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A More Sustainable Energy Strategy for India

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Abstract

The COP-21 meeting in Paris produced an important result. For the first time all countries developed and developing agreed to take some mitigation action. However even if all countries deliver on what they have promised by 2030 and progress thereafter continues only at the same rate global temperature is likely to be more than 3°C degrees above pre industrial levels by 2100. To get on a 2-degree trajectory will require much more ambitious pledges from all countries and the developed countries have a specially important role to play not only in achieving more ambitious mitigation goals themselves but also in offering financial support for developing countries to do more. Assuming that developed countries show a willingness to do more, it will be necessary for developing countries to consider what more they can do.

In the spirit of such an exercise this paper analyses what is possible as a low carbon scenario for India using India Energy Security Scenarios-2047 tool developed by the erstwhile Planning Commission and later refined by its successor NITI Aayog. The calculator allows us to adopt the more ambitious targets deemed feasible and consider the outcomes in terms of reduction in carbon emissions reduction, improvements in air quality, water constraints, and budget implications. The paper elaborates the multiple policy interventions that are needed to achieve these objectives.

We find that there is scope for a low carbon growth path which would greatly reduce the level of emissions compared to a business as usual projection for the same growth rate of GDP. This calls for a combination of measures which increase energy efficiency i.e. reduce the emissions intensity of GDP, and shift the composition of energy towards cleaner energy sources. Interestingly we find that although most of the public attention is devoted to green sources of energy, about 86% of the mitigation potential in India comes from interventions focussing on energy efficiency measures, building better cities and encouraging behaviour changes among consumers. The remaining 14% comes from deploying low carbon technologies in the electricity and the fuels sector. The different policy instruments involved in bringing about these changes are indicated. They fall in the domains of different levels of government national, state and local and coordination of all these levels to achieve a common end is a challenge.

Keywords: *Climate Change, Global Warming, Intended Nationally Determined Contributions (INDCs), Sustainable Development, Green House Gas (GHG) emissions, Carbon Credits, Energy Security, Air Pollution, Water Crisis.*

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A More Sustainable Energy Strategy for India

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Introduction

On April 22 2016, in a special meeting at the UN Headquarters in New York, 175 heads of state/government, formally signed the Climate Change Agreement reached in the meeting of the UNFCCC in Paris in December 2015. Each country thereby committed itself to take action to mitigate emissions up to 2030 as outlined in its Intended Nationally Determined Contributions (INDCs). This was a historic step forward in the effort to combat climate change because, for the first time, almost all countries, including the major developing countries, accepted that they had to take some responsibility for the mitigation of GHG emissions. India was one of the signatories, and its INDCs covered three areas. These were (i) a reduction in the emissions intensity of GDP by 33% to 35% from 2005 levels by 2030; (ii) an increase in non-fossil-fuel-based electricity capacity from 12% of total capacity in 2014/15 to 40% by 2030; and (iii) increasing forest cover to absorb 2.5 to 3 billion tonnes of CO_2 by 2030.

Historic though it was, the Paris agreement cannot be said to have "solved the problem" because, even if all countries deliver on their INDCs and progress after 2030 continues only at the same rate as implied by the current INDCs, global temperature is likely to be more than 3^{o}C degrees above pre industrial levels by 2100. It is clear that if we really want to stabilise the global temperature at 2^{o}C above the pre industrial levels by 2100,[4] all countries will have to take much stronger action. The scale of the challenge is reflected in the fact that the 2 C target requires global GHG emissions to be reduced to "net zero" by 2080, net zero being defined as a position where GHG emissions from various sources (e.g. fossil-fuel combustion, deforestation, HFCs) are balanced by the GHG levels absorbed by the sinks (e.g. oceans, forests or new techniques such as carbon-capture and storage). The idea of reaching net zero may seem over ambitious, but we have to recognise that as long as GHG emissions are net positive, the concentration of GHGs in the atmosphere will increase and global temperatures will keep rising. Stabilising global mean temperature implies reaching net zero at some date; the higher the level at which it is acceptable to stabilise, the later the net zero date can be set, but it cannot be avoided if stabilisation is to be achieved.

We are obviously very far from where we need to be, but the fact that all the major countries, including the large developing countries, have set themselves some targets for mitigation action can be viewed as a good start. They have also agreed to review progress before the end

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4 This refers to the increase in average global surface temperatures relative to the second half of the 19th century, the usual benchmark

of five years and that could become an occasion to work towards agreement on stronger action in future by all countries. The industrialised countries have a particularly important role to play in this process. First, they must reduce their own carbon footprint much faster than what is outlined by the INDCs. If they do undertake such a commitment, it will invariably involve the development and application of new technologies that will then should also be available to developing countries, making it easier for them to take strong action. Second, they must be willing to provide much needed public resources and also promote the flow of private resources into the development of infrastructure in developing countries that will help contain GHG emissions.

The developing countries on their part can legitimately expect the developed countries to take the lead in accelerating mitigation action, and also do more by way of providing financial assistance. However, they must also recognise that they will also have to do more to reduce their GHG trajectory and provide policy stability to foster investment and guide the transition. Fortunately, there is today a growing perception that the objectives of growth and poverty reduction can be combined with the objective of sustainable climate change through appropriate choices of technology and large investments in critical sectors. There are also important "co-benefits" from a low carbon scenario that could be realised, notably in the form of health benefits from reduced air pollution.

