



## International Journal of Management and Commerce

www.managementjournal.in

Online ISSN: 2664-6854; Print ISSN: 2664-6846

Received: 05-02-2019; Accepted: 07-03-2019; Published: 14-03-2019

Volume 1; Issue 2; 2019; Page No. 29-38

### India's energy and emissions future: An interpretive analysis of model scenarios

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#### Abstract

As a significant emitter of greenhouse gases, but also as a developing country starting from a low emissions base, India is an important actor in global climate change mitigation. However, perceptions of India vary widely, from an energy-hungry climate deal-breaker to a forerunner of a low carbon future. Developing clarity on India's energy and emissions future is challenged by the uncertainties of India's development transitions, including its pathway through a demographic and urban transition within a rapidly changing policy context. Model-based scenario analyses provide widely varying projections, in part because they make differing assumptions, often implicit, about these transitions. To address the uncertainty in India's energy and emissions future, this letter applies a novel interpretive approach to existing scenario studies. First, we make explicit the implied development, technology and policy assumptions underlying model-based analysis in order to cluster and interpret results. In a second step, we analyse India's current policy landscape and use that as a benchmark against which to judge scenario assumptions and results. Using this interpretive approach, we conclude that, based on current policies, a doubling of India's CO<sub>2</sub> energy-related emissions from 2012 levels is a likely upper bound for its 2030 emissions and that this trajectory is consistent with meeting India's Paris emissions intensity pledge. Because of its low emissions starting point, even after a doubling, India's 2030 per capita emissions will be below today's global average and absolute emissions will be less than half of China's 2015 emissions from the same sources. The analysis of recent policy trends further suggests a lower than expected electricity demand and a faster than expected transition from coal to renewable electricity. The letter concludes by making an argument for interpretive approaches as a necessary complement to scenario analysis, particularly in rapidly changing development contexts.

**Keywords:** energy, emissions, interpretive, scenarios

#### Introduction

India's energy future carries implications for both global outcomes and national development objectives. From a global perspective, India's current and expected future emissions are sufficiently large to affect global mitigation efforts. In 2014, India emitted 6.6% of global emissions. This share will invariably grow since India is starting at a low base of per capita emissions—2.5 tons capita<sup>-1</sup>, which is 37% of the global average (WRI 2014)<sup>[59]</sup>. This growth presents a challenge at a time when global emissions need to decline. From a national perspective, however, India's development future cannot be assured without increasing levels of energy use for millions, which likely requires some increase in emissions. Clearly, these are inter-related challenges—India's efforts to increase energy use are shaped by a climate mitigation context that is driving rapid changes in energy technology, which provides opportunities but also creates uncertainties.

The resultant effect can be hard to interpret, with India variously tagged as a climate villain or hero. Some recent literature projects India on a rapid growth path fuelled by carbon-intensive coal, with alarming implications for climate change (van Breevoort *et al* 2015, IEA 2015, Shearer *et al* 2017, Steckel *et al* 2015)<sup>[4, 26, 47, 52]</sup>. The counter narrative, on the other hand, hails India as the forerunner of a low-carbon future based on its efforts to rapidly deploy renewable energy (Höhne *et al* 2017, Anand 2017, Balaraman 2017)<sup>[23, 1, 2]</sup>. What accounts for these different perceptions, and how credibly are they rooted in facts and analysis? Despite the existence of several studies attempting to

project India's energy future, the scope for widely varying conclusions persist for two reasons. First, India is undergoing rapid economic and social transition, which amplifies the usual uncertainties that derive from technology and economic growth rates. For example, India is going through simultaneous demographic and urbanisation transitions, and has to overcome the burden of low levels of access to reliable commercial energy. Thus, assumptions about whether India will follow a manufacturing or services led approach to providing jobs, whether its cities are compact or sprawling, and how it provides energy to its citizens will all affect projections about energy and emission futures. In brief, India's uncertain development choices condition its energy and emissions outcomes. Second, and related, in recent years the Indian policy environment around these issues has been shifting rapidly, further complicating the task of projection. As we show, individual studies often produce widely disparate results, in part because each study makes their own assumptions about uncertain development and policy futures.

In this letter, we deploy a novel, interpretative approach to understanding and bounding uncertainties in India's emission and energy projections. This approach is needed because existing studies are based upon separate, often implicit, assumptions about uncertain development and policy futures. While each is plausibly defensible, they collectively generate a wide range of results that require further interpretation in order to yield insights. Starting with fifteen scenarios drawn from seven studies, we

show how an interpretive approach is a useful, perhaps even necessary, complement to model-based scenario analysis.

We adopt a two-step approach. While we begin by quantitative comparison across the studies, our innovation lies in making explicit the implied development choices, technology futures, and policy assumptions made by these studies, which allows us to cluster results in a manner that enables interpretation. In a second step, we examine trends in India's current policy landscape, with a focus on electricity, and use this as a benchmark against which to judge the scenarios' assumptions and projections. The application of careful interpretive techniques to model results and the reality-check against current policy trends, we suggest, represents an innovation in the literature on energy and emissions projections. This complementary step is particularly important in the context of rapidly changing emerging economies.

