INFORMING INDIA'S ENERGY AND CLIMATE DEBATE: POLICY LESSONS FROM MODELLING STUDIES

RESEARCH REPORT

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EXECUTIVE SUMMARY

What should India put forward as the mitigation component of its climate contribution (or 'Intended Nationally Determined Contribution' (INDC))? Since energy accounts for 77% of India's greenhouse gas emissions, this question can only be answered as one part of a larger discussion about India's energy future. To inform this discussion, models provide one potentially useful tool, if used appropriately. It is important that assumptions are clear, relevant policy questions are credibly explored and that results are clearly explained.

This study conducts a comparative review of seven recent India-focused (not global) modelling studies that cover CO_2 emissions from the energy and industry sectors to explore Indian energy and emissions futures until 2030, with the explicit intention of informing several policy salient questions. The analysis focuses on the substantive results and bases of the reference scenarios that project the effect of current policies, and comments on the construction and comparability of the various low-carbon policy scenarios.

How do studies inform the multiple sustainable development objectives of energy policy?

India's 12th Five Year Plan, and National Action Plan on Climate Change, promote a sustainable development approach to achieving multiple development objectives, highlighting energy for growth, energy security, inclusion, local environmental goals and addressing climate change. At the moment, however, available modelling approaches provide a limited analytical base to inform such multiple objective-based decision-making. Key gaps include:

Energy demand and hence energy efficiency potential is comprehensively discussed by fewer than half the studies. There is also very limited coverage of non-commercial biomass use;

Energy security is addressed by three studies, but with limited effect, since they do not fully internalize future production, world energy prices, or reserves;

Income distribution is included in the analysis by one study, but with limited insights for policy;

Local environmental issues, such as air quality are considered, but not presented, by two studies, although none examine land or water implications.

Incorporating multiple policy dimensions into models requires significant additional effort. Nevertheless, filling these gaps in the future would make modelling studies more relevant for policy.

What are the future trajectories of Indian energy demand and supply?

Energy demand

Despite its significance for understanding the scope for energy efficiency, several studies (more than half) do not provide comprehensive data on final energy demand. Based on the limited available data (3 out of 7 studies), transport and industry are projected to increase their share of total demand in reference scenarios, while the buildings sector share declines considerably, and agriculture reduces to a lesser extent. Notably, in comparison to recent growth rates in these sectors, these projections imply that growth in the buildings sector (including cooking) would slow down considerably and growth in agriculture would increase marginally. The basis for these latter trends is not explained, though likely driven in part by shifts from inefficient biomass to LPG for cooking.

Fossil fuel energy supply and energy security

Energy supply trends diverge considerably across studies, even in reference cases that seek to project the effects of current policies.

However, a few policy relevant aspects of India's fossil energy supply future can be discerned:

By 2030, coal use is projected in reference cases to be 2.5-3 times current levels. Even under additional energy/climate policy scenarios, coal use is projected by all but one study to be more than 2 times current levels;

Oil use projections for 2030 reference cases diverges considerably (1.5 times to 3.1 times current use), likely because of different transport sector assumptions, while gas use diverges from 2.1 to 3.5 times current levels, reflecting varied assumptions about gas use for electricity;

Available results for energy security (3 studies) in 2030 reference cases suggest import levels would increase significantly, to 40-52% for coal (more than double today), 88-93% for oil (compared to 78% today), and 40-70% for gas (versus 30% today). Due to model limitations, these results tend to reflect underlying assumptions rather than endogenous model choices;

In order to keep coal imports at current levels (about 20%), coal production would need to grow at between 5.1% and 6.4% per annum until 2030. If the target of increasing domestic coal production from 600 MT to 1000 MT by 2019 is met, coal production would have to continue growing at between 3.9% and 5.9% per annum until 2030 (versus a current growth rate of 4.2%) to meet projected demand.

Electricity supply

Differences in the fuel mix assumed for electricity generation play an important part in explaining divergence in energy supply trends:

The studies project the 2030 share of coal in electricity output to range from 56% to 90% in reference scenarios, compared to 70% in 2012. This divergence, despite more agreement at the primary energy level, is likely due to diverse assumptions about the efficiency and utilization of the coal power plant fleet;

Nuclear power appears to be systematically overestimated; the studies project additions of 15-42 GW by 2030 (from a current base of 5 GW) although only 2 GW of nuclear capacity have been brought on line in the last decade;

Renewable energy as a share of electricity supply in 2030 ranges widely from 2-12% under the reference scenarios and 12-31% under the policy scenarios. The reference range appears an under-estimate relative to recent trends;

Fossil fuel free electricity sources are projected to provide anywhere between 7-31% of supply under reference scenarios by 2030 compared to 20% today, which can rise to 25-55% under policy scenarios.

Carbon dioxide emissions

The studies project India's future greenhouse gas emissions, which is highly salient information in the context of preparing an INDC. Notably, the studies use GDP growth rates of 7.0% to 8.75%, which assumes that over the next fifteen years, India can repeat the performance of the 2004-2012 period, when GDP growth averaged above 8%, while it has been far lower for most other periods of Indian history:

The studies project 2030 carbon dioxide emissions in the reference case of between 4000 MT and 5674 MT, an increase of two to three times 2011 emissions. In per capita terms, the range is 2.8 to 3.6 tonnes per capita, which is below the current global average of 4.6 tonnes per capita;

The annual emissions policy scenarios represent approximately a 10-15% reduction from the reference range in 2030, with a considerable overlap between the two ranges;

The range of modelled emissions intensities suggest that India's Copenhagen/Cancun 2020 target of 20-25% reduction from 2005 levels falls within the overlap between reference and policy ranges. A similar range of overlap in 2030 -- the low end of the reference range and the high end of the policy range – represent an emission intensity decrease of about 40-45% below 2005 levels.

What are the cost implications of alternative energy and climate policies?

Evaluating the costs of alternative policies is critically important to policy choices. However, the studies offer insufficient data or insight to inform a robust discussion on costs:

Two of the bottom-up energy models report incremental energy investments for particular low-carbon scenarios. However, since they represent distinctly different alternative futures of the energy sector, the associated costs are not directly comparable. Further, they do not have the capacity to quantify the economy-wide impacts of higher energy prices.

The two macroeconomic models, on the other hand, only report GDP losses from low-carbon policies, but have limited granularity in energy sector representation. One study (NCAER) estimates annual discounted GDP losses in the range of $54 billion for a $10/tonne carbon tax to $175 billion for an $80/tonne carbon tax, equivalent to about 1-3 percent of GDP today. Another study (LCSIG) estimates annual average undiscounted GDP loss of $62 billion in 2007 prices (about $26 billion discounted at 10%), if spread equally across the period, which translates to an annual decrease of 0.16% over the period. These numbers too lack direct comparability, not only because of using different low-carbon policies, but also because of different underlying representations of the energy sector.

Enhancing the effectiveness of modelling studies for policy

The constructive use of models for policy would benefit from a structured process of dialogue and interaction between modelling groups and policymakers, aimed at the following improvements:

Develop a credible reference scenario for all studies based on a common set of key assumptions, such as on the implementation of current policies and GDP growth, informed by expert and stakeholder opinion;

Develop policy scenarios through a process involving policymakers and stakeholders, including some common policy scenarios to enable comparison across models;

Develop a common set of relevant outcome variables based on salient development outcomes, including economic costs of abatement, and social and environmental co-benefits and impacts;

Clearly and accurately communicate model results, notably including sensitivity analysis, key drivers and assumptions, such as on technology cost data, and the capacity and limits of different models, such as on assessment of costs.

Key Messages

First, Indian energy policy-making would be well-served by greater clarity on future energy and emission trends. Existing studies present a broad range of reference case results, driven by divergent assumptions, making their use for policy-making a challenge. Studies would better inform policy if accompanied by greater explanation of their results, points of divergence (e.g., renewable and nuclear penetration) and more information on particular areas (e.g. energy demand and overall cost accounting). Policy scenarios lack common measures necessary to make their results comparable.

Second, the studies collectively provide, at best, a limited basis for selecting an economy wide pledge for India's INDC, such as an emissions intensity target. Reference emissions ranges are broad and limited information is available on costs of policy options. A consideration of sectoral actions would provide a complementary approach that relies less on long-term economy-wide projections.

With an eye to the future, India needs to enhance the process for energy and climate scenario analysis, led by the government, but built on an ongoing process of engagement with the broader modelling and policy research community. Further, over time, modelling capacity should be extended to analyze social and environmental outcomes. A structured process to inform strategic thinking on energy and climate change would be a prudent long-term investment.

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INTRODUCTION

What should India put forward as the mitigation component of its climate contribution (or 'Intended Nationally Determined Contribution' (INDC)) for the Paris Climate conference? Since 77% of India's greenhouse gas (GHG) emissions (excluding LULUCF) in 2011 came from the energy sector (WRI-CAIT 2.0), this immediate policy question can only be answered as one part of a much larger discussion about India's energy future.

Formulating energy policy in India is a challenging task. The multiple economic, social and environmental implications are increasingly recognized, including in India's 12th Five Year plan (Planning Commission 2013). Effective energy policy must juggle economic considerations such as adequacy of energy supplies, macroeconomic costs of energy imports and incentives for efficient energy use, social considerations such as energy access, environmental factors such as local air and water pollution, and global greenhouse gas emissions. The task is made more complex by considerable uncertainties about India's energy future, such as future energy needs, alternative supply options, the cost of different sources and technologies and the trajectory of local pollutant and greenhouse gas emissions. Modelling studies that explore these futures and the uncertainties around them provide one potentially useful policy tool to assist consideration of long-term energy and climate policy.

This study conducts a comparative review of seven recent modelling studies that focus on exploring Indian energy and emissions futures, with the explicit intention of informing several policy salient questions, around which the paper is organised:

1. How do studies inform the multiple sustainable development objectives of energy policy?

2. What are the future trajectories of Indian energy demand and supply?
    - i) What is the future energy demand pattern?
    - ii) What is the profile of likely future fossil fuel dependence and implications for energy imports?
    - iii) What is the future of Indian electricity supply and the composition of the supply mix?

3. How might Indian CO_2 emissions grow over time and with what implications for India's climate 'contribution'?

4. What are the cost implications of alternative energy and climate policies?

5. How can modelling studies best inform policy discussion?

We conclude with key messages.

There are important qualifications to addressing these questions with a model review study approach. First, existing studies are typically undertaken by different institutions for a variety of different purposes, such as exploring energy security, development, and climate mitigation scenarios. Moreover, different models have different capabilities — some models are better suited to represent the energy sector in detail, while others are better able to capture interactions at an economy wide level. These different purposes and capabilities require that any comparison across studies only be undertaken with a limited scope. Our approach here is predominantly to focus on the 'reference' or baseline scenarios of each study, which are comparable because they all aim to represent current policies and targets. We comment only in broad terms on the various model 'policy' scenarios that provide outcomes due to a particular policy.

Second, modelling studies are only one input into policy discussion; it is essential that energy and climate planning is also complemented by detailed sector-specific analysis that accounts for both technical and implementation challenges.

Third, the studies considered here are focused on India and cannot provide information on larger changes in world markets or global regulatory frameworks such as around climate change.

APPROACH AND METHODS

This report reviews seven recent studies. Our criteria for selection were: recent vintage (2013 and beyond, with the exception of NCAER - 2009); a focus on India-specific studies (rather than global studies with an India component)[1]; direct application to the INDC context; and direct or indirect linkage or use by the government. Where a modelling group has multiple studies, we selected the most relevant given the criteria above, often in consultation with the group, and refer to additional supporting studies in the analysis.