Because of its size, India's mitigation plans are important for the world as a whole and if all countries do indeed make efforts to improve upon their INDCs, India would also be expected to do so. This paper attempts to explore the options India has by comparing the implications of two alternative scenarios for energy use and GHG emissions[5] that are consistent with achieving a high growth rate of GDP. One is a business-as-usual (BAU) scenario, which projects energy requirements and the consequent GHG emissions if no special efforts are made to mitigate emissions other than a continuation of past trends. The other is an alternative Low-Carbon (LC) scenario, based on strong action to mitigate GHG emissions, promote greater energy efficiency and shift to cleaner energy sources.

The projections presented in this paper are based on the India Energy Security Scenario (IESS) calculator Version 2, published by NITI Aayog[6]. A brief description of the calculator and methodology for this paper is provided in Appendix I. As pointed out in the Appendix the calculator is not a structural model of the economy in the conventional sense, where critical inter-related macro-economic and sectoral variables are determined within the model. It is essentially a "calculating tool" which allows the user to simulate the effect of alternative assumptions about energy efficiency and alternative sources of energy. The rate of growth of GDP has been exogenously fixed in both scenarios at an average of 7.4% per annum between 2012 and 2047 (the IESS chose 2047 as the terminal year because it is the hundredth

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5 The scenarios in this paper only include those focused on energy usage from energy and industrial sectors. Total GHG emissions for India will comprise of emissions due to agriculture, land-use change, energy related emissions and emissions from industrial processes. Non-energy emissions from agriculture and land-use change have not been looked at.

6 Available from: http://indiaenergy.gov.in/default.php

anniversary of India's independence but it is close enough to the benchmark date 2050 which is commonly used in climate change discussions).

The 7.4 percent growth projection over the period of the simulation is broadly consistent with what may be called a high-growth path for India. Although growth rates between 8% to 10%, are often mentioned in official statements, these are in the context of shorter horizons of the next ten years or so, and do not take account of the likely slowdown over time. Given the long time horizon up to 2047, a lower average growth is appropriate. If India grows at 8.5% for next ten years, then slows down to say 7.5% for the following ten, and then to 6.5% for the next ten, and down to 6% in the last five, the average growth rate of GDP would be around 7.4%.

We emphasise that a growth rate of 7.4% over 35 years is in no sense pre-ordained. To achieve this rate of growth will require adoption of policies that will promote the investment and efficiency levels necessary to produce this result. The results presented here assume that the policies needed to achieve higher growth can be separately identified and implemented.

This paper contains seven sections. Section I presents a BAU energy scenario up to 2032 and to 2047[7]. Section II discusses the scope for charting an alternative low-carbon future, which is based on efforts to reduce energy requirements and bring about a shift towards cleaner energy. Section III considers the implication of the LC scenario on GHG emissions. Section IV examines the co benefits from the LC scenario in terms of energy security, reduced demand for water, and most importantly reduced air pollution which has important health benefits and has become a major problem in Indian cities. Section V outlines the investment needs associated with moving to the alternative low-carbon scenario. Section VI discusses the multiplicity of policy instruments that might be necessary to realize the alternative path. Section VII summarises the main messages from our analysis.

I. The Business-As-Usual Scenario.

The IESS calculator generates total energy demand from eight broad energy-using sectors, including agriculture, industry, commercial buildings, residential buildings, passenger transport, freight transport, telecommunications and cooking. Services contribute significantly to GDP, but since most services are effectively produced in buildings, the use of energy in services is reflected in the energy used in the above list of sectors (see Appendix 1 for details).

Total energy demand

The energy demand projections for each of the eight energy-using sectors for the year 2047 for the BAU projection are summarised in Table 1. The total final energy demand of the eight sectors increases at an average rate of 4.2% per year from 423 Mtoe in 2012 to 1,703 Mtoe in

[7] The IESS has been calibrated to run up to 2047 and not the more conventional 2050 because it will be the hundredth anniversary of Indian independence.

2047. The growth rate in total energy demand is significantly lower than the 7.4% growth rate of GDP, implying that the BAU projection includes some movement towards energy efficiency[8]. The energy elasticity over this period is 0.52, compared with 0.63 in the previous decade and 0.73 in the preceding two decades.

Table 1: Final Energy Demand from Different Sectors in BAU Scenarios

Sector	Units	2012	2047
Transport	Mtoe	79.9	487.5
Buildings	Mtoe	20.5	192.1
Industry	Mtoe	202.8	895.9
Agriculture	Mtoe	20.4	68.6
Cooking	Mtoe	92.2	43.8
Telecom	Mtoe	7.1	15.8
Total Demand	**Mtoe**	**423**	**1,703**

The energy intensity of GDP, i.e. energy used per unit of GDP, in the BAU scenario falls from 0.24 kgoe/US$ in 2012 to 0.14 kgoe/US$ in 2032 and further to 0.08 kgoe/US$ in 2047. This decline of 67% in three decades is impressive but since total GDP will be twelve times larger in 2047, total energy demand will be four times larger in this year than in the base year, with obvious implications for the absolute level of emissions.

Energy supply assumptions

In projecting domestic supply, we focus on primary energy sources that consist of coal, oil and gas as fossil fuels, and non-fossil energy sources such as hydro, nuclear, solar, wind, biofuels etc. Electricity is directly used in many sectors, but it does not figure separately in the supply side projection because it is produced by one or other of the primary energy sources and it is these sources that are included.

