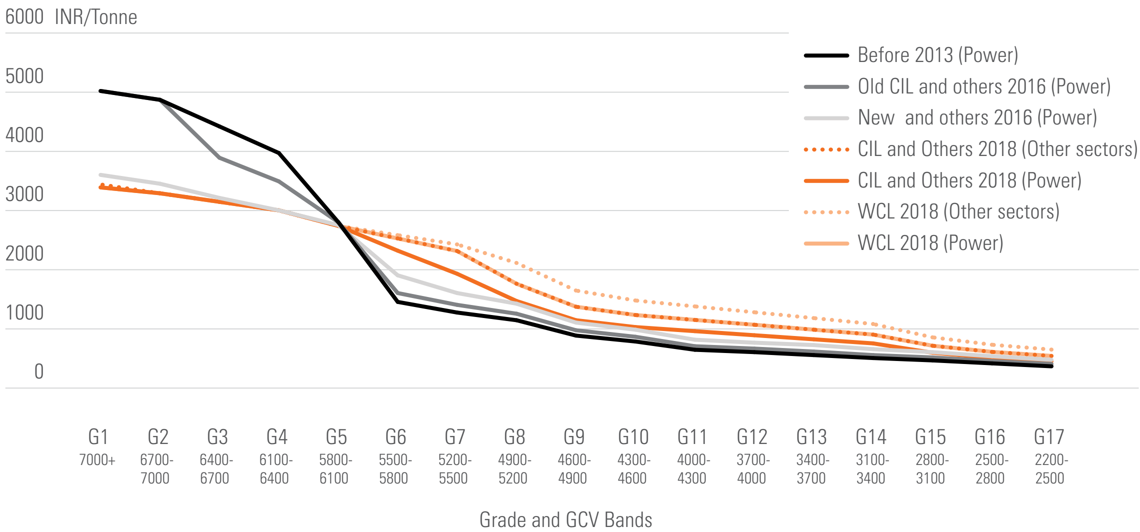
ments in coal infrastructures that have to be managed in case coal use has to be strongly discontinued in India. Coal production, transport, usage, ash disposal and associated businesses employ more than one million persons. Income from coal royalties constitutes almost 50% of total earnings of states like Jharkhand and Odisha (Agarwal & Dhritiman, 2015; GoO, 2007), which are some of the least developed (and largest coal-producing) large Indian states.
The Indian coal mining workforce has reduced in the past decade, primarily due to increase of mechanization of processes. A reduction of about 0.2 million

Table 4. Import price of coal from different countries

Country	2014-15	2015-16
Indonesia	3,823	3,283
Australia	7,246	6,029
South Africa	4,967	3,851
USA	7,028	5,572
Canada	7,768	6,015
Mozambique	6,750	5,114
Russia	6,366	5,285
New Zealand	7,704	6,426
Chile	3,211	2,812

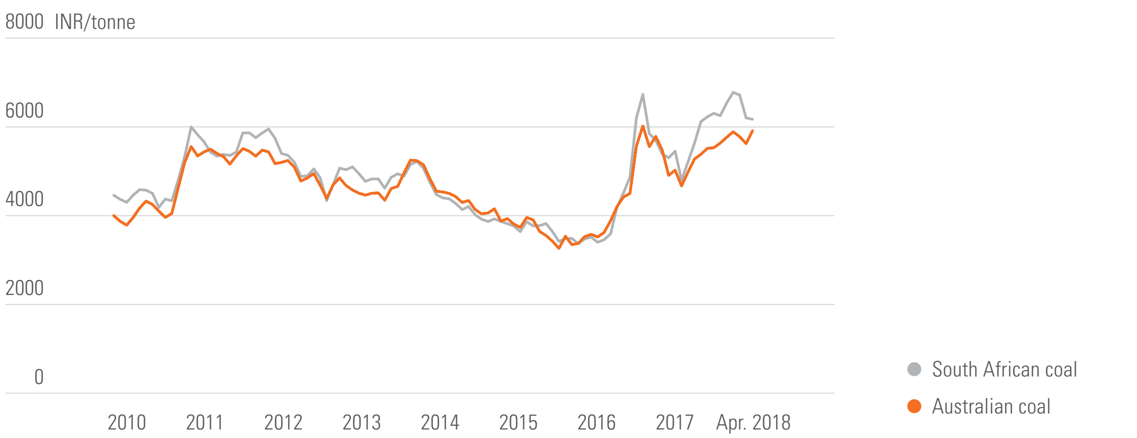
Source: Infraline (2017).

Figure 8. Pithead price of coal – Grade and GCV band wise



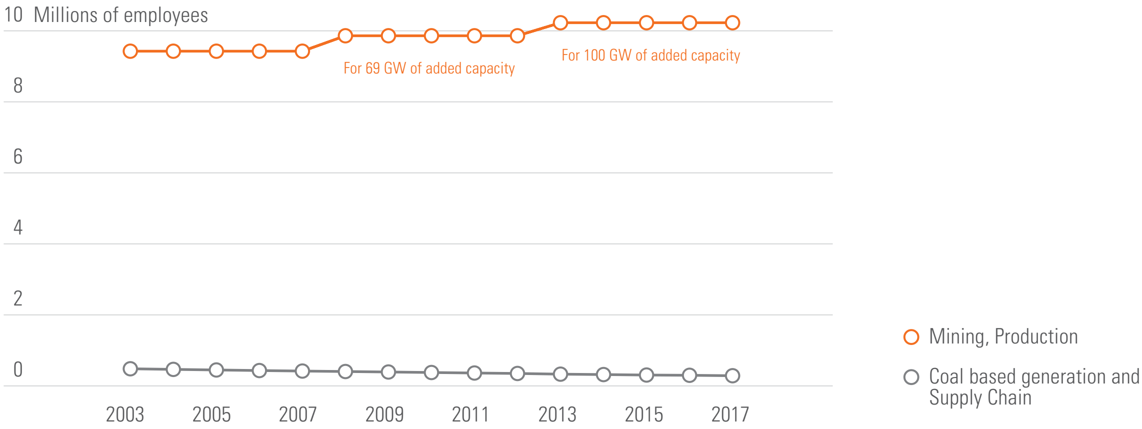
Source: CIL 2018; CIL 2016

Figure 9. Import price of coal from Australia and South Africa (2010-2018)



Source: Indiastat 2018

Figure 10. Labour in mining, production, coal based power generation



Source: CIL 2017

coal-mining jobs was observed between 2002 and 2017 (presented in **Figure 10**) as a result of rationalization of workforce. Today, around million plus jobs in India still depend directly or indirectly (mining, production, transport, generation) on coal. Total manpower of CIL including its subsidiaries was 313,829 as on December 31, 2016, which is less than 326,032 on December 31, 2015. CIL is also a source of employment to nearby villages. About 99,000 contract workers are employed through registered contractors for outsourced works. In 2016, the labour productivity (output per miner shift in tonnes (OMS)) in surface mines is 16.57 tonnes as compared to 0.73 tonne in underground mines (Sengupta, 2017; CCI, 2017). The overall labour productivity is around 7 OMS (Table A1) as compared to global OMS of 15 Mt. An average Indian coal miner produces less than 2.5 kt of coal per year, while an Indonesian counterpart is at least 50% more productive (3.75 kt), a miner in China produces more than 5 kt per year and an Australian worker mines up to 13 kt per year on average (IEA, 2015).

2.3. Policy aspects of the transition

India's NDC submission to UNFCCC under the Paris Climate Agreement proposes a reduction in the emissions created per unit of economic activity, ensuring it can continue to grow its economy in an efficient and sustainable manner. NDC lists its mitigation and adaptation options to be achieved by 2030. The climate strategies along with non-climate policies will lead to transformation of energy systems which will impact all sectors especially coal and power sector. The following section summaries these strategies across coal, power and associated sectors.

2.3.1. Coal Sector

Several polices have been issued to respond to the challenges faced by coal sector due to economic and environmental factors. It has been projected the production to be more than 1 Bt by 2019-20, however the target may be achieved by late 2030s. The government plans to ensure energy security by increasing domestic coal production, reducing coal imports and diversifying import resources and domestic energy mix. The report outlays a three year action agenda to boost coal production in India. Some of the strategies are listed as follows:[9]

- Exploration of 25% of the country's untapped 5,100 sq. km coal bearing lands to find new reserves
- Completion of three railway projects to assist in the transport of coal
- Reduce the prevalence of low quality coal
- Improve quality of coal through washeries
- Establishing research centre to encourage experimentation and pilot studies on carbon capture, utilization and storage

The Coal Distribution Policy lays down guidelines for distribution and pricing of coal. The latest amendment to the policy increases the annual cap of coal through State Nominated Agencies and amending the definition of small and medium sector. New

9 NITI Ayog Three Year Action Agenda (2017).

Gross Calorific Value (GCV)[10]-based pricing policy have come into effect from April 1, 2018 (**Figure 8**) to charge the consumer based on the actual GCV consumption, which eliminates the scope of losing revenue making the process more transparent, fairer, and much more linear.

The auctioned coal-blocks and other captive mines are estimated to produce around 150 Mt by 2020. This would still mean around 100 Mt demand-supply gap, which has to be met through imports and expanding domestic coal production through CIL and private players. On May 17, 2017, Cabinet Committee on Economic Affairs (CCEA) approved a new policy, Scheme for Harnessing and Allocating Koyala (Coal) Transparently (SHAKTI) in India for allocation of future coal linkages in a transparent manner for power sector (GoI, 2018a). CIL has also taken various steps to substitute imports through source rationalization with part supply from higher grade coal sources. Coal from various sources including higher grade were offered through various types of e-auction including special forward e-auction with ease-of-business initiatives like flexi tenure of lifting, reduction of Earnest Money Deposit (EMD) and floor price to cater to requirement of various consumers including Thermal Power Plants (TPPs) not having Fuel Supply Agreement (FSA) with CIL sources (GoI, 2018c).

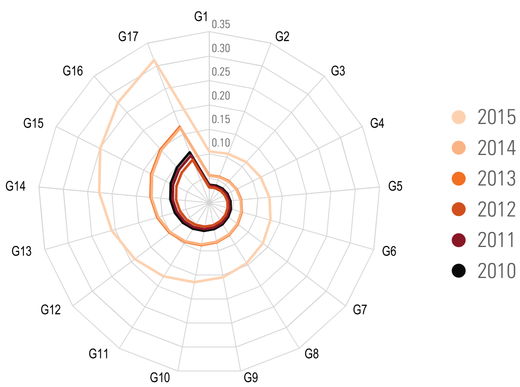
10 Appendix A

The policy was an important initiative in alleviating one key challenge in power sector, viz. lack of coal linkage and is expected to positively contribute in resolution of a number of stressed assets. Partly as a consequence, in December 2017, Adani cancelled a 2 billion AUD contract with a mining services company for work on its proposed Carmichael coal mine in Australia due to its failure to raise funds (FT, 2017).

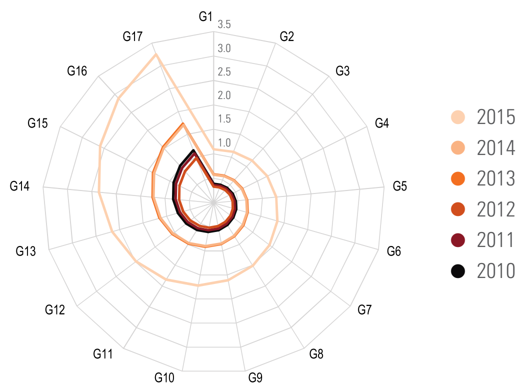
The Clean Energy Cess was introduced to promote and finance clean environment activities and fund its related research activities. Under the Tenth Schedule to the section 83 of the Finance Act, 2010 the Government of India started levying a Clean Energy Cess at the rate of Rs50/tonne(t) of coal (DoR, 2010). This cess has been levied on coal, lignite and peat. The funds collected will be used under the National Clean Energy Funds (NCEF). In the Union Budget 2014-15, the scope was also expanded to include financing and promoting clean environment initiatives and funding research in the area of clean environment. In the Union Budget of 2015-16, the cess was raised further to Rs.200/t (USD2.99/t) and further to Rs.400/t (USD5.97/t) in the Union Budget 2016-17. **Figure 11** shows the growth of the cess collected with the production of coal (Garg *et al.*, 2017b)

The trend of the amount of cess collected in terms of the energy content of the coal, we can see that the values have been constantly increasing across the

Figure 11. Coal grade wise cess collected



a. Cess collected
per energy of coal (USD/GJ)



b. Cess collected
per emissions from coal (USD/tCO2)

Source: Garg et al., 2017b

grades of the coal, along with the increase in the cess amount over the years (Figures 11a and 11b). The coal cess is increasing over 2010-2016 periods in USD terms, despite exchange rate increasing. It could be seen that the coal cess is regressive if seen from energy content perspective. The lower quality of coal is used for power generation, a regressive carbon cess increases the relative production cost of electricity with respect to other commodities that are using higher grade coal such as steel (Garg *et al.*, 2017b).

The policy has been implemented without any major challenge on the collection side. However, the utilization of collected funds has not happened strictly as envisaged.

2.3.2 Power sector

National Action Plan on Climate Change (NAPCC) and NDC lists out the following strategies to improve efficiency of coal-based power sector:

- Assigning mandatory targets to improve energy efficiency in 144 old thermal power stations
- Stringent emission standards applied to old, inefficient power plants
- Installation of forty units of supercritical thermal power stations with capacity of 27.5 GW by 2022
- Development of ultra-super critical technology to reduce emissions by 20%
- Reduce AT&C losses to 6-8% by 2030
- Smart grid projects sanctioned in 1,412 towns
- Adoption of "clean coal technologies" such as coal gasification. These technologies will make coal plants more efficient by converting coal to gas, which can be burned more cleanly in power stations but actually has a higher lifecycle carbon footprint than directly burning coal.

2.3.3 Socio-economic Perspective

Coal is the second most hazardous industrial occupation in India, after ship breaking, in terms of fatalities in the line of duty. This is one of the reasons organized coal workers have been able to negotiate a decent wage for themselves. In October 2017, historic wage agreement was signed, where workers' wages were raised by 20% of their current wages. The new recruitment, however, becomes necessary for the company due to the large scale displacement of population in order to mine the coal (particularly by the opencast method) for which the company provides employment to displaced persons (or project affected persons) according to its rehabilitation and resettlement (R&R) policy. The company also has to provide employment on compassion grounds to the dependents of those employees who die or become permanently disabled while in job. Safety from coal fires is another major concern amongst coal miners after wage increases (GoI, 2018f; GoI, 2017c). Currently, the impact of phasing out of coal and/or shift towards renewable forms of energy and associated skilled labour is not considered as major threat by workers and their unions.

2.3.4 Additional factors impacting coal sector

Declining solar tariffs: The cost of generation in solar plants have substantially reduced during the span of three years in India especially after INDC ratified and adopted by present government regime. The falling prices of solar electricity are making it more attractive and competition raised due to strong policy push is driving down the cost further. The solar power has seen plunging tariffs of Rs.2.44 per KWh (3.5 cents per kWh) at Bhadla in Rajasthan in October 2017 from Rs.12.16 per KWh (12.1 cents per kWh) in 2010, a decline of nearly 80% (PIB, 2017). These rates pose competition to coal and subsequently can encourage climate security.

Enhanced energy efficiency: Earlier assessments of future installed capacity in various studies (including IEA) have been revised and lowered down as energy efficiency has brought significant decrease in demand. The trend in reduced demand is expected to continue through policy instruments like PAT scheme for industries, LEDs for lighting etc. Regulatory and disciplinary actions are also resulting in reducing commercial and line losses. Promoting smart grids and smart meters would rationalize the consumption and improve the grid performance.

Coal despatch: Coal reserves are available mostly in the eastern part of India whereas the demand of coal is through-out India. This leads to high transportation cost of coal or higher transmission losses of power generated at pit-head power plants. Coal plants have suspended operations in the past due to stock out at plant sites despite coal availability at mine site.

Growing water crisis: In summer of 2016, growing water shortages forced shut down major thermal power companies in Maharashtra and West Bengal (Bhaskar, 2016; Sally, 2016). As of February 2018, power outage losses due to water shortage for 2017-18 is about 3.4 billion units (BU) which lower compared to 9.5 BU in 2016-17 (GoI, 2018d). Extreme climates will impact electricity generation from fossil fuel (thermal) especially due to water crisis across the country. With uncertain climate in future, the probability of shut downs can increase during summers when the likelihood of water shortages rises.

Local air quality: Coal power plants are one of the main polluters, increasing the SO2 by 32% and PM2.5 by 34% (Tripathi 2018). Power plants have not met the required compliance in spite of the 2015 law notified by the environment ministry. Delhi for instance has been facing air pollution crisis for the past few years, 2017 being the worst when it experienced the Great Smog. Badarpur power plant that supplies electricity to Delhi was temporarily shut down for 3 months to alleviate the acute air pollution (PTI 2017c).

Fly ash management: Indian coal has very high ash content. Based on coal consumption, the total ash produced in 2015 is 176 Mt and is expected to rise to 321 Mt annually in 2030 (GoI, 2018e; NEP, 2017). While fly ash can be used in other processes (e.g. cement production, agricultural soil fertilisation), the demand is lesser than supply, thus potentially adding to concerns about local air pollution, soil pollution, and indirect impacts of fly ash management (e.g. water usage for coal washing).