The resulting analysis concludes that a doubling of India's CO<sub>2</sub> emissions from energy from 2012 levels is a likely upper bound for India's 2030 emissions, beyond which the models, collectively, do not enable comment. This trajectory through 2030 is consistent with meeting India's Paris emissions intensity pledge. Model scenarios that project the effect of additional policies suggest scope for lower emissions growth for India through 2030, but this scope is more limited for development focused scenarios than pure decarbonization scenarios.

### Approach and methods

The dominant approach to understanding energy and climate futures is the use of scenario-based modelling studies. We argue

that when a range of studies with differing assumptions and results are available, interpretive approaches provide a necessary complement, particularly in rapidly changing developing country contexts. In particular, we shine the spotlight on the implications of development choices and policy baselines.

Existing studies of India's energy and environmental future fall into three categories. The first are global or regional-scale models, that allow isolation of India or South Asia-specific projections (den Elzen *et al* 2016, Jackson *et al* 2016, Robiou du Pont *et al* 2016, van Soest *et al* 2015, Tavoni *et al* 2015, UNEP 2017, Wu *et al* 2015, Gambhir *et al* 2014)<sup>[18, 27, 43, 50, 53, 56, 60, 20]</sup>. Because these studies necessarily cannot account for country-specific detail but are intended to capture progress toward a global goal, such as carbon mitigation, they do not lend useful insights for an India-specific analysis. A second, much smaller, set of studies seek to synthesize Indian results and compare them to China (Hof *et al* 2015, Johansson *et al* 2015, Mittal *et al* 2016)<sup>[22, 29, 35]</sup>. These studies also analyse India's future trajectory in the context of global GHG reduction pathways rather than national development and technology choices, and are limited to the analysis of variation in standard model parameters such as population, economic growth and energy intensity. A third set focus explicitly on India and develop scenarios, often informed by sector-specific assumptions, to project energy and emissions futures. This category of studies provide the necessary granular level of detail on energy-development choices, and seven of the most recent such studies, summarized in table 1, form the source material for this letter.

**Table 1:** Model scenarios reviewed.

Study name (abbreviation)	Institution/project	Study timeline	Year of current policies	List of scenarios (selected for analysis in bold)
Expert group on 'low carbon strategies for inclusive growth' (LCSIG) (Planning Commission 2014) <sup>[40]</sup>	Planning Commission Government of India	2007–2030	2011	Baseline inclusive growth (R), low carbon inclusive growth (P)
The energy report—India. 100% renewable energy by 2050 (TERI-WWF) (WWF-India and TERI 2013) <sup>[61]</sup>	The Energy and Resources Institute	2001–2051	2012	Reference energy scenario (R), 100% renewable energy scenario (P)
Energy-emissions trends and policy landscape for India (Shukla) (Shukla <i>et al</i> 2015b) <sup>[49]</sup>	Indian Institute of Management-Ahmedabad	2005–2050	2014	Business as usual, scenarios 1 (R), 2,3,4 (P), 5a
Quality of life for all: a sustainable development framework for India's climate policy (CSTEP—QoL) (CSTEP 2015) <sup>[15]</sup>	Centre for Science, Technology and Environment Policy	2012–2030	2015	Business as usual (R), sustainable scenario (P)
India energy security scenarios 2047 version 2.0 (IESSv2) (NITI Aayog 2015) <sup>[38]</sup>	Energy Division, NITI Aayog, Government of India	2012–2047	2015	Least effort, heroic effort, aggressive effort, determined effort (DS) (R), maximum energy security(MES) (P-1), possible energy efficiency and energy mix, maximum clean and renewable energy pathway (MCRE) (P-2), (across three growth scenarios: A, B, C)b
India energy outlook (IEA) (IEA 2015) <sup>[26]</sup>	International Energy Agency	2013–2040	2015	New policies scenario (NPS) (R-1), India vision case (IVC) (R-2)c
Pathways to deep decarbonization in India (DDPP) (Shukla <i>et al</i> 2015a) <sup>[48]</sup>	Deep Decarbonisation Pathways Project	2010–2050	2015	Conventional deep decarbonization (CDD) (P-1), sustainable deep decarbonization (SDD) (P-2)d

<sup>a</sup>Shukla: scenario 1, which models partial implementation of current policies is chosen as the reference scenario because it is most comparable to reference scenarios in other studies. Scenario