The full list of studies, along with salient details is presented in Table 1.[2] The report focuses on CO_2 emissions from energy and industry, since this is almost exclusively the scope of the studies. It is important to note that only one study (World Bank) doesn't include all industrial CO_2 emissions, and only four studies include all residential cooking demand.[3]

For each study we have designated a reference scenario (identifying current policies/targets and their full implementation) and one or more policy scenarios, categorized as *weak*, *intermediate*, and *stringent* (based on emissions profile) where there are three or more scenarios. Our analysis focuses on comparable results across models, and also examines and explains underlying assumptions and interprets specific results, where possible. Most of the models use an end-date of 2030 (or in some cases 2031 or 2032). Where models use a longer period, such as 2050, we show results for 2030 for comparability. Select model results are presented in visual form with supporting text. Detailed data underlying the figures are in the Appendix.

Our methodology included consultations with each of the modelling groups, in the form of individual meetings, correspondence over data details, and a stakeholder workshop to provide input and feedback to our findings.

TABLE 1: STUDIES REVIEWED

Study Name (Abbreviation)	Institution/author and Date	Model Type	Study Timeline	List of Scenarios (scenarios selected for analysis in **bold**)
Expert Group On "Low Carbon Strategies for Inclusive Growth" (LCSIG)	Planning Commission, Government of India, April 2014	Activity Analysis Model (Top-Down)	2007-2030	**Baseline Inclusive Growth (Reference), Low Carbon Inclusive Growth (Single Policy)**
Climate Change Impact on the Indian Economy – A CGE Modelling Approach (NCAER)	National Council for Applied Economic Research (NCAER), December 2009	Computable General Equilibrium (CGE) Model (Top-Down)	2003/04-2030/31	**Reference (Reference),** Revenue Positive Carbon Tax at $10, $20, $40, $80, **Revenue Neutral Carbon Tax at $10 (Weak Policy),** $20, **$40 (Intermediate Policy), $80 (Stringent Policy)**
The Energy Report – India. 100% Renewable Energy by 2050. (TERI – WWF)	The Energy and Resources Institute (TERI), December 2013	MARKAL Model (Bottom-Up)	2001-2031*	**Reference Energy Scenario (Reference), 100% Renewable Energy Scenario (Single Policy)**
Energy-Emissions Trends and Policy Landscape for India (Shukla et al.)	P. R. Shukla, Amit Garg, Hem H. Dholakia, January 2015	Integrated Assessment Model (IAM)	2005-2030**	**Business As Usual (Reference),** Scenarios **1 (Weak Policy),** 2,3,**4 (Stringent Policy), 5 (Intermediate Policy)**
A Sustainable Development Framework for India's Climate Policy (CSTEP)	Centre for Science, Technology and Environment Policy (CSTEP), January 2015	Integrated Energy Model (Bottom-Up)	2012-2030	**Business As Usual (Reference), Policy Scenario (Single Policy)**
Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development (World Bank)	World Bank, February 2014	World Energy Model (Bottom-Up)	2007-2031	**Scenario 1 (Reference),** Scenario 2, **Scenario 3 (Single Policy)**
India Energy Security Scenarios 2047 (IESS)	Planning Commission, Government of India, IESS web-tool	Excel based simulation model (Bottom-Up)	2012-2032***	**Determined Effort Scenario (All Level 2s) (Reference), Maximum Energy Security Scenario: Determined Effort (Weak Policy), Maximum Energy Security Scenario: Heroic Effort (Intermediate Policy), Minimum Emissions Scenario (Stringent Policy)**

* The study provides data till 2051. However, the range of data for 2001-2031 has been selected to enable comparison with other studies.

** The study provides data till 2050. However, the range of data for 2012-2030 has been selected to enable comparison with other studies.

*** Data from IESS web-tool, accessed on 31 January 2015. IESS provides data till 2047 and data for 2012-2032 was selected to enable comparison with other studies.

How do studies inform the multiple sustainable development objectives of energy policy?

India's 12th Five Year Plan, and National Action Plan on Climate Change (NAPCC), promote a sustainable development approach to simultaneously achieve multiple benefits: energy for growth, energy security, inclusive growth, local environmental goals, and addressing climate change (Planning Commission 2013, 112-143; PMCCC 2008). Ideally, model projections would also incorporate multiple objectives in order to be fully policy relevant, recognizing that there are considerable challenges to developing models that can address the full breadth of objectives. Table 2 inventories the coverage of various objectives across the studies.

Energy, Energy Security and Emissions: All the studies explicitly discuss energy supply. However, less than half the studies provide comprehensive details on demand side energy, a key element for understanding any future energy representation. Some studies include a demand representation as part of their model, but do not provide sufficient data to inform policy or make clear their demand characterization. Similarly, only CSTEP, IESS and TERI-WWF quantitatively assess energy security. While all the studies report emissions, only the macroeconomic models explicitly derive emissions intensity. The results of energy and emissions findings are discussed in the next two sections.

Inclusive Growth: Only one study, the LCSIG, sets out to explicitly address inclusive growth. The model includes ten expenditure classes to model income distribution and represents inclusive policy through government transfers for social objectives. However, because income distribution across classes is assumed using a constant Gini coefficient[4], and because both scenarios adopt the same inclusion criteria, the effects of inclusion versus non-inclusion aren't informative.[5]

Local Environment: Two studies, CSTEP and Shukla et al., consider local environmental effects. Both studies suggest a calculation of air pollution outcomes, such as from transport, although neither presents these in their study outcomes. CSTEP notes that their current study is in an interim form and that future reports will look at additional sustainability considerations such as air, water and land quality.

In summary, existing studies provide limited insight into policy relevant objectives beyond energy supply and emissions. Costs of alternate policies are unevenly covered across studies, and are discussed in detail in a subsequent section. It should be noted, however, that incorporating multiple policy dimensions, such as air pollution, requires significant additional effort. Nevertheless, filling these gaps in the future would help the policy relevance of modelling studies.

TABLE 2: INFORMING MULTIPLE OBJECTIVES

Objectives		LCSIG	NCAER	TERI-WWF	Shukla et al.	CSTEP	World Bank	IESS
Energy for growth	Supply	●	●	●	●	●	●	●
	Demand	o		●		●		●
Energy Security				●		●		●
Inclusive growth		o						
Local environmental objectives					o	o		
CO_2 mitigation	Emissions	●	●	●	●	●	●	●
	Intensity	●	●					
Costs		●	●	o			o	

● Full coverage: Reasonably comprehensive and transparent treatment

o Partial coverage: Addressed to an extent, but falls short in some respects, including accessibility

What are the future trajectories of Indian energy demand and supply?

It is necessary to understand the possible evolution of India's energy sector in order to assess future development pathways. All the studies discussed examine the energy sector, albeit to different levels of detail. Here, we focus on how the studies project the near energy future until 2030, by examining the reference scenarios that seek to capture current policy, assuming their full implementation and also comment, in brief, on the policy scenarios run by the models. This section examines final energy demand, fossil fuel primary energy supply, and the electricity sector.

What is the future energy demand pattern?

Understanding future patterns of energy use is critical for energy and climate policy because there is significant potential for reducing energy dependence and emissions from demand-side measures. Sectors such as buildings, transport, and industry can form the bulk of reduction in emissions intensity, up to 23-25% from 2005 levels by 2020 (Planning Commission 2011). Future fossil fuel needs and consequently future import shares also depend on realistic projections of energy demand. In addition, the sectoral composition of final energy is fundamental to assessing the scope for co-benefits, as targeted demand side interventions can simultaneously achieve savings of energy, carbon and cost, better local environments, and increased energy security.

Despite these potential gains, only three of the seven studies report data on final energy demand – CSTEP, IESS and TERI-WWF (Figure 1, Table 3), even though five of the seven models are technology-detailed and therefore suited to examine energy sub-sectors. Moreover, even among these three, the studies provide sectoral assumptions at various levels of specificity, and with limited linkages between salient assumptions, integrated narratives or storylines, and aggregate trends. Macroeconomic studies have less fine-grained energy sector representation and use broad assumptions across sectors about autonomous energy efficiency improvements.

There are a limited number of overarching trends apparent from Figure 1 and Table 3. For example, transport and industry are projected to increase their share of total demand in reference scenarios, while the buildings sector share declines considerably, and agriculture reduces to a lesser extent. Notably, when compared against recent growth rates in these sectors, these projections imply that growth in the buildings sector would slow down considerably (from 5.1% in the last decade to between 0.9% and 3.3%) and growth in agriculture would increase somewhat.

One explanation for the slowing of building demand growth is that residential cooking demand reduces considerably due to the replacement of inefficient traditional cook stoves with efficient LPG stoves. For instance, both IESS and TERI-WWF's reference scenario assumes this switch, though at a more aggressive rate in IESS than in the TERI-WWF study. However, besides TERI to an extent, none of the studies explicitly discuss non-commercial biomass demand and the uncertainties in assessing its evolution and contribution to GHG emissions. Shukla et al. report non-commercial biomass, but only as part of primary energy. This relatively thin treatment of non-commercial biomass across the models neglects an important part of future energy demand, particularly for India's poorest.

The resulting total and sectoral final energy demand in 2030 differs considerably across these models. For instance, the range for buildings demand is 2470-4081 TWh (factor of 1.65) and that for transport demand is 2571-4488 TWh (factor of 1.75). While such a range of uncertainty is entirely reasonable, being able to identify key drivers and pinpoint particular points of departure between studies would make the projections more useful for policy.

TABLE 3: FINAL ENERGY DEMAND: CURRENT AND PROJECTED SHARES (CSTEP, IESS AND TERI-WWF)

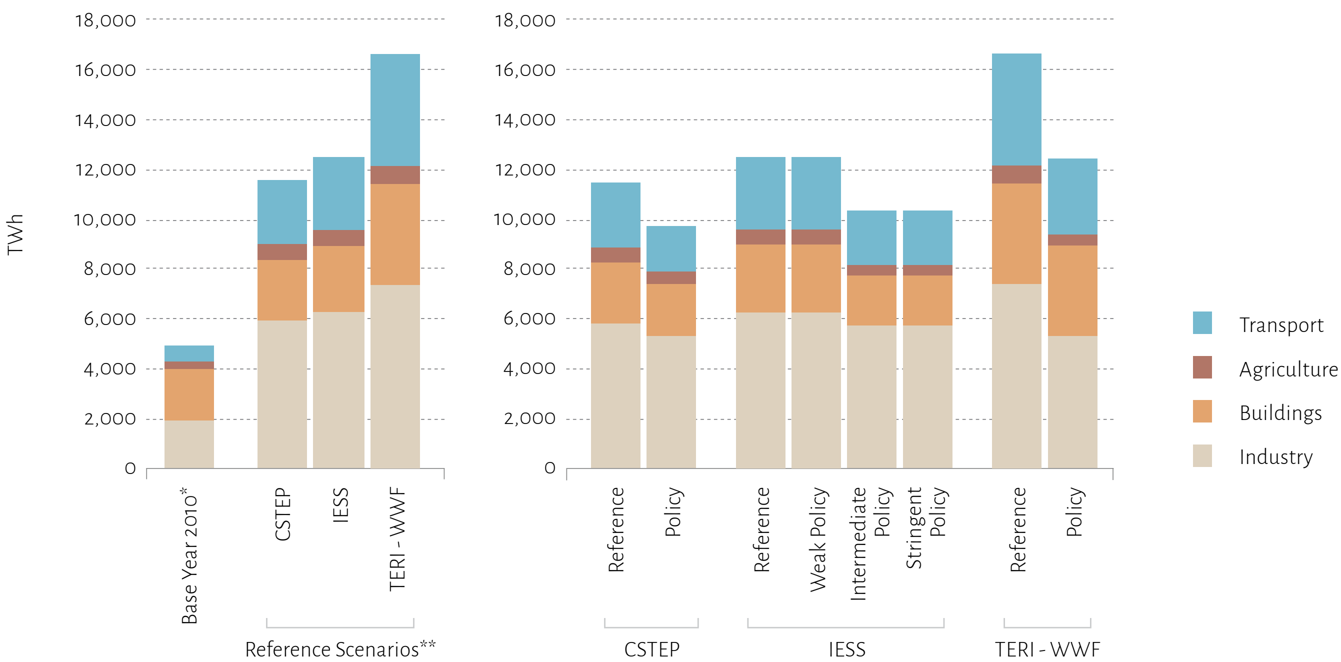
	Recent Trends		Reference Scenarios (2030/31/32)		Policy Scenarios (2030/31/32)	
	Share (%) 2010-11*	Growth Rate (%)** 2001/02 - 2010/11	Share (%)	Growth Rate (%)	Shares (%)	Growth Rate (%)
Industry	35-44	7.5	44-51	5.6-6.6	43-56	5.1-5.6
Buildings* **	39	5.1	22-25	0.9-3.3	19-30	-0.17 to 2.8
Agriculture	5-7	2.6	4-5	3.7-4.3	3-6	2.0-3.7
Transport	13-18	7.4	22-27	6.9-9.4	18-24	5.0-7.4