Some of these factors have led to temporary shutdown of coal power plants in the past, and may lead to increase in probability of stranded assets in future which will not only impact the immediate revenue but also influence the associated businesses as well as regional economy.

3. National coal transition scenarios

This section presents methodology used for modelling energy systems in India, followed by detailed description and exploration of national transition scenarios for coal.

3.1. Quantitative Coal Scenarios

3.1.1 Methodology

The aim of the current study is to capture the energy and environment systems of major sectors in India to observe the impact of multiple objectives (energy and climate security) of existing and future policies (energy efficiency, addition of renewables etc.) on energy and associated systems. International dimensions such as carbon budgets were treated as the "boundary conditions" of the analysis (Tavoni *et al.*, 2014; Shukla *et al.,* 2015; CDLINKS, 2017). There is an emerging narrative for the need to decouple fossil fuel energy demand from the energy intensive economic activities within the constraints of emission intensity (Shukla *et al.*, 2015). In the past decade, the costs in power sector especially renewables and various energy efficient technologies have undergone drastic changes. Bottom up techno-economic models are well suited for this kind of analysis and, hence, AIM/Enduse has been used in the current study because it can provide a techno-economic perspective at the national level with sectoral granularity. The model has been developed to report primary and final energy mix, emission from the energy system, electricity generation capacity additions and related costs for various sectors. Additionally, the model has been further developed[11] to capture the water-energy nexus by simulating the water demand for reference and alternate scenarios for various sectors and the impact of water constraints on major energy systems.

Additionally, it is a partial equilibrium model with myopic expectations,[12] and is flexible at spatial scales, as it can be developed at regional, national and/or state level. We have developed the model for national level. Simulation of the policy mixes are quick which in turn, helps to communicate the impact of policy options on both energy and material (such as resources like metals,

11 Parts of this section have been used in MILES reports and journal papers under review.

12 Myopic expeactations assumes that the agents see and examine only the alleged dangers of rising CO_2 levels in the atmosphere while ignoring the potential harmful effects of managing for CO_2.

water) systems to policy makers and stakeholders in a short time. The modelling framework is used to estimate the energy and water demand potential, resource use efficiency and technology substitution across sectors under physical, technological and economic constraints. The model has been calibrated to historical agriculture, industry, residential, commercial and energy data from 2000 to 2015 and runs in annual time steps to 2050. The current modelling framework addresses questions pertaining to energy efficiency, technology transition, and identifying high impact opportunities in addition to accounting for energy demand and subsequent carbon dioxide emission level (Vishwanathan *et al.,* 2018). We have also added a water module to estimate water demand across sectors and to look into the impact of water on energy systems and vice versa.

3.1.2 Scenario Architecture

In the current study, three scenarios are explored, which are described as the (Intended) Nationally Determined Contribution (INDC) scenario, and two contrasting 2 °C scenarios - one follows a conventional path and the other captures a sustainable path. The 2 °C_conventional scenario assumes coal to remain as the backbone of India's energy mix, while 2 °C_sustainable scenario move towards cleaner fuels such as natural gas and renewables.

INDC scenario

The INDC scenario takes into account India's pledge in response to the Conference of Parties (COP) decisions 1/CP.19 and 1/CP.20 for the period of 2021 to 2030 in every major sector. Based on the values of consideration and moderation, the scenario results in a reduction of emission intensity by 33-35% in 2030 from 2005 level, and sets a target of attaining 40% of energy from renewable sources by 2030 through enhancement of the existing policies in selected priority areas (INDC, 2015), including:

- Introduction of new and efficient technologies in power sector (thermal power plants);
- Promoting renewable energy generation and increasing the share of alternative fuels in the overall fuel mix;
- Reducing emissions in transportation sector;
- Promoting energy efficiency in industry, transportation, and building sectors.

2°C contrasting scenarios

The 2°C scenario follows policies, and programs that will not only support development but also attempt to meet the carbon budget constraints likely for India for a global 2°C target (Vishwanathan et al. 2018). These are projected to be in the range of 115-147 Bt-CO_2 during 2011-2050 (Tavoni *et al.,* 2014), as against 165 Bt-CO_2 for the reference scenario.

Table 5 lists these scenarios—INDC, 2 °C_conventional and 2 °C_sustainable scenario. These scenarios segregated as energy futures are differentiated along two dimensions of short-term policy dimension and long-term carbon budgets. We explore 2 °C_conventional scenario with CCS and 2 °C_sustainable scenario with shift towards cleaner and renewable forms of energy to limit the emissions within carbon budget.

Table 6 catalogues sector-wise for scenario development for all scenarios in more detail.

Table 5. Scenario assumptions in current and alternate futures

Scenarios	Policies	Comments
(Intended) Nationally Determined Contribution (INDC) (3- 3.5 °C)	Existing policies + Implementation of INDC polices	33-35% emission of GDP during 2005-2030, 40% non-fossil fuel capacity
2 °C scenario-Two pathways:		Carbon budget: 115-147 Bt CO_2 during 2011-2050.
Conventional scenario	Existing policies + Stringent implementation of INDC polices + Demand reduction + CCS	This scenario assumes coal sector to play a prominent part in power generation. CCS is hence encouraged as a mechanism to capture CO_2 to limit overall carbon emissions.
Sustainable scenario	Existing policies + Stringent implementation of INDC polices + Demand reduction + Gas and renewables	This scenario assumes shift from coal to new and cleaner forms of energy such as nuclear, gas, and renewables with storage.

Source:

3.1.3 Results

Current NDC based scenario and implications for coal

Aggregate energy and carbon emissions for NDC[13] scenarios and associated indicators are summarized in **Table 7**. The emission intensity to GDP for INDC scenario will be more than 33-35% as stated in the INDC report as India will strictly adheres to the renewable generation capacity target (40%) of power sector. Carbon intensity of its population is estimated to increase by 58% in 2030 and 80% in 2050, while carbon intensity to GDP decreases by 49% in 2030 and 67% by 2050. Similarly, energy intensity of population is observed to increase by 91%, while energy intensity of GDP declines by 75% in 2050. The carbon intensity of energy decreases at the rate of about 0.15% per year to 59.3 Mt CO_2/EJ which is slightly higher than global average of 2010 (56.8 MT CO_2/EJ).

13 The NDC scenarios refers to INDC scenario in this study. INDC 2015 became NDC for India in 2016 after it ratified the Paris Climate Change Agreement.

Table 6. Alternate futures sector-wise for scenario development

INDC	2 degree C Conventional	2 degree C Sustainable
Emission Intensity		
33-35% during 2005-2030	Carbon budget: 115-147 Bt CO_2 during 2011-2050	Carbon budget: 115-147 Bt CO_2 during 2011-2050
Power		
Solar: 100 GW by 2030 Onshore Wind: 60 GW by 2030 Small hydro: 15 GW by 2030 Biomass: 25 GW by 2030 AT&C losses: Reduce to 6-8% Introduction of smart and micro grids	Additional P&Ms being included Early retirement of low efficiency coal based power plants Super Cr., PC, IGCC brought in more strongly Gas based power generation Increase in renewables with storage Enhancing smart and micro-grids	Additional P&Ms being included Early retirement of low efficiency coal based power plants Super Cr., PC, IGCC brought in more strongly Increased share of gas based power generation Increased nuclear share Increase in renewables with storage Enhancing smart and micro-grids
Agriculture		
EE and solar pumps	EE, Solar pumps with drip irrigation	EE, Solar pumps with drip irrigation
Building (Residential and Commercial)		
LED to save 100 TWh annually, Standards and Labelling (S&L) programme for 21 equipment, LEED and ECBC std.	Shift to electric appliances for residential, increased S&L programme, dematerialization	Shift to electric appliances for residential, increased S&L programme, dematerialization
Transport		
Share of railways: 36 to 45%, Dedicated Freight Corridor (DFC), improve vehicle efficiency, introduce electric vehicles (EV), increase public transit (metro)	Encourage 0-5% work from home, encourage non-motorized transportation	Encourage 0-5% work from home, encourage non-motorized transportation
Industry		
PAT (enhanced sectoral and plant coverage) Addition of railways, refineries and distributed companies	More aggressive PAT -Addition of MSMEs and SMEs; Demand reduction, CCS in cement , steel and fertilizer	More aggressive PAT -Addition of MSMEs and SMEs; Demand reduction

Super Cr.: Super-critical, PC: pulverized coal technology, IGCC: integrated gas combined cycle

Table 7. Indicators – Population, economy, emissions, and energy in NDC scenario

	2010	2020	2030	2040	2050	
Population	1,201	1,370	1,523	1,651	1,751	Million
GDP	0.9	2.1	3.5	7.5	10.1	tn $US\$_{2010}$
CO_2	1,800	2,889	3,604	4,317	4,721	Mt CO_2
Energy Demand	29	43	58	72	80	EJ
CO_2/capita	1.5	2.1	2.4	2.6	2.7	t CO_2 / capita
CO_2/GDP	2,000	1,376	1,030	576	467	Mt CO_2 / tn $US\$_{2010}$
Energy / capita	24	31	38	44	45	PJ / capita
Energy / GDP	32	21	17	10	8	EJ / tn $US\$_{2010}$
CO_2 / energy	63	67	62	60	59	Mt CO_2 / EJ

Figure 12 presents sectoral breakdown of emissions in NDC scenario. The share of emissions from power sector initially increases to 48% in 2020 from 43% in 2010, and subsequently decreases to 37% in 2050. This trend is observed due to a combined impact of 1) increase in renewable share, 2) decrease in ATC losses, and 3) increase in fuel and technical efficiency in thermal based power plants. The share of industry sector is observed to decrease from 41% to 39% due to implementation of energy efficient programme (PAT) under NMEEE. There is an observed increase in share of building sector from 5% to 9% and transport sector from 11% to 15% due to growing energy demand resulting from rising urbanization and increasing income of the population

The demand for electricity has been increasing considerably at a rate of 5-7% across all the sectors. The energy supply mix is heavily dependent on the fuel based on its availability, accessibility, affordability, geographical location, demand of end-use sectors and price. As observed in **Figure 13**, coal occupies more than 70% of the fuel mix in 2010, which is reduced to 28% in 2030 and 24% in 2050. At the same time, the share of natural gas increases form 13% in 2010 to 35% in 2050. With cancellation of several UMPPs and bouts of acute shortage of coal stock in new super-critical power plants, cutting tax rate , natural gas will grow to be a good contender against coal as it takes very less time to start-up or shut down for NTPC and state-owned power plants that have fully and/or partially operated systems. Efforts have been made by the central government to shift towards cleaner and renewable fuels in order to meet the NDC commitments by 2030. The government push has resulted in solar gaining prominence in the renewable mix share. Solar energy occupies 17% of energy mix in 2050 followed by wind (5%).

Figure 12. Sectoral breakdown of emissions NDC scenario

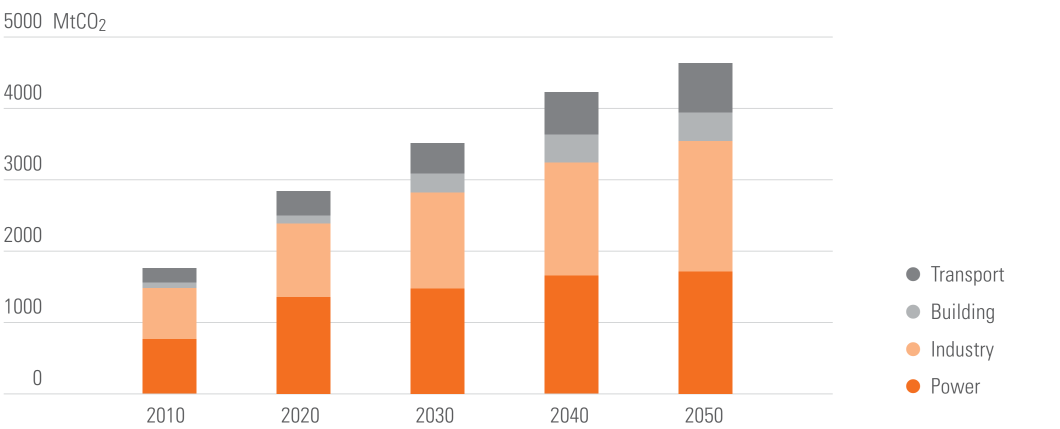
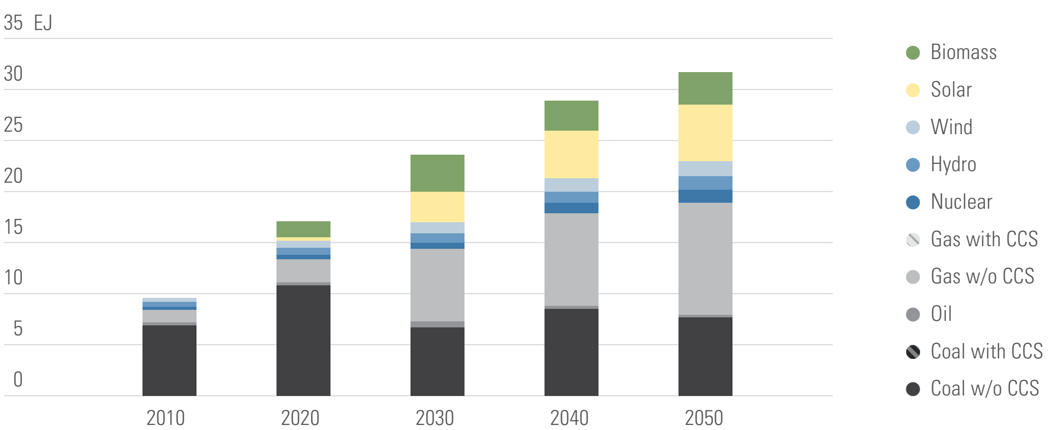


Figure 13. Energy mix in power sector NDC scenario [EJ]



Industry is the second largest energy consumer. The energy demand has been growing since 2000 and is targeted to increase further due to renewed thrust on industrial growth under the 'Make in India' policy of the present government (Vishwanathan *et al.*, 2017). The introduction of perform, achieve and trade (PAT) represents an attempt to reduce energy intensities along with overall energy consumption by targeting LPS that have been identified as energy-intensive designated consumers. **Figure 14** shows the fuel mix in industry sector. The share of coal in the energy mix reduces from 56% (2010) to 54% (2050), while that of gas and electricity increases 6% and 12% to 13% and 18% respectively. The decrease in coal consumption is due to improved efficiency and fuel shift to natural gas and electricity in energy intensive industries (iron and steel, cement).

Thermal coal consumption increases at growth rate of 2.2% till 2030 and at a rate of 0.5% from 2030-2050. The share of coal in power sector decreases due to increase in natural gas and renewables. With increase in demand of iron and steel, cement due to increase in building stock, the share of coal (coking and non-coking) is estimated to increase (**Figure 15**). Coking coal constitutes about 14%, non-coking coal consists of 85% in 2050, while the remaining share is lignite as shown in **Table 8**.

Table 8. Coal demand projection by type in NDC scenario (Mt)

Year	Coking	Non-Coking	Lignite
2010	66	507	41
2020	80	777	32
2030	92	804	64
2040	93	860	41
2050	122	895	26

Figure 14. Energy mix in industry sector NDC scenario

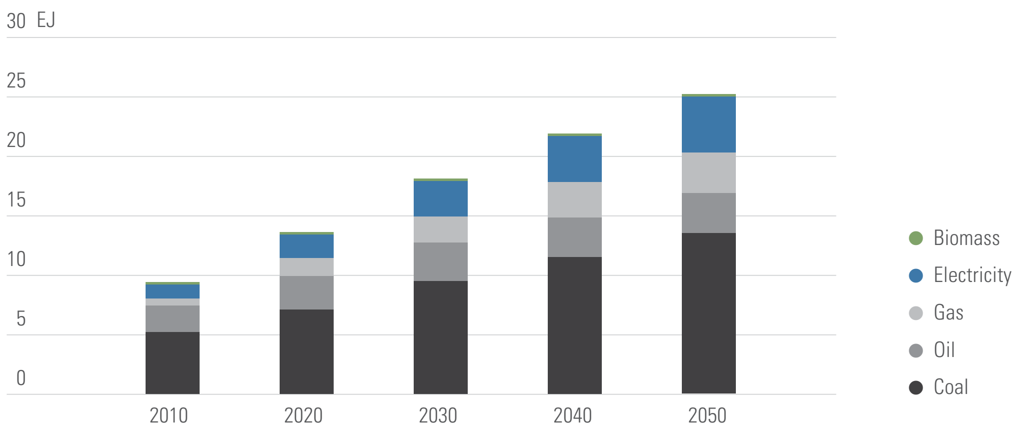
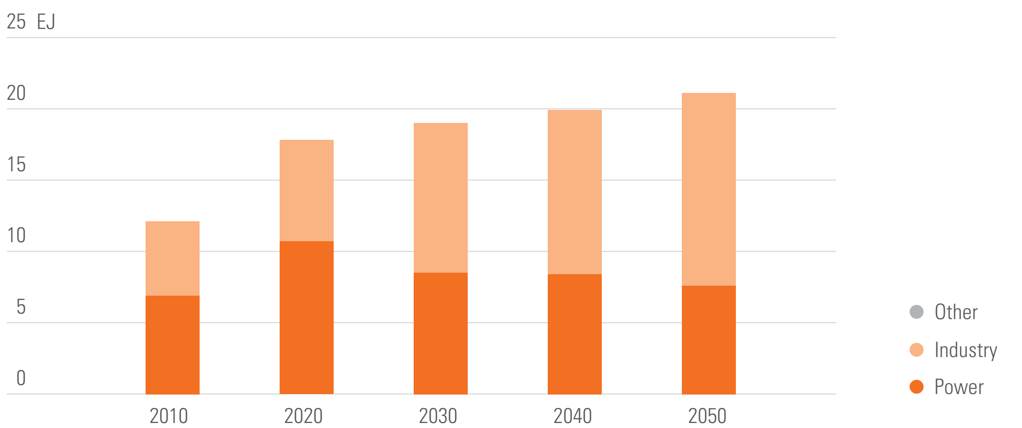


Figure 15. Thermal coal consumption NDC scenario



National 2°C-consistent coal transition scenarios

Aggregate energy and carbon emissions for 2°C scenarios and associated indicators are summarized in **Table 9**. The carbon emission intensity to GDP for 2°C scenarios will be 40-54% less than 2010. Carbon intensity of its population is estimated to increase by 40-70% in 2030 and 24-44% in 2050. Similarly, energy intensity of population is observed to increase by 51-74%, while energy intensity of GDP declines by about 78-80% in 2050. The carbon intensity of energy decreases from 63 $MtCO_2$/EJ to 52 Mt CO_2/EJ in 2050.This is lower than global average of 2010 (56.8 Mt CO_2/EJ).