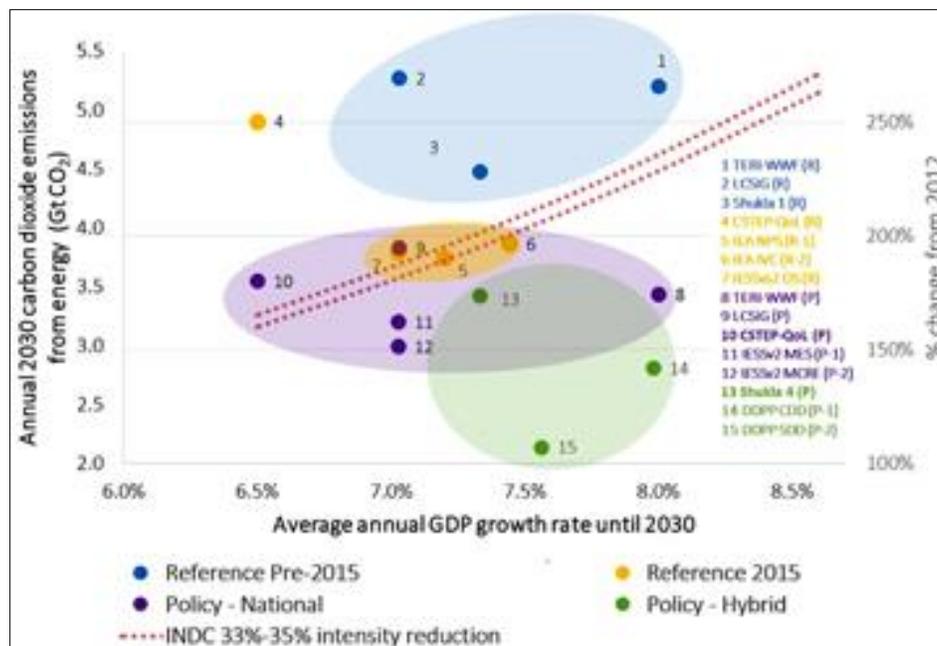
4 is chosen as the policy scenario as it is the mid-level policy scenario, and it is categorized as 'policy-hybrid' because it combines national and international policy targets. <sup>b</sup>IESSv2: the

'determined effort' scenario was chosen as the reference case as this is the closest to a current policy option in the study. Two policy scenarios were chosen-'maximum energy security' and 'maximum clean and renewable energy' because they provide distinct and complementary insight on future energy policy. The mid-level growth scenario (B) was chosen for all three scenarios. 'IEA: both IEA scenarios are designated reference scenarios, since neither seeks to represent an energy transition explicitly but rather represents alternative development scenarios. The new policies scenario represents partial implementation of current policies, and the India vision scenario represents the full pursuit of current high-priority policy objectives, notably enhanced domestic manufacturing and electricity access. 'DDPP: both the DDPP scenarios model a combination of domestic objectives and a low carbon reorientation of India's energy system through additional policies and are therefore considered policy scenarios.

The first step in our approach compares and interprets scenario results. This comparative exercise is necessary because, given the large uncertainties in India's future development outcomes, the result of each study is strongly determined by individual assumptions about those outcomes and related policy choices. To undertake this, we examine outputs and assumptions of fifteen

scenarios drawn from the seven studies, and group the studies into interpretive categories to extract conclusions on future emissions, energy demand and energy supply. In comparing emissions projections, we report only the component that is comparable—CO<sub>2</sub> emissions from energy, excluding CO<sub>2</sub> emissions from industrial processes and land use changes. In 2012, this subset of CO<sub>2</sub> emissions represented about 68% of India's total GHG emissions (WRI 2014) [59]. We report emissions projections for 2030, the target date for India's 'nationally determined contribution' (NDC) under the Paris Agreement. To more completely interpret emissions projections, we further examine and compare scenario projections on India's energy needs for development. This is a critical additional step, since divergent assumptions about energy needs, often implicit, may help explain disparate emissions projections.

The second step further analyses model results in light of recent Indian policy trends. In India's fast-moving policy environment, this is necessary to benchmark model assumptions against the direction of recent policy changes. This analysis provides information with which to comment on and confirm likely bounds on model projections. For this purpose, we focus on the fast-moving electricity sector, which accounts for about half of India's greenhouse gas emissions.



**Fig 1:** 2030 annual carbon dioxide emission from energy projections for India. The figure plots 2030 carbon dioxide emissions from energy against average annual GDP growth rates used by each scenario.

The secondary y-axis indicates the percent change of CO<sub>2</sub> emissions from India's 2012 level. Scenarios are categorized into reference (R) and policy (P) scenarios. Reference scenarios are further subdivided into reference-pre-2015 and reference-2015, referring to the base year of 'current policies' assumed by the different studies. Policy scenarios ('P') are subdivided into policy-national and policy-hybrid, to identify policy scenarios aimed at national objectives, and those with a hybrid of national development and global decarbonization aims. When more than one scenario is included from the same study, we annotate the scenario acronym with a number e.g. (R-1), (R-2), (P-1), (P-2).

**India's CO<sub>2</sub> emissions projections in 2030**

The India modelling studies project a wide range of 2030 projections for CO<sub>2</sub>, the lowest projecting a 9% increase from 2012 levels, and the highest a 169% increase. Figure 1 plots these outcomes against the range of average annual GDP growth rate projections used by the studies, ranging from 6.5%–8.0%. Indeed, the range of projected 2030 emissions is so large as to be of the same order of magnitude as India's current emissions. To interpret this range, we cluster the results in four categories. We first draw a distinction between 'reference' scenarios that estimate India's energy future based on the current policy

environment, and 'policy' scenarios that model aspirational policies. We further sub-categorize reference scenarios into 'reference 2015' and 'reference pre-2015' to indicate the base year of current policies and capture the rapid changes in policy. We also sub-categorize policy scenarios into 'policy-national' for policies shaped primarily by national development objectives, and 'policy-hybrid' to represent scenarios that include national development and global climate objectives. Where a study includes multiple reference or policy scenarios, we choose those that best represent the categories described above, explained further in table 1.