* Source: MoSPI (2012) for lower range and TERI (2013a) for higher range.

** Source: Calculated from TERI (2013a)

*** Buildings includes residential and commercial sectors. For recent trends, 14% is from commercial use and the rest is non-commercial (TERI, 2013a). Recent trends growth rates are commercial only.

FIGURE 1: FINAL ENERGY DEMAND BY SECTOR IN 2030



The range of study end-years is 2030/31/32. See Appendix, Table A1.

* Data for 2010-2011.

** Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.

Interestingly, although policy scenarios incorporate additional energy and climate policies, the sectoral shares in policy scenarios are relatively similar to those in reference scenarios. This could mean that energy efficiency opportunities have comparable potential across sectors, or it could also mean that the results are driven by relatively aggregate assumptions of efficiency improvement that cut across sectors. Without further detail or discussion of results, it is unclear how to interpret these outcomes.

What is the profile of likely future fossil fuel dependence and implications for energy imports?

Projections of future fossil fuel energy needs and the relative share of imports are of considerable policy significance for India. Availability of these fuels, or their substitutes, could enable or limit growth, but also increase reliance on imports and exacerbate local environmental problems. To what extent and how do the studies inform these policy questions? Figure 2 and Table 4 summarize projections of total primary fossil energy supply for the five studies (except NCAER and World Bank) for which this information was available.

According to reference cases, fossil fuel use is projected to continue rising through 2030, at a slightly lower rate than recent trends for coal, and in line with recent trends for oil and gas. Notably, GDP growth rates used tend to be higher than recent trends, as discussed further in the section on emission trends below.

According to the reference scenarios, it is immediately apparent that there is fairly close convergence across the studies on future coal use, at around 2.5-3 times current coal use in 2030, with coal continuing to dominate the fossil energy mix. Even under the policy scenarios, under various energy or climate policies, the scenarios suggest coal use will at least double, with the exception of the TERI-WWF 100% renewables scenario where coal is 1.5 times current use in 2030.

There is far greater divergence in oil and gas supply projections in the reference cases, with a factor of two between the lowest and highest projections for oil (1.5 and 3.1 times current levels) and 1.5 for gas (2.1 to 3.5 times current level). The broader spread on oil likely reflects varying assumptions about the future transport sector, which today contributes almost 40 percent of oil consumption. However, there isn't enough information on transport demand characteristics to fully understand the different views. The divergence in gas projections is driven by different views of gas penetration in India's electricity mix, ranging from 3% (LCSIG) to 8% (TERI-WWF).

Notably, under policy scenarios as well, both oil and gas increase by at least 1.5 times. For gas, almost all the policy scenarios (with the exception of the IESS) project higher gas use in the policy scenarios than in the reference case, suggesting that increased gas use is likely to be a major share of any future CO_2 emissions reduction approach. As with reference scenarios, the spread of projected growth rates is much larger for oil and gas than for coal.

The most significant implication of these patterns of fossil use is that fossil import dependence would rise to over 50% in the reference cases, and drop significantly below that under the various policy scenarios (Table 5). Three studies (TERI-WWF, C-STEP, IESS) explicitly examine energy imports, of which only one (TERI-WWF) endogenously determines coal penetration based on its relative costs.[6] Table 5 starkly shows the high degree of overall import dependence. Coal imports are estimated at 40-52% versus about 20% today (Ministry of Coal 2014) and 88-93% for oil. Interestingly, while some policy scenarios envision steeply reducing coal imports to more manageable levels, oil imports stay high across all scenarios in all the three studies.

Notably, import shares are driven more by construction rather than by endogenous model choice. This is because none of the models have the capabilities (as yet) to represent domestic and foreign upstream fuel sectors. For instance, TERI-WWF assumes oil production will plateau by 2016/17. IESS defines its maximum energy security scenario by import constraints (of 21%). The relationship between domestic production and imports is most pertinent for coal, and merits some elaboration.

Since coal imports have grown at 23% per annum in the last decade, restricting further growth would be of policy interest. In order to keep imports at current levels (~20%), coal production would need to grow at between 5.1% and 6.4% per annum (based on the range of reference scenarios) until 2030. This would be equivalent to meeting the Coal Minister's target of increasing domestic coal production from 600 MT to 1000 MT by 2019, and then growing at between 3.9% and 5.9% per annum until 2030.

Accelerating or maintaining growth rates of domestic production for purposes of energy security is, however, only one aspect of the necessary policy context. Also of policy salience are the local environmental consequences of coal use. For instance, a two-to-three fold increase in coal consumption could contribute to a doubling of local air pollutants such as particulate matter, leading to a doubling of health impacts (Conservation Action Trust, India and Urban Emissions, India 2014). Specifically, premature mortality from coal-fired power plants would rise to 229,000 annually by 2030, and asthma associated with these plants may affect 42.7 million people. Another study highlights the water stress that thermal power plants can lead to, especially as there is a track record of clustering plants in particular locations. Thus, plants granted environmental clearance as of 2011 are estimated to require 4.6 BCM of water per year (Dharmadhikary and Dixit 2011). By way of comparison, Delhi's population is estimated to require about 1.6 BCM per year.[7]

In sum, to enhance the value of fossil energy projections for informing policy, a deeper understanding of the drivers of these projections would help. Key sectoral assumptions, such as the implications of different transport scenarios for oil use, and the role of gas in the future grid, need to be adequately debated and explored within the context of the models. Further, the discussion on energy security requires a consistent framework for reporting of data, but also, over time, better integration between energy sector models and those that explore broader macro-economic effects and world energy prices. Finally, the biggest lacuna is a lack of attention to local environmental effects.

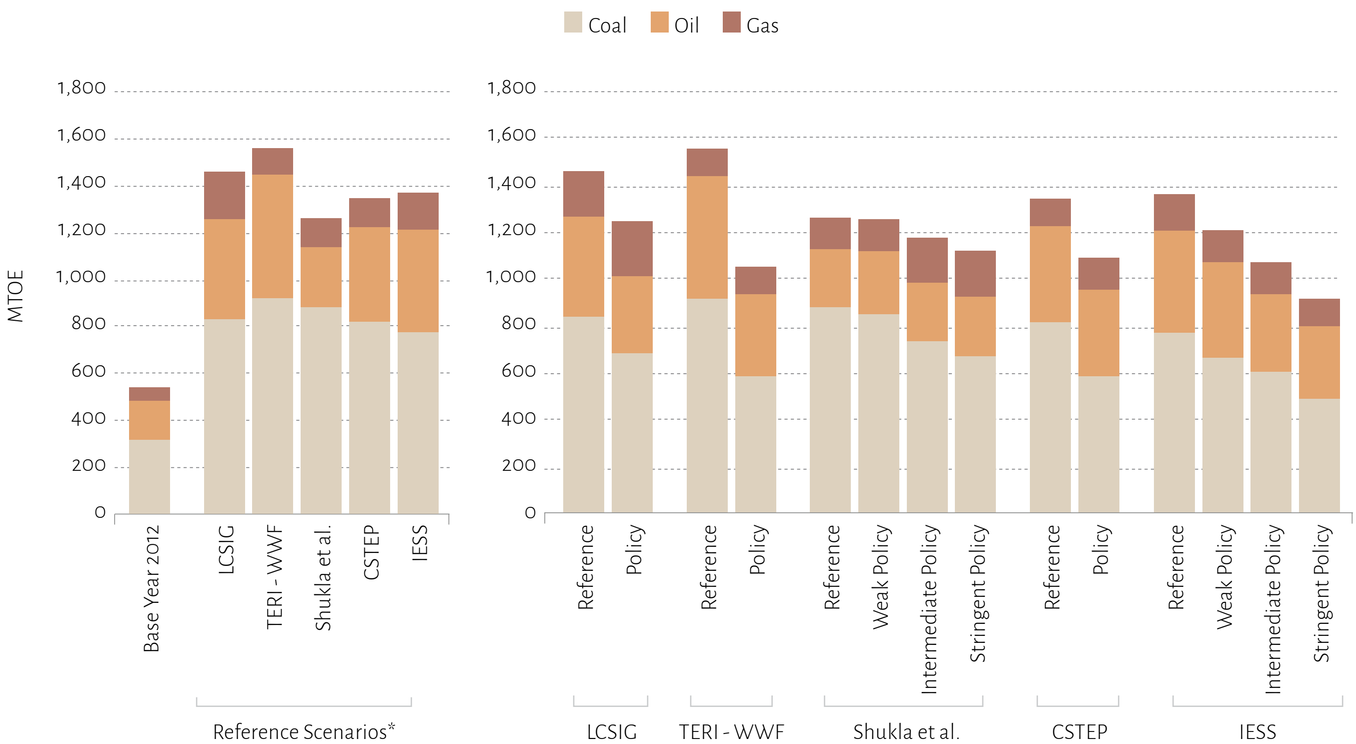
TABLE 4: CURRENT AND PROJECTED TRENDS IN FOSSIL FUEL SUPPLY

	Recent Trends 2003-4 to 2013-14**		Reference Scenarios (2030/31/32)		Policy Scenarios (2030/31/32)	
	Total growth rates (%)	Domestic production growth rate (%)	Multiple of current (2012) use in 2030	Growth rate (%)	Multiple of current (2012) use in 2030	Growth Rate (%)
Coal	7.5	4.2	2.5-3.0	4.7-6.0	1.5-2.8	2.2-5.8
Oil	4.1	1.3	1.5-3.1	2.4 – 5.3	1.5-2.4	2.3-4.5
Gas	5.5	1.1*	2.1 - 3.5	4.3 – 7.2	2.2-4.0	4.0 – 8.0

* Gas production dipped sharply after 2011-12 due to decline in production in the K-G basin. If 2001/2-11/12 is taken the rate goes up to 5.2%

** Recent Trends from Coal Controller's Organization (2012), Ministry of Petroleum & Natural Gas (2013), Ministry of Coal (2011).

