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Future CO_2 emissions and electricity generation from proposed coal-fired power plants in India

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Key Points:

- India's currently proposed coal plants exceed its future projected energy demand
- India will have a hard time meeting its climate goals given its current coal plant proposals
- India's current coal proposals risk either locking out lower-carbon energy and/or being stranded assets

Supporting Information:

- Appendix S1

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Abstract With its growing population, industrializing economy, and large coal reserves, India represents a critical unknown in global projections of future CO_2 emissions. Here, we assess proposed construction of coal-fired power plants in India and evaluate their implications for future emissions and energy production in the country. As of mid-2016, 243 gigawatts (GW) of coal-fired generating capacity are under development in India, including 65 GW under construction and an additional 178 GW proposed. These under-development plants would increase the coal capacity of India's power sector by 123% and, when combined with the country's goal to produce at least 40% of its power from non-fossil sources by 2030, exceed the country's projected future electricity demand. The current proposals for new coal-fired plants could therefore either "strand" fossil energy assets (i.e., force them to retire early or else operate at very low capacity factors) and/or ensure that the goal is not met by "locking-out" new, low-carbon energy infrastructure. Similarly, future emissions from the proposed coal plants would also exceed the country's climate commitment to reduce its 2005 emissions intensity 33% to 35% by 2030, which—when combined with the commitments of all other countries—is itself not yet ambitious enough to meet the international goal of holding warming well below 2°C relative to the pre-industrial era.

1. Introduction

Combustion of coal for energy is the largest source of carbon dioxide (CO_2) emissions on the planet, making up 41% of all CO_2 emissions in 2015 [*Quéré et al.*, 2016]. In India, where over 20% of the population (~300 million people) lack access to electricity, expansion of energy infrastructure has been seen as a crucial factor for human and economic development [*United Nations Framework Convention on Climate Change (UNFCCC)*, 2015]. Given India's large coal reserves (estimated at 87 billion metric tons [Gt]), and heavy reliance of its existing energy system on coal (44% of total primary energy and 70% of electricity generation in 2015), the magnitude of global coal emissions and the prospects of international efforts to avoid dangerous climate change are impacted by the extent to which India expands its coal-burning energy infrastructure [*International Energy Agency*, 2015a, 2015b].

In the 2015 Paris climate agreement, the world's nations agreed to limit the increase of global mean temperatures to well below 2°C and make efforts to limit temperature increase to 1.5°C above pre-industrial levels. This aim is in turn to be reflected in country-level emission pledges, known as Nationally Determined Contributions (NDCs). In its NDC, India did not pledge any specific reduction of its greenhouse gas emissions, but instead pledged (1) to reduce its emission intensity (i.e., emissions per unit GDP) by 33–35% from 2005 levels by 2030, and (2) to increase its share of non-fossil-based power generation capacity to 40% of installed electric power capacity by 2030.

India's electricity emissions intensity was 901.7 gCO_2/kWh in 2005 and increased to 926 gCO_2/kWh in 2012, much higher than global averages in those years, which were 542 and 533 gCO_2/kWh, respectively [*IEA*, 2015b]. The high emissions intensity reflects the large fraction of Indian electricity generated from coal; the targeted intensity decrease by 2030 will almost certainly require drastic reductions in the fraction of electricity being generated by coal. Although the exact make-up of the 40% of non-fossil electricity capacity is unspecified, plans laid out in the country's NDC document includes installing 100 GW of solar power and 60 GW of wind power by 2022 (over the current levels of 7 and 26 GW, respectively), and raising nuclear capacity from 6 GW presently to 63 GW in 2032 [*United Nations Framework Convention on Climate Change (UNFCCC)*, 2015].

While the NDCs reflect the first legally binding international agreement to address climate change, they are currently insufficient to meet international climate goals [*Raupach et al.*, 2014; *Peters et al.*, 2015]. The goals thus depend not only on NDC targets being met but also strengthened over time [*Rogelj et al.*, 2016]. Specifically, the Intergovernmental Panel on Climate Change (IPCC) estimates that to have a 66% probability of avoiding a 1.5°C or 2°C increase in global mean temperatures, cumulative anthropogenic CO_2 emissions after 2011 (including land-use changes) should be limited to approximately 400 Gt or 1,000 Gt, respectively [*Pachauri et al.*, 2014]. Between 2011 and 2016, cumulative CO_2 emissions (including land-use changes for all years but 2016) are estimated to have been 235 Gt [*Quéré et al.*, 2016], leaving remaining "carbon budgets" of 165 and 765 Gt for the 1.5°C and 2°C targets, respectively.