Table 2 shows the projections in the BAU of the demand for, and the domestic production and import requirements of, the primary fuels required to meet the final energy demands reported in the section above.

[8] At least in the sense of a reduction in energy use per unit of output, although it is recognised that this is also influenced by economic structure.

Table 2: Import Dependence in BAU

		Units	2012	2032	2047	CAGR (2012-2047)	CAGR (2000-2012)
Coal	Consumption	Mtce	706	1,707	2,704	3.9%	6.8%
	Production	Mtce	582	1,152	1,157	2%	5.5%
	Import Dependence	%	**18%**	**33%**	**57%**		
Oil	Consumption	Mtoe	166	459	707	4.2%	4.4%
	Production	Mtoe	38	49	59	1.2%	0.5%
	Import Dependence	%	**77%**	**88%**	**90%**		
Gas	Consumption	Bcm	60	148	215	3.7%	17.0%
	Production	Bcm	48	69	128	2.9%	6.2%
	Import Dependence	%	**22%**	**56%**	**43%**		
Overall[9]	Consumption	Mtoe	**609**	**1,451**	**2,262**	**3.8%**	**5.3%**
	Production	Mtoe	**421**	**756**	**925**	**2.3%**	**n.a.**
	Import Dependence	%	**31%**	**48%**	**59%**		

Note: CAGR is the compound annual growth rate, Mtce is million tonnes of coal equivalent, and Bcm is billion cubic meters.

The BAU supply projection assumes that growth of domestic coal production will be slower than in the past, in part reflecting continuing constraints coming from the impact of environmental regulations that have limited the ability of Coal India to increase production. The projections imply a slight increase in the growth rate of oil production, but a slowdown in gas reflecting the lack of proven reserves.

The net impact of these assumptions is that import dependence increases for all fossil fuels. Import dependence for coal increases from 18% in the base year to 57% in 2047; in the case of oil it increases from 77% in 2012 to 90%, and for gas from 22% in 2012 to 43% in 2047. The total import dependence for all fuels increases from 31% to 59%. Increases of this order are clearly unacceptable from the energy security point of view.

Table 3 presents the projected share of different primary energy sources in the total supply of energy in India. Coal remains the dominant source of primary energy in the BAU, with a marginal increase in its share. There is also an increase in the share of oil and in the group of nuclear, renewables and hydro. The share of the other primary energy sources (mainly biomass and agriculture residues) is expected to fall.

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[9] The overall category includes the three primary energy sources in the table plus non fossil fuels: hydro, nuclear, bio-energy etc.

Table 3: Share of Primary Energy Mix

Share in Primary Energy Supply	2012		2032		2047	
	MToe	%	MToe	%	MToe	%
Coal	282	46.3%	682	47.0%	1,081	47.8%
Oil	166.3	27.3%	459.1	31.6%	707	31.3%
Gas	49.3	8.1%	120.6	8.3%	174	7.7%
Solar	0.2	0.0%	15.1	1.0%	50	2.2%
Wind	2.8	0.5%	21.8	1.5%	48.1	2.1%
Nuclear	6.6	1.1%	28.5	2.0%	45	2.0%
Hydro	13.4	2.2%	24.2	1.7%	27.6	1.2%
Others: Biomass, Agricultural Waste	88.4	14.5%	99.7	6.9%	129.3	5.7%
Total	**609**	**100%**	**1,451**	**100%**	**2,262**	**100%**

Table 4 presents the composition of electricity-generating capacity by fuel source. Some change in the composition of electricity capacity by energy source is evident even in BAU. There is a sharp increase in the share of both solar and wind generating capacity and a decline in the share of coal-based capacity. There is also a decline in gas-based generation reflecting lack of domestic supply of this fuel. There is also a decline in the share of hydro capacity and the nuclear capacity share is about the same. This reflects the lack of exploitable hydro capacities once the more obvious sites are exhausted and persisting problems with scaling up nuclear capacity. We note that the share of solar and wind in electricity generating capacity is much larger than their share in total electricity generated because utilisation levels in renewable electricity capacity are generally much lower.

Table 4: Electricity Generation Capacity by Type in BAU (GW)[10]

Electricity Generating Capacity	2012	2032	2047
Coal	125(56%)	319 (48%)	465 (42%)
Gas	24(11%)	41(6%)	50(5%)
Nuclear	5(2%)	17(3%)	26(2%)
Hydro	41(18%)	66(10%)	75(7%)
Solar	1(0%)	78(12%)	243(22%)
Wind	17(8%)	114(17%)	222(20%)
Other Renewables	9(4%)	23(3%)	30(3%)
Total	222	658	1,111
Share of Electricity in the Energy Mix	**15%**	**17%**	**18.6%**

An important feature brought out in Table 4 is that electricity accounts for only 15% of the total energy used in India in the base year 2012, and this increases slowly to 18.6% in 2047 in the BAU. Since the scope for using solar and wind power as energy sources lies primarily in using them to generate electricity, India's ability to shift to green energy depends critically upon expanding the pace of electrification. A comparison of Tables 1 and 4, shows that in the

10 Figures in parentheses are the share in total capacity.

BAU scenario total energy goes up by a factor of four, while electricity usage increases by a factor of five, implying some increase in electrification.