FIGURE 2: TOTAL PRIMARY FOSSIL FUEL ENERGY SUPPLY IN 2030



The range of study end-years is 2030/31/32. See Appendix, Table A2.

* Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.

TABLE 5: FOSSIL FUEL IMPORT DEPENDENCE (TERI-WWF, CSTEP, IESS)

	Recent Trends 2003-4 to 2013-14*		**Reference scenarios (2030/31/32)**	**Policy scenarios (2030/31/32)**
	Import Share (%)	**Import Growth Rate (%)**	**Import Shares (%)**	**Import Share (%)**
Coal	26	23	40 – 52	0 – 21
Oil	78	5	88 – 93	81 – 86
Gas	30	13***	40 – 70	20 – 73
Overall Import Dependence**	43		51 – 52	24 – 36

* Recent trends from Department of Commerce (2012).

** Overall import dependence ranges do not include TERI – WWF.

*** Gas imports are for 8 years (2005/6 to 2013-14) because gas imports were zero before 2005.

What is the future of Indian electricity supply and the composition of the supply mix?

Electricity production accounted for 38% of total primary energy use in India (2010),[8] and 38% of greenhouse gas emissions or 47% of CO_2 emissions (2007).[9] Adequate and reliable electricity is required for industrial development, and to meet social objectives such as health, education and livelihood. The future evolution of India's electricity sector carries economic, social and environmental implications. For example, 400 million people in India are currently unserved by electricity (Ministry of Home Affairs 2011). What do the studies reviewed tell us about the future of Indian electricity, and what questions do they throw up with regard to clarity about the future (Figure 3, Table 6)?

There is broad agreement across studies that electricity supply needs will substantially increase in the coming two decades. Total electricity supply is projected in reference scenarios to increase three- to four-fold between 2012 and 2030 (See Figure 2). Even the lowest policy scenario projects an increase of 2.5 times current levels.

Coal continues to dominate the electricity supply mix under reference scenarios, but there is substantial variance across the studies on the extent of that dominance, ranging from a low of 56% share of generation to a high of 90% (compared to 70% in 2012). This divergence, despite more agreement at the primary energy level, is likely due to diverse assumptions about the efficiency and utilization of the coal power plant fleet. Among the policy scenarios the lowest possible coal share projected was 43% (IESS Stringent scenario), which is highly unlikely, as it would require turning off power plants that are already under construction today (IESS Report, 54).

The share provided by gas and hydro are projected, in the reference scenario, to at most retain their current shares, or, at the low range of the scenarios, to decline. In the policy scenarios, the share of gas increases from 9% to at most 14%, and hydro marginally increases. At the low end of the policy scenarios, both their shares decrease. Together, the projections suggest that gas and hydro, while continuing to provide scope for moderate share of electricity (on the order of 10%) are unlikely to dramatically ramp up their contribution, even under stringent policies.

Perhaps most striking, the reference case projections for future nuclear power and renewables seem most at odds with the past. Though only 2 GW of nuclear capacity have been brought on line in the last decade, the models project additions of 15-42 GW by 2030 (excluding one model that projects no additions) from a current base of 5 GW.[10] The basis for such an optimistic view of nuclear power potential in the studies is unclear.

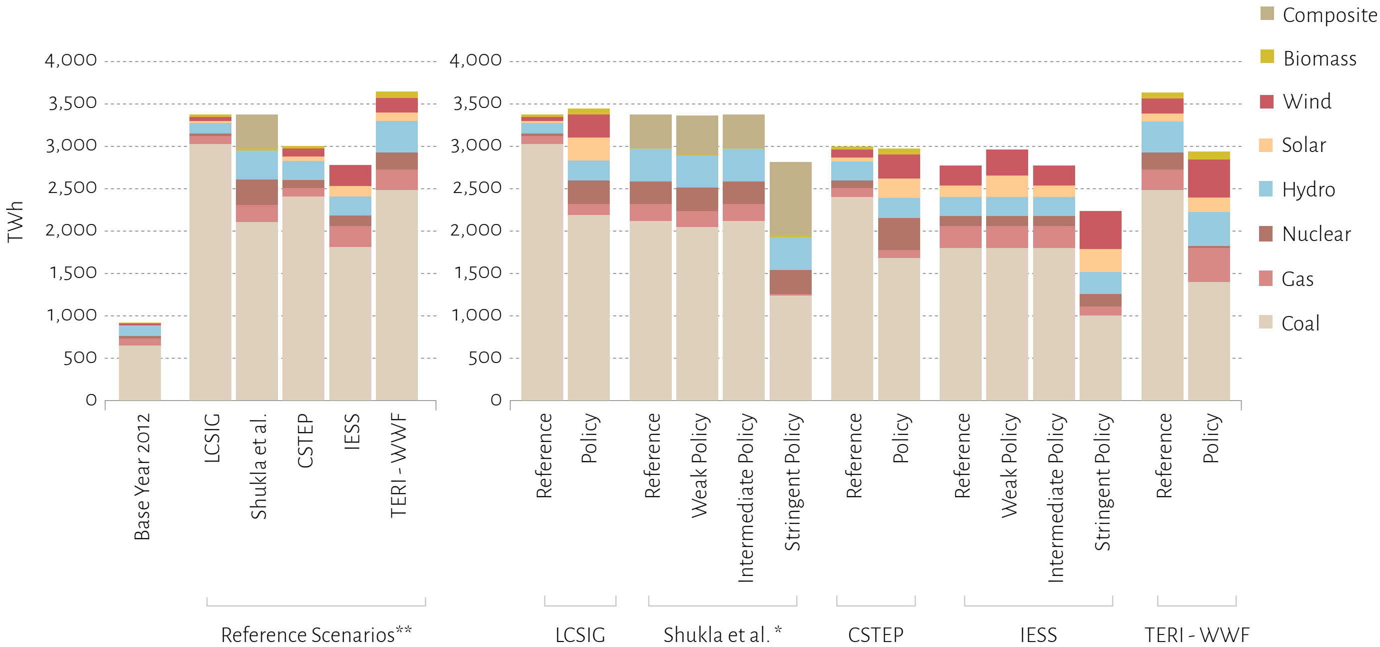
The largest uncertainties relate to the growth rates of renewable energy, which, under reference scenarios, vary by a factor of four in the reference scenarios. The low range of these scenarios are highly conservative with respect to recent growth, while the upper end are more moderate than recent ambitious government targets for 2022 (100 GW solar and 60 GW wind power).[11] At the lowest end of the range, the LCSIG projects an RE share of 2% in 2030, which is below the current share of 3.9%, and would presume a growth rate of 3.9%, compared to the short run three year growth rate for renewables of 21.5% from 2010-11 to 2013-14 and for wind (RE's primary driver) of 20.1% from 2005-06 to 2013-14. The high end projects a 12% share (393 TWh by 2030, Shukla et al.), which would require a growth rate of about 14%, until 2030, as compared to the (aspirational) growth rate of 23% until 2022 required to meet the government's targets of 100 GW solar and 60 GW wind (which corresponds roughly to 297 TWh) for 2022[12].

Under policy scenarios representing supportive policies, the highest projected shares of RE range from 12-31%, with corresponding growth rates of 12.3-19.3%. The high end of this range would require that recent RE growth rates are sustained for the next fifteen years.

Finally, in the context of climate discussions, it is useful to examine the fossil fuel free (FFF) share of electricity, comprising renewables discussed above plus hydro and nuclear.[13] The reference scenarios project a broad range of FFF share from 7% to 31%, while the current 2012 share is 20%. Given that RE is the most rapidly growing segment of the electricity sector, and hydro and nuclear are projected to grow rather than shrink, it is difficult to imagine circumstances where the low end of this range will become reality. The policy scenarios project a FFF range from 25% to 55%, with the majority clustered around 25% to 35% and two substantially higher between 50% and 55% (driven by a 100% renewables goal and explicit assumptions about high levels of renewable penetration respectively).

These projections of India's future electricity mix suggest widely divergent projections on the future electricity mix in 2030 even in reference scenarios. Adequately informing policy will require narrowing these reference case divergences by more informed and reasoned assumptions for each fuel source. The ranges are particularly large in the rapidly changing renewables sector, with implications for India's share of fossil fuel free electricity.

FIGURE 3: ELECTRICITY SUPPLY MIX IN 2030



The range of study end-years is 2030/31/32. See Appendix, Table A3.

* Composite includes non-biomass renewables, including geothermal, ocean, solar (PV and CSP), wind (onshore and offshore). Individual renewables shares not available.

** Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.

TABLE 6: PAST AND PROJECTED FUTURE TRENDS IN ELECTRICITY SUPPLY

	Recent Trends***		Reference scenarios (2030/31/32)		Policy scenarios (2030/31/32)	
Sources	**Generation Share (%) 2012**	**Growth Rate (%) 2002-03 to 2012-13***	**Shares (%)**	**Growth Rates (%)**	**Shares (%)**	**Growth Rates (%)**
Coal	70.2	6	56- 90	5.2-8.9	43-63	2.2-7.0
Gas	8.6	-3	3-8	0.9-6.2	1-14	-5.9-9.0
Nuclear	3.5	7	1-8	-0.1-12.7	1-14	-1.8-14.5
Hydro	13.1	6	4-11	0.4-6.6	7-14	3.2-6.6
Solar	0.1	322.3	0-4	11.4-27.0	5-11	27.0-35.6
Wind	2.8	20.1	1-7	3.7-11.8	8-19	11.8-16.2
Biomass	1.0	14.6	0-2	-12.7-12.1	0-3	-12.7-13.1
Total**	100.0	4	100	6.4-7.5	100%	4.8-7.6
RE	3.86	21.5	2-12	3.7-14.2	12-31	12.3-19.3
FFF (Fossil Fuel Free)	20.51		7-32	1.1-10	25-55	6.9-12.3

* Historical growth rates for renewable energy sources are based on available data, since 2002-03: 3 years for solar, 9 years for wind and 6 years for biomass. Because of inconsistencies across sources, the growth rate for FFF has also not been computed.

** The total does not exactly equal the sum of the rows above, as it excludes an additional "other" category that is defined differently in the various studies.