These remaining carbon budgets are furthermore opposing a tremendous socio-economic inertia: as previous studies have pointed out, the world's existing fossil infrastructure can be expected to emit substantial CO_2 over their remaining design lifetimes, which can be estimated through "commitment accounting" [*Davis et al.*, 2010; *Davis and Socolow*, 2014]. Cumulative future emissions from the world's existing infrastructure was estimated at ~729 Gt in 2014, unless retired early [*Raupach et al.*, 2014]. The world's proposed coal plants would emit an additional 245 Gt if operated at average capacity factors (i.e., energy output compared to the maximum possible) over a 40-year lifetime, pushing the budget well beyond both the 1.5°C and 2°C targets [*Shearer et al.*, 2016]. Equipping plants with carbon capture and storage (CCS) may allow reduced emissions from this proposed and existing infrastructure, but the high costs of installing and operating such technology have so far limited its use [*Pachauri et al.*, 2014; *IEA*, 2015a]. Researchers have also noted that current CCS technologies do not eliminate emissions entirely, but reduces them by 70–90%, such that the residual emissions from proposed coal plants would still jeopardize international climate goals [*González-Eguino et al.*, 2017]. The more CO_2 emitted, the more climate models rely on future "negative emissions" technologies such as bioenergy with CCS to recover excess cumulative emissions over time [*Fuss et al.*, 2014]. However, there are reasons to suspect that the scale of negative emissions available may be limited, and many of the proposed technologies have not been well-studied or demonstrated at full-scale, making them risky [*Anderson and Peters*, 2016; *Smith et al.*, 2016].

Here, we assess coal-fired power plants currently under construction or proposed in India, and compare the electrical generating capacity and future emissions of proposed plants with India's stated climate and energy targets. To capture the cumulative climate effects of India's coal plant proposals, we apply Davis and Socolow's method of assessing "committed" CO_2 emissions of power plants over their expected lifetimes [*Davis and Socolow*, 2014] together with updated data on proposed coal plants collected by the nonprofit group CoalSwarm [*Shearer et al.*, 2016]. We find that, combined with already operating fossil capacity, India's proposed coal plants would preclude a 33–35% reduction in the country's 2005 electricity emissions intensity by 2030, if the coal plants are utilized at a capacity factor of 65% or higher. Additionally, when combined with current power capacity and the country's non-fossil goals, the electricity that will be generated by the coal plants under construction will not be needed through 2024 based on projected electricity demand, and not through 2030 if the country maintains its building of solar and wind power beyond its 2022 goals—as the government has recently stated it plans to do. The under construction and proposed coal plants therefore risk either locking out India's non-fossil ambitions, or becoming stranded assets operating well below their designed utilization rates.

2. Methods

Our analysis of India's proposed coal plants is based on survey data compiled by the nonprofit group CoalSwarm on all active India coal plant proposals between January 2010 and May 2016. The database is publicly available and can be accessed on the CoalSwarm website, at http://coalswarm.org/trackers/india-coal-plant-tracker-map-and-table/. It also includes operating and retired coal plants, and is limited to coal units under 30 MW. Proposed plants are evaluated according to their status and categorized into one of six categories: announced, pre-permit development, permitted, under construction, shelved, or canceled. Project permitting data are available from the India Ministry of Environment, Forest and Climate Change (MoEFCC) website.

"Announced" projects are those that have been reported in the press or by sponsors, but that have not yet formally entered the permitting process. "Pre-permit development" plants are those for which companies have completed the first permitting step and have already received a "Terms of Reference" letter from the MoEFCC, which sets the conditions for sponsors to undertake an environmental impact assessment (EIA) report for the project. "Permitted" plants are those that have had their EIA approved and received environmental clearance. Plants "under construction" (but not fully commissioned) are determined based on the construction activity and plant commissioning data updated by the India Ministry of Power, as well as widely reported in India media. Finally, any proposals that show no development, permitting, or construction activity for at least 2 years is classified as "shelved," and if there has been no activity for 4 or more years as "canceled."