Figure 16 presents sectoral breakdown of emissions in 2°C scenarios. The share of emissions from power sector initially increases to 43-47% in 2030 from 43% in 2010, and subsequently decreases to 22-35% in 2050. This trend is observed due to a combined impact of 1) aggressive renewable share, 2) decrease in ATC losses, 3) increase in smart grids, 4) increase in energy efficiency in thermal based power plants, and 5) decrease in demand of end-use sectors due to changing lifestyles. Introduction of carbon capture, utilization and storage (CCUS) technologies plays an essential role for conventional scenario carbon mitigation, whereas aggressive push of renewables and increase in nuclear is observed in 2°C_sustainable scenarios. The share of industry sector is observed to increase from 41% to 52% in 2050 for conventional scenario while it decreases to 31% in sustainable scenario with addition of CCUS for energy intensive industries. The building sector share increase from 5% to 11-12% and from 11% to 16-22% in 2050 respectively.

In **Figure 17**, the coal share is reduced to 28-37% in 2030 and 0% (2°C_sustainable)-22% (2°C_conventional) in 2050. The quantity of coal increases over INDC scenario due to the introduction of CCS in conventional scenario while it decreases considerably in sustainable scenario. Coal will remain as a major source of energy for 2°C_conventional scenario, while in sustainable scenario, coal is replaced by natural gas as a transition fuel. The share of natural gas increases form 13% in 2010 to 27-47% in 2050. Solar energy occupies 26% of energy mix in 2050 in both scenarios. The share of nuclear power increases in sustainable scenario from 3% to 12% in 2050 compared to 4% in conventional scenario.

Figure 18 shows the fuel mix in industry sector. The share of coal in the energy mix reduces from 56% (2010) to 49-53% (2050), while that of gas and elec-

Table 9. Indicators – Population, economy, emissions, and energy intensities over time in 2°C scenarios

Indexed numbers (2010=100)	2010	2020	2030	2040	2050	2030	2050	
Population	1,201	1,370	1,523	1,651	1,751	127	146	Million
GDP	0.9	2.1	3.5	7.5	10.1	389	1,122	Trillion $US\$_{2010}$
CO_2								
2 °C_conventional	1,800	2,831	3,221	3,602	3,792	179	211	Mt CO_2
2 °C_sustainable	1,800	3,578	4,202	3,369	3,266	233	181	Mt CO_2
Energy Demand								
2 °C_conventional	29	37	53	66	73	185	254	EJ
2 °C_sustainable	29	44	56	59	63	196	220	EJ
CO_2/capita								
2 °C_conventional	1.5	2.1	2.1	2.2	2.2	141	144	t CO_2 / capita
2 °C_sustainable	1.5	2.6	2.8	2	1.9	184	124	t CO_2 / capita
CO_2/GDP								
2 °C_conventional	2,000	1,348	920	480	375	46	19	Mt CO_2 / Trillion $US\$_{2010}$
2 °C_sustainable	2,000	1,704	1,201	449	323	60	16	Mt CO_2 / Trillion $US\$_{2010}$
Energy/capita								
2 °C_conventional	24	27	35	40	41	146	174	PJ / capita
2 °C_sustainable	24	32	37	36	36	154	151	PJ / capita
Energy/GDP								
2 °C_conventional	32	18	15	9	7	48	23	EJ / Trillion $US\$_{2010}$
2 °C_sustainable	32	21	16	8	6	50	20	EJ / Trillion $US\$_{2010}$
CO_2/energy								
2 °C_conventional	63	76	61	54	52	97	83	Mt CO_2 / EJ
2 °C_sustainable	63	81	75	57	52	119	82	Mt CO_2 / EJ

Figure 16. Sectoral breakdown of emissions 2°C scenario(s)

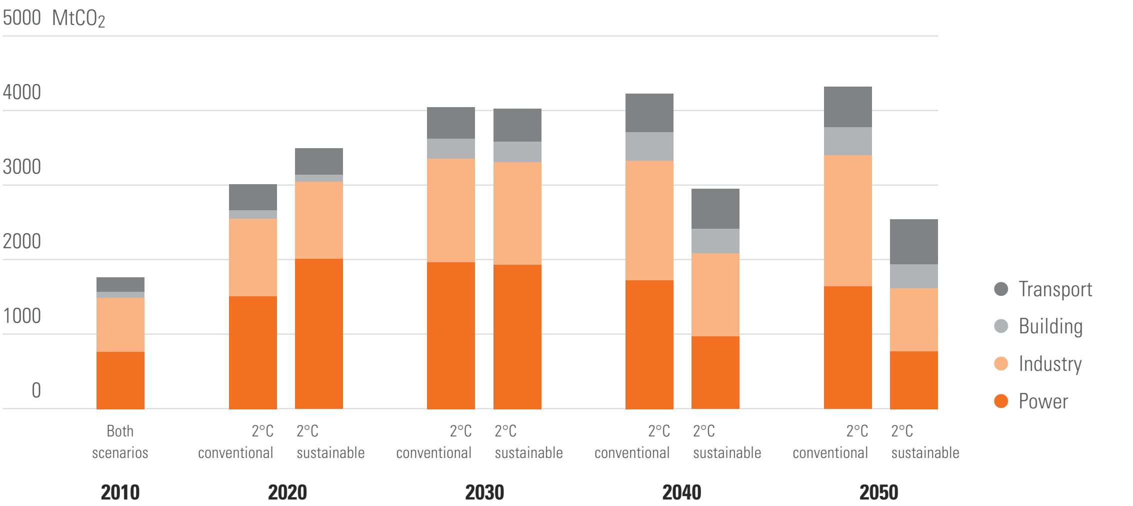


Figure 17. Energy mix in power sector 2°C scenario

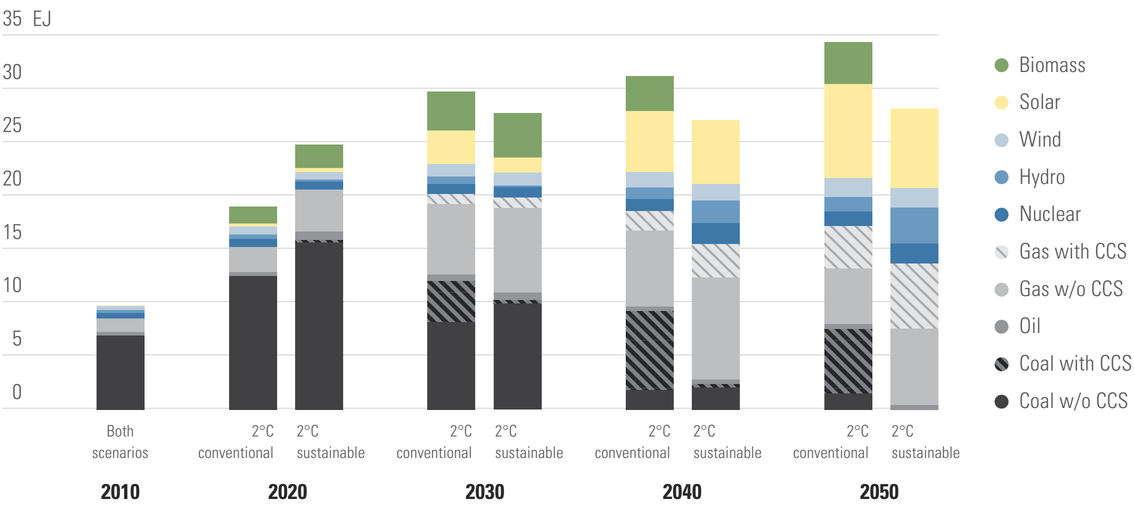
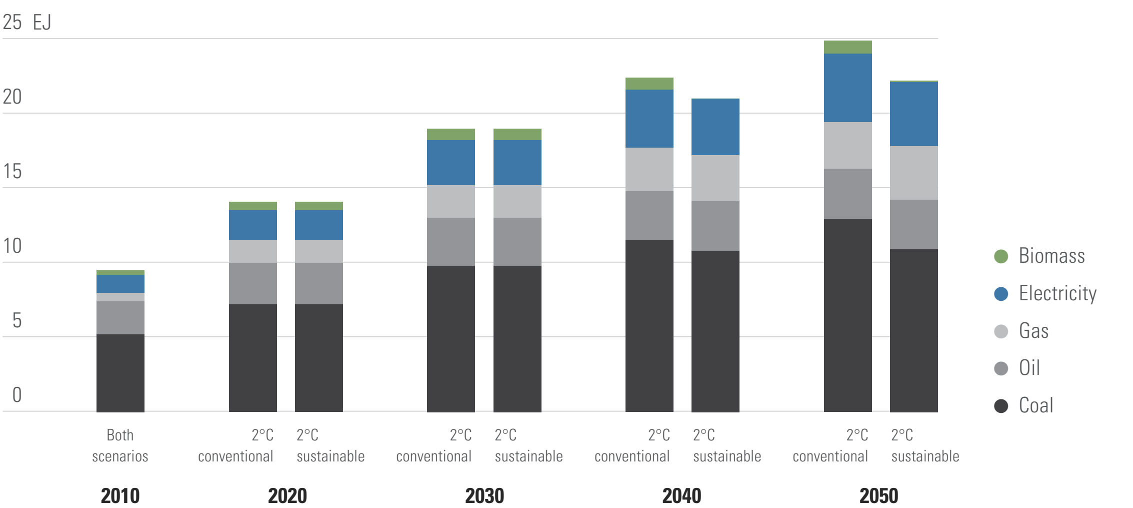


Figure 18. Final energy consumption mix in industry sector 2°C scenario



tricity increases from 12% and 16% to 13-16% and 18-19% respectively in 2°C scenarios. There is an ongoing a shift towards low-carbon fuels like cleaner fuels such as natural gas and electricity in many energy intensive industries especially iron and steel. The electricity is generated mainly from coal sources, as there is a lack of storage technologies for grid balancing the power generated from solar technologies.

Thermal coal consumption increase at growth rate of 1.4-1.6% till 2030 while decreases to a rate of 1.1-1.4% from 2030-2050. The share of coal in power sector increases due to increase CCS in conventional scenario, however in sustainable scenario, coal is phased out by natural gas, renewables and nuclear power after 2030 (**Figure 19**). **Table 10** presents the demand for coking, non-coking and lignite across sectors in 2020, 2030, 2040 and 2050. With increase in demand of iron and steel, cement due to increase in building stock, the share of coal (coking and non-coking) is estimated to increase till 2030.

Steam coal is observed to decrease in 2030 and 2050 in 2°C_conventional scenario subsequently due to energy efficient technologies in power sector. The demand is observed to decrease after 2030 and phase out by 2038 in sustainable scenario. The demand in industry is observed to increase with increase in demand of steel and cement. In sustainable scenario, the demand of coking coal and steam coal decreases when compared to 2°C_conventional scenario, because of shift towards cleaner fuel and more EE technologies. The model estimates of total coal requirement have been observed to fall in the range of NEP 2017[14] estimates.

14 The total projected coal requirement by NEP in 2021-22 is 735 Mt and 2026-27 is 877 Mt (NEP, 2017).

Table 10. Coal demand projection by sector in 2°C scenarios (million tonnes)

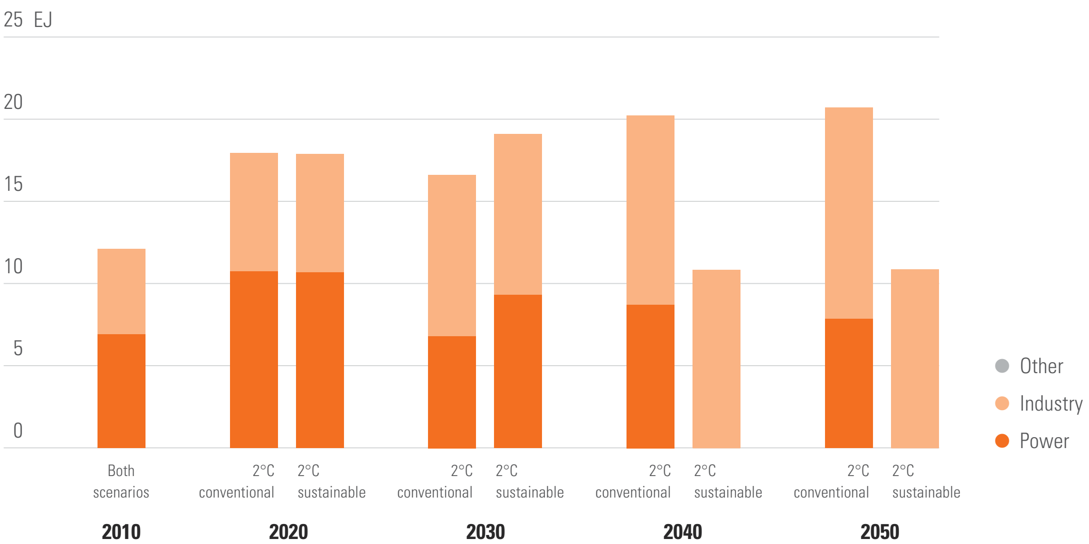
2°C_conventional scenario

	Power		Industry	
Year	Steam Coal	Lignite	Coking Coal	Steam Coal
2010	326	41	66	180
2020	522	32	80	262
2030	309	64	94	375
2040	410	55	94	460
2050	376	35	122	495

2°C_sustainable scenario

	Power		Industry	
Year	Steam Coal	Lignite	Coking Coal	Steam Coal
2010	326	41	66	180
2020	511	48	80	262
2030	434	66	94	375
2040	0	0	95	426
2050	0	0	105	415

Figure 19. Coal consumption 2°C scenario



Coal Imports

Thermal Coal Imports, 2005-2050, 2°C scenario(s) [Mt]

Imports help to secure supplies when a country faces coal shortages. The major import countries for India have been Indonesia, Australia and South Africa in the past few years. **Table 11** shows the increase in coal demand for Adani's import-based coal power plants. The import in 2020 is estimated to be around 100 Mt. Another option (extreme) that can be assumed is that the coal is imported only for import based power plants (IPP) (50 Mt). This is due to improvement in coal quality as a result of third party sampling. There was an observed decrease in thermal coal by 25 Mt in 2016-17, which impacted the import of coal. The projected decrease in demand of thermal coal is 40 Mt and 60 Mt for the years 2017-18 and 2018-19 respectively. Due to limited reserve, coking (metallurgical) coal will need to be imported, however import of non-coking coal will be observed to decrease with improving coal quality through third party sampling, addition of washeries and decrease in demand due to increased energy efficiency and shift to renewables.

Table 11. Coal demand in Adani (2004-2015)

Import Year	Adani TPS	Adani UMPP	Comments
2004-05	26		
2009-10	77		
2015	91	26	Adani UMPP commenced from 2012

Note: Figures are in Million tonnes. Adani, Reliance, Essar and Tata own some of the import based power plants (IPP) in private sector.
IPP account for about 50 % of imports.

Table 12. Future projections - Coal production and Imports (Mt)

2°C_conventional scenario

	Production		Imports	
Year	Coking*	Non-coking** (Steam coal)	Coking**	Non-coking* (Steam coal)
2020	18	684-734	62	50-100
2030	20	584-634	74	50-100
2040	23	770-820	71	50-100
2050	25	771-821	97	50-100

2°C_sustainable scenario

	Production		Imports	
Year	Coking*	Non-coking** (Steam coal)	Coking**	Non-coking* (Steam coal)
2020	18	673-723	62	50-100
2030	20	709-759	74	50-100
2040	23	376-426 #	72	0
2050	25	365-415 #	80	0

Note:
**Assumed numbers, **Estimated numbers,*

 # Domestic producers may try maintaining the current higher production levels, but export markets would be difficult to find due to climate change pressure globally on coal phase out and domestic coal demand is projected to go down in this scenario.

If the central government retains the suggested zero-import policy, India will still need at least a minimum of 100 Mt of steam coal due to demand from its import-based power plants. Additionally, coking coal reserves for India do not exceed 25 Mt/year. Assuming, the former (import constraint) and latter (coking coal reserve/production constraint), **Table 12** presents the estimated production of non-coking and import values of coking coal under 2°C scenarios. Due to complete phase down of coal in power sector, the overall demand of steam coal reduces by 8% in 2°C_conventional and by 59% in 2°C_sustainable scenario over INDC scenario.