*** Recent trends from Central Electricity Authority (2012a, 2012b).

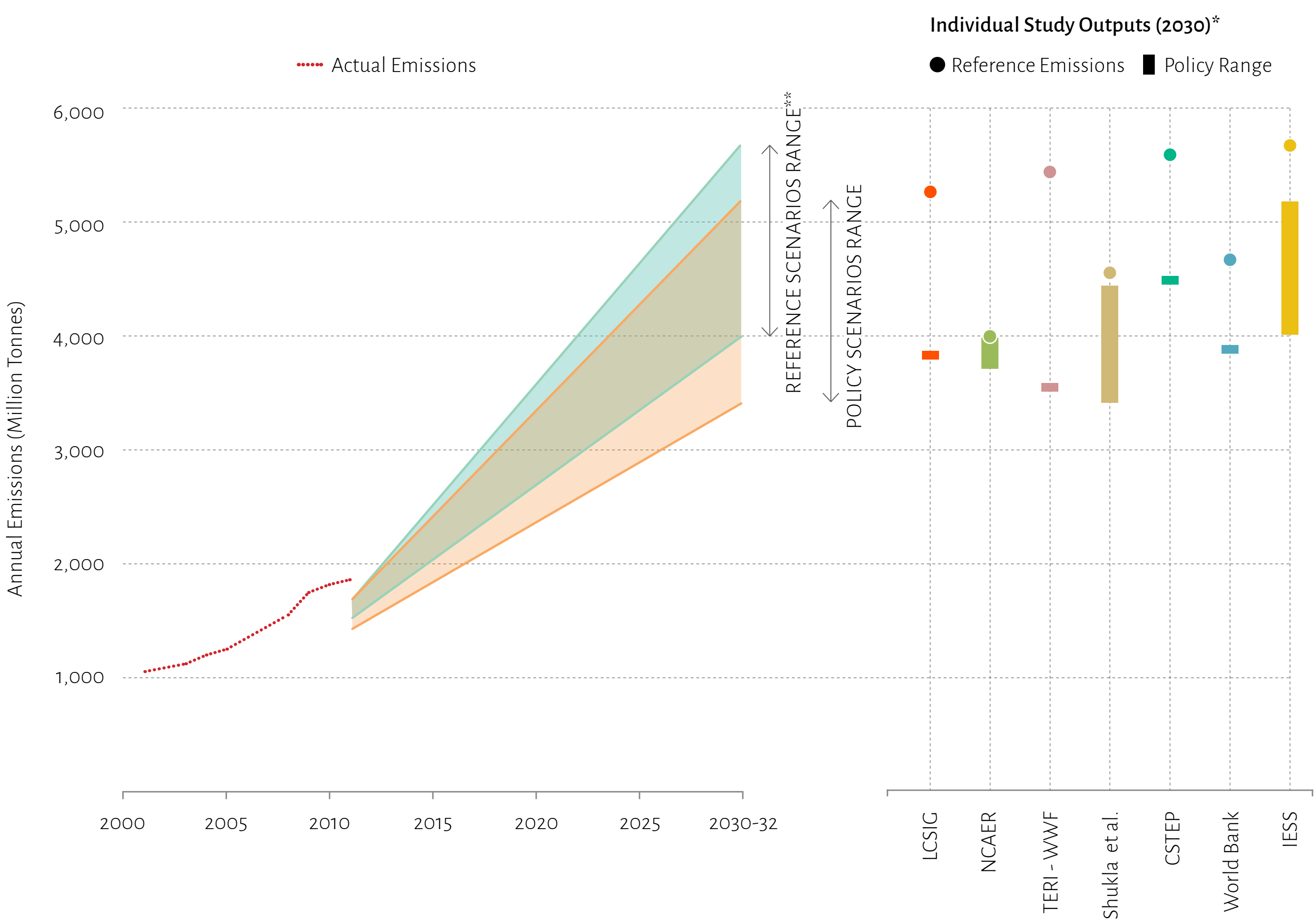
How might Indian CO_2 emissions grow and with what implications for India's climate 'contribution'?

India's climate positions, as discussed earlier, need to be built on a solid understanding of energy needs and likely futures. Figures 4 to 7 illustrate the range of emission futures for total CO_2 emissions, per capita emission, emissions intensity and emissions versus energy intensity respectively. For each graph, the envelope of possible trends drawn using only available beginning and end year data is plotted on the left, with the specific study data on the right of each graph. Table 7 further summarizes the range for each metric.

Together, the studies represented in Figure 4 provide what is probably a robust upper bound and a probable lower bound on emissions in 2030. The upper bound is likely robust because it represents an increase in fossil use from a relatively high GDP growth rate of 7.0-8.75% between 2015 and 2030 along with an increasing share of coal in primary energy. The lower bound is likely because although the scenarios at the lower end of the range entail an aggressive penetration of renewables and nuclear, they too assume equally aggressive GDP growth, which, if overstated, would counteract the effect on emissions reductions of overestimating renewables. The lowest emissions reference scenario for which data is available (Shukla et al.) projects an increase in fossil fuel free share of electricity ranging 20% in 2012 to 31% in 2030 (or 11 times and 9 times increase in generation over today, for renewables and nuclear respectively).

The reference scenario projections show annual emissions of 4000-5674 MT by 2030, an increase of between a factor of 2 and 3. To put these numbers in international context, US emissions in 2011 were 5333 MT, toward the higher end of the Indian 2030 projections, and Chinese emissions were 9035 MT in 2011, almost double India's projected 2030 emissions.[14] Based on the US INDC of a reduction by 26-28% below 2005 levels by 2025 (UNFCCC 2015), US GHG emissions (including non-energy sources) would be about 4.5 Gt in 2025 (Damassa 2014), suggesting India could be the second largest global emitter within the next decade.

FIGURE 4: ANNUAL CARBON DIOXIDE EMISSIONS



* The range of study end-years is 2030/31/32. See Appendix, Table A4.

** Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.

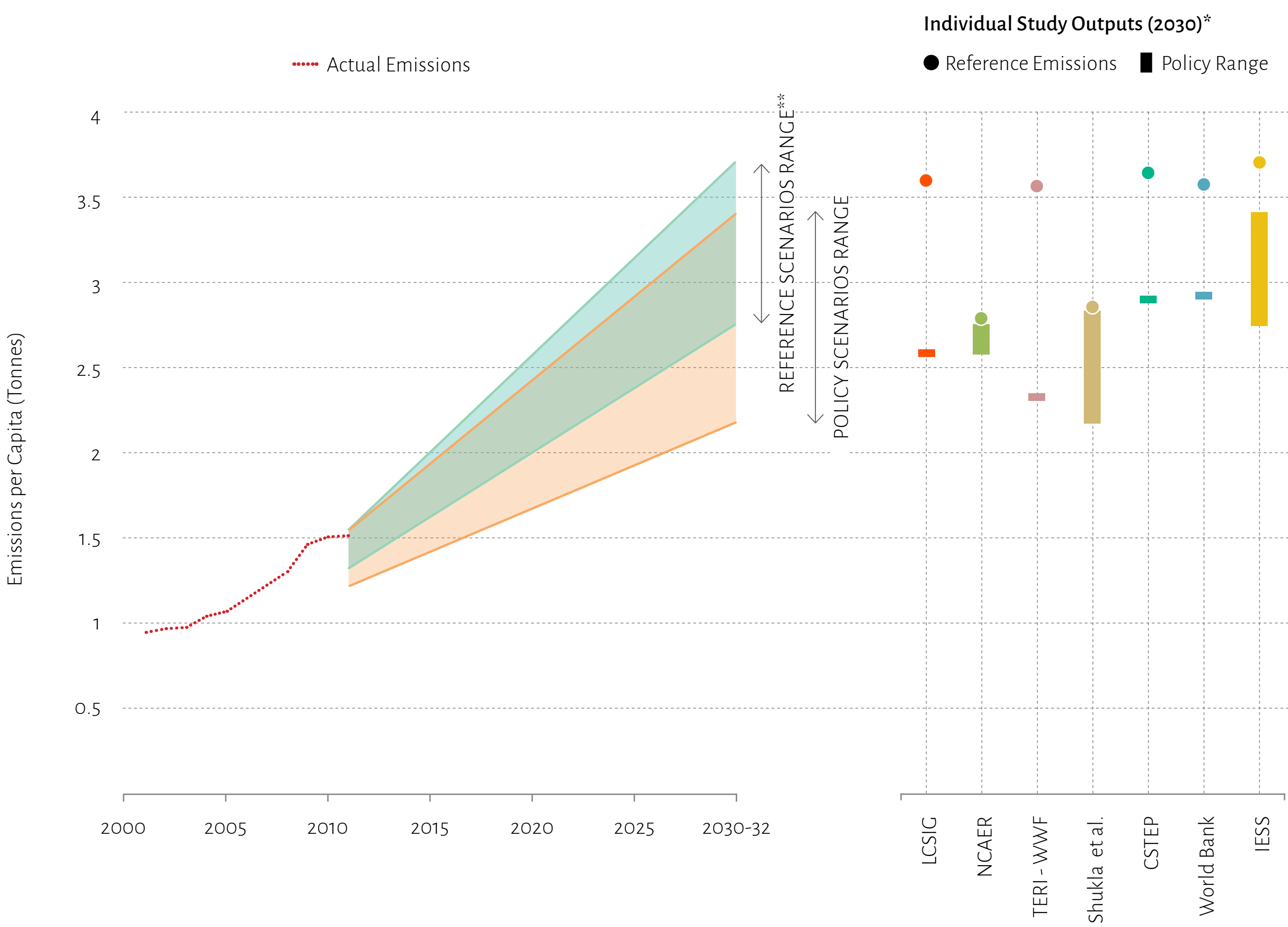
TABLE 7: INDIA'S CO_2 EMISSION TRENDS

	Base Year 2011	Reference scenarios (2030/31/32)	Policy scenarios (2030/31/32)
CO_2 Annual Emissions (MT)	1861	4000-5674	3421-5186
CO_2 Emissions/capita (Tonnes)	1.5	2.8-3.7	2.2-3.4
Emissions Intensity (kgCO_2/$GDP PPP-2007)	0.44	0.26-0.36	0.17-0.28

However, the picture looks very different with per capita emissions (Figure 5). Even after doubling or tripling per capita emission levels, India's 2030 emissions are in the range of about 3.25 tonnes/capita, +/- 0.45 tonnes, which on a global scale is relatively narrow. Notably, this 2030 range is well below the current 2011 world average of 4.6 tonnes/capita.

The policy scenario range, at 3421-5486 MT, represents approximately a 10-15% reduction in the envelope of possible annual 2030 emissions (Figure 4). However, there is a substantial overlap between the bottom end of the reference range and the top end of the policy range, suggesting that across studies, there is considerable uncertainty in how and what current policies will be implemented. To unpack this requires attention to the details of individual scenarios. Notably, however, even the lowest end of the policy range (the minimum emissions scenario in Shukla et al.) projects a near doubling of emissions from 2011. The policy projections as a group, therefore, are hard to interpret as compared to reference ranges, but do suggest that, even under stringent policy conditions, India's emissions are likely to grow considerably in order to meet development needs.

FIGURE 5: CARBON DIOXIDE EMISSIONS PER CAPITA



* The range of study end-years is 2030/31/32. See Appendix, Table A5.
**Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.