II. A Low-Carbon Scenario

The key elements involved in moving to a low-carbon growth path are reflected in the identity:

Emissions/GDP = (Energy/GDP) x (Emissions/Energy)

The identity shows that the emissions associated with any given level of GDP (the left hand side of the identity) can be reduced either by decreasing the energy intensity of GDP (the first term in round brackets), which broadly covers what may be called demand-side interventions[11], or by reducing the emissions intensity of energy (the second term in round brackets) which refers to supply-side interventions switching the composition of energy to greener energy sources. The demand and supply-side actions simulated using the IESS V 2 calculator, which together produce the LC scenario, are discussed below.

Demand - side actions to lower energy intensity of GDP

The demand for energy for any given level of GDP can be reduced by using more energy-efficient equipment, e.g. switching from incandescent light bulbs to newer LED bulbs, using more energy-efficient air conditioners, or switching to better insulated buildings. It can also be reduced by switching to more energy efficient systems e.g. from private transport to public transport or switching freight transport from road to rail. These latter options depend not just on individual decisions, but also on conscious public policy action aimed at putting the more efficient system in place. The IESS calculator allows us to vary seventeen different parameters (listed in Boxes 1 to 8) to simulate the scope for reducing the energy demand in the eight sectors that are covered in the exercise. The reduction in energy demand compared to the BAU from shifting each parameter to a more aggressive energy saving level is shown for the year 2032 and 2047 in the relevant column of each box in Boxes 1 to 8.

Some of the changes in parameter values may seem too optimistic. For example, the share of public road transport is projected to increase from 42% in 2012 to 79% in 2047, and the share of electric two-wheelers is projected to increase from less than 1% to 74%. Similarly, we assume a very large increase in the percentage of buildings using energy-efficient insulation and also a very high penetration of smart appliances. While these changes may seem implausible, we know from experience that things often change much faster than we can imagine. No one in the early 1980s could have foreseen how the digital revolution, internet, smart phones, etc. would change lives and possibilities as much as they have not just in developed countries but even in developing countries. With a global focus on energy efficiency, it is reasonable to expect that there will be large changes in innovation, cost etc. in

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[11] Change in the economic structure to less energy-intensive activities can also play an important part. We do not investigate this in detail in this paper.

these areas in the next 35 years. Demand and economic structures may also move towards less energy-intensive activities, thereby making the proposed changes more likely than they seem.

Box 1. **Potential Demand Reduction in Passenger Transport**	**Year**	
	2032	**2047**
BAU Scenario demand (Mtoe)	**167.3**	**278.8**
1. Smart Cities and better urban planning leading to 21% reduction in travel demand in cities.	12.8%	22.0%
2. Shift from 14% rail share in 2012 to 19% in 2047.	2.8%	5.2%
3. Share of Public Road Transport to increase from 42% in 2012 to 79 %.	19.3%	23.6%
4. Share of EVs and FCVs to increase as follows: for buses from 0. % in 2012 to 13% in 2047, for cars from 0% to 44% and for two wheelers from 0.8 % to 74%.	5.7%	7.0%
Low- Carbon Scenario Demand (Mtoe)	**99.3**	**117.8**

Box 2. **Potential Demand Reduction in Freight Transport**	**Year**	
	2032	**2047**
BAU Scenario demand (Mtoe)	**126.5**	**208.7**
5. Dedicated Freight Corridors and Integrated Logistic Planning leading to 20% reduction in freight transport demand in 2047.	10.2%	17.6%
6. Reversing the trend of a declining share of freight being carried by rail and increasing it from 42% in 2012 to 45% in 2047. This is actually a major reversal of the trend since extrapolating the past trend would reduce the share of the railways to 26% by 2047.	10.4%	16.3%
Low-Carbon Scenario Demand (Mtoe)	**100.3**	**138.0**

Box 3. **Demand Reduction in Residential Buildings**	**Year**	
	2032	**2047**
BAU Scenario demand (Mtoe)	**73.0**	**125.9**
7. High-rise buildings constituting 60% of the overall buildings space in 2047 from 34% in 2012.	1.5%	3.5%
8. More than 80% of the buildings have energy-efficient insulations compared to 0% in 2012.	1.4%	3.5%
9. Penetration of Smart Appliances (LED: 75% and other home appliances 80% in 2047 as against 3% and 1% respectively).	28.4%	33.3%
Low-Carbon Scenario Demand (Mtoe)	**50.2**	**75.2**

Box 4. **Potential Demand Reduction in Commercial Buildings**	**Year**	
	2032	**2047**
BAU Scenario demand (Mtoe)	**23.1**	**66.2**
10. Increasing share of high-efficiency appliances to 80% in 2047, against 0% in 2012.	7.9%	9.0%
11. Share of buildings with energy efficient insulation increases from 10% in 2012 to 100% in 2047	2.8%	13.8%
Low-Carbon Scenario Demand (Mtoe)	**20.7**	**51.2**

Box 5. Potential Demand Reduction in Industry[12]	Year	
	2032	**2047**
BAU Scenario demand (Mtoe)	**550.2**	**895.9**
12. Increasing in penetration of EE units best-in-class energy-efficient technology (83% in Cement and 80% in Steel) and Improvement in SEC	12.0%	22.0%
13. Cement: SEC reduction due to shift to grid-based electricity	1.2%	1.8%
14. Steel: SEC reduction due to shift to grid-based electricity.	5.0%	7.2%
Low-Carbon Scenario Demand (Mtoe)	**449.5**	**618.2**