3.2 Coal-related policy needs for achieving NDCs and moving to 2°C scenarios

India's energy demand is going to surge significantly driven by a growing economy, and rising urbanization. A number of policies have been recently implemented that will limit the growth in Indian coal consumption and thus reduce coal related CO_2 emissions. These are discussed below in Section 3.2.1. The following sections (3.2.2 and 3.2.3) then discusses what policy requires to be more stringent to address both the need to tackle non-climate policy developments that are buffeting the coal sector and also put the Indian coal sector on a pathway to 2°C-compatible future.

3.2.1 Coal-related policy issues relevant to achieving India's NDC

India is currently expected to meet its NDC targets for 2030 emission intensity to GDP and renewable generation capacity before the target year of 2030 in part due to its current policy and other energy trends. The INDC scenario thus largely reflects the continuance of current policies and practices with moderate changes.

Coal Sector Policies

Improve coal quality to increase energy efficiency of existing production capacity

Indian coal contains high percentage of ash and moisture. This deteriorates the plant and machinery during operations, thus, coal use from indigenous sources is restricted in many industrial applications. Upgrade of coal quality is required to make it suitable to be used in all plants. In the past, the coal sector has faced supply as well as quality issues. Two major steps were implemented since 2014, which include a) revision of fuel supply agreement between suppliers and major buyers (power, cement and steel) and, b) improvement of coal quality through beneficiation rules and third party verification along with installation of more washeries. Coal washing has been recommended for steel—up to 17% ash and below 34% ash for power industry in 2017 (NEP 2017). These steps have and will improve fuel efficiency of coal for end-users under all the scenarios.

In June 2016, Council of Scientific & Industrial Research - Central Institute of Mining and Fuel Research (CSIR-CIMFR) signed a Memorandum of Understanding (MoU) with coal supplying companies and power utilities to improve quality of coal being supplied to power utilities by coal companies in order to enhance energy efficient use of coal by power sector. NTPC has reported a reduction of nearly 20% in the cost of coal, largely by reducing the imports of coal and equally important by improving the quality of coal, that is supplied by the coal companies (PIB, 2016).

This initiative has resulted in multiple benefits which include 1) improvement in overall performance of power plants and thus reducing CO_2 emissions, 2) savings on transportation costs, 3) ensuring coal quality is maintained at both loading/unloading ends deterring adulteration during transit, and 4) reducing dependence on imported coal. The power generation cost is reduced by 39.5 paisa per unit for NTPC and by 60 paisa per unit for Obra Thermal plant. Additionally, the cost of electric generation on across India basis has been reduced to from 20 to 60 paisa per unit of generation (PTI, 2017b). The drop in power prices has leveraged benefits to the consumers in particular and society at large.

Coal pricing

Currently, pricing of coal is determined by CIL while allocation of coal through linkages is controlled by the central government. Traditionally, with multiple producers (in future) a market structure needs to be designed and this will require setting up an efficient regulatory framework. This can impact the pricing of coal across the country. Apportioning of linkages has led to reduction in transport costs and subsequently the landed cost of coal. Fuel cost is a pass through in the power tariff calculations. This affects the final tariff competition among alternate options, such as renewable energy and natural gas. This is necessary especially for the implementation of India's NDC and future climate policy goals, as distorted prices may lead to stranded assets if the true market prices are ultimately higher compared to other cleaner energy options.

Coal cess and carbon taxation

A carbon tax is a form of non-technological intervention to mitigate coal use which could lead to gradual decline of the fuel, thus decoupling the energy systems and thus economy from coal. In 2010, the GoI started clean energy cess on coal at the rate of Rs.50/t (74 cents/t) which is a form of implicit carbon/environmental tax collected to discourage coal production, consumption. It is also used to simultaneously fund green development and clean energy projects. The rate was further revised from Rs.100/t (74 cents/t) to Rs.200/t (1.48 USD/t) and presently is at Rs400/t (2.95 USD/t) in 2016-17. According to the Comptroller and Auditor General (CAG), the centre has collected about 8 billion USD between 2010-11 and 2016-17 and is estimated to collect about 15 billion USD between 2018 and 2020 (Sengupta 2018). This is expected to add nearly 4.5 billion USD in 2018-19 and another 5.93 billion USD by 2020. This fund was expected to promote clean and green activities, however after the introduction of goods and services tax (GST) in 2017, the present central government has been discussing to direct the fund towards compensation of revenue loss to the states due to GST. If this policy is implemented, it may impact the investments in new and cleaner forms of energy.

Power

Phasing out of old, inefficient power plants with new super-critical plants

India has cancelled 52% (451.6 GW) of planned coal capacity between 2006-07 and 2016-17 (Shearer *et al*. 2017). As mentioned in Section 1, NTPC (along with state and private) plans about 92 GW of super-critical plants by 2027 and phase out about 50 GW of old power plants due to age and other problems (air pollution, water). At the same time, it is renovating and modernizing the middle aged power plants (above 20 years). NDC scenario does observe stranded power plants in lieu of shifting towards cleaner fuels after 2025. Nevertheless, the share of stranded assets in sustainable 2°C scenario increase by 34% due to shift towards natural gas, renewables and nuclear. Each of the fuel sources faces unique opportunities and challenges in the event of rapid scale up in the next decade.

Adjusting the power market design to more efficiently integrate renewables and thermal power generation.
As higher levels of renewables enter the market, the remuneration design may need to change in order to provide power to the entire Indian population including energy poor at reasonable prices. Efficient power production needs to be promoted with increasing share of renewables while keeping the average and marginal costs of power within reasonable levels. While the existing coal-based power plants may have higher operational expenses (opex), the renewable plants may have a higher capital expenditure (capex). The peak and off-peak scheduling needs, and intermittency of renewable power creates further challenges. The asset ownership model, the opex model and the capex model would need to be therefore improved for an optimum economic dispatch of power so that overall power delivery costs remain viable for producers and affordable for users. Moreover, coal-based power plants are not flexible to adjust to load variations. The market design may therefore need to evolve to allow for more effective remuneration of coal assets that follow the residual load and which are remunerated not just for schedule-based generation, but rather for generation and for market services in addition to basic generation.

Removing existing barriers to the achieving India's current renewable energy goals in the power sector
India has seen a massive boost in the scale up of renewable energy sources such as onshore wind and solar photo-voltaic (PV) in the past decade. This is largely due to government's existing policy goals increasing NDC targets to achieve 175 GW of renewable energy by 2022. 60 GW of renewables have been installed as of March 2018. Achieving the renewable targets will be one of the keys to meeting India's NDC objectives and serving the country's growing needs for sustainable energy. Existing barriers will be required to be addressed to scale up renewable capacity. These include:

- The development of a more localised and high-quality solar manufacturing industry;
- Providing better guarantees of solar panel quality;
- Strengthening economic incentives for consumers under regulated power tariffs to opt for decentralised energy options;
- Reforms to better ensure for consumer contract fulfilment;
- Repowering of inefficient first generation capacity;
- Limiting dust and other factors that negatively affect solar efficiency;
- Market design reforms to avoid unnecessary curtailment and scheduling risks for investors;
- Scaling up international financing of projects;
- Ensuring reliable project delivery through effective tender design.

3.2.2 Non-climate policy issues with India's coal sector

While the above policy measures will be important to ensuring the achievement of India's NDC, the coal sector will probably be even more strongly affected by other policy constraints in the coming decade. These challenges include competition for water resources, concerns about fly-ash disposal, local air pollution, and land and soil degradation. Indeed, it is possible that the economic competitiveness of the coal-fired power sector will begin to suffer from a steady accumulation of new costs and constraints in the face of these challenges.

Water
Water is required to produce nearly all forms of energy. In thermal power generation, water provides cooling and other process-related needs like ash handling, coal washing etc. The quantity of water withdrawn depends on water availability and type of cooling systems. However, over the past decade coal-fired power sector has faced water availability constraints, especially during drought years. In recent years, water shortages have caused shutdowns of coal based thermal power stations such as Raichur, Rayalseema, Farakka and, Parli plants (CEA, 2015-17). **Table 13** presents actual range of water consumption in India, notification on water consumption limit as on December 2015 and best available water efficient technologies for power plants.

Table 13. Water consumption – Actual range, notification 2015, and best available technologies

Fuel	Cooling System	Boiler Type	Actual range India (m^3/MWh)	Notification 2016-17 India (m^3/MWh)	Best Available Technology (m^3/MWh)
Coal	Once-Through (OT)	Sub-critical	1.2-80	-	0.52
Coal	Once-Through (OT)	Super-critical	-	-	0.47
Coal	Closed Loop (CL)	Sub-critical	Feb-36	OT – CL: 4 m^3/MWh within 2-year period of notification	1.75
				Existing CL: 3.5 m^3/MWh within 2-year period of notification	
Coal	Closed Loop (CL)	Super-critical		Existing CL: 3.5 m^3/MWh within 2-year period of notification	1.96
				New CL: 2.5 m^3/MWh within 2-year period of notification	

Source: Numerous databases, annual reports, MOEF&CC Notification 2015.

Table 14. Notification to regulate air pollution in power sector

mg/Nm^3	Unit Size	Installed before Dec. 31, 2003	Installed Between Jan. 1, 2004 and Dec. 31, 2016	Installed from Jan. 1, 2017
Particulate matter	All	100	50	30
SO2	<500 MW	600	600	100
	>=500 MW	200	200	100
NOx	All	600	300	100
Mercury	All	0.03 (>=500 MW)	0.03	0.03

Source: GoI Notification (2015)

Additionally, tariff policy of 2016 mandates power plants to use water from sewage treatment plants of municipal or local bodies located with 50 km radius (GoI, 2018d). In NDC scenario, water constraint will increase the number of stranded power generation assets form coal.

Local pollution

Power sector contributes to 60% of the PM (particulate matter—of all dimensions), 45% of SOx (sulphur dioxide), 30% of NOx (nitrogen oxides) and 80% of mercury emissions. India contributes to nearly 50% of the world's SOx emissions, most of it from the thermal power plants (CSE, 2015). So, on December 7, 2015 MOEFCC put out norms to regulate the local air pollution resulting from inefficient operations (**Table 14**).

To meet the new pollution norms for SOx the plants are necessarily required to retrofit or install a technology called flue-gas desulfurization (FGD) which helps remove sulphur dioxide from exhaust flue gases of fossil-fuel power plants. Industry estimates suggest installing the FGD costs about Rs5-7.5 million (~0.1 million USD) per megawatt of plant capacity. CEA (2017) suggests that PM and NOx standards will be achieved by March 2019, while SOx standards by December 2020. To comply with new norms without disrupting power supply, a phased FDG installation has been planned by CEA for 161 GW (141 units) and upgradation to electrostatic precipitator for a capacity of 65 GW (222 units) (GoI, 2018b). Coal power plants have been provided with subsidies for co-firing of biomass from agricultural residues within coal plants (a goal of 6-10% co-firing was often mentioned[15]).

Flyash Handling

Indian coal is inferior in quality and has high ash content unsuitable for most industrial applications. India generated 169 Mt of ash in 2016-17, of which 107 Mt (63%) was utilized. To increase the fly ash utilization to 100%, a mobile application "ASHTRACK" has been launched to establish link between flyash users and power plant executives (GoI, 2018e).

Land Degradation

Land degradation due to mining and its reclamation has always been challenging. Indian coal is of high ash content (up to 45%). Most of the coal occurs below forest, agriculture lands and dense population. Mining

15 NTPC recently used 6% biomass co-firing in Badarpur Delhi Plant.

leads to environmental issues relating to deforestation, land degradation, air and water pollution. With increasing mining activities, land acquisition, reclamation and rehabilitation (R&R) and livelihood problems have been observed to be on rise.

Focused efforts are being made by government companies such as BCCL to protect the ecological security of the region and creation of healthy ecosystems. BCCL has developed 45 forest/ vegetation sites since 2011 on spoil dumps & mined out areas spread over 260 hectares (**Figure 20**). These efforts aid in achieving the NDC goal to create additional carbon sink of 2.5-3 Bt of CO_2 equivalent through additional forest and tree cover (increase of about 680 - 817 Mt of carbon stock).

3.2.3 Moving from NDCs to 2°C compatible transitions

For both 2°C scenarios, India will need to implement synchronized actions to achieve the 2°C global carbon budget.

Improving the efficiency of the existing coal fleet

As a first step, India can and should significantly enhance the efficiency of its coal resource use by improving on current NDC policies, such as:

- Phasing out more old, inefficient plants. The power plants commissioned to be built after 2022, or 2027 should not be installed. This is because there is a high probability that they will become stranded due to shift in energy mix under a carbon constraint;
- All newly built plants that have been mandated should have super-critical technologies with water efficient or dry cooling technologies based on their geographic locations;

Figure 20. Ecological restoration of Gondudih-kusunda colliery, BCCL

- Improve PLF of coal (current 60% to 75-90%) and gas (current 25% to 70-90%) power plants;
- Reduce energy demand through energy efficiency and energy conservation measures in power and other end use (PAT sectors and 778 plants, transport, buildings, agriculture) sectors through smart grids and micro-grids.

Scaling up new and cleaner fuel options

Secondly, India will need to remove barriers to scale up of new and additional cleaner sources of energy. India has also been one of the first countries to have a dedicated ministry for renewable energy. While lower tariffs have favoured the scaling up of large grid-scale projects, renewables do have hidden costs and other technical issues that need to be addressed. As noted above, governments will need to address:

- Reforms to power market design to better integrate renewables alongside conventional assets;
- Scaling up and bring down storage costs;
- Development of a broader range of renewable energy options (e.g. offshore wind) to raise load factors and overcome land use constraints;
- Raising the technical efficiency of installations;
- Contract enforcement;
- Incentives for small scale decentralized solar under regulated tariffs;
- Project delivery risks under tendering procedures;
- The lack of a domestic manufacturing sector;
- Infrastructure build out.

Without careful planning, one of the major issues that has emerged is the wastage of energy generated from renewables especially in Tamil Nadu (Hindu, 2017). Currently, 80% of installed capacity is located in western states where the power demand is only 38%. Indian needs to develop new transmission lines for grid powered solar, institutional infrastructure for decentralized solar rooftops and addition of storage to reduce curtailment and increase flexibility of supply curve. These actions need to occur simultaneously for renewable energy to be picked up and not be wasted.

However, even if the above measures were fully implemented, land and resource constraints would require India to go beyond a renewables only strategy. The 2°C_conventional scenario favours coal (with CCS) to remain a peak load fuel, whereas 2°C_sustainable scenario favours gas to be the peaker fuel after 2035 and a stronger role for nuclear. Natural gas is a cleaner alternative to coal with substantially lower SOx, NOx, mercury and particulate matter emissions with lower CO_2 emissions (Alvarez *et al.,* 2012). India has the required infrastructure to accommodate transition to low-carbon futures. It could potentially also explore alternative options to open-cast mining of coal in order to increase gas reserves, for instance through coal-bed methane (CBM) extraction and underground combustion. However, the challenge for scale up lies in importing natural gas due to high upfront costs and geopolitical risks associated with transporting the fuel through Pakistan and Afghanistan as well as supplier preference. For instance, the suppliers Iran and Myanmar may favour exporting gas to China rather than India (Boersma *et al.*, 2017, Panwar, 2009). Additionally, city gas distribution (CGD) which has observed tremendous growth, has observed problems that revolve around gas allocation, gas availability issues, logistics, investment rate of return and market exclusivity (Sircar *et al.,* 2017).

Nuclear power is a reliable source of energy unlike renewables and is being approached by focussing first on indigenous production of pressurized heavy water reactors (PHWR). India is already making moves to increase its nuclear capacity, with a recent cooperation agreement being signed between France's Electricité de France (EDF) and India's Nuclear Power Corporation (NPCIL). However, in order to move towards low-carbon power sector, nuclear capacity needs to increase to at least 60 GW and also become a peaker fuel along with gas especially in the 2°C_sustainable scenario. For this to happen, India needs to work on its international collaboration with China in order to become a member of nuclear supplier group (NSG) which can solve issues related to fuel supply, and manufacturing constraints. Additionally, challenges such as locational factors, reactor safety, nuclear waste and skilled manpower shortage need to be addressed for scale up to be feasible for a longer term (Grover, 2017). India has begun to work on some of these challenges, for instance, through the successful commissioning of a commercial scale fast breeder reactor (a new, more efficient and safer form of nuclear technology) in Kalpakkam in 2015. Further experience and investment in these technologies and the surrounding policy framework for broader commercialisation will be needed however to confirm this as a viable technology option. If this technology were to prove viable, however, it could potentially be a much needed source of alternative, CO_2-free and safe energy, as well as one in which India would have a comparative advantage.