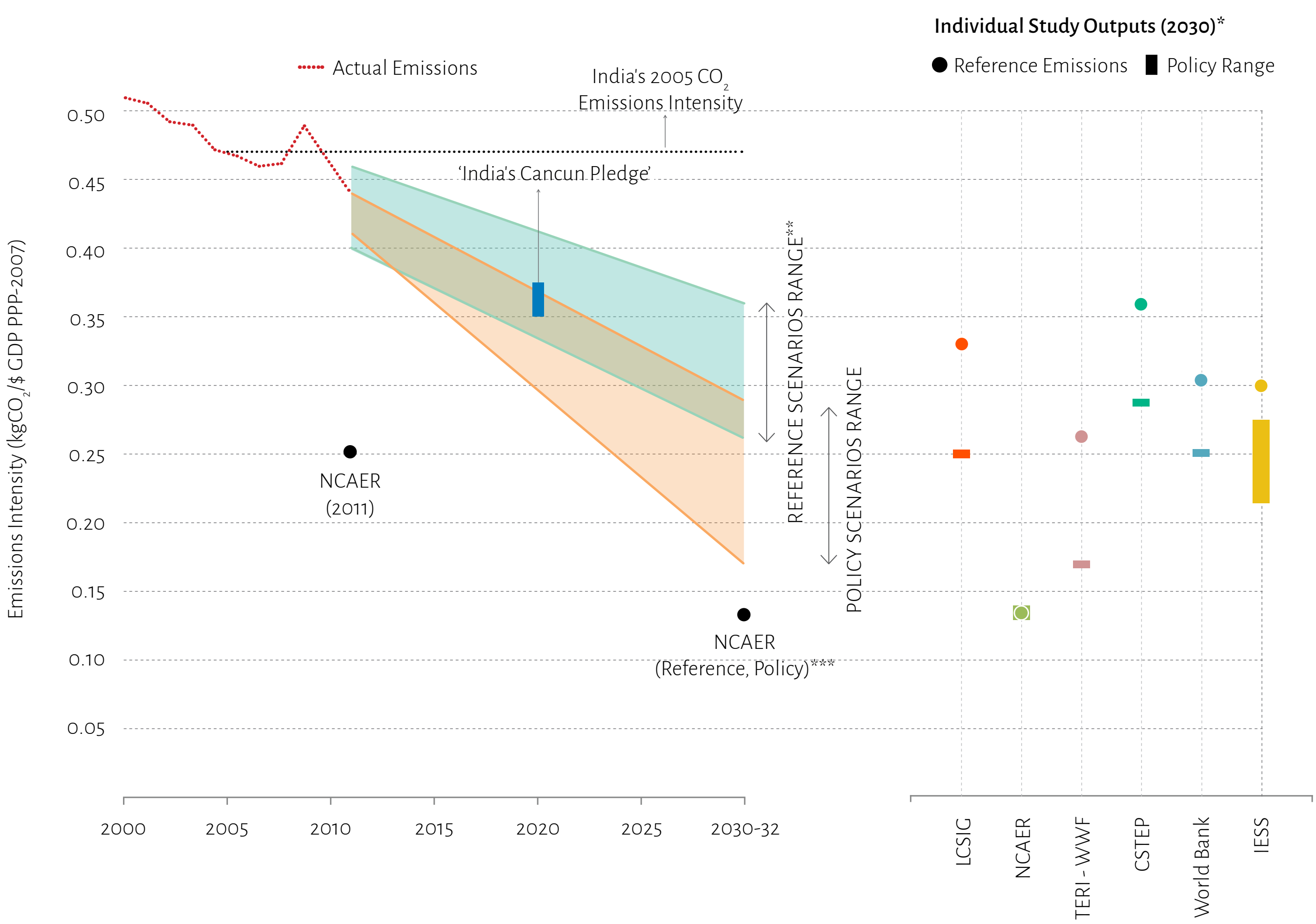
Figure 6 on emission intensity trends portrays particularly policy salient information, including India's earlier Copenhagen/ Cancun pledge juxtaposed against future projections. However, this graph has to be interpreted as an illustration of trends, rather than a reference for particular values. The five bottom-up or technology-detailed studies (besides LCSIG and NCAER) set GDP exogenously, and so implicitly assume policies have no impact on GDP. Their GDP in 2030 has thus been simply derived based on assumed growth rates.[15]

With these caveats, Figure 6 suggests that reference projections range from 23% to 45% below 2005 levels of emission intensity, and the policy scenarios range from 40% to 64% below 2005 levels. Given these ranges, India's Copenhagen/Cancun pledge of 20-25% below 2005 levels in 2020 falls about at the low end of the range projected by reference scenarios and the high end of the range projected by policy scenarios. Equivalently, for 2030, the low end of the reference range and the high end of the policy range are about 40-45% below 2005 levels.

Figure 7 provides a way of analyzing the relative emphasis, in reference scenarios, of energy efficiency versus a shift to low-carbon energy sources for a sub-set of studies for which this computation was possible. Thus, TERI-WWF projects a 30 percent decline in energy intensity versus a 40 percent decline in emissions intensity, suggesting a relative emphasis on low carbon sources, while CSTEP represents the other extreme of relatively more emphasis on decreasing energy intensity.

Interpretation of emission trends, however, has to be undertaken with caution and informed by an understanding of how these projections were derived. Studies use somewhat different interpretations of what constitute 'reference' emissions; some studies hold current ***outcomes*** constant, such as the share of renewables in the case of LCSIG, while others

FIGURE 6: CARBON DIOXIDE EMISSIONS INTENSITY



* The range of study end-years is 2030/31/32. See Appendix, Table A6.

** Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.

*** NCAER data have been plotted but excluded from the envelopes, because, since the study dates from 2009, the starting point falls substantially short of actual historical data.

hold current ***plans*** constant (e.g., Shukla et al., World Bank), with implications for direct comparability.

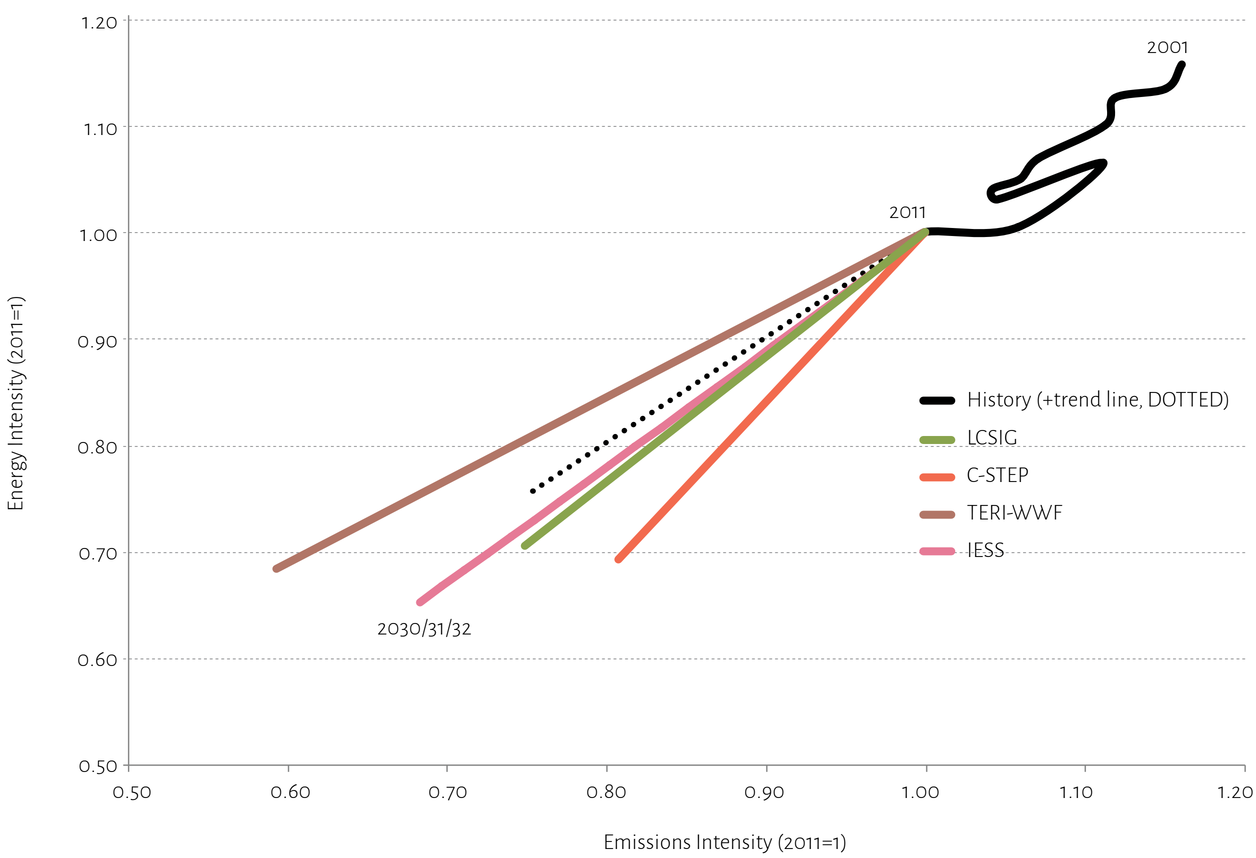
In addition, emissions are substantially driven by GDP growth assumptions. The studies here use (or project) a range of GDP growth rates of 7.0-8.75%; this range likely accounts for a substantial portion, but not all, of the variation in reference scenario emissions. Past trends were 6.1% from 1991-2000, 7.1% from 2001-2010, and 5.5% from 2011-2013, with the strongest period of growth from 2004-2012, when growth averaged above 8%.

A few key assumptions can over-determine outcomes, particularly in top-down economic models that characterize the energy sector through a limited number of parameters such as total factor productivity and autonomous energy efficiency improvement. For example, the LCSIG and NCAER use very different numbers for total factor productivity growth with substantial consequences for the outcome – LCSIG uses 1% for the agriculture sector and 1.5% for the non-agriculture sector while NCAER uses 3% across all sectors. While differing assumptions are justifiable, it is important that the reasons for these assumptions are transparent and are explained in the narrative accompanying discussion of model results.

Interpreting and comparing policy scenarios is particularly challenging since the studies reflect different constructions of policy. For example, Shukla et al. is driven by a total CO_2 emissions cap, C-STEP's scenarios are constructed within a sustainable development framing, and NCAER studies the impact of a carbon tax. Each policy scenario ideally should be interpreted in the context of the policy question that is being asked.

Finally, projections of emissions intensity are particularly fraught. This requires modelling both GDP accurately as well as the feedback between different energy futures and policy and GDP outcomes.

FIGURE 7: ENERGY INTENSITY VERSUS EMISSIONS INTENSITY IN REFERENCE SCENARIOS



- Reference scenarios are not equivalently defined, but in general, attempt to reflect full implementation of currently committed policies.
- Actual values of energy and emissions intensity for 2011 are 0.134TOE/$GDP PPP-2007 and 0.441 kgCO2/$GDP PPP-2007 respectively.
- 35% subsitution equivalence considered for nuclear, hydro and renewables to calculate primary energy supply values (Source: Global Energy Assessment, Chapter 1: Energy Primer)

What are the cost implications of alternative energy and climate policies?

Evaluating the costs of alternative policies is critically important to policy choices. However, the studies offer insufficient data or insight to inform a robust costs discussion. To begin with, different types of models account for different types of economic cost. The bottom-up energy models have the capacity to track energy investments, but not the economy-wide and energy demand adjustments to higher energy costs. The two macroeconomic models (LCSIG and NCAER), on the other hand, do characterize GDP losses from low-carbon policies, but have limited granularity in the energy sector representation to detail investments. Moreover, since the models all construct different policy scenarios and have different technology cost assumptions, the policy costs aren't comparable across models. Notably, none of the studies present mitigation costs, per unit of carbon reduction, as an explicit output.

Substantively, two bottom-up energy model studies show incremental investment costs, but for very different policy scenarios. The World Bank estimates investments of $1.4 billion/year discounted at 10% for a low-carbon scenario that entails a number of low-carbon measures across the economy. However, these estimates do not account for all the costs of energy efficiency measures (World Bank 2011, 36). To place these numbers in context, India's renewable investments were about $6 billion in 2013 (Frankfurt School-UNEP Centre/BNEF 2014). In contrast, TERI –WWF calculates future (primarily between 2036-2051) incremental investment costs of at least Rs. 517 trillion (or $81 billion per year in $2007-PPP discounted to 2007 at 10%), to achieve (close to) 100% renewables by 2050. As these scenarios aren't comparable, neither are the costs. Though the effective mitigation costs (per tonne of CO_2) may be inferred from the studies, this comparison may be inappropriate without placing them on a common footing or accounting for complete economic costs.