Where available, the survey also collected data on the type of the proposed plant (e.g., subcritical, supercritical) and coal (e.g., bituminous, lignite, waste coal, etc.) the proposed plant would burn. Plant technology is known for 81% of coal plants under development, and is dominated by supercritical (74% of those under construction and 87% of proposed), while most of the remaining plants would use the less efficient subcritical technology, as ultra-supercritical makes up only 4% of all proposals. None of the proposals currently plan to have carbon capture and storage (CCS) technology, which is designed to capture a portion of the plant's CO_2 emissions and store them underground. We estimate future CO_2 emissions from proposed plants by multiplying the nameplate capacity of the plant with the heat rate of the plant type and the emissions intensity of the coal, varied by capacity factor (the amount the plant is used). More information about the heat rates [*Sargent and Lundy*, 2009; *International Energy Agency*, 2012] and emission factors [*Hong and Slatick*, 1994] used can be found in the Supporting Information.

Data were also collected on sponsors of the project, and whether they are government or privately owned. Where type of sponsorship is known (70%), state-owned companies made up 69% of coal plants under construction and 62% of proposed plants, with the remaining coal plants sponsored by private companies (31% of plants under construction and 38% of proposed, respectively). The main sponsor of both coal plants under construction and proposed is the state-owned National Thermal Power Corporation (NTPC).

3. Results

As of May 2016, India had 56 GW of coal capacity in the announced stage, 78 GW in the pre-permit development stage, 44 GW permitted, and 65 GW under construction. Altogether, 369 plants totaling 243 GW of coal-fired generating capacity is under development—123% of the country's currently operating coal capacity (197 GW). (See Tables S1 and S2, Supporting Information for a breakdown of proposed and operating coal plants by state.)

Figure 1 shows average annual capacity additions from 1960, and future additions based on the survey of coal proposals. From 1960 to 2006 India added few coal plants, averaging under 0.5 GW a year in the 1960 to 1970s and around 2 GW a year in the 1980–1990s. This changed in 2007, after the government instituted policies to speed up the expansion of thermal power capacity, including opening the market to private companies [*Dharmadhikary and Dixit*, 2011]. Since 2011, India's power sector has added between 15 and 22 GW of coal power each year. The year 2015 was the first dip in India's nearly decade-long uninterrupted coal growth, from a high of over 22 GW in 2014 to just over 20 GW in 2015.

All but 23 coal units under construction have a proposed completion date, while about 40% of coal proposals in the pre-construction pipeline (permitted, pre-permitted, and announced) do not have a specified year for completion. To examine how this pipeline may affect future capacity growth, this analysis assigned a completion date to all units without one: 2018–2019 for construction, 2020–2021 for permitted, 2022–2023 for pre-permitted, and 2024–2025 for announced. This gives each project 4–5 years to complete the permitting process, and an additional 4–5 years for construction, in line with the global average [*Intergovernmental Panel on Climate Change (IPCC)*, 2014].

Based on the projected commissioning dates, Figure 1 also shows annual coal power capacity additions from 2016 to 2025 by plant status category. If completed within the 10-year timeframe, plants currently under construction and permitted would continue adding 12–40 GW a year of coal-fired capacity through 2025. At a 40-year average lifetime [*Davis and Socolow*, 2014], coal capacity would reach 435 GW by 2025, and have coal plants operating in India through 2065, unless retired early. The cumulative capacity takes into account past and planned coal plant retirements.