Boosting innovation and commercialisation of CCUS

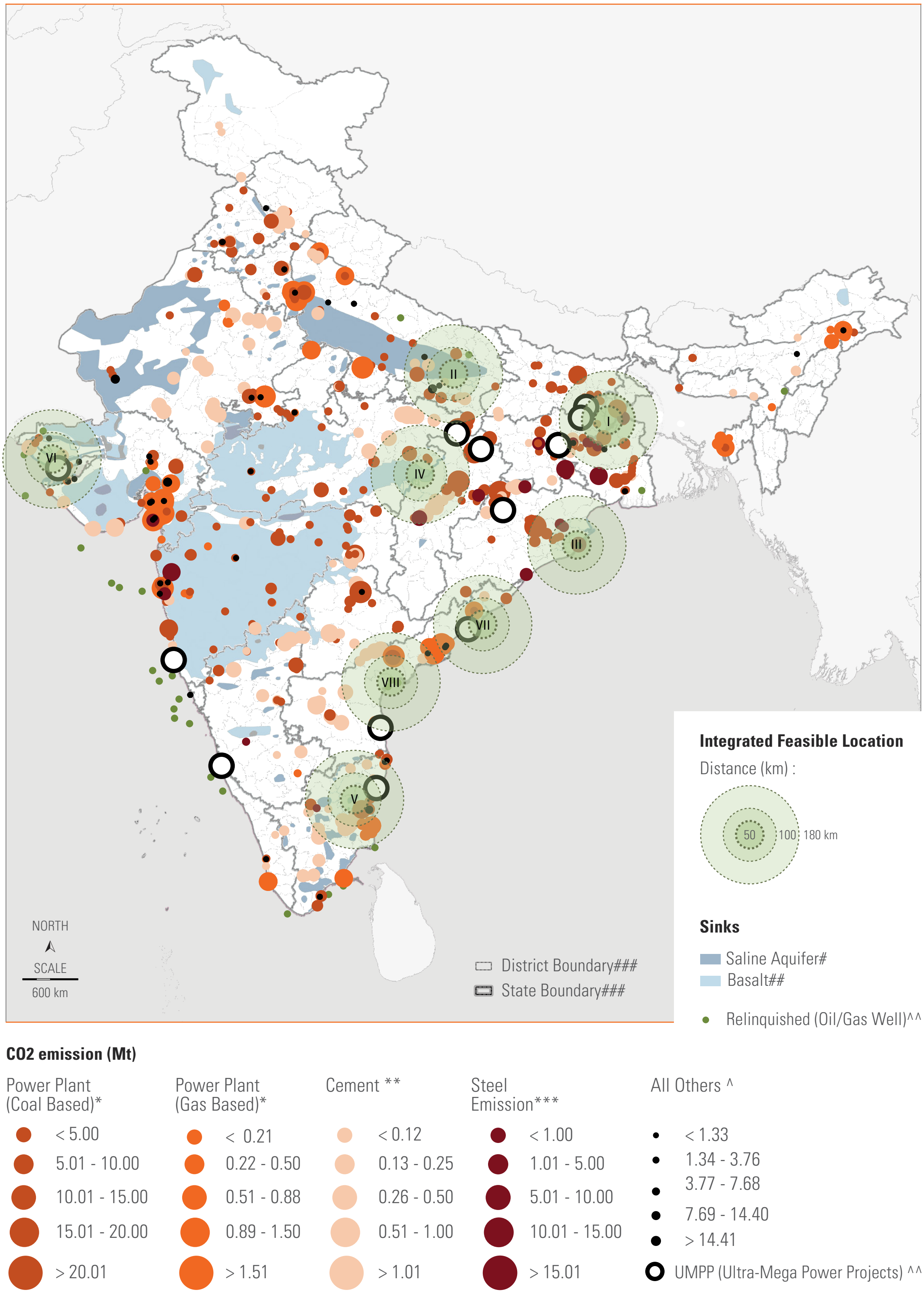
CCUS plays an essential role in 2°C scenarios. The difference in the scenarios is dependent on the time frame when the technology is deployed. In the 2°C_conventional scenario, we observe CCS after 2025. Garg *et al.* (2017) have developed source-sink mapping by plotting the large point sources (LPS) on map and have created LPS location clusters through predictor modelling (**Figure 21**). The large point sources include power plants, and energy intensive industries such as cement, steel, fertilizer and refinery, while the sinks include basalt, saline aquifers and relinquished oil and gas wells. CCS is also being used to explore alternative sources from mines. These include coal-bed methane (CBM), underground coal gasification (UCG), enhanced oil recovery (EOR), coal to gas (CTG) and coal-to-liquid (CTL) (GoI, 2017b; GoI, 2017d; GoI, 2016). Most technologies are still distant options for India for coal to be utilized to reduce emissions. The only current project commissioned is related to enhanced oil recovery (EOR) activities. These technologies can be pushed after 2030-35 under 2°C scenarios for alternative fuel sources. The central government in three-year agenda has stated to support implementation of pilot projects in the next three years (Garg *et al.,* 2017a).

Avoiding stranded assets

The preceding discussion has highlighted numerous risks and uncertainties for Indian coal assets looking forward beyond the next decade. This raises the question of stranded assets and how they can be avoided. This will be an essential aspect of any robust policy package to implement a successful coal transition as part of a 2°C compatible scenario in India.

Stranded assets are defined as "assets (mines, reserves and/or power plants) which are available but not in use". As an economic concept, they are defined as "assets that have been put off or force to face a shutdown even if it has technical and economic life". IEA defines stranded assets as "those investments which have already been made but which, at some time prior to the end of their economic life (as assumed at the investment decision point), are no longer able

Figure 21. Map of large point carbon sources and sinks



Adapted from Central Electricity Authority, 2011: Cement manufacturers Association, 2012**; Joint Plant Committee, 2012***; The Fertilizer Association of India, 2012 and Ministry of Petroleum & Natural Gas, 2012^; Directorate of Hydrocarbon (DGH), Noida, India^^ Infraline 2015^^^; Dr Ajay Singh ppt on Coal Bed Methane and Basalts during CCS workshop at IIM Ahmedabad on 5 November 2014#; Central Ground Water Board Ministry of Water Resources Government of India (2012)##; National Boundaries as per Survey of India#.*

Source: Vishwanathan et al., 2018

to earn an economic return as a result of changes in the market and regulatory environment brought about by climate policy" (IEA, 2013). The most prominent reasons for an asset to be stranded include: lack of demand, availability of better competitive alternative, disruption in continuous supply of fuel and water, lack of sufficient policy and regulatory support, policy shift due to regional/international climate protocols and commitments. Stranded assets in coal and power sector therefore can be categorized as follows:

Stranded coal reserves

In India, total coal extracted since 1950 up to 2016-17 is around 15 Bt. Around 790 Mt of coal was produced in 2016-17. Considering nearly 250 Bt of proven coal reserves with higher geological confidence, and the expected rate of coal exploitation in coming 30 years as per various estimates, not more than 30-40 Bt of coal can be mined before it may be embargoed. Roughly one can say that nearly 220 Bt of coal will remain to be unutilized and the total cost of it would be roughly around 6.7 trillion USD, if we take average cost of coal at Rs.2,000 per tonne (29.54 USD/t). It renders huge coal reserves to be stranded if not put to any alternate use and great socio-economic losses to the nation.

Stranded power plants

Around 222 GW of capacity is coal based out of total 367 GW of installed capacity. Of which around 100 GW of coal based capacity has been added during previous decade. This entire capacity is new and around 70% of it is based on inefficient sub-critical PC technology and vulnerable to techno-economic-regulatory shocks as it is not fully depreciated and has considerable technical life remaining. Stranded assets in power plants are categorized according to physical (resource, pollution) constraints and dynamic of national and international market.

Water shortages. In 2016, India had around 52% of coal based capacity were stranded due to various reasons during certain time of the year,[16] around 45% of these plants were located in water stressed regions. India is severely suffering from water crisis due to increasing urbanization leading to higher demand of water, which has become more repugnant in summers. The incidents of plant closures in summer due to water unavailability have been increasing over the past decade and are observed to worsen during drought years. Government has already issued notification to limit water consumption, however socio-economic studies are required at regional level on shift to dry cooling systems in future to avoid temporary shutdown in water stressed regions.

Coal supply/coal stock issue at plants. Declining renewable energy prices have started to impact the energy dynamics, however it has not directly affected the coal sector yet. Nevertheless, the decreasing prices of PV is making it easier for investor to consider renewable energy as a viable option. The overall cost of power generation has been observed to decrease due to improved coal quality and installation of fuel efficient technologies in the past few years. Nonetheless, additional coal and carbon taxes will conversely increase the overall cost of coal compared to other fuels, making switch to gas and renewables easier in future.

Seasonal phenomenon like smog. There is an emerging trend of rising local pollution leading to smog especially during winters in cities located in land-locked northern regions resulting complete suspension of operations. In 2017, states like Delhi and Odisha have observed unprecedented high levels of local pollutant that have resulted in smog and resulted in numerous health problems along with losses to local businesses, and stalled transportation. One option could be to install new power plant outside current city premises with best available water efficient and air pollution control technologies and quickly phase out old power plants. Another option could be to switch to gas and renewables technologies for electricity.

Stranding due to national market dynamics.

Incidents of non-performing coal assets have increased in the past decade. Coal assets are going to be excessively expensive in view of several factors especially rising concerns for climate change. As discussed above coal will become costly due to increasing production price (increasing production from underground mines and new mines developed with costly capital), coal tax (cess etc.), mandatory FGD installations in plants, CCS retrofits (cost + energy penalty, lowering the net efficiency). Additionally dry water cooling to avoid shutdowns under severe water constraints, reduce fly ash production and management may lead to natural phase down of coal from energy basket (market) in the longer run.

16 The duration differed from a day to six months.

Table 15. Current and projected PLF of power plants

2°C_conventional scenario

	Coal	Gas	Hydro	Nuclear
2015	61%	25%	35%	72%
2020	77%	83%	51%	67%
2030	52%	108%	60%	78%
2040	41%	104%	67%	73%
2050	29%	58%	60%	71%

2°C_sustainable scenario

	Coal	Gas	Hydro	Nuclear
2015	61%	25%	35%	72%
2020	75%	81%	49%	52%
2030	45%	90%	49%	79%
2040	0% *	92%	57%	75%
2050	0% *	94%	66%	74%

** All coal power plants are all phased out by 2038.*

Mandatory component of renewables power in states and favourable economics are making the competition tougher for coal to remain a major fuel in the energy mix. Additionally, subsidies and incentives through renewable energy certificate (REC) and renewable purchase obligation (RPO) for renewable generation are encouraging aggressive expansion.

Moving to 2°C scenario would require the implementation of a managed phase out strategy for unabated coal plant and for related coal mines. **Table 15** shows the importance of this. It highlights that as higher amounts of renewable and alternative energy sources are phased in, the load factor of remaining coal plant declines to make space. This phenomenon has been observed also in countries undergoing a phase in of low-carbon technologies, such as Germany and the United States. It will be important for incumbent coal plant to anticipate and adapt to the risk of declining load factors. This can be supported by changes in plant technology and role in the power system—e.g. moving from base load to peak or balancing roles—as well as by a time limit on operating hours until plants are obligated to retire. These developments would however require changes to power market regulations and market design to anticipate these changes.

This situation is in favour of coal phase down in 2°C scenarios, however on the other hand non-performing gas (due to supply dynamics), nuclear (due to fuel supply, manpower, safety) and renewable (due to performance) assets can pose a major challenge for the sustainable scenario to be a viable/feasible option in the long run.

Stranding due to international market dynamics (International policy implications).

Coal reserves abroad offer attractive, cleaner but expensive (depending on internal market dynamics) proposition and business deals to sell coal. Foreign developed countries having coal reserves and are in the process to de-coal domestic energy systems may attempt to cater energy starved nations at substantially below market prices.

International coal trade may hit the rock bottom before it gets exhausted due the domestic coal phase down policies in energy starved nations. Cheaper coal available in international market would render the domestic coal reserves in-situ stranded for countries such as India in absence of strict import polices.

Some of the private plants such as Mudra power plant have been designed specifically on the basis of imported coal characteristics. It may remain a stranded asset if government plans to impose stringent zero import policy for non-coking coal in the next decade. Consequently, Indonesia, Australia, South Africa and other countries that supply to India will divert their export to nations with coal favouring policies to avoid abandoning their coal mines which is a major portion of their revenue.

Preparing the socio-economic transition

Social, employment and regional economy

Coal brings in significant revenue in the form of royalty for state (sub-national) and cess for central government. Coal production generates local employment and livelihood in the region. It also impacts directly and indirectly its allied businesses such as railways and end consumers (power, steel and cement) in terms of both revenue and employment. A sudden transition will not be favourable to national, state as well as local economy.

Political economy challenges

Policy coherence across sub-sectors of energy such as ministry of coal, power and renewables is essential. The national target to provide energy access to all by 2022 is achievable provided parallel policy instruments are successfully implemented across states. For instance, PLF will improve by phasing out old power plants (implemented policy), installing EE retrofits and new fuel efficient power plants (implemented policy). At the same time, aggressive promotion of renewable energy through grid and decentralised mechanisms by

2030 is in sync with global climate commitment made by India to UNFCCC. Enabling environment through regulatory and economic instruments in congruence with innovative business and financial models by regional/geographic location is the need of the hour to scale up the penetration of the aforementioned technologies. CCUS technologies need central and state government support for pilot demonstration to check if the technology is a viable/feasible option for India.

3.2.4 Uncertainties in 2°C alternative decarbonisation options

The aforementioned scenarios represent alternative visions of how India's energy mix might evolve in the coming decades while following to attain the global 2°C carbon budget. Nevertheless, the feasibility of each of these scenarios reflect implicit hypotheses that could be challenged. For instance, in the 2°C conventional scenario, uncertainties remain about the extent to which CCS could be deployed at the necessary scale to enable the continuation of a significant degree of thermal coal usage in the power sector. Observing the current trends, CCS could be an essential element of Indian energy policy going forward with around 780 Mt mitigation possible each year at under \$60/t-CO_2 and around one Bt at \$75/t-CO_2 (Garg *et al.*, 2018). There still remain questions about its social acceptability and geological uncertainties. There have been proposals for enhanced oil recovery, nonetheless there have not been any industry level large CCS implementation so far. This scenario also assumes an enhanced role of biomass in the power sector than the 2°C sustainable scenario, consequently managing water and biomass supply chain remain the main source of uncertainty for this action (Garg *et al.*, 2015).

The 2°C sustainable scenario explores alternative options, including a stronger role for nuclear power and natural gas in energy supply-side complemented by with reduction in end-use energy consumption through behavioural change and energy efficiency measures on demand side. Each of these options is also accompanied with their respective uncertainties and risks. For instance, a shift to natural gas is feasible in principle given large suppliers in India's neighbourhood. The uncertainty lies in increased energy supply risks as 80% of gas is imported and infrastructure security risks for transport routes pass through Afghanistan and Pakistan (CII, 2016; Dhar *et al.*, 2010). Significant LNG and distribution infrastructure are required to be built across country. Indian nuclear power also has its share of risks and uncertainties. This mainly involves international sanctions (U.S.–India Civil Nuclear Agreement, India's bid for entry into Nuclear Supplier's Group), and national factors (feasibility and success of India's pressurized heavy water reactor programme). Some experts have indicated total nuclear power potential to be around 63 GW as against the current capacity of 6.7 GW (Grover, 2017).

Similarly, uncertainties also exist with respect to the future development of renewable energy technologies globally. For instance, innovative offshore wind or tidal solutions could potentially be an important complement to onshore wind and solar in India, depending on cost and the speed at which these industries can be developed internationally. Higher shares of renewables penetration will also need to be accompanied by advances in locally suitable storage technologies.

It should thus be noted that ultimately the two 2°C compatible scenarios serve to highlight the envelope of alternatives solutions possible for transitioning beyond unabated coal. These should arguably be pursued as part of a portfolio of solutions that could collectively enable India to envision a more sustainable and 2°C consistent future for its energy systems.

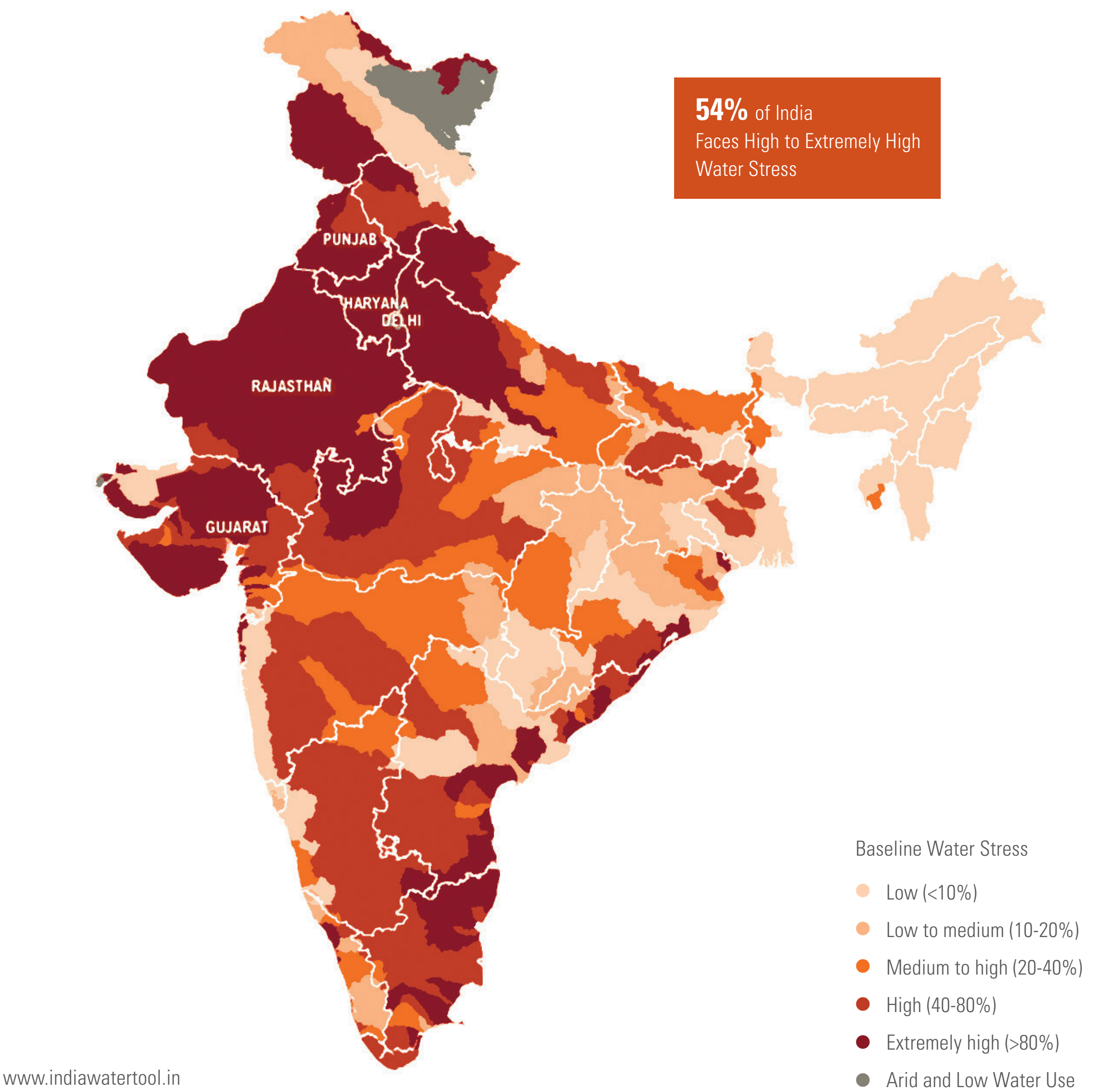
4. National case study: Water-energy nexus in thermal power plant*

* This section is a combination of two working papers. Please cite this section only after permission from the authors.