The macroeconomic top-down studies are able to model the interaction between the broader economy and energy policies. NCAER estimates annual discounted GDP losses in the range of $54 billion for a $10/tonne carbon tax to $175 billion for an $80/tonne carbon tax,[17] equivalent to about 1-3% of GDP today. Notably, however, the model is calibrated to the structure of the economy from 2003-04, which it carries forward to the end of the scenario period in 2030. As a result, the model has limited ability to capture structural changes in the economy such as technological shifts, which likely introduces an upward bias in costs.

The LCSIG, on the other hand, estimates a cumulative loss of $1344 billion (2011 prices), which translates to an annual average undiscounted GDP loss of $62 billion in 2007 prices, or about $26 billion discounted at 10%, if spread equally across the period.[18] This translates to a decrease in GDP of 3% in 2030 or an annual decrease of 0.16% over the period. Due to lack of full details on cost accounting, it is hard to conclude whether this is an under-estimate or an over-estimate. As with NCAER, the LCSIG model uses a fixed structure of the economy over the fifteen year period. The energy sector changes are driven by explicit assumptions such as higher total factor productivity growth in certain subsectors, specific penetration rates of renewables and so on. The GDP loss figures are driven by the re-direction of investment due to expensive energy, which extracts an opportunity cost in other areas of the economy. The net effect is that GDP loss figures are shaped by estimates of investment needs, which are in turn determined by technology costs that are not explicitly discussed in the report.

Collectively, the studies give a mixed impression of costs. Some of the bottom up models suggest low costs while others are high, but these are not directly comparable. The two macro-economic models present a wide range of costs but for different, and non-comparable, policy scenarios. A better estimate of cost would require a careful integration of granular energy sector representation and macroeconomic effects.

Lessons on using models to effectively inform policy

As this analysis of energy studies shows, models can potentially assist policymakers in understanding the influence of future technology choices, use patterns, and market developments based on a stylized representation of the energy sector and the economy. However, to avoid being misleading, it is also important that policy-makers understand the assumptions being made about the business as usual future, the policy questions being asked in the scenarios, the capabilities and limits of the underlying model and the relationship between these and the final results. Ensuring models effectively inform policy is useful not only for India's 2015 INDC process, but also for broader energy planning in India. This review suggests a few lessons to enhance the effective use of models for policy-making.

First, the policy value of the modelling exercise is enhanced by a credible 'reference' or 'business as usual' scenario to serve as a baseline against which the implications of additional policies modelled can be understood. The studies are relatively contemporaneous (2013-2015 with one exception) and use a relatively similar set of current policies as the basis for their reference scenarios. Yet the reference scenarios diverge considerably. This is likely because of different assumptions about GDP growth rates and different interpretations of policy implementation, such as in renewables and nuclear energy. For instance, solar capacity expansion by 2030 is assumed to be almost nil in one case (LCSIG) and about 80 GW in the most optimistic case (IESS), and in many cases without adequate explanation.[19] While there may be a basis for different views about technology adoption in the next fifteen years, these positions need to be carefully argued and justified.

Since reference scenarios are meant to serve as a baseline, they would be more useful to policymakers if they were grounded in common expert judgment of the *likely* achievement of currently known policies and targets based on an assessment of path dependence and government efforts, and a reasoned assessment of likely trends. This process of reasoning would be greatly assisted by a mechanism for discussion and sharing of information across modelling groups.

Second, the policy scenarios are intended to provide informed answers to 'what-if' questions associated with particular future policy choices. These include the effect of different policies, technologies or economic futures on energy and emission trends, trade-offs and co-benefits. For example, scenarios could focus on different economic growth rates, an emphasis on energy security, or the implications of different nuclear energy adoption. In addition, the time-frames used for the study shapes the questions that can be asked. For example, a focus on 2030 emphasizes lock-in effects, while a longer term time period to 2050 (Shukla et al. and TERI-WWF) allows for transformative shifts (e.g., an all-electric vehicle fleet) and the effect of delayed policies (as done by Shukla et al.).

To increase the utility of modelling tools for policy, it would help greatly to have more up-front involvement by policymakers and stakeholders in identifying the key questions and providing input on assumptions. It is particularly helpful if there is a process through which policy-makers can interact with modellers to specify and discuss policy-relevant questions. Indeed, the more the modelling process is used as a process of dialogue, both to understand the priorities of various stakeholders, as well as use their knowledge to generate input assumptions, the more modelling studies can inform policy. A useful illustration is the South African Long Term Mitigation Scenario process, which was built around sustained interaction between government, stakeholders and modellers to explore alternative visions of South African energy and climate futures (Raubenheimer 2011).

Moreover, the value of modelling studies is enhanced if the same question can be asked of multiple models, in order to develop a more robust analysis. To do so requires harmonizing key input assumptions (e.g., GDP growth) and constructing a ***common*** set of scenarios. For example, in the international Integrated Assessment Modelling (IAM) community, there is increasing reliance on protocols that specify such harmonization (Kriegler et al. 2014, Supplementary materials; Kriegler et al. 2015, Appendix A, 39), an approach that could fruitfully be followed for national models. Such common scenarios need not limit the diversity of modeled scenarios. Rather, they can complement them by providing a basis for isolating the effect of model peculiarities.

Third, it is important for policymakers to understand the potential and limits of the models. For example, as the discussion on costs above suggests, since energy bottom-up models and macroeconomic models can better characterize different types of costs (investment costs and macroeconomic effects, respectively), creating soft links between these models can improve the overall characterization of policy costs. None of the models presented here credibly combine energy specificity with macroeconomic effects. Of critical importance to scenario analysis for climate policy is the resulting costs of mitigation in different sectors and for different scenarios; this, as an explicit outcome, is missing across all studies.

If models are set up to incorporate multiple policy objectives, scenario analysis can be used to understand trade-offs between different objectives. However, the studies at best consider cost minimization and energy security, while several just project emissions. Several studies aim to address environmental co-benefits such as water and air pollution, which is a welcome development, but as yet, have made at most a beginning in doing so.

Fourth, in order to communicate clearly with policymakers, it is helpful if the representation of outputs is clear and appropriately explained. Perhaps most important, understanding a model's sensitivity to different key input assumptions, such as technology cost or GDP, is essential for policy interpretation. None of the model scenarios studied here present sensitivities of outcomes to various inputs. In addition, selectively presenting underlying data, such as critical cost data for different technologies would help explain different outcomes across models without being burdensome.

In addition, studies should ideally explain the key drivers of results and their associated uncertainties to help policymakers intuitively understand the dynamics of models, so that results are understood within the scope of their original intention (Krey 2014). For example, CSTEP and IESS explain clearly that their approach is an accounting rather than optimization approach, with the addition of electricity and transport sector specific models for CSTEP. In the case of LCSIG, key outcomes such as on the rate of penetration of renewables and electric vehicles are driven almost entirely by input outcomes rather than by choices made by the model, but this link between input and outputs are not presented sufficiently clearly.

Finally, the constructive use of models for policy would benefit from an institutional framework that can formalize dialogue and interaction between modelling groups and policymakers, as well as the development of a common platform of key assumptions and scenarios. This would help provide consistency of input assumptions and construction of more robust reference scenarios as well as an ongoing platform for model comparison. This need not stifle diverse approaches across modelling groups as long as the scope for harmonization is clearly defined and agreed. Critically, any such institutional structures need to be long-lasting and foster a conversation over time. India has the benefit of several modelling groups and relatively high capacity. Building on this base to address the issues discussed here would yield even greater returns and greatly enhance the robustness and policy salience of modelling efforts.

KEY MESSAGES

First, Indian energy policy-making would be well-served by greater clarity on future energy and emission trends. Existing studies present a broad range of reference case results, driven by divergent assumptions, making their use for policy-making a challenge. Studies would better inform policy if accompanied by greater explanation of their results, points of divergence (e.g., renewable and nuclear penetration) and more information on particular areas (e.g. energy demand and overall cost accounting). Policy scenarios lack common measures necessary to make their results comparable.

Second, the studies collectively provide, at best, a limited basis for selecting an economy wide pledge for India's INDC, such as an emissions intensity target. Reference emissions ranges are broad and limited information is available on costs of policy options. A consideration of sectoral actions would provide a complementary approach that relies less on long-term economy-wide projections.

With an eye to the future, India needs to enhance the process for energy and climate scenario analysis, led by the government, but built on an ongoing process of engagement with the broader modelling and policy research community. Further, over time, modelling capacity should be extended to analyze social and environmental outcomes. A structured process to inform strategic thinking on energy and climate change would be a prudent long-term investment.

NOTES

1. Hof et al. (2014) suggest that there are systematic difference between national and international studies for India and China.

2. The Government of India has commissioned a study to inform India's climate contribution, but the results of this study are not available as yet.

3. All studies limit their scope to only CO_2, except NCAER which also includes N_2O emissions. Since N_2O emissions were <5% of CO_2 emissions in 2011, with a decreasing over time, our analysis focuses only on CO_2. All studies except for the World Bank include all industrial CO_2 emissions (including from electricity use, fossil fuel combustion and chemical processes), though it is likely that small- and medium- industry are universally not well represented due to limited data. The World Bank includes only the six energy intensive industries, which comprised about 2/3rd of industrial output in 2005, and notably exclude agriculture. Regarding residential cooking demand, the macroeconomic models (LCSIG and NCAER) include fossil use, but not traditional biomass, while among the energy models World Bank does not include cooking demand.

4. Personal communication, authors, LCSIG, January 30, 2015.

5. A similar model by the same group provides more detail on inclusion (IRADE 2014).

6. TERI has a complementary Energy Security Outlook study (Soni et al. 2015) that discusses this issue in detail, which is not considered here because GHG emission numbers were not available.

7. Computed as 1000 MGD which is approximately 1.6 BCM/y. See Government of Delhi (no date).

8. Computed from 'India: Balances for 2010', Statistics, International Energy Agency. http://www.iea.org/statistics/statisticssearch/report/?year=2010&country=INDIA&product=Balances (accessed April 7, 2015).

9. See Planning Commission (2011).

10. Calculated by authors as follows: 99-282 TWh at a capacity utilization factor of 77%, results in 15-42 GW of capacity.

11. See MNRE (2010); Press Information Bureau (2015).

12. Recent government targets of 100GW solar capacity translate to 166 TWh, and wind capacity of 60GW to 131 TWh for a total of 297 TWh. Computed by authors assuming capacity utilization factors from CERC of .25 for wind and 0.25 for solar. See CERC (2015).

13. For example, China intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. See U.S.-China Joint Announcement on Climate Change. Beijing, China, 12 November 2014.

14. CAIT 2.0: WRI's climate data explorer. http://cait2.wri.org/ (accessed March 2, 2015).

15. In order to make the studies comparable, GDP figures have been converted to USD at 2007 prices.

16. Costs do not include R&D, institutional and other related infrastructure costs. See TERI (2013), pp. 72.

17. Calculated from NCAER Table 4-5, to net present value, using 10% discount rate, and converted to annual $2007-PPP.

18. Converted from $1,344 billion cumulative for 2011-2030 in 2011 prices to annual $2007PPP. Discounted value assumes equal losses per year, because actual values are not known.