A closer examination of reference scenarios shows that recently introduced policies (2015 and beyond), summarized in table 2, are projected to have a material impact on reducing India's future emissions, and would bring them in line with its NDC pledge. This result is reflected in a comparison of reference scenarios based on pre-2015 policies with those that include policies introduced in 2015 and later. Thus, under the *reference 2015*

*scenarios*, Indian emissions are projected to rise to 3.8–4.9Gt, or 91%–151% above 2012 levels. However, the upper-limit is driven by an outlier scenario (#4), which unlike its category counterparts, includes an assumption of full implementation of India's target to increase domestic coal production. This assumption which, as we discuss later, is questionable, drives its significantly larger emission and coal generation projections, leading us to exclude this study from the *reference 2015* cluster in figure 1. Without the outlier scenario (#4), the reference 2015 scenarios form a tighter pattern, projecting India's emissions to rise 3.8–3.9 Gt, or 91%–98% above 2012 levels, which is a level consistent with its NDC pledge of 33%–35% reduction in emissions intensity from 2005 levels by 2030 (Government of India 2015). By contrast, *reference pre-2015 scenarios*, which have been rendered less relevant by recent policy developments, are projected to lead to a significantly higher rise of 4.5–5.3Gt or 129%–169% above 2012 levels.

**Table 2:** India's existing policies relevant to mitigation and energy.

Year	Policy area	Description
<b>Energy Supply</b>		
2015	Renewables	175 GW target of renewable energy capacity by 2022a
2015	Domestic coal production	Increasing domestic coal production to 1 BT from government and 0.5 BT from private firms by 2020
2010	Coal cess	A coal cess to finance clean technology. Set in 2013 at INR 50/t, it doubled annually to INR 400/t until 2016.a
<b>Energy Efficiency and Clean Technology</b>		
2012	Industrial energy efficiency	A 'Perform, Achieve and Trade' domestic energy efficiency credit trading scheme for industriesa
2014, updated in 2015	Subsidized LED bulbs	Aims at replacing 770 million inefficient bulbs by 2019.a
2013, updated in 2015	LPG access	Targeted subsidies for LPG cylinders and gas connections to women from families 'below poverty line'a
2015	Light vehicles fuel standards	Leapfrogging from Euro IV to Euro VI standards by 2020.a
2013, updated in 2017	Electric mobility	Aims at penetration of hybrid and electric vehicles, targeting no new fossil fuel powered vehicles by 2030a
<b>Infrastructure Transitions</b>		
2006	Dedicated freight corridors	Enhancing rail freight infrastructure between major metrosa
2014, updated in 2017	Electricity for All	Aims at 24/7 supply to all households by 2019a
2015	'Make in India'	Encouraging manufacturing in Indiaa
2015	Urban infrastructure	Smart cities missiona, basic servicesa and housing for All by 2020
2007, updated in 2017	Commercial building energy standards	A voluntary energy conservation building code.

**Sources:** authors' own assessment from websites of Government of India Ministries <sup>a</sup>Mentioned in India's INDC

The red dotted lines represent the CO<sub>2</sub> emissions from energy in 2030 at different average annual GDP growth rates from 2005, corresponding to India's INDC target of a 33%–35% reduction from the GHG intensity level in 2005. In constructing these lines, we make the simplifying assumption that the share of emissions from energy (our scope here) remains the same in 2030 as in 2012.

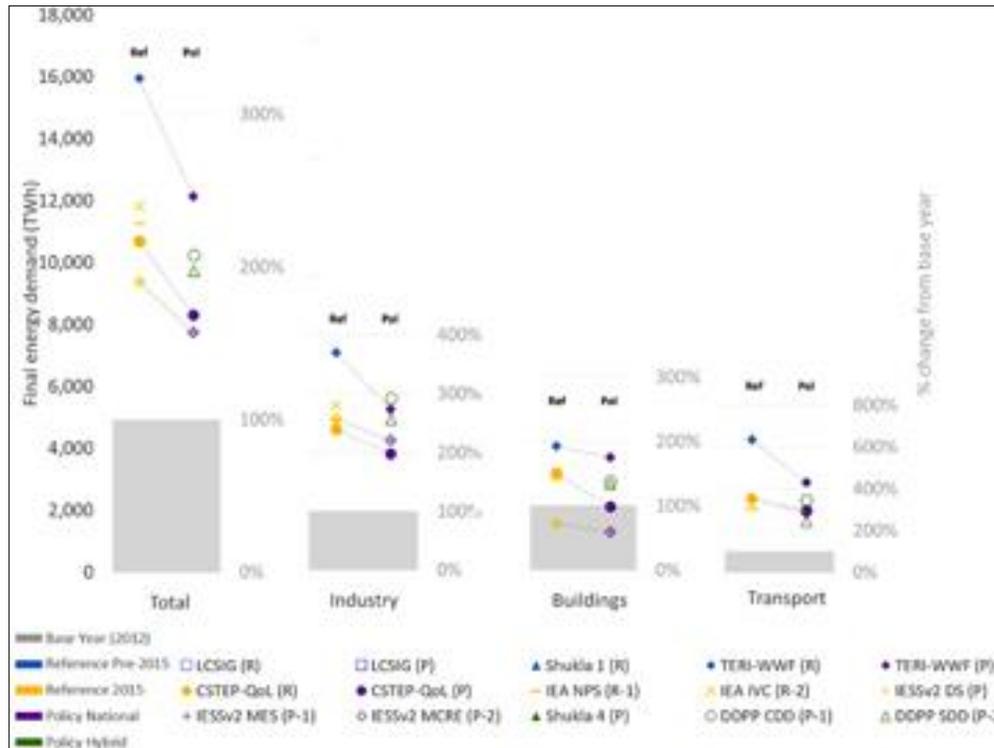
Additional policies beyond those in place in 2015 (see policy scenarios in table 1) could feasibly lower 2030 emissions considerably: emissions from these policy scenarios are 32%–45% lower than their respective reference cases. However, policy scenarios fall into two types. *Policy-national* scenarios driven primarily by national interests—such as clean energy, energy security, job creation or their mix—result in a modest over-compliance with the NDC pledge, at about 53%–96% above 2012 levels. A second category of *policy-hybrid* scenarios, which explicitly also include a global carbon objective, result in