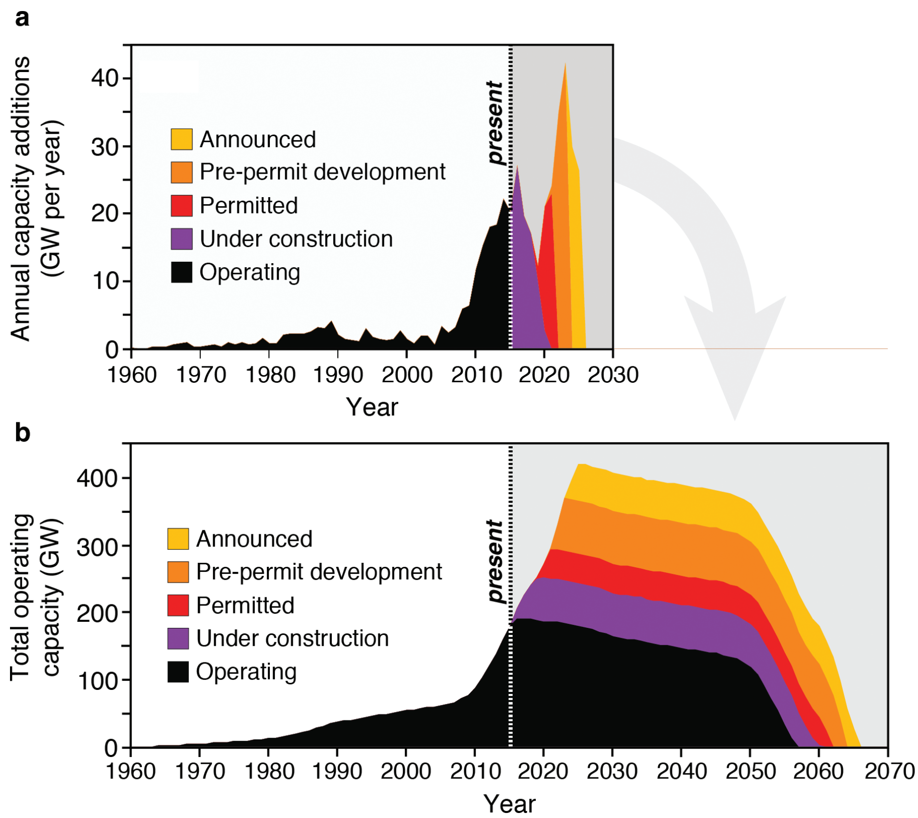

Figure 1. Annual coal-fired capacity additions in India averaged under 3.6 gigawatts (GW) a year until 2008, when new coal capacity increased every year until 2015. There is an additional 65 MW of coal plants under construction, and 178 GW permitted or proposed, adding up to 12–40 GW of new coal capacity annually through 2025 (a). At a commissioning rate of 10 years, coal plants under development would reach 435 GW of coal capacity by 2025 and, over an average lifetime of 40 years, would have coal plants operating through 2065 (b).

It should be noted that it is unclear if all or even most of the proposed coal plants will be built. From 2010 to May 2016, just over 261 GW of coal-fired capacity was implemented (i.e., in construction or completed) while 431 GW was halted (i.e., shelved or canceled), for an overall implementation rate of 38%. Many plant proposals were deferred or abandoned due to issues such as financial distress by the proponents, difficulty securing a coal supply, lack of power demand from cash-strapped state electricity distribution companies, and an inability to secure permitting or compulsory land acquisition because of community resistance [*Dharmadhikary and Dixit*, 2011; *Sharda and Buckley*, 2016]. These factors still affect many current coal proposals [*Shearer et al.*, 2016].

Figure 2 estimates CO_2 emissions for coal plants currently operating, under construction, and in the pre-construction pipeline, considering both their annual and lifetime emissions. Already operating coal plants have emitted about 11 Gt of CO_2 since 1960. If operated for forty years at a 75% capacity factor, currently operating coal plants would emit an additional 31 Gt through 2065, unless retired early. Coal plants under construction would add 14 Gt over their lifetimes, and proposed coal plants another 38 Gt, for a total of 83 Gt of CO_2 emissions from the country's coal plants in 2016–2065 (Figure 2a). The emissions estimate takes into account plant type, where known, and thus incorporates India's recent move toward more efficient supercritical plants over subcritical plants. The amount of CO_2 emissions could vary by the percentage of coal proposals completed (Figure 2b), and average capacity factor used (Figure 2c). From 1985 to 2015, the average annual plant load factor in India fluctuated between 52% and 79%, for an average of 66%, according to the India government [*India Ministry of Power,* 2015].