Box 6. Potential Demand Reduction in Agriculture	Year	
	2,032	**2,047**
BAU Scenario demand	**54.3**	**68.6**
15. Energy efficiency improvements in tractors and pumps and phase out of diesel pumps by 2047.	30.5%	33.2%
Low-Carbon Scenario Demand (Mtoe)	**37.7**	**45.8**

Box 7. Potential Demand Reduction in Cooking	Year	
	2,032	**2,047**
BAU Scenario demand	**50.8**	**43.8**
16. Efficiency improvements in cook stoves and switch to electricity and Induction based cook stoves.	36.2%	25.6%
Low-Carbon Scenario Demand (Mtoe)	**32.4**	**32.6**

Box 8. Potential Demand Reduction in Telecom	Year	
	2,032	**2,047**
BAU Scenario demand	**15.9**	**15.8**
17. Efficiency improvements in BTS and switch to solar/electricity from diesel.	45.2%	64%
Low-Carbon Scenario Demand (Mtoe)	**8.7**	**5.7**

The combined effect of the changes envisaged in the demand for energy due to changes in the 17 parameter listed in Boxes 1 to 8 are summarised in Table 5.

12 Note: Savings in 13 and 14 arise from the reduced consumption of captive power, which uses much more fossil-fuel energy than grid-sourced power where the share of fossil fuels is less.

Table 5: Demand - Side Reductions in 2047 in the L.C Scenario

Sector	Units	2047			
		BAU Scenario	LC Scenario	Difference	% Reduction
Transport	Mtoe	488	256	232	48%
Buildings	Mote	192	126	66	34%
Industry	Mtoe	896	618	278	31%
Agriculture	Mtoe	69	46	23	33%
Cooking	Mtoe	44	33	11	26%
Telecom	Mtoe	16	6	10	64%
Total Demand	**Mtoe**	**1,704**	**1,085**	**619**	**36%**

Total energy demand under the LC scenario in 2047 is 619 Mtoe lower than under BAU, a reduction of 36%. This reduction is driven by the industry, transport and buildings sectors, which together accounted for 92.5% of total energy demand in the BAU and contribute 93% of the reduction in energy use.

Supply-side actions for sustainable energy

The demand-side energy savings options outlined can be supplemented by actions on the supply side, which reduce the emissions intensity of a given demand for energy by shifting to cleaner fuels beyond the level built into the BAU. The potential additional supply-side interventions built into the IESS V2 are:

- Introduction of super-thermal technology for electricity generation,
- Reduction of transmission and distribution (T&D) losses,
- Deployment of bio-energy,
- Deployment of solar PV (utility and distributed) and wind (offshore and on-shore) over and above the increase built into the BAU scenario.

Since the adoption of renewable electricity generation is usually regarded as a critical element of any strategy for emissions reductions it is useful to consider the extent of the shift envisaged to towards solar and wind based capacity. Table 6 shows the projected composition of electricity capacity according to fuel source in the LC scenario and a comparison with Table 4 shows the change from the BAU. Two features of the comparison are worth noting. First, the total electricity generating capacity in the LC Scenario is only slightly higher than in the BAU, but the share of electricity in total energy demand is much higher: 24.8 % instead of 18.6%. This is because total energy demand is substantially lower in the LC scenario, thus increasing the share of electricity. Second, the share of wind and solar in total electricity generating capacity in the LC scenario is much higher, at 60%, compared with only 42% in the BAU.

Table 6: Electricity Generation Capacity (GW) by Type (LC Scenario)[13]

Electricity Generating Capacity	2012	2032	2047
Coal	125(66%)	292(44%)	261(23%)
Gas	24(11%)	41(6%)	50(4%)
Nuclear	5(3%)	17(3%)	26(2%)
Hydro	41(13%)	66(10%)	75(7%)
Solar	1(0%)	107(16%)	401(35%)
Wind	17(8%)	132(20%)	290(25%)
Other Renewables	9(4%)	15(2%)	44(4%)
Total	**221**	**670**	**1,147**
Share of Electricity in the Energy Mix	**15%**	**21.3%**	**24.8%**

The expansion in solar generation capacity in the L.C. scenario reflects an increase in grid and off grid capacity from GW (2012) to 107 GW (2032), and up to 401 GW by 2047. The corresponding figures in Table 4 for the BAU were 78 GW and 243 GW respectively. The expansion in solar generation capacity in the LC scenario is roughly in line with the more ambitious targets announced recently in the context of the INDC (Ministry of New and Renewable Energy, 2016).

The increase in solar and wind capacity in the LC scenario is matched by a corresponding decline in the share of coal-based generation. Whereas in the BAU, coal-based generation capacity increased to 360 GW in 2032 and 515 GW in 2047, in the LC scenario it reaches a peak of 292 GW in 2032, i.e. fifteen years from now, and then declines to 261 GW in 2047. The share of coal based generating capacity in total capacity falls from 43 % in the BAU to 23% in the LC scenario. This has implications for the domestic production of thermal generating equipment. Production would still be required for replacements, but the scale of such replacement needs to be carefully considered in planning domestic production capacities.

Other supply-side measures that are proposed include the reduction in T&D losses in the electricity grid. Measures to reduce T&D losses include upgrading infrastructure, deploying smart-grid measures and implementing new transmission technologies (e.g. super-conductors). When introducing a variety of these technologies into the model, it is assumed that under the LC scenario that electricity losses will fall from around 22.7% at present to 7% by 2047[14].