substantially lower 2030 emissions, the low end of which is only 9% above 2012 emissions, which would be a substantial over-compliance with the NDC pledge.

Significantly, despite a considerable increase in absolute emissions under most scenarios, India's per capita emissions under all scenarios remain modest—2.5–3.6 t cap<sup>-1</sup> under all *reference* scenarios, and 2–2.6 t cap<sup>-1</sup> under all *policy* scenarios. These results would place India's 2030 per capita CO<sub>2</sub> emissions, even after two decades of steep rise in absolute emissions, well below the 2014 global average of 4.7 t cap<sup>-1</sup> (Boden *et al* 2017) <sup>[3]</sup>. of these scenario clusters, we suggest that the *reference-2015* cluster, corresponding to a doubling of emissions by 2030 from a 2012 base, represents a likely upper bound for India's 2030 emissions for three reasons. First, *reference-2015* scenarios best capture the current policy environment. Second, as the studies factor in political realism by assuming only partial rather than full implementation of recent

policies in table 2, full implementation of low-carbon policies would result in even lower emissions. Third, the *reference-2015* studies assume average annual GDP growth rates between 7.0%–7.5% over until 2030, which are higher than historical average annual growth rates of 6.1% for the 1990s and 7.1% for the 2000s (World Bank 2017). While a higher growth rate is feasible, it is unlikely to be sustained over fifteen years; a likely lower average growth rate would result in lower emissions.

Notably, China's 2015 emissions from energy of 9085 Mt CO<sub>2</sub> is more than double India's projected 2030 emissions from energy that we consider an upper bound (IEA 2017a, p 96)<sup>[24]</sup>. Thus, over the next decade or so, India's emissions growth, while significant, is at a lower scale and pace than China's in the preceding two decades. Equally, however, as discussed below, India's energy needs for development suggest that some increases in energy use and emissions are near unavoidable if India is to fully realise development opportunities.



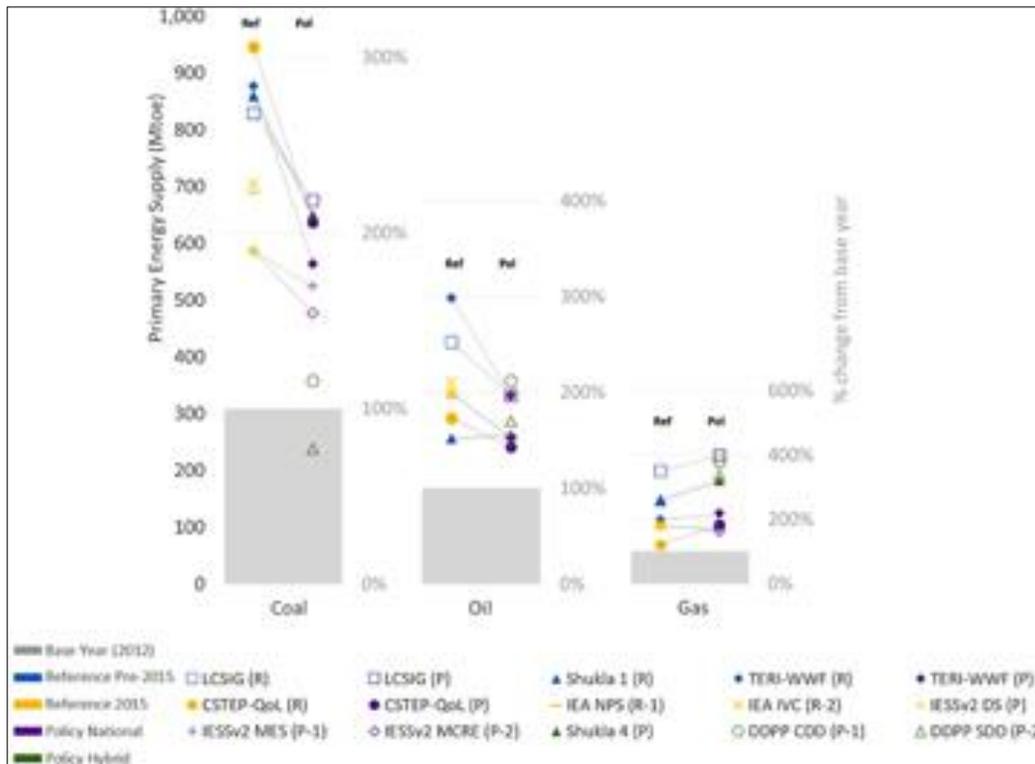
**Fig 2:** 2030 final energy demand projections for India.