4.1. Introduction

Water is a critical resource integral to life and the socio-economic development of a country such as India. It has been estimated that the demand for water in India will exceed its supply by 2020 and will be 50 per cent more than its supply by 2030 (WRI, 2015). **Figure 22** presents the water stress level in different states of India. Northwest regions in Rajasthan, Punjab, Haryana and parts of Gujarat as well as parts of Maharashtra, Karnataka, Andhra Pradesh and Tamil

Figure 22. Water Stress in India



Source: World Resource Institute (2015).

Note: In this context, stress is defined the as ratio of total water withdrawals to the total water supplied in the state.

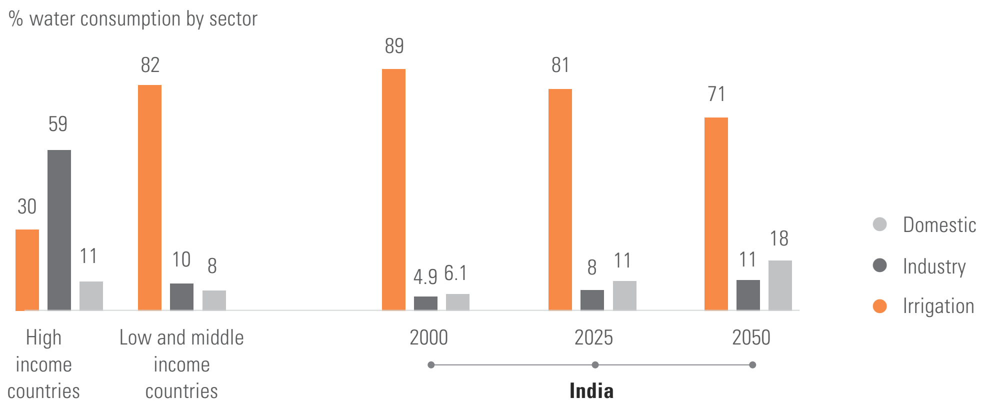
Nadu are observed to be located in high to extremely high water-stressed regions. Increasing population and transition of India towards more urbanized and industrialized areas has shifted and will shift the share of water consumed by irrigation to industrial and residential uses (**Figure 23**). However, the actual volume consumed by irrigation remains above 80%, while an increase is observed both surface and ground water consumption in residential and industrial sector (**Figure 24**). There is no data available at national level on the water consumed for commercial and recreational purposes.

In summer of 2016, growing water shortages forced to shut down major thermal power companies in Maharashtra and West Bengal. 91 major reservoirs which store 157.8 billion cubic metres (BCM)[17] across the country contained only 19% of the total 'live'[18] storage water capacity impact power generation from hydropower plants (Bhaskar, 2016; Sally, 2016). Floods have also affected the generation through hydropower projects especially in north India. So, extreme climates have influenced and will influence electricity generation not only from fossil fuel (thermal) but also from cleaner sources (hydro) of energy across the country. The extreme conditions also put stress on ground water.

17 These resevoirs store 62 per cent of the live storage capacity that is estimated to have been created in India.

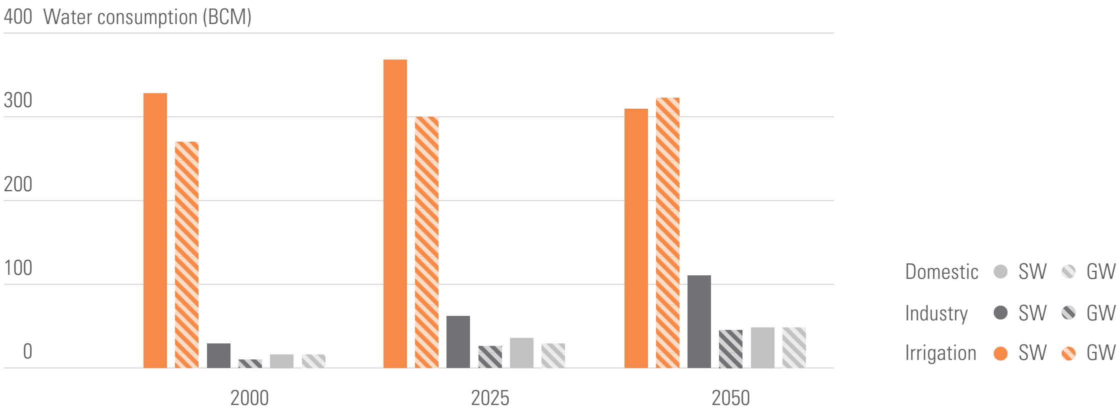
18 'Live storage' is the portion of a reservoir that can be utilised for flood control, power production, navigation and downstream releases.

Figure 23. Water consumption in high, middle and low-income countries and India (2000-2050, sectoral %)



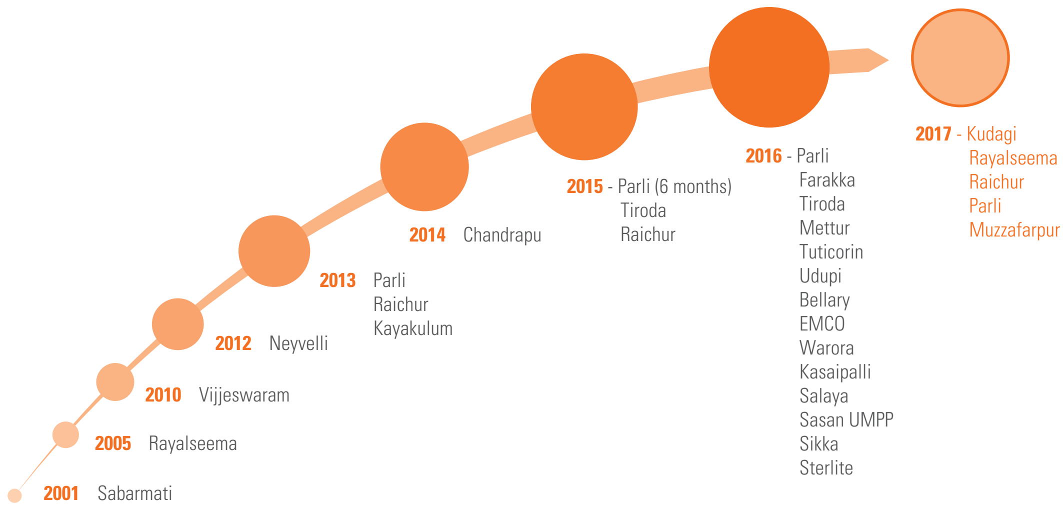
Source: IWMI (n.d.)

Figure 24. Sectoral surface and ground water consumption in India (2000-2050)



Source: AQUASTAT (2010)

Figure 25. Temporal power plant shut down (2001-2017)



Source: Numerous sources (newspaper articles, government documents, Lok Sabha Question documents)

Years 2002, 2004, 2009, 2014, 2015 and 2016 were declared as drought years in various parts of India (IMD, 2017). **Figure 25** present the trend in shut down of power plants since 2000 that do not always correspond to extreme conditions, however there is an observed increase in frequency of shut downs that amount to 1-2 days to 6 months due to water shortage.

As of March 2018, 59% of India's power capacity is coal, which produces more than 75% of total electricity. Almost all these power plants rely on freshwater for cooling purposes. Since 2013, there is an observed increase in power plant shut downs due to water outages amounting to 19.5 billion units (from 2013-14 to 2017-18) of power loss (GoI, 2018d). The loss was observed to be higher during drought years. This case study attempts to understand the magnitude of water availability issues especially on coal power plants, which lead to increase in stranded assets and loss in billions of dollars in revenue in future.

4.2. Methodology

Data has been collected on 150 existing and 100 future coal power plants. Past generation and water consumption data has been integrated from numerous databases and reports (CMIE, CEA, NTPC, CSE, GoI) from 2006 to 2017 for existing coal power plants. Estimates on water withdrawal for energy sector vary due to lack of data on water consumption and type of cooling technologies at plant level.

Figure 26 presents the soft-linking of availability of water from climate and hydrological models at basin level to the newly developed W-E AIM/Enduse bottom-up optimization model for India. This improves the dynamics of the water resource supply curve, which is used as a resource constraint in the techno-economic AIM/Enduse W-E model to understand how it impacts both energy supply and sectoral demand of water. **Figure 27** the schematic of data (energy and water) flow between models.

We have profiled the water requirement in more than 250 existing and future coal power plants according to ownership, cooling systems and water-source. Climate-hydrologic models have been used to estimate the water budget for 18 Indian sub-continental basins using the Variable Infiltration Capacity (VIC) model from 1901 to 2100 (Shah and Mishra, 2016). The data from the VIC model is routed to the rivers and canals near the possible large point sources (in this study power plants) to help estimate the daily stream water flow (Lohmann *et al.*, 1998). Water availability has been estimated using Water Available Resource Model (WARM) from 2000 to 2050 using MATLAB and R software. The data estimated from 2006 to 2016 is validated using the water data collected from individual plants and basin stream flow data for the same period, to check for accuracy of the estimation from the model.

Figure 26. Conceptual framework water resource availability model to AIM/Enduse model

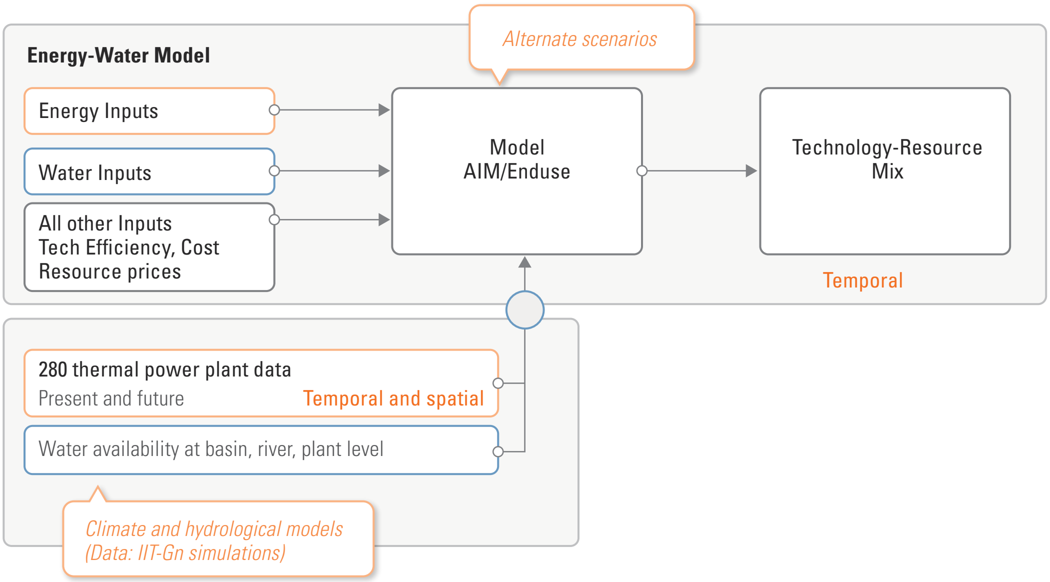
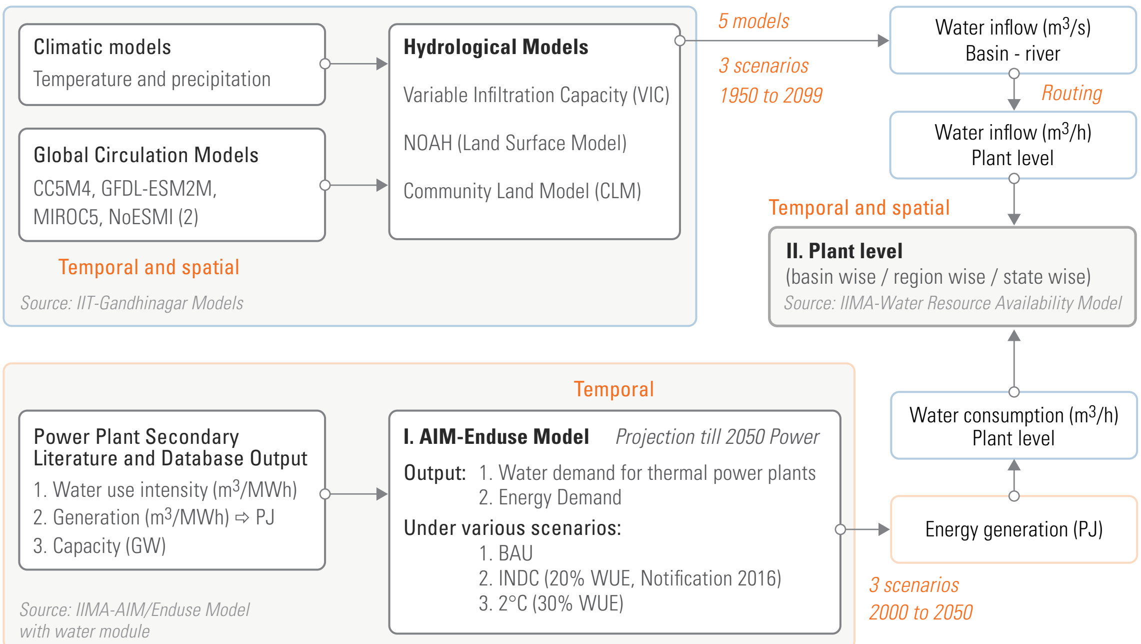


Figure 27. Schematic representation of available water projections—water availability resource model (WARM) and AIM/Enduse model



4.3 Results

In thermal power generation, water provides cooling and other process-related needs like ash handling, coal washing etc. Hydropower plants harness the momentum of water for electricity generation. 'Almost 70% of India's industrial water is consumed by thermal power plants alone' (CSE, 2013). Thermal power plants (including fossil-fired and nuclear) require some form of cooling and, within the power sector in India, coal-fired power plants are responsible for around 95% of total water withdrawals, the rest being split between gas-fired and nuclear power stations. The cooling technology used together with the overall efficiency of the power plants determines the amount of fresh water that is withdrawn from local sources (water withdrawals) and the amount that is withdrawn but not returned to the local water basin (water consumption) (IEA, 2012).Thermal plants consume more water than hydropower plants which mostly are water withdrawing units. India's coal-fired power sector has already faced constrained water availability lately. In recent years, water shortages have caused shutdowns of coal based thermal power stations such as Raichur, Rayalseema, Farakka and, Parli plants (CEA, 2015-17).

Figure 28 presents the power plants according to the cooling systems, while **Figure 29** shows the source of water for cooling systems state-wise. It is observed that 84% of the power plants in the study have closed looped systems. There are still 6% plants that are once-through and need to shift to closed looped or dry cooling systems. 87% of the plants have water sourced from a nearby reservoir or river, while there are plants especially in the coastal regions sourcing the water from sea. It is observed that water-stressed regions also use ground water as alternative resource. Delhi is one of the cities (union territories) that uses recycled water along with some plants in Tamil Nadu. With draft notification to increase use of recycled water, power plants are looking at options to install recycling plants nearby, instead of building transportation infrastructure to convey recycled water to power plants across cities.

Figure 30 presents the spatial locations of the power plants selected for the study and **Figure 31** presents the some of the power plants that were shut down between 2006 and 2017. It can be observed a few of the power plants all in medium water-stressed region while Farakka in the Ganga basin is located in low water-stressed region. Three units of Farakka thermal power plant were shut down for the first time since its inception which resulted in Eastern India faced a power shortage of around 1,500 MW enough to light 38,000 households (Das, 2016).