Figure 3 shows the amount of electricity the country's coal plants could generate through 2030, if all coal plants currently under construction and proposed are completed as outlined in Figure 1. The projection incorporates the Indian government's May 2016 announcement that it plans to shut down 37 GW of older

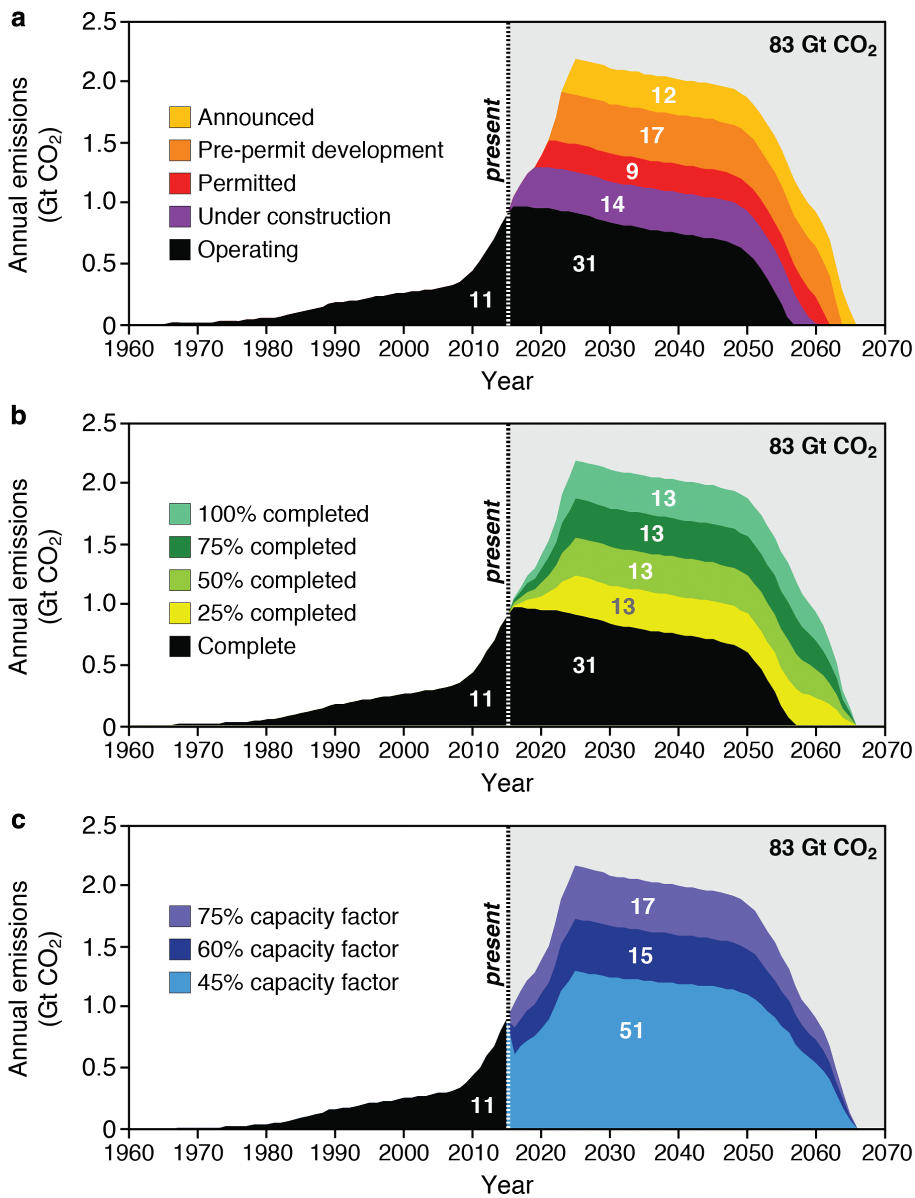

Figure 2. Currently operating coal plants have emitted an estimated 11 billion metric tons (gigatonnes [Gt]) since 1960, and over a 40-year lifetime and 75% capacity factor, would emit an additional 31 Gt through 2065. Coal plants under construction would add 14 Gt through 2065, and proposed coal plants another 38 Gt (a), although this could vary by the percentage of the coal proposals completed (b), and average capacity factor used (c).

coal plants, with the retirements spread out evenly over the next decade, from 2016 to 2025, since the exact dates of retirement are not yet known. The red line shows the India government's forecast for electricity demand, from 776 terawatt-hours (TWh) in 2012–2,499 TWh in 2030—growing about 6–7% a year in line with a projected 7–8% annual growth in GDP [*United Nations Framework Convention on Climate Change (UNFCCC)*, 2015]. The government also plans to reduce transmission and distribution losses to between 10% and 15% by 2018–2019, and lessen the impact of remaining losses by getting more output from demand through improvements in energy efficiency [*Krishna and Fernandes*, 2016].