The bar in grey indicates India's final energy demand in 2012. Colors designate the scenario sub-categories, while shapes are unique to each scenario. Each point represents a model projection for final energy demand in 2030, on the same scale. Reference cases are plotted in the left, while policy cases are plotted on the right. A dotted, grey line connects reference and policy scenarios from the same study. The secondary axis indicates percentage change of values from 2012.

**India's energy needs for development**

Underlying the substantial range of emissions projections—from a low of 12% above 2012 levels in 2030 to a high of 169%—are diverse assumptions about India's energy future. The scope for

variation in these assumptions is large because India has not, as yet, locked into infrastructure, socio-economic patterns and technology choices around energy use (Seto *et al* 2016)<sup>[45]</sup>. For example, in the coming decades India will have to undergo three major transitions: provide commercial cooking energy to 800 million people and electricity to 300 million (Jain *et al* 2015, IEA 2015)<sup>[28, 26]</sup>; manage a shift from 30%–50% urbanization (MoHUPA Government of India 2016); and provide jobs for an estimated 10 million new job seekers a year (FICCI-Ernst and Young 2015). The choice of energy futures will be shaped, in part, by the pathways chosen for these development transitions. Models face the challenging task of simulating these choices and their effects.



**Fig 3:** 2030 primary fossil fuel supply projections for India. Follows the format of figure 2, but represents primary fossil fuel supply projections for 2030.

To do so, many of the India studies are framed around development futures from which energy implications are indirectly derived. For example, the Government of India's low carbon study (LCSIG) interprets inclusive growth in terms of direct provision of services to the poor—housing, clean cooking fuel and electricity, health and education services (Planning Commission 2014). The International Energy Agency's India Vision case (IEA IVC) highlights two high-profile government objectives: generating jobs through manufacturing; and providing full energy access (IEA 2015) [26]. CSTEP highlights sustainable development (CSTEP 2015) [15]. Other studies focus more narrowly on energy and carbon related outcomes such as decarbonisation (DDPP) (Shukla *et al* 2015a) [48], low carbon policies (Shukla) (Shukla *et al* 2015b) [49], energy security and clean energy (IESS) (NITI Aayog 2015) [38], and accelerated renewable energy adoption (TERI-WWF) (WWF-India and TERI 2013) [61]. The spread in emission outcomes derives, at least in part, from a spread in the framing of the studies.

These varied foci for development and energy futures complicate demand-side projections since they lead to different choices about the large-scale transitions upon which India is embarked. Despite this diversity, three demand-side commonalities emerge from the studies, which help explain the emission trajectories discussed above. First, energy demand will invariably increase through 2030 as India transitions; India has to find ways of meeting this additional demand (figure 2). Second, recent policy actions are projected to reduce future demand; comparison of pre-2015 to 2015 reference cases indicate that recent demand-reducing policies (see table 2) considerably lowers demand projection, from 223% for *reference-pre 2015* to 90%–140% for *reference-2015*. Third, additional policies can reduce demand still more; comparing reference to policy scenarios within

individual studies shows a consistent demand reduction. So while India's energy demand will invariably grow, the magnitude of growth is indeed amenable to policy intervention, and recent policies have begun to curtail India's future demand.

On the supply side, meeting India's far greater 2030 energy demand rests on untangling the complex inter-connected projections of coal use and renewable energy growth. First, through 2030, the extent of coal growth will likely remain the dominant determinant of India's energy future (figure 3). While oil and gas use are both projected to rise, the magnitude of change is swamped by projected coal increases. This ranges from a doubling or more in reference scenarios to a more modest, but still substantial, 54%–118% increase in *policy-national* scenarios. Two of the three *policy-hybrid* scenarios project smaller increases, or even a decrease, in coal use. This result turns on a shift to gas and extremely high rates of renewable energy uptake in electricity which, in 2012, accounted for 49.6% of the emissions covered by the studies (NITI Aayog 2015) [38]. Displacement of fossil fuels is likely to turn on the speed of decarbonisation in the electricity sector.

Second, as figure 4 shows that the studies uniformly project high rates of non-fossil fuel electricity growth, primarily from modern renewables. Indeed, even in reference cases, India is projected to generate as much non-fossil fuel electricity by 2030 as it generated from all sources in 2012, with even steeper increases under policy scenarios suggesting lower fossil fuel use. Despite these gains, further decarbonisation may be limited because total electricity demand will rise even faster than renewables, necessitating an overall growth in fossil fuel use. However, as we will explore in the next section, these results need to be interpreted in the light of falling renewable energy prices globally, increasing stranded coal assets and decreased estimates

of coal requirements in India and increasing consideration of environmental co-benefits such as air quality which collectively

Point to a lower carbon future than currently projected.