From 2016-17, 24 units with installed capacity of 9.5 GW were affected due to raw water shortage related problems which resulted in a total loss of 7.15 billion units (at 80% PLF). It was observed that closure of units due

Figure 28. Power plants - Cooling systems

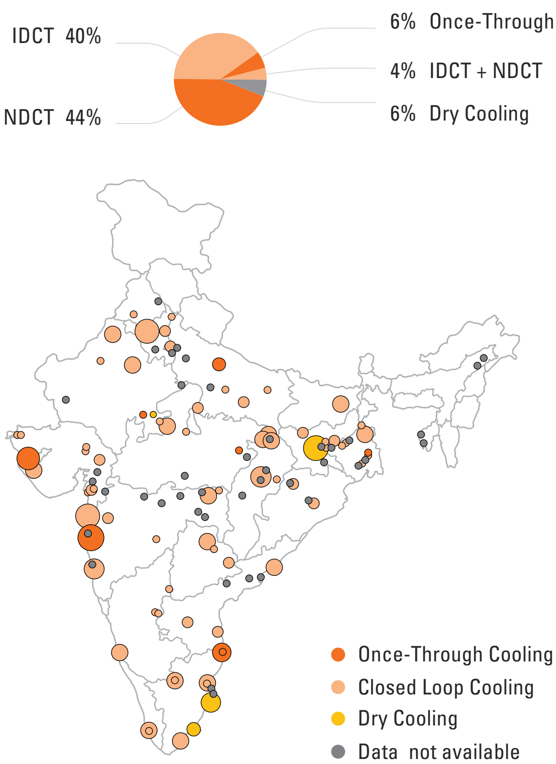
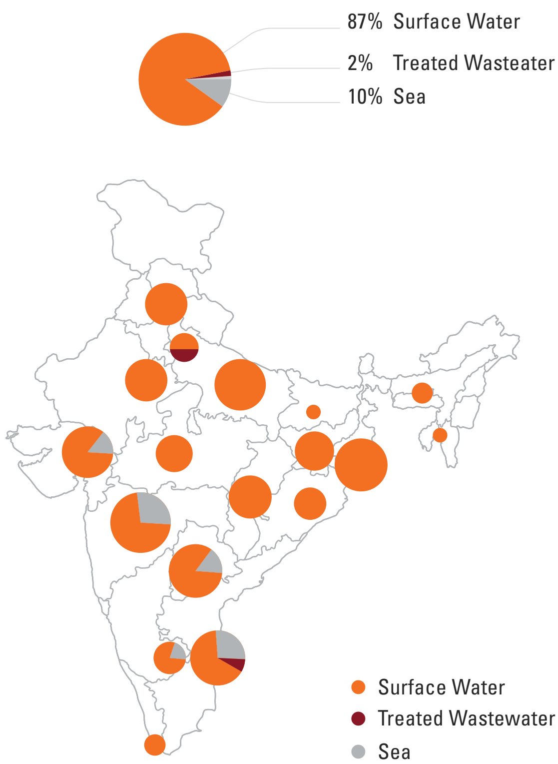
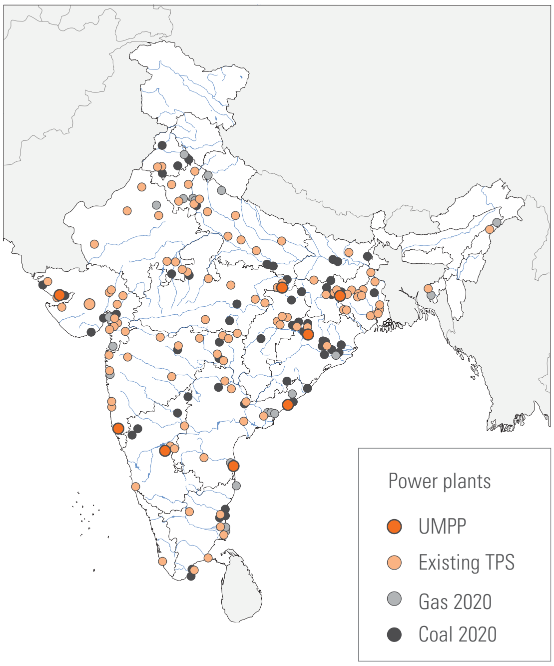


Figure 29. State-wise - Water source



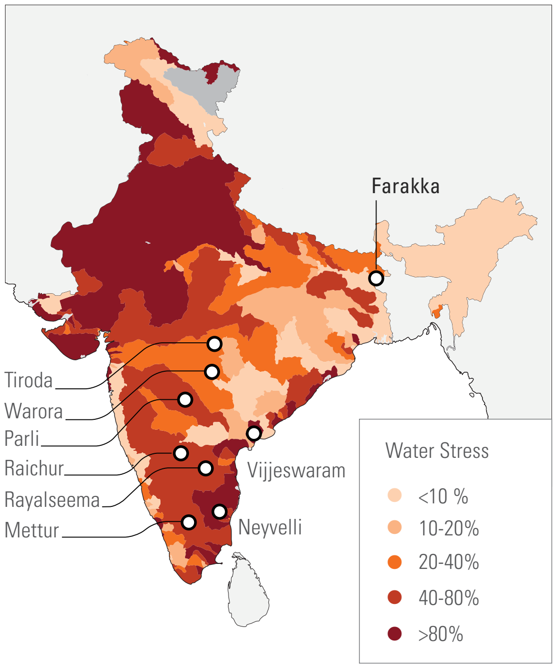
Source: World Resource Institute (2015).

Figure 30. Power plants in this study



Source of Rivers Map (WRIS 2011)

Figure 31. Spatial power plants shut down (2006-17)



Source of Water Stressed Map (WRI 2015)

to water shortages were referred as reserve shut down, low schedule, maintenance issues in CEA documents. In such cases, the data were supported by newspaper articles and other reports. In response to a question in Lok Sabha on March 16, 2017 in relation to shortage of water in thermal power station, Mr. Piyush Goyal, Minister of Power, Government of India, provided the following **Table 16** about the number of units which had to undergo shutdown during certain periods due to non-availability of water.

One GW power plant consuming water at 10 m^3/MWh running at 90% PLF for 350 days consumes 75.6 million m^3 of water per year. This is equivalent to irrigating 15-125[19] thousand hectares of land or nominal water requirement for about 1.6[20] lakh people per year. A majority of coal and gas power plants in India by ownership (**Figure 32**) and by age (**Figure 33**) are above 4 m^3/MWh (or 4 litres/kWh) water consumption limit set by the government. A lot of water could be diverted to building (especially residential) sector if the power plants will comply with the water consumption notification by 2019.

Figure 34[21] presents water availability under RCP 4.5 and RCP 8.5 along with water consumption trend (in current water consumption patterns) for the power plant from 2006 to 2045.[22] It projects the frequency of shut down due to water availability in Rayalseema power plant located in the Pennar Basin (Andhra Pradesh). If the water availability trend (RCP 4.5 scenario, RCP 8.5 scenario) is lower than water consumption trend, it is considered probable shut down. The next step will be to observe if stricter norms (draft notification 2017) and/or shifting to

Table 16. Generation losses for power plants shut down due to water scarcity during 2013 to 2017

Year	Number of Units	Loss of generation in million units*
2013-14	16	5253
2014-15	9	1,258
2015-16	15	4,989
2016-up to Feb 2017	21	5,870

Source: GoI (2018d) *Note: * One unit = kilo watt-hour*

19 Assuming 600-5000 m^3 required to irrigate land.
20 Assuming 135 lpcd (litres per person per day).

21 This figure is work in progress output from an ongoing study on impact of water on thermal power plants for 2016-2045. Please do not cite this figure without authors' approval.
22 This part is a work in progress to illustrate water availability projections for about 250 power plants. (Please do not cite this figure without authors' approval.)

Figure 32. Current power plant water consumption (by ownership)

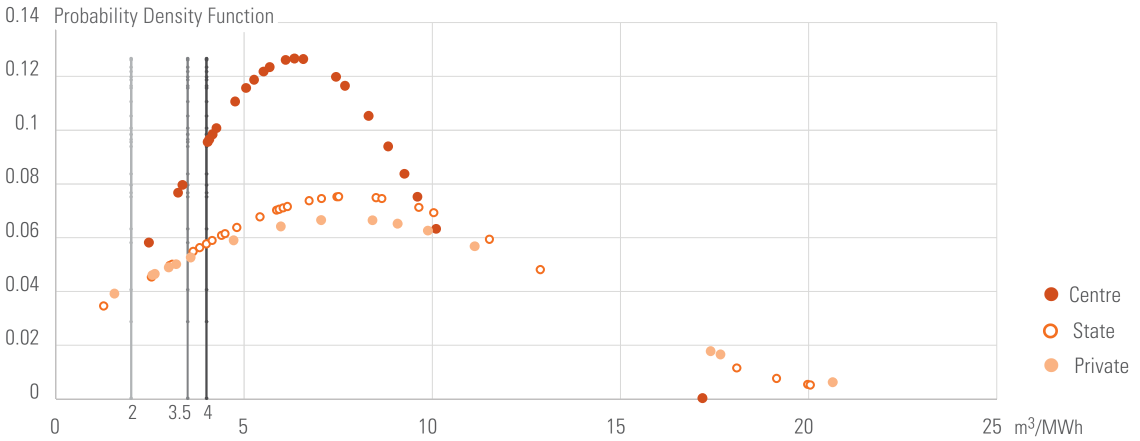


Figure 33. Current power plant water consumption (by age)

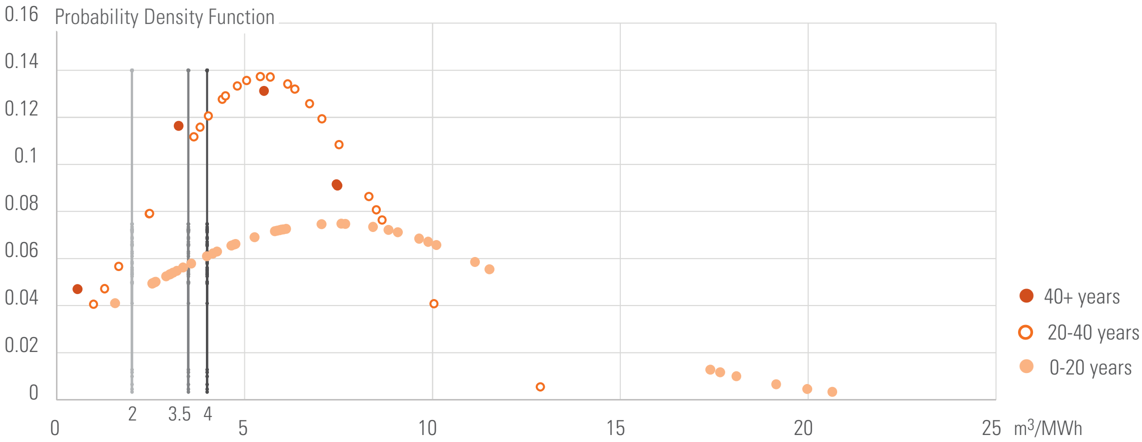
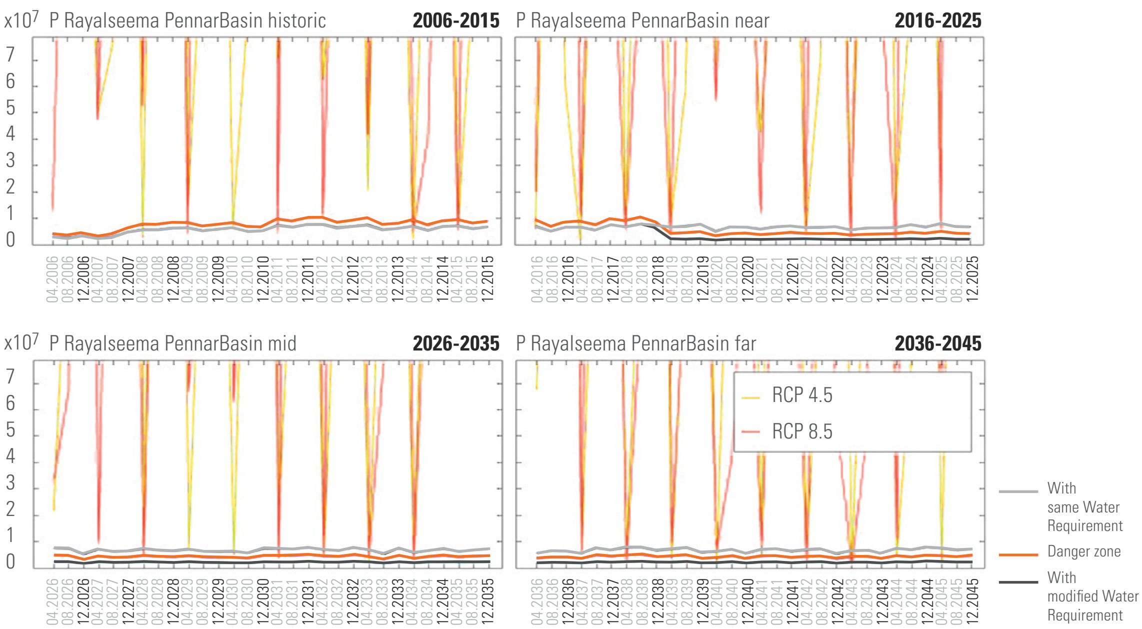


Figure 34. Rayalseema shut down trends in historic, near, mid, and far timeframes



X | Apr=PreMonsoon | Aug=PreMonsoon | Dec=ProMonsoon hybrid cooling and dry and systems. This modelling approach can be useful to assess current and future water imbalances between water supply and demand at plant level as presented in **Figure 30**.

4.4 Implications

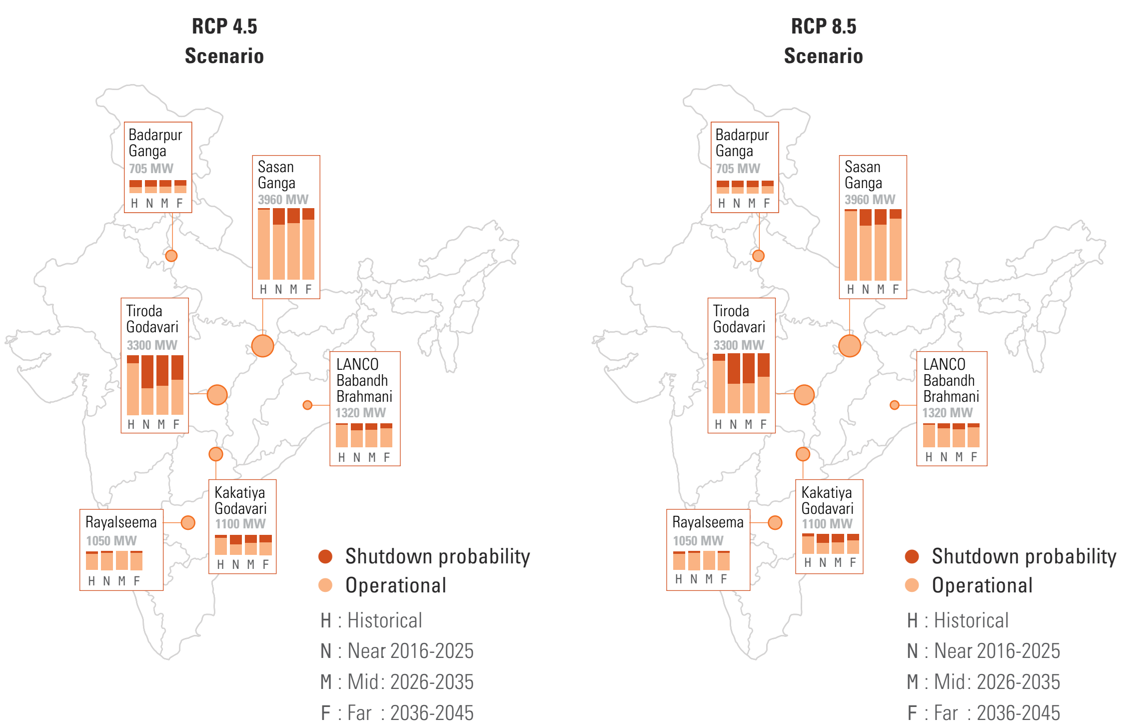
With growing population, urbanization, and industrialization, the demand of water will increase substantially in future. The limited supply in the availability and accessibility of fresh water, will lead to widening of the demand-supply gap across major end-use sectors in future.

Additionally, there is an observed growth in competition and conflict for freshwater, between not only power and industrial sectors but also agriculture, which is a core sector for food security. Furthermore, these power plants will face acute water challenges due to varying and uncertain weather across the country.

In 2016, a few of the power plants (such as Farakka) were located in water-abundant areas and while others are located in water-stressed areas. So, if the current scenario continues the coal thermal power plants will face water availability challenges. The existing along with new power plants commissioned, being installed will have a high probability to become more vulnerable. One GW of power plant shut down for a day, faces a loss of approximately INR 10 crore (USD 1.5 million) in revenue (Greenpeace 2017). **Figure 35**[23] presents the probable shutdowns in selected existing power plants in near (2016-2025), mid (2026-2035) and far (2036-2045) for RCP 4.5 and RCP 8.5 scenarios. This kind of information can be used to avoid increase in stranded assets. This impacts the subsequent revenue, hence planners and policy makers need to review the upcoming and planned power plants in locations experiencing historical shut-downs and high-water stressed areas.

23 This figure is work in progress output from an ongoing study on impact of water on thermal power plants for 2016-2045. Please do not cite this figure without authors' approval.