The share of biofuels in the total liquid fuels consumed is projected to increase from 2% under the BAU scenario to 15% in the LC scenario. This will require raising production from both second generation and advanced biofuels, including micro and macro algae, to 122 Mtoe by 2047, which is almost six times India's present oil-based production of biofuels. However, this ambitious target could be constrained by a land requirement of 2.85% of India's total

[13] Figures in parentheses are the share in total capacity
[14] In principle, we refer to 'genuine losses' as opposed to theft, which involves a loss of revenue.

land area. If some of this land is diverted from currently cultivated area, there would be a loss of agricultural production although this could be offset by higher land productivity. Availability of water should be less of an issue with advanced and second-generation biofuels than with the traditional jatropha based biofuels. Macro-algae for example would need to be grown along the coastline. The rest would come from cellulosic-based ethanol.

We could also see an expansion in electric vehicles, which would require a corresponding increase in the electricity sector, which would have to be “green” if emissions are to be controlled. Understandably, we are not in a position to anticipate solutions at this stage to all problems, but developments in technology could offer some solutions in future.

Impacts of interventions on the electricity sector

The additional renewable capacity coming on stream in the LC scenario amounts to 401 GW of solar generation capacity (consisting of 248 GW of grid connected solar photovoltaics, 46 GW of concentrated solar power and 111 GW of rooftop solar photovoltaics) and 290 GW of wind-based electricity capacity. This is about 60% of total capacity in 2047 though it will account for only 45% of electricity generated. Since electricity from renewable sources has substantial intraday and inter-seasonal variation, integrating a large proportion of such capacity into the grid could present technical problems, because the grid has to be able to deliver a steady, stable supply of electricity.

The extent of this problem in the Indian context was studied by the Lawrence Berkeley National Laboratory (LBNL) in California using their grid-dispatch model. They concluded that solar and wind have spatial and temporal complementarity which reduces the requirement of balancing during summer and monsoon peaks. The western part of India is rich in wind, while north and central parts are rich in solar. The wind peak matches the evening demand peak and the solar peak matches the afternoon demand peak. The variability of electricity from RE can also be moderated by introducing grid-scale storage capacity to store electricity when there is a surplus, and release it for use during down times or when required. Based on the LBNL study it was estimated that only 4% of renewable electricity generated in the summer would need to be “stored” during summers and used to meet energy demands in winter, possibly using pumped hydro as a cross-seasonal storage support. Even so, the study estimated that 140 GW of balancing capacity in the form of gas turbines, or battery storage, would be needed to support the grid in 2047. The need to introduce balancing capacity would have to be counted as part of the cost of shifting to renewable capacity.

Balancing demand and supply would be greatly aided if the grid is made smart, i.e. is able to monitor and manage demand and supply patterns more effectively and trigger balancing actions, including calling on available backup and stored capacity. This too would involve additional costs and these have been taken into account in our discussion in section V.

These considerations imply that the management of the grid, not only at the national level but also at the state level, has to be made highly professional both in terms of management systems and upgrading of personnel capacity. This will be a major challenge at the state level where distribution and intra-state transmission is largely in the hands of state public-sector enterprises. There is a strong case for modernising the distribution sector as quickly as possible. Inducting more private players, subject to good quality regulation, could help to set benchmarks of efficiency which the public sector can then be pushed to meet. The regulatory system should also be professionalised as quickly as possible, giving it genuine independence from political influence.

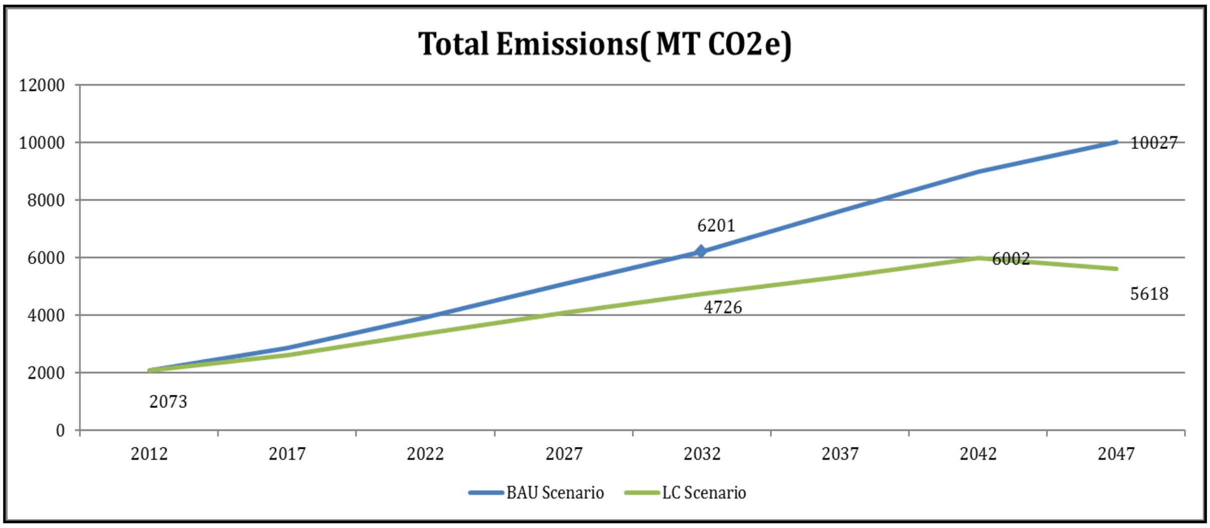
III. GHG Emissions in the Low-Carbon Scenario

In this section, we present the impact of the LC scenario on total GHG emissions, as well as the emissions intensity of GDP and emissions per capita.