Coal plants made up 63% of India's electricity capacity in mid-2016, while non-fossil power made up 28%. India's NDC targets 40% non-fossil based power capacity in 2030, but does not specify how much of this power will be renewables (wind, solar, hydro), biomass, or nuclear by 2030. Our projection therefore only

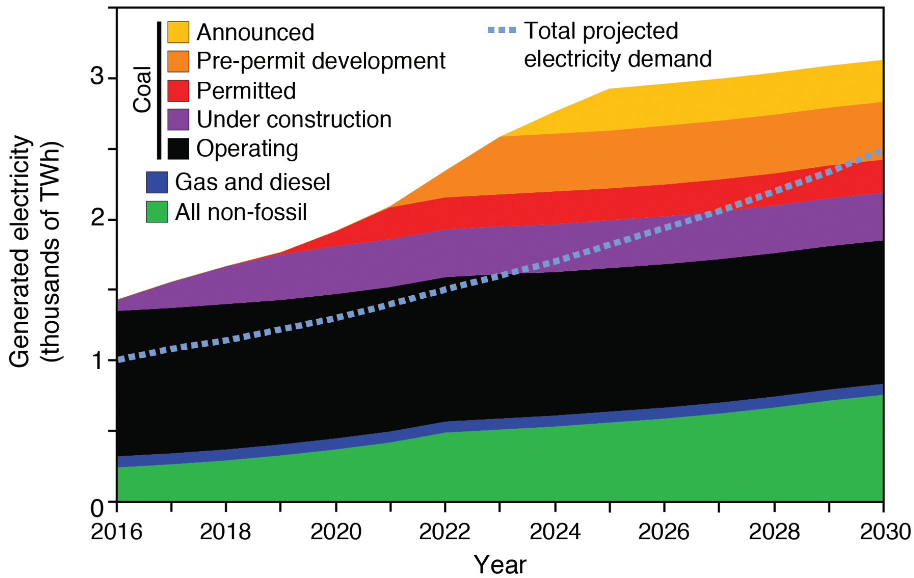

Figure 3. The electricity output generated from India's non-fossil goals (green), and current oil/gas (blue) and coal capacity (black) are enough to meet the country's projected electricity demand (dotted line) through 2023. Coal plants under construction are not needed until 2024, while those in the more preliminary stage (announced and pre-permit) are not needed through at least 2029, and likely longer if India continues building solar and wind capacity past its current 2022 goals. Electricity generation is calculated using the 2015 global average capacity factor for the different energy sources.

incorporates the country's specific capacity growth goals for non-fossil electricity, as laid out in the government's NDC document: 100 GW of solar power, 60 GW of wind power, and 10 GW of biomass by 2022; 63 GW nuclear capacity by 2032; and 10.5 GW of hydropower under construction, on top of the 42.9 GW of hydropower operating in 2016 [*United Nations Framework Convention on Climate Change (UNFCCC)*, 2015].

As shown in Figure 3, the electricity output generated from India's non-fossil goals (green), and current oil/gas (blue) and coal capacity (black) are enough to meet the country's projected electricity demand through 2023. Coal plants under construction are not needed until 2024, and likely longer if India continues building solar and wind capacity past its current 2022 goals. Electricity generation is calculated using the 2015 global average capacity factor for the different energy sources [*IEA*, 2015b], which has been increasing for solar and wind, and thus may underestimate their future contribution.

Coal plants in the more preliminary stage (announced and pre-permit) are not needed through at least 2030. If the coal plants are operated at only 45% capacity factor, all but 14 GW of proposed coal power would be used by 2030, although this would increase expenditures for construction, fuel, and operation and maintenance by spreading the costs across several plants for the same electricity output as less plants, leading to under recovery of energy charges. If the coal plants are operated at a 75% capacity factor, none of the proposed coal plants are needed through 2030.

The excess capacity represents a potential loss in capital investment. Table 1 shows the coal capacity above what is needed to meet power demand in 2030, and the capital expenditures. Plant construction costs are estimated at USD$1290/kW in South Asia [*International Energy Agency*, 2014]. The excess capacity represents potential "stranded assets"— plants that are unneeded and therefore operating well below their optimal utilization rates or retired early, leading to lost revenues [*Leaton et al.*, 2013]. Here, the excess coal plant capacity represents USD$18 (INR 1.2 trillion) to USD$230 billion (INR 15.37) in potentially wasted capital expenditures, without accounting for fuel or maintenance costs.