Figure 35. Probable shutdowns in selected existing power plants in near (2016-2025), mid (2026-2035) and far (2036-2045) for RCP 4.5 and RCP 8.5 scenarios



5. Conclusions

India is one of the key nations that is and will be looked upon to lead the climate actions by example along with Europe and China. As India moves towards a crucial decade, planning of the future infrastructure and technology projects plays a crucial role; as this decision will lock in its emission pathways for the next three decades. Setting international carbon budget as boundary conditions, along with pledge made to fulfil the Paris Climate Change Agreement it has been observed that India can better its current Nationally Determined Contribution. There is still an enormous scope of improvement for India to achieve low-carbon, sustainable growth. The government, associated ministries, public as well as private sector need to synchronize between policy and action to look after not only energy security but also climate security.

Three detailed transition pathways have been considered in order to discuss on alternative roadmaps to move towards a low carbon economy that is consistent with 2C stabilization targets (**Table 5 and 6**). AIM/Enduse modelling framework (**Appendix C**) has been used to delineate the optimized energy mix, and estimate the final energy demand and subsequent CO_2 emissions. The report addresses key debates held at international and national level on a) revision of current NDCs, b) the future of coal in Indian energy systems, c) its influences on international coal trade, d) possibility of resulting stranded assets, and e) impact of external variables such as water on coal-related assets.

Revision of NDCs

The Facilitative Dialogue of 2018 re-evaluates the progress of each country and will subsequently request them to revise NDCs and raise their overall ambitions to mitigate GHG emissions. NDC scenario needs to be implemented need to entail mitigation and adaptation strategies in coal, power and major energy intensive sectors. Table B lists the revised NDC targets by raising the current GHG emission reduction targets for NDC as well as contrasting 2°C scenarios. Aggregate energy and carbon emissions for NDC, and 2°C scenarios and associated indicators are summarized in **Table 7** and **Table 9** respectively.

Section 3.2 detail the policies required to be implemented by coal sector for NDC and to move towards 2°C alternate futures. Major strategies include a) improve coal quality to increase energy efficiency of existing production capacity, b) coal pricing and c) coal cess and carbon tax. Similarly, power sector polices that need to be stringently followed include a) retiring older, inefficient coal power plants, b) installation of efficient technologies in the middle aged thermal power plants to increase thermal efficiency along with advanced resource efficient technologies in new and upcoming plants to diminish the impact of infrastructure lock-ins, c) enhancing renewable energy penetration for initiating effective coal technology transitions in mid and long terms.

While the above policy measures will be important to ensure the achievement of India's NDC, both coal and power sectors may probably be strongly affected by other natural, man-made and/or policy-related constraints in the coming decade. These consist of competition for water resources with other sectors, concerns about fly-ash disposal, local air pollution, and land degradation.

Future of Coal in India

Section 3.2.3 details the steps taken according to selected deep decarbonization pathway. These actions need to emphasize more on:

- For Both 2°C scenarios
  - Improving efficiency of the existing coal fleet
  - Scaling up new and cleaner fuel options
  - Demand reduction in the end-use sectors through dematerialization, recycling, reuse and changed behaviour
- For 2°C_conventional scenarios
  - Deployment of CCUS as required and feasible in both power and industry sector
- For 2°C_sustainable scenarios
  - Increase in gas power generation
  - Increase in nuclear power generation
  - CCS required in industry sector

With limited domestic reserves of coking coal, other conventional fuel such as oil and gas, and shift to new, cleaner and renewable forms of energy from coal in addition to resource constraints (such as water, land) and local pollution, the coal and associated businesses/ infrastructure lock-ins are and will be facing challenges in the coming decades. These include technological (grid integration, storage for renewables), economic (low returns in solar), socio-economic and socio-political (coal transitions) levels.

International Trade

On international trade front, even if the central government retains the suggested zero-import policy, India will still need at least a minimum of 100 Mt of steam coal due to demand from its import-based power plants. Assuming, the former (import constraints) and latter (coking coal production constraint), **Table 12** presents the estimated production of non-coking and import values of coking coal under 2 C scenarios. Due to complete phase down of coal in power sector, the overall demand of steam coal reduces by 8% in 2C_conventional and by 59% in 2C_sustainable scenario over INDC scenario.

Stranded Assets

Stranded assets in the form coal reserves and coal based power plants will increase as consequence of selected alternate pathways. About 220 billion tonnes of coal will remain to be unutilized and the total cost of it would be roughly around 6.7 trillion USD, if we take average cost of coal at Rs.2000 per tonne (29.54 USD/t). Around 100 GW of coal based capacity has been added during previous decade. This entire capacity is new and around 70% of it is based on inefficient sub-critical PC technology and vulnerable to techno-economic-regulatory shocks as it is not fully depreciated and has considerable technical life remaining. Stranded assets in power plants have also been categorized according to physical (resource, pollution) constraints and dynamic of national and international market. Therefore, both coal and power sectors need to develop a coherent strategy for future energy systems to manage risks and avoid stranded assets.

In addition to increase of stranded assets, the feasibility of each of these scenarios reflects implicit hypotheses that could be challenged. Uncertainties will be observed at supply level depending on the type of fuels (natural gas import, nuclear fuel production/import and supply chain), future development of renewables including lack of storage, in addition to social acceptability and geological uncertainties of CCS.

Another important facet that has not been touched upon in the current report but will play an important role is studying impacts of coal transitions from social, political as well as economic perspective at regional level.

Impact of water resources on coal-based power plants

Water will become one of major cause (in addition to local pollution) for temporary shutdown of coal power plants rendering them stranded. The power plant owners need to upgrade their cooling systems, improve the plant efficiency in addition to monitoring their daily water availability data. Furthermore, the specific water consumption notification in 2017 requires to be implemented by 2019. The existing and forthcoming power plant owners need to be prepared for risk due to water access/availability (climate driven and/or man-made) in near and mid-terms. Additionally, future studies need to look into cost-benefit analysis of shifting to dry-cooling (which brings in energy penalty) in comparison to water-less, and/or water efficient source for power generation (such as renewables).

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Appendix

APPENDIX A

Table A1. Output per miner shift in tonnes for open and underground mines

Year	OMS (Open Cast)		OMS (Underground)		OMS (Overall)	
	CIL	SCCL	CIL	SCCL	CIL	SCCL
2006-07	8.00	9.50	0.71	0.90	3.54	1.91
2007-08	8.60	10.76	0.73	1.02	3.79	2.10
2008-09	8.85	10.60	0.76	1.05	4.09	3.01
2009-10	9.48	10.71	0.78	1.08	4.48	3.36
2010-11	10.06	11.98	0.77	1.10	4.74	3.59
2011-12	10.40	13.26	0.75	1.10	4.92	3.94
2012-13	11.68	11.87	0.77	1.13	5.32	3.14
2013-14	13.16	11.10	0.76	1.12	5.79	3.86
2014-15	14.63	12.14	0.78	1.10	6.50	4.20
2015-16	15.28	13.78	0.79	1.25	7.11	4.20

APPENDIX B

The globally accepted standard practice for pricing of coal is GCV based pricing but in India Useful Heat Value (UHV) pricing was prevalent. On the basis of various UHV ranges, non-coking coal was graded. It is suffering from great deficiency of wide band of calorific value. Several complaints have been received by consumers that coal companies are supplying coal at the lower of the band and charging the notified price for the grade. Due to wide variation in bands suppliers were erroneously manipulating the grade and kept at the bottom of the band. This situation called for more objective and transparent pricing mechanism based on quality of coal means consumer will only be charged as per the quality. In the GCV system, the consumer has the benefit of paying for the specific quality of non-coking coal received and the producer has an incentive to improve the quality of his production. Historical background:

The basic premise of UHV lies on the subtraction of ash penalty from the Gross Calorific Value. The UHV defines energy (kilo calorie) in every kilogram of coal after discounting the moisture and ash content. The empirical formula proposed by CFRI for both low and high moisture coals. The cumbersome procedure for calculating UHV was obviated by using two formulae:

For high moisture coals-

UHV = 8,900 – 138(A+M)

A and M are ash and moisture percentages at 60% RH & 40C

For low moisture coals-

UHV = 8,900 – 138(A+M) – 150(19.0-VM)

A, M, VM are ash, moisture and volatile matter percentages on as analysed basis.

But this procedure for grading of coal has always been debated since beginning. GCV based pricing is advocated by experts principally for two reasons, first inherent deficiencies in the grading pricing structure and second, to make it compatible with international practices. UHV parameter is used to determine the grade and hence the price of coal. When this empirical formula was adopted for grading the coal about 85% of the production were used to come from the underground mines which was superior in many ways than the coal mined from opencast mines presently. Therefore the values of constants (8,900 and 138) in the formula which were relevant to then available quality of coal has changed significantly under present conditions and became irrelevant. Hence, the calculation would not yield the justified grading of coal. Coal prices should be made fully variable based on Gross Calorific Value (GCV) and other quality parameters. CIL accordingly notified the prices of non-coking coal based on GCV vide its price notification dated 31.12.2011 applicable w.e.f. 01.01.2012. 7 grades of non-coking coal under UHV classified into 17 grades under GCV. The top end of the GCV range taken at 7,000 kCal/Kg and the bottom end at 2,200 kCal/Kg. The GCV band width for the purpose of pricing considered to be 300 kCal/Kg meaning that the price will remain same within a particular bandwidth. The idea behind reducing the band width to 300 kCal/Kg is to incentivize the improvement in supply quality of coal to the consumer and commensurate realization for the coal company. This is expected to encourage efficient use of coal and promote use of washed coal. (MoC, 2014).

Under the UHV system of grading and pricing, the prices for a particular grade were different for different subsidiary coal companies of CIL and under the GCV regime w.e.f. 01.01.2012 a uniform price were kept for a particular GCV band across all the subsidiary coal companies of CIL.

APPENDIX C

Model set-up and drivers[24]

The AIM/Enduse model is a bottom-up optimization model built on a disaggregated, sectoral representation of the economy, it provides a detailed characterization of technologies and fuel based on their availability, efficiency levels and costs. (Figure B1). The model is driven by exogenous sectoral service demands and assumes that the agents of change (in this case policymaker and stakeholders) are myopic in nature. Hence, it is assumed that the agents see and examine only the alleged dangers of rising CO_2 levels in the atmosphere while ignoring the potential harmful effects of managing for CO_2. The model accounts for final energy consumption and CO_2 emissions in end-use sectors based on actual energy use and the way energy services are satisfied by energy device. It calculates the future demand for energy services in different sectors and determines the optimal set of technologies that can be used to satisfy the service demand through total cost optimization. Based on the energy consumed by the selected set of technologies, the model estimates the future energy consumption of various devices, as well as of the system as a whole. The model uses annual discount rate which is determined exogenously so as to fit the rate of payback period exogenously. Unlike other bottom-up techno-economic models, the cost of device/technology/system is annualized (Shukla, 2013), therefore it can also capture the technology transitions that have been observed due to the rapid policy changes in the past decade.

In the AIM/Enduse model, the technology selections in a country's energy-economy-environment system are made using linear optimization that meets the exogenous service demand at the least cost while satisfying techno-economic, emissions- and energy-related constraints. However, the AIM/Enduse model only provides a broad framework, and the analysis of a sector or a country requires detailed model development to facilitate the analysis of the energy consumption, technology choices and emission trajectories in a given context (Shukla, *et al.*, 2004; Kainuma, Matsuka, and Morita, 2003).

24 This section has been published as a book cited as: Vishwanathan, S.S., Garg, A., Tiwari, V., Kankal, B., Kapshe, M., Nag, T. (2017). Enhancing energy efficiency in India: Assessment of sectoral potentials. Copenhagen: Copenhagen Centre on Energy Efficiency, UNEP DTU Partnership. ISBN: 978-87-93458-13-0.

The model has been set up for India for five major sectors and their respective services, technologies, reference years and discount rates. These sectors are power, industry, buildings, transportation and agriculture. Multiple services in each sector have been examined to provide a better understanding of the sector. For example, fifteen industries have been selected to represent the industry sector, while passenger and freight characterize travel demand in the transport sector. Each service is further disaggregated based on the mode of transport used, such as road, rail, air and water. The technologies considered in the model range from those currently available to those that are still in the research and development stage. The new technologies and their years of introduction are based on various Indian and international reports and expert opinions.

Exogenous service demands trigger decisions regarding technology selection based on information on costs, which in turn define the energy mix and CO_2 emissions resulting from information on the emission characteristics of fuels, materials and technologies. The methodology for demand projection used by Kapshe *et al.* (2003) has been adapted in this study along with a few revisions. The maximum shares for the base year are taken from various government and research publications. We estimate the shares for the projected years based on population, economic growth, sectoral transformation and government planning (using current and future policies). The model provides scope to present energy transitions in the economy through energy demand of various services and share of technologies. The AIM/Enduse model contributes to addressing these issues by taking into account the shift in technology choices due to the introduction of efficient policies. In the present study, the model has been used to support policy formulation by quantifying outputs.

Various driving forces influence a combination of parameters based on which supply and demand for a service can be determined (Shukla, Rana, Garg, Kapshe, & Nair, 2004). These include:

Sectoral demand

This sectoral demand explains the growth in service demand in each sector based on socio-economic drivers such as population and economic growth. This also depends on the service demand of each sub-sector or industry in every sector. 'Energy service' refers to a measurable energy need within a sector that must be satisfied to supply an output from a device. It can be defined in either tangible or abstract term.

Energy

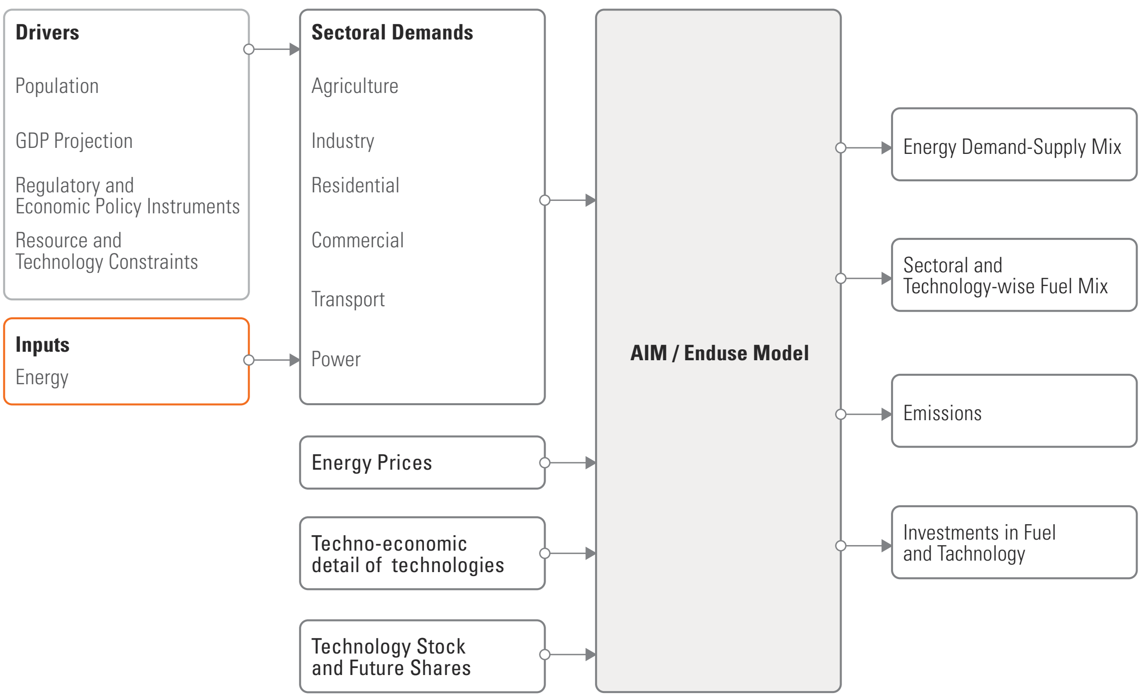
Energy parameters are included in the model for each technology, in the form of specific energy consumption for each technology, the data for which were collected or estimated. As the model links energy supply with demand, electricity supply and demand are consistent across sectors.

Technology

The model selects a set of energy technologies in order to minimize the total annual cost of fulfilling the energy service demand under circumstances of energy and emission constraints, and technology diffusion. The payback period represents the time required to get back the investment in a project. The changes that are taken into account simultaneously in the AIM/Enduse model include: 1) selection of a new technology at the end of the service life of an older technology, or to meet an increase in service demands; 2) improvements in the energy efficiency of an existing technology; and 3) replacement of an existing technology by a new technology.

Vishwanathan et al. (2017) presents in detail the afore-mentioned driving forces used in the current study.

Figure C1. Model structure of AIM/Enduse model



Source: Modified from Shukla, et al., 2004; Kainuma, et al., 2003, Garg et al., 2017c, Vishwanathan et al. 2018.

COAL TRANSITIONS: RESEARCH AND DIALOGUE ON THE FUTURE OF COAL

COAL TRANSITIONS is a large-scale research project leaded by Climate Strategies and The Institute for Sustainable Development and International Relations (IDDRI) and funded by the KR Foundation.

The project's main objective is to conduct research and policy dialogue on the issue of managing the transition within the coal sector in major coal using economies, as is required if climate change is to be successfully limited to 2°C.

THIS PROJECT BRINGS TOGETHER RESEARCHERS FROM AROUND THE GLOBE, INCLUDING AUSTRALIA, SOUTH AFRICA, GERMANY, POLAND, INDIA AND CHINA.

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