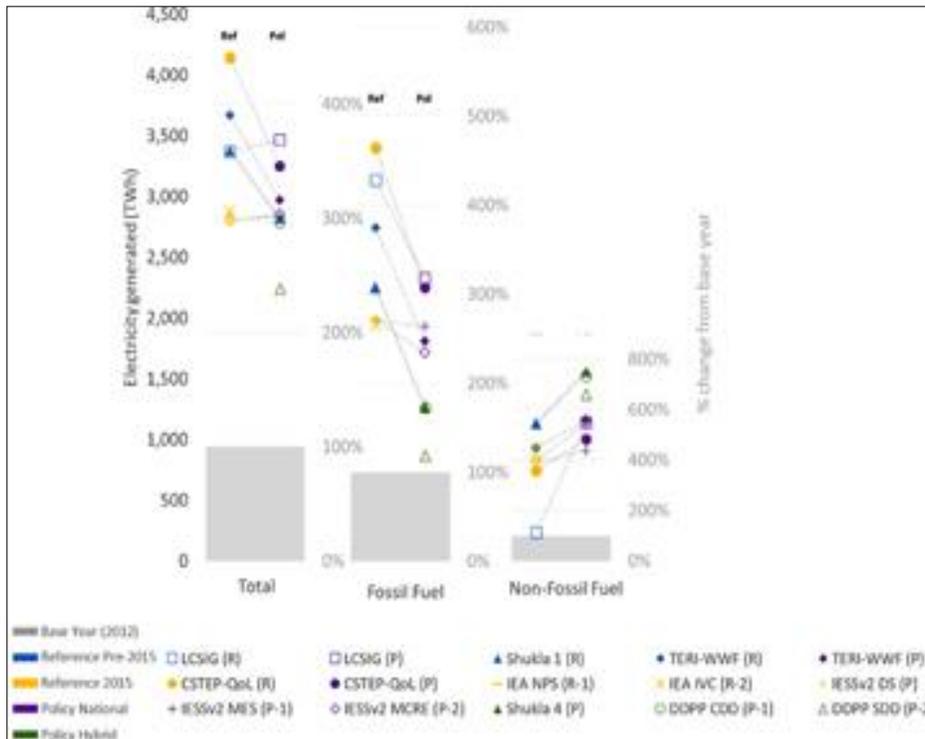


Fig 4: 2030 electricity generation projections for India. Follows the format of figure 2, but represents electricity generation projections for 2030.

**Recent electricity policy trends and implications for model results**

India's energy policy landscape is evolving rapidly. The country makes frequent policy announcements that carry implications for efforts to project future energy and emission patterns. Consequently, as a second step of the analysis, we revisit the model results presented above in light of emergent policy or price trends. In addition, this analysis allows us to identify key contingent factors that could drive future trends. In this section, we focus only on the electricity sector, where policy has been particularly fast moving, and which is an important component of India's emissions.

First, there are systematic indications from recent policy that growth in electricity demand, and therefore generation, is likely to be lower than previously expected. The Government of India's 'Electric Power Survey', an official document used by Indian State governments to plan electricity investments based on the self-assessment of demand by utilities, lowered its projection of electricity generation needs in 2026/27 by 24.4%, from 2710 TWh in its 2012 edition to 2047 TWh in the most recent 2017 edition (CEA 2017b, p 9) [6]. This reduced growth in generation is due both to lower actual generation realized by utilities between 2012 and 2016 than that projected in 2012, and lower projections for the future, through 2026/27. The resultant projections are broadly in line with the *reference 2015* estimates of the modelling studies.

However, future electricity generation is likely to be contingent on several factors, which muddy the waters. The pace and extent of adoption of energy efficiency, loss reducing measures and off-grid electricity such as rooftop solar will be key factors, as also

highlighted by the Electric Power Survey (CEA 2017b, p 81) [6]. India has had a particularly strong track record in the area of energy efficiency, with high-profile LED lighting and appliance efficiency programs, with plans for expansion (Chunekar *et al* 2017) [13]. Recent policy announcements signalling Indian intent to accelerate transition to electric vehicle sales by 2030 (Ministry of Power 2018, IEA 2017b) [25], if realised, would exercise considerable upward pressure on electricity generation needs, although these would be compensated in emission terms by decreased need for transportation fossil fuels. Another significant contingent factor is the future state of India's problematic electricity distribution system. Since 2016–17 India has witnessed the curious phenomenon of surplus electricity capacity coexisting with millions unserved (CEA 2016b, p i) [7], because providing power to the unserved would further worsen distribution company finances (Josey *et al* 2017) [30]. If this situation is reversed and latent demand is unleashed, electricity demand could rise; if this situation persists, electricity demand could remain even below that officially projected.

Second, there has been a steep decline in prices of renewable energy in India, as globally, suggesting the potential for a faster ramp-up in renewable electricity adoption than assumed in previous studies. The cost of solar electricity has plummeted from 0.356 USD kWh<sup>-1</sup> (17.91 INR kWh<sup>-1</sup>) in 2010 (CERC 2010) [10] to 0.038 USD kWh<sup>-1</sup> (2.44 INR kWh<sup>-1</sup>) by 2017 (MNRE 2017), all in 2017 prices, driven both by falling hardware costs but also by well-structured policy based on a reverse auction mechanism (Chawla and Aggarwal 2016) [12]. Wind energy prices have also fallen steeply to 0.053 USD kWh<sup>-1</sup> (3.46 INR kWh<sup>-1</sup>) (CERC 2017) [11]. While some have raised questions about the

sustainability of these low prices, and whether they reflect over-aggressive bids (Bridge to India 2017, Kamili 2017)<sup>[5, 31]</sup> there is little doubt that, at minimum, the price trend is firmly in the direction of cost competitiveness with coal-based electricity.