When combined with the coal plants under development, the growth in non-fossil capacity add up to just 38% of non-fossil capacity by 2030 (gas and oil electricity capacity is kept constant), short of the 40% non-fossil capacity goal. The India Central Electricity Authority (CEA) has recently proposed in its most recent Electricity Plan for non-fossil capacity to increase, reaching 57% of all power capacity by 2027 [*India Central*

Table 1. Excess Capacity From Coal Plants Under Development Compared to 2030 Electricity Demand, and the Estimated Capital Expenditures, Depending on the Average Capacity Factor Used for the Coal Plants

	75% Capacity Factor	60% Capacity Factor	45% Capacity Factor
Excess coal capacity	178 GW	134 GW	14 GW
Cost (USD/INR)	$230 billion/₹15.37 trillion	$173 billion/₹11.56 trillion	$18 billion/₹1.2 trillion

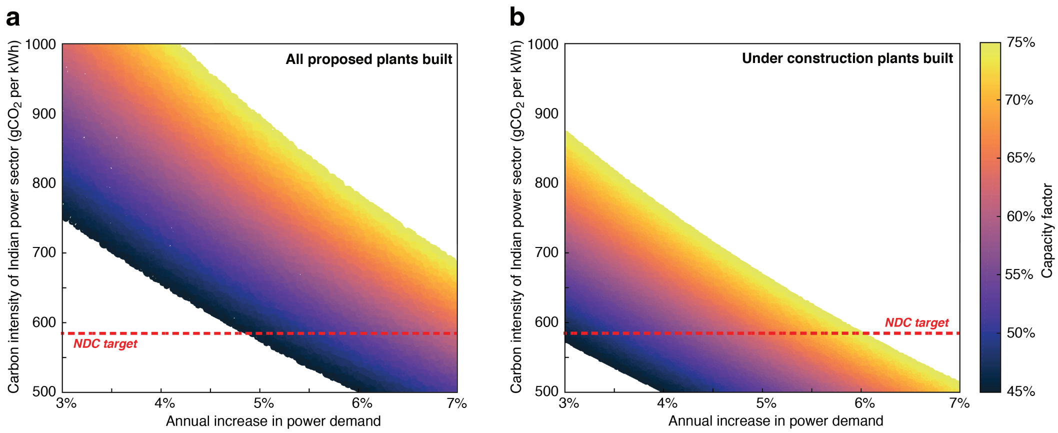

Figure 4. The emissions intensity of generated power (*y*-axis) varies depending on how much power demand grows (*x*-axis) and the plant's capacity factor changes (colors). The red line demarcates a 35% decrease in the 2005 emissions intensity of power, in line with India's Nationally Determined Contributions (NDC) target. If all coal plants under development are built and power demand grows by 7% a year, in line with government projections, the currently proposed plants could still prevent the NDC intensity goal from being reached in 2030 if they are operated at 65% capacity factor (orange) or above (a). If coal plant use by 2030 is limited to just what is currently operating and under construction (b), the plants could be operated at 75% capacity factor (yellow) and be within the NDC target, if power demand grows at 6% a year or above.

Electricity Authority, 2016], suggesting the estimates used here are conservative and the country is determined to meet its non-fossil goals.

The India government also pledged in its NDC to reduce its overall emissions intensity 33–35% below 2005 levels by 2030. As can be seen in Figure 4, the emissions intensity of generated power (*y*-axis) varies depending on how much power demand grows (*x*-axis) and how the plant's capacity factor changes (colors). The red line labeled "NDC target" demarcates a 35% decrease in India's 2005 emissions intensity of power, from 901.7 gCO_2/kWh in 2005 to 586 gCO_2/kWh by 2030.

As shown in Figure 4a, if power demand grows by 7% a year, in line with government projections, the currently proposed plants could still prevent the intensity goal from being reached if they are operated at 65% capacity factor or above. Thus if all coal plants under development are built and power demand grows slowly, the target cannot be achieved unless plants are operated at relatively low capacity factors—without accounting for any additional coal plant proposals in the future or any other fossil sources of electricity. If the government caps coal capacity through 2030 to only what is currently operating and under construction, as shown in Figure 4b, then the plants could be operated at a capacity factor of 75% while still meeting the NDC, if power demand grows at 6% a year or above.