Reduction in GHG Emissions from BAU to LC Scenario

In the BAU scenario, total GHG emissions reach 10,027 MTCO_2e or around 10 GtCO2e in 2047. Under the LC scenario, this reduces to 5.6 GtCO_2e in 2047. The trajectory of the BAU and LC scenarios to 2047 can be seen in Figure 1.

Figure 1: Total GHG Emissions in the BAU and LC Scenario[15]



The contribution of each of the various demand and supply-side interventions to reducing GHG emissions in the LC scenario are presented in Table 7.

15 Only includes GHG emissions from energy and process emissions from the industry sector. Overall emissions would include those (non-energy) associated with agriculture and land-use.

Table 7: Sources of Reduction in Emissions from BAU to LC in 2047

Source of Mitigation Action	MT CO_2e
GHG Emissions in 2047 (BAU Scenario)	**10,027**
Demand-Side Actions	
Residential Buildings	(622)
Commercial Buildings	(161)
Passenger Transport	(472)
Freight Transport	(231)
Industry	(2,128)
Agriculture	(141)
Telecom& Cooking	(41)
Sub Total	**(3,796)**
Supply-Side Actions	
Introducing efficiency in coal thermal generation	(56)
Reducing T&D losses	(112)
Deployment of Bio Energy	(170)
Deployment of Renewable Energy (Solar PV -Utility and Distributed and Wind)	(275)
Sub Total	**(613)**
Total GHG Emissions Reductions (LC Scenario)	**4,409**
GHG Emissions in 2047 (LC Scenario)	**5,618**

The most important aspect of the results presented in Table 7 is that as much as 86% of the total reduction in GHG emissions from the BAU scenario, come from demand-side interventions and only 14% to the supply side in 2047. Reductions in the demand for energy from industry because of greater energy efficiency account for 48% of the total reduction in emissions followed by transport (passenger and freight combined), which contributes 16% and then residential buildings at 14%. Green energy (solar, wind and bio energy) together make the next largest contribution, but this is only about 10% of the total reduction in emissions.

In other words, although green energy is the focus of much public discussion, and also generates enthusiasm because it is new, the largest part of the low-carbon transition in India will come not from this source, but from the adoption of energy-efficient technologies or shifts to more energy-efficient systems (e.g. shift from private transport to public transport or from freight from road to rail). The relative importance of these measures is not adequately recognised in public discussion and the policy initiatives that can bring this about receive much less attention than they deserve. [16]

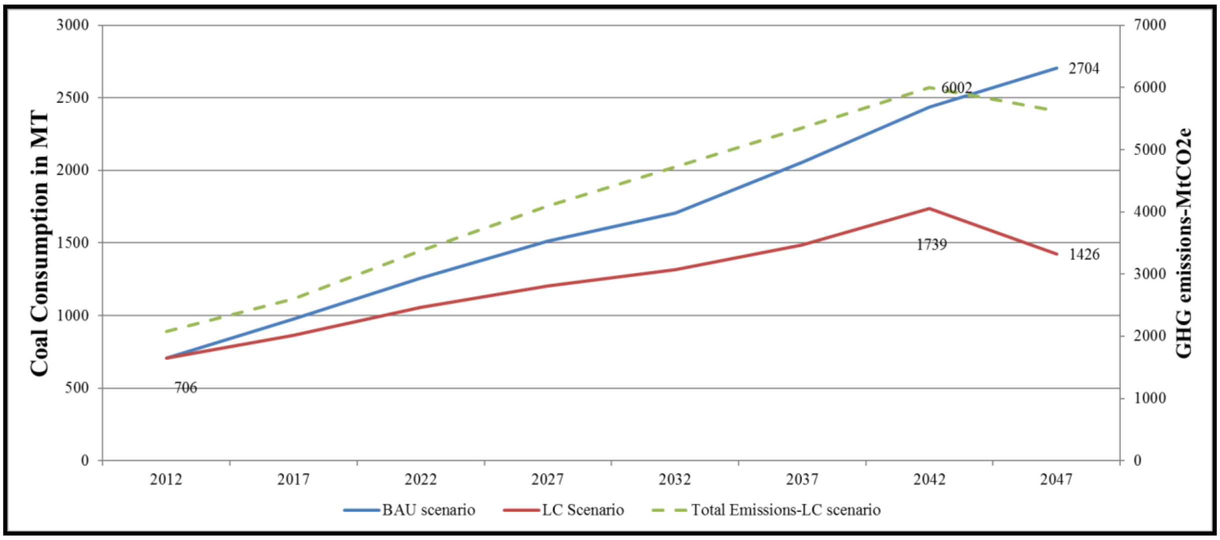
Another interesting feature of our estimates is that although the energy savings of 278 Mtoe in Industry is only about 20% larger in absolute terms than the energy saving of 232 Mtoe in Transport (see Table 1 and 5, and Boxes 1 and 2 for details), the reduction in GHG emissions

[16] One should also consider potential changes in industrial structure, including moving towards "lighter" services sector.

in the case of the industry sector (as shown in Table 7) is about three times the emissions reduction in the transport sector (passengers and freight combined). This is because the energy used in transport is mainly gasoline and diesel, which is much "cleaner" (in terms of CO_2e), whereas the dominant source of energy in industry is coal. Direct coal consumption accounts for 45% of the energy used in industry, while electricity accounts for 15%, which in turn is predominantly coal-based.