Third, despite mixed policy signals, evidence is gradually mounting that interest in coal production and coal-based electricity generation is diminishing based both on policy statements and private sector reactions. In 2015, the Government pronounced the need for substantial increases in coal production—up to 1.5 BT from government and private sources, representing a 120% increase over 2016 levels by 2019–20 (Ministry of Coal 2017, 2015, PWC and ICC 2016). A range of evidence, however, suggests that at least based on electricity needs, which in 2015–16 accounted for about 84% of coal use (Ministry of Coal 2017, p 4.30), this expansion in coal production is unjustified.

While a recent estimate suggests 243GW of new coal-fired capacity is in planning or construction (Shearer *et al* 2017)<sup>[47]</sup>—a substantial 120% of 2017 capacity (CEA 2017a, p 1)<sup>[7]</sup>, estimates of required plants are far lower. Thus, an independent bottom-up analysis suggests only an additional 81–110 GW is needed between 2015 and 2020, which would require less coal than mooted in the government target (Sehgal and Tongia 2016, p 31)<sup>[44]</sup>. An even lower estimate of 44 GW of additional coal-fired capacity required to meet the country's needs through 2026–27 is projected by the Government's own draft National Electricity Plan, which draws on the Government's authoritative Electric Power Survey (discussed above) (CEA 2016a, p xxv)<sup>[6]</sup>. Since 50GW is already under construction, the Plan states no further investment in coal fired power is required. There are other, contradictory government statements, notably a draft National Energy Policy produced by a different government agency that projects growth of coal capacity by 330–441GW by 2040 (NITI Aayog 2017, p 34)<sup>[39]</sup>, counter-intuitively implying rapid coal-fired expansion after 2026–27, when renewable energy is likely to be even cheaper. Moreover, this is a projection, while the National Electricity Plan is an operational document, which provides the basis, for example, of a tender for preparation of a 'Coal Vision 2030' document (Coal India Limited 2017, p 36).

There remain vested interests in coal usage and investment which can generate opposition to the uptake of renewables (Edenhofer *et al* 2018)<sup>[17]</sup>. However, analysis aimed at private investors notes declining attractiveness and increasing risk of coal-based power investments (Shearer *et al* 2017, Sharda and Buckley 2016)<sup>[47]</sup>, based on a track record of cancellation of plants because of surplus requirements, a steep increase in a coal tax, low coal plant load factors, and falling renewable energy costs. Finally, additional downward pressure on coal comes from likely environmental constraints around air pollution (The Lancet 2016)<sup>[54]</sup> and water (Srinivasan *et al* 2018, Dharmadhikary and Dixit 2011)<sup>[51, 16]</sup>.

In brief, Indian policy discussions since 2015 in the electricity sector suggests a lowering of demand growth expectations, increasingly favourable conditions for renewable electricity development and lower, if inconsistent, projections for coal use and growing pessimism about its future. However, there are also several contingent factors on which these conclusions depend, particularly with regard to the pace of demand growth. Taken collectively, a reading of recent policy and investor signals suggest that in the electricity sector, while energy needs will

certainly grow, the trends reinforce a perception that this increase will continue at a decreasing rather than increasing rate relative to past expectations. Consequently, modelling results for 2030 based on 2015 policy trends can reasonably be interpreted as an upper bound on future emissions.

### Conclusion

This interpretive analysis of Indian energy models' results, combined with insights from recent Indian policy trends suggests two conclusions on India's energy and emissions future. First, a doubling of India's energy-based CO<sub>2</sub> emissions from 2012 levels, based on projections of 2015 policies, can reasonably be considered an upper bound for 2030 emissions, although the studies do not enable a projection beyond 2030. This trajectory through 2030 is consistent with India's Paris NDC pledge. That this is an upper bound is reinforced by recent trends toward lower than expected electricity demand, although there remain significant uncertainties on this point, and a faster than expected transition from coal to renewable energy. Also, despite a doubling of absolute emissions, India's per capita emissions in 2030 will remain well below today's global average. Notably, even after a doubling by 2030, Indian emissions will be considerably below that of China's current emissions, suggesting that within the next decade, India is unlikely to play as dominant a role in shaping global emissions futures as China has played in the past decade.

Second, given development needs, India's emissions will almost certainly grow. However, policy scenarios suggest there is scope for reduction in the rate of that growth. Among scenarios, those based on policies determined by national development objectives, consistent with the NDC approach, project more moderate reduction in the rate of growth than scenarios that lay significant emphasis on decarbonisation. There is insufficient evidence to indicate whether deep decarbonisation scenarios are consistent with attainment of India's development aspirations; the national development focused scenarios offer a more likely basis for discussion given India's considerable future energy needs.

Finally, this analysis for India suggests a broader methodological point: particularly in rapidly changing developing economies, interpretive approaches provide a useful, and even necessary, complement to quantitative scenario analysis. It also reinforces the importance of greater transparency in model assumptions. Because countries such as India are facing large scale socio-economic and demographic changes, and starting from a low base of energy use, modelling studies have to take into account not just energy futures, but alternative national development pathways which are often reflected in rapidly changing policy directives (Winkler 2014, 2009, Raubenheimer 2011)<sup>[57, 42]</sup>. Despite the greater analytical challenge of such a broad framing, future modelling studies on energy and environment will be more useful if they explicitly engage with the implications of alternative ways of addressing nationally determined development choices.

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