4. Discussion and Conclusions

According to the survey completed in May 2016, India had 65 GW of coal plants under construction, and an additional 178 GW proposed (Figure 1). Altogether, the large amount of proposals appear to legitimate analyses by the IEA that future coal demand will continue to grow based on demand from industrializing nations such as India [*IEA*, 2015a]. Yet, we also find the proposals are incompatible with the country's climate goals, and exceed the country's projected power demand.

As stated, in its NDC the India government has pledged to reduce its overall emissions intensity 33–35% below 2005 levels by 2030. A 35% in the country's 2005 emissions intensity of 901.7 gCO_2/kWh would be

586 gCo_2/kWh, and at a projected electricity demand of 2,499 TWh in 2030, the reduction would equal CO_2 emissions of less than 1.5 Gt in 2030. Currently proposed coal plants would have overall coal plant emissions of between 1.3 to 2.1 Gt in 2030, depending upon the average capacity factor (45–75%, respectively) (Figure 2), without accounting for other existing fossil sources or new proposals. The proposed coal plants cannot be used at an average capacity factor above 65% and meet the NDC emission intensity reduction, unless new coal plants are limited through 2030 to just what is currently under construction (Figure 4).

Researchers have found the country's NDC is itself incompatible with the international goal of limiting warming to 2°C [*Raupach et al.*, 2014; *Peters et al.*, 2015; *Rogelj et al.*, 2016]. Comparing the allowable cumulative CO_2 emissions with the emission pledges of the EU, USA, China, and India, *Peters et al.* [2015] found the combined emission pledges left no room for other countries to emit CO_2 for a 2°C temperature limit. In considering a "fair" carbon budget for the country that considers its need for economic growth and projected population growth, Peters estimates India's annual CO_2 emissions can rise to a little over 3 Gt total by 2025, but would need to decline by 2030. For 1.5°C, reductions in India would have to begin immediately [*Peters*, 2016].

The proposed coal plants would also exceed the country's planned growth in power demand (Figure 3), creating the potential for declining utilization rates and stranded assets. The country already faces the decreasing use of its existing coal plants. From 2007 to 2015, the average plant load factor fell from 79% to 64% [*India Ministry of Power,* 2015]. State energy distribution companies have been unable to buy power at prices sufficient to cover the operating costs of generators, leading to 30 GW of stranded plants in June 2016 [*Bureau*, 2016]. That month the government scrapped plans for four ultra-mega coal-fired power plants of ~4,000 MW each due to lack of demand.

Moreover, average costs for plants coming online in 2020 are INR 4.40/kWh for domestic coal and INR 5.15/kWh for imported coal [*Klynveld Peat Marwick Goerdeler (KPMG)*, 2015], while prices for photovoltaic solar and onshore wind power have reached a low of INR 2.97/kWh and INR 3.46/kWh, respectively [*Mahapatra*, 2017]. Unless national electricity demand increases significantly beyond government forecasts, the country's current coal proposals will likely lead to either more underused or "stranded" coal plants, and/or lock-out of lower carbon and potentially less costly electricity sources [*Unruh*, 2000]. In China, coal overcapacity and declining power demand has led the central government to suspend indefinitely over 100 GW of coal projects in January 2017, including coal plants that were already well under construction, with more suspensions expected [*Forsythe*, 2017].

The India government itself recently concluded that few if any new coal plants are needed for the next decade. Its most recent Draft National Electricity Plan calls for 57% of the country's power capacity to be non-fossil by 2027. The proposed Electricity Plan includes only 50 GW of new coal plants currently under construction, and finds the new coal plants are unneeded until 2022, and only possibly before 2027. In addition, the average plant load factor for coal plants could fall even further, to 48% by 2022, as additional non-thermal power capacity comes online [*India Central Electricity Authority,* 2016].

The new Draft National Electricity Plan did not state what the government will do about the 178 GW of proposed coal plants. Although state-run companies like NTPC dominate as sponsors, over a third (38%) of identified sponsors for proposed plants are private companies. It is unclear if the proposals would be canceled, and whether coal or power companies will resist the suspension of coal projects. Yet, the data presented here suggests the Indian government may need to curtail permitting and construction of new coal plants, because further additions to the coal fleet threaten to crowd out India's low-carbon energy ambitions, create stranded coal plant assets operating well below their designed utilization rates, and jeopardize India and the world's climate commitments.

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