19. Calculation by authors: 138 TWh (IESS) in 2030, assuming 20% capacity utilization factor, yields 79 GW.

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APPENDIX

TABLE A1: FINAL ENERGY DEMAND (FED) BY SECTOR (TWh)

Study Name [1,2,3]	Base Year [4] 2010	CSTEP 2030		IESS 2032				TERI - WWF 2031	
Sector		Reference Scenario	Policy Scenario	Reference Scenario	Weak Policy Scenario	Intermediate Policy Scenario	Stringent Policy Scenario	Reference Scenario	Policy Scenario
Industry	1899.0	5871.0	5350.0	6236.0	6236.0	5809.0	5809.0	7314.0	5348.8
Buildings [5]	2077.2	2470.0	2088.0	2679.0	2679.0	2001.0	2001.0	4081.4	3686.0
Agriculture	281.3	590.0	548.0	631.0	631.0	439.0	439.0	674.4	430.2
Transport	674.6	2571.0	1788.0	2900.0	2900.0	2178.0	2178.0	4488.4	3000.0
Total FED	4932.1	11502.0	9774.0	12446.0	12446.0	10427.0	10427.0	16558.1	12465.1

Notes

1 Data obtained upon request from co-authors when unavailable in reports.
2 See Table 1 for a description of the Reference and Weak, Intermediate and Stringent Policy Scenarios.
3 No data available for LCSIG, NCAER, Shukla et al. and World Bank studies (email correspondance with report co-authors).
4 Data for 2010-2011, Ministry of Statistics and Program Implementation (2012).
5 Includes domestic and commercial lighting and appliances, green building design and envelope savings, and cooking.

TABLE A2: TOTAL PRIMARY FOSSIL FUEL ENERGY SUPPLY (MTOE)

Study Name [1,2,3,4]	Base Year [5] 2012	LCSIG [6] 2030		TERI - WWF 2031		Shukla et al. 2030				CSTEP 2030		IESS 2032			
		Reference Scenario	Policy Scenario	Reference Scenario	Policy Scenario	Reference Scenario	Weak Policy Scenario	Intermediate Policy Scenario	Stringent Policy Scenario	Reference Scenario	Policy Scenario	Reference Scenario	Weak Policy Scenario	Intermediate Policy Scenario	Stringent Policy Scenario
Coal	309.3	829.8	675.7	914.0	579.0	878.4	859.5	728.2	651.1	819.7	588.8	768.4	654.7	608.3	478.4
Oil	168.8	426.0	332.0	525.0	341.0	256.8	256.0	266.6	262.7	398.5	356.9	437.6	404.6	311.4	311.4
Gas	56.6	198.0	225.0	118.0	130.0	133.3	146.6	178.2	181.4	120.3	129.1	153.3	145.6	149.7	124.2

Notes

1 For NCAER and the World Bank, data for TPES were requested but were unavailable.
2 See Table 1 for a description of the Reference and Weak, Intermediate and Stringent Policy Scenarios.
3 Data obtained upon request from co-authors when unavailable in reports.
4 Conversion factors used: 1 EJ = 23.885 MTOE (Source: IEA), 1 TWh = 0.086 MTOE (Source: IEA).
5 Base Year data from Coal Controller's Organization (2012), Ministry of Petroleum & Natural Gas (2013), Ministry of Coal (2011).
6 Sourced from Table 2.3 in the online version of the report, instead of Figure 2.11, or Table 2.3 in the published version of the report, to enable comparability between fossil fuel share in the report's electricity supply mix and total primary fossil fuel supply. Conversion factors are from conversion tables on page xi of the report.

TABLE A3: ELECTRICITY SUPPLY MIX (TWh)

Fuel Type [1,2,3]	Base Year [4] 2012	LCSIG [5] 2030		Shukla et al. [6] 2030				CSTEP [7] 2030		IESS [8] 2032				TERI - WWF [9] 2031	
		Reference Scenario	Policy Scenario	Reference Scenario	Weak Policy Scenario	Intermediate Policy Scenario	Stringent Policy Scenario	Reference Scenario	Policy Scenario	Reference Scenario	Weak Policy Scenario	Intermediate Policy Scenario	Stringent Policy Scenario	Reference Scenario	Policy Scenario
Coal	652.2	3038.0	2200.0	2124.2	2052.4	2124.2	1238.3	2405.0	1682.0	1811.0	1811.0	1811.0	1002.0	2488.5	1398.9
Gas	80.2	95.0	128.0	195.1	195.1	195.1	26.8	105.0	102.0	250.0	250.0	250.0	110.0	251.8	410.7
Nuclear	32.6	32.0	280.0	282.4	282.4	282.4	282.4	99.0	371.0	116.0	116.0	116.0	146.0	199.8	22.9
Hydro	122.1	131.0	230.0	388.9	388.9	388.9	388.9	224.0	243.0	231.0	231.0	231.0	270.0	358.6	398.7
Solar	1.2	8.0	275.0	-	-	-	-	50.0	237.0	138.0	263.0	138.0	263.0	102.6	180.6
Wind	25.9	50.0	279.0	-	-	-	-	93.0	280.0	240.0	304.0	240.0	452.0	173.4	448.9
Biomass	8.9	13.0	70.0	0.8	0.8	0.8	21.9	27.0	71.0	0.0	0.0	0.0	0.0	77.1	91.1
Others	8.5	3.0	3.0	392.2	458.9	392.2	862.4	-3.0	-242.0	432.0	109.0	92.0	109.0	18.6	19.7
Total	931.4	3370.0	3465.0	3383.4	3378.4	3383.4	2820.6	3000.0	2744.0	3218.0	3084.0	2878.0	2352.0	3670.4	2971.7

Notes

1 See Table 1 for a description of the Reference and Weak, Intermediate and Stringent Policy Scenarios.

2 Data obtained upon request from co-authors when unavailable in reports.

3 No data available for NCAER study (email correspondance with report co-author on 29 January 2015). World Bank available only in GW and hence not included due to lack of comparability.

4 Base year data from Central Electricity Authority (2012a, 2012b).

5 Coal numbers include sub-critical and super-critical coal.

6 Data converted from EJ to TWh as follows: 1 EJ = 277.78 TWh (Source: IEA). Coal values include coal with and without CCS; gas values include gas with and without CCS; biomass includes biomass with and without CCS.

7 Solar includes solar PV and CSP; wind includes onshore and offshore wind; others forms the electricity balancing requirement with the addition of electricity imports and reduction of electricity exports. A negative number implies net exports.

8 Coal includes domestic coal and imported coal-based generation (for reference: 771 TWh and 2451 TWh respectively); solar includes solar PV and CSP; wind includes onshore and offshore wind; others includes small hydro, biomass and biogas, waste to electricity, and imports.

9 Solar includes Solar PV and Solar Thermal. Wind includes Onshore Wind and Offshore Wind, Others includes Waste, Geothermal, Tidal and Diesel.

TABLE A4: ANNUAL CARBON DIOXIDE EMISSIONS (Million Tonnes)

Study Name [1,2,3,4,5,6]	Base Year		2030/31/32 [7]			
	Year	Emissions	Reference Scenario	Weak Policy Scenario	Single Policy or Intermediate Policy Scenario	Stringent Policy Scenario
LCSIG (2007-2030)	2007	1429.0	5271.0	-	3830.0	-
NCAER (2003/04-2030/31)	2003	1004.6	4000.1	3965.5	3876.2	3756.2
TERI - WWF (2001-2031)	2001	920.0	5440.0	-	3550.0	-
Shukla et al. (2005-2030)	2005	1213.9	4531.3	4475.1	3864.9	3420.5
CSTEP (2012-2030)	2012	1800.0	5600.0	-	4500.0	-
World Bank (2007-2031)	2007	1324.0	4686.0	-	3872.0	-
IESS (2012-2032)	2012	1726.0	5674.0	5186.0	4717.0	4071.0

NOTES

1 All data show CO_2 emissions except NCAER, which includes N_2O emissions. The breakdown was unavailable. N_2O emissions were <5% of CO_2 emissions in 2011, and its share has been decreasing with time.
2 CO_2 emissions are for all sectors except for the World Bank study which excludes agriculture.
3 In all the charts, only the base year and 2030 (or equivalent) year's data were available from the model studies. The reference and policy range lines have been interpolated.
4 See Table 1 for a description of the Reference and Weak, Intermediate and Stringent Policy Scenarios.
5 End year varies by study from 2030 to 2032.
6 Data obtained upon request from co-authors when unavailable in reports.
7 Some reports provide data upto 2047-2051. Available data in the range 2030-32 has been selected to enable comparison between studies.

TABLE A5: CARBON DIOXIDE EMISSIONS PER CAPITA (Tonnes)

Study Name [1,2,3,4,5,6]	Base Year		2030/31/32 [7]			
	Year	Per Capita Emissions	Reference Scenario	Weak Policy Scenario	Single Policy or Intermediate Policy Scenario	Stringent Policy Scenario
LCSIG (2007-2030)	2007	1.30	3.60	-	2.6	-
NCAER (2003/04-2030/31)	2003	0.95	2.77	2.75	2.69	2.60
TERI - WWF (2001-2031) [8]	2001	0.89	3.57	-	2.33	-
Shukla et al. (2005-2030) [9]	2005	1.02	2.86	2.82	2.44	2.16
CSTEP (2012-2030) [10]	2012	1.60	3.65	-	2.93	-
World Bank (2007-2031) [11]	2007	1.29	3.58	-	2.96	-
IESS (2012-2032)	2012	1.40	3.70	3.40	3.10	2.70

NOTES

1 to 7 See Table A4 Notes.
8 to 11 CO_2 Per Capita in the base year calculated as = Total CO_2 (base year)/Population(base year), and CO_2 Per Capita for all scenarios calculated as = Total CO_2 (2030-32)/Population(2030-32).

TABLE A6: CARBON DIOXIDE EMISSIONS INTENSITY ($kgCO_2$/$GDP PPP-2007)

Study Name [1,2,3,4,5,6,8,9]	Base Year		2030/31/32 [7]			
	Year	Emissions Intensity	Reference Scenario	Weak Policy Scenario	Single Policy or Intermediate Policy Scenario	Stringent Policy Scenario
LCSIG (2007-2030) [10]	2007	0.430	0.330	-	0.250	-
NCAER (2003/04-2030/31) [11]	2003	0.333	0.135	0.135	0.135	0.135
TERI - WWF (2001-2031)	2001	0.475	0.261	-	0.171	-
Shukla et al. (2005-2030) [12]	2005	No data	No data	No data	No data	No data
CSTEP (2012-2030)	2012	0.413	0.356	-	0.286	-
World Bank (2007-2031)	2007	0.490	0.304	-	0.251	-
IESS (2012-2032)	2012	0.396	0.301	0.275	0.250	0.216

NOTES

1 to 7 See Table A4 Notes

8 Historical Emissions Intensity is calculated using total annual emissions ($MTCO_2$)from WRI-CAIT for the base year and GDP numbers from the RBI for 2004-05 base year market prices converted to 2007 dollar GDP.

9 All numbers are in units of $kgCO_2$/$GDP PPP-2007. Numbers were converted from their original units to enable comparison. For reports specifying both annual emissions and GDP, emissions intensity has been computed by dividing annual emissions by GDP with approriate conversion factors. For the CSTEP and IESS reports, the base year GDP has been sourced from statistical data provided by the RBI (http://dbie.rbi.org.in/DBIE/dbie.rbi?site=statistics) and the CAGR provided by the report has been factored in to compute scenario end-year GDPs.

10 Data sourced from the LCSIG report, Section 2.4 (page 27) after clarification with the modelling team at IRADe, and not from figure 2.8 which shows different emissions numbers.

11 NCAER data have been plotted but excluded from the envelopes, because, since the study dates from 2009, the starting point falls substantially short of actual historical data.

12 No data available for the Shukla et al. study (email correspondance with report co-author on 29 January 2015).

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