An important difference between the BAU and the LC scenario is that there is no peaking of total GHG emissions within the 2047 horizon in the BAU scenario, but in the LC scenario emissions peak at a level of about 6,000 $MTCO_2e$ in 2042. This reflects what is expected to happen to coal consumption. As shown in Figure 2, under the BAU scenario coal consumption rises continuously, reaching 2,704 million tonnes in 2047. In the alternative LC scenario, coal consumption peaks at about 1,739 million tonnes in 2042, and then begins to decline in absolute terms to 1,426 million tonnes in 2047.

Figure 2: Total Coal Consumption and Total Emissions, BAU and LC



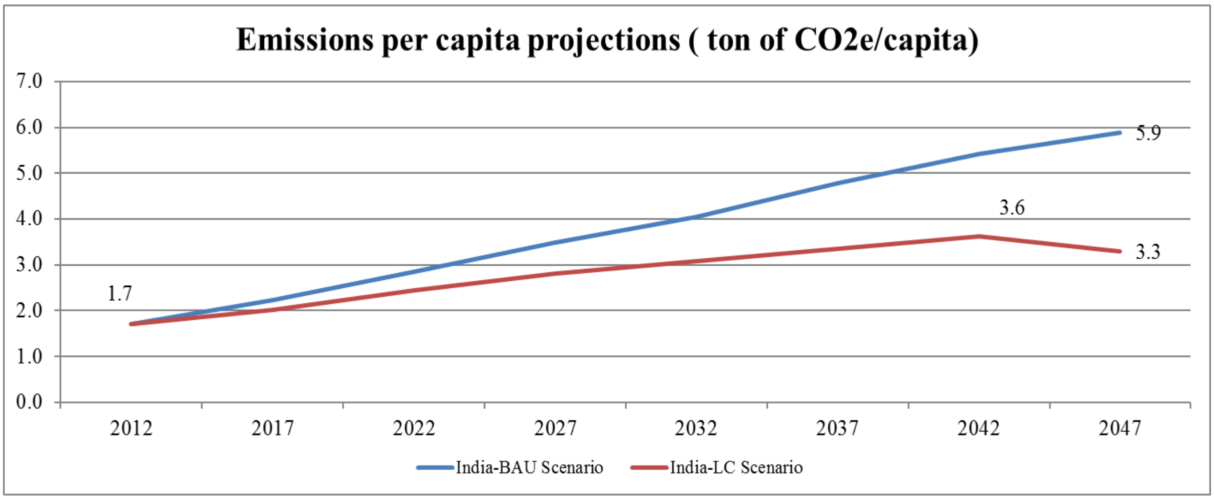
GHG emissions intensity and emissions per capita

In the BAU scenario, the emissions intensity of GDP falls from 1.18 tCO_2e/1000 US$ of GDP in the base year 2012, to 0.47 tCO_2e /1000 US$ of GDP in 2047. In the LC scenario the emissions intensity of GDP is much lower in 2047 at 0.29 tCO_2e. This reflects a 75% decline from the base year of 2012. As the emissions intensities in this paper are confined to emissions from energy used in commercial, industrial and personal use, comparisons with the INDC target are difficult as it includes other sources (e.g. land-use). However, the projections suggest that India's INDC targets of 33-35% reduction in emissions intensity in the period 2005-2030 are likely to be met even in the BAU scenario[17].

[17] Note that the INDCs are with reference to an earlier base year 2005

The decline in total GHG emissions also leads to a fall in emissions per capita. In the BAU scenario it is projected that GHG emissions per capita will be in the region of 5.9 tCO_2e/per capita in 2047. In the LC scenario, this will fall to 3.3 tCO_2e per capita. The trajectory of GHG emissions per capita in the two scenarios can be seen in Figure 3. The terminal year emissions per capita at 3.3 tCO_2e is much lower than the BAU, but it is still above the global average of 2 tCO_2e for mid-century which is consistent with containing global warming to 2^oC.

Figure 3: Emissions per capita for India in BAU and the LC Scenario



Comparison with China

The IESS scenarios for India provide some basis for comparing with China. China's rapid economic growth has enabled China to increase GDP per capita to US$7,590 and lift many people out of poverty, while becoming the world's 2nd largest economy. However, its growth has been driven by fossil-fuel powered industrialisation, which has led to China becoming the largest contributor to GHG emissions of 10,975.5 $MtCO_2e$ in 2012 (World Resources Institute, 2016). India's per capita income is much lower than China's, but in recent years has begun to grow rapidly and the projection of 7.4% growth implies that it will grow more rapidly than China, which has begun to slow down. India is currently the world's 9th largest economy, but is the 4th largest GHG emitter (3,013.8 $MtCO_2e$)[18].

The two countries' trajectories on projected per capita GHG emissions and the emissions intensity of GDP to 2030 are compared in Figures 4 and 5, respectively. In India's case the two trajectories relate to BAU and the LC scenario. In China's case the two trajectories relate to peaking in 2030 as China has itself announced, and another trajectory in which China peaks earlier in 2025, as projected by Green and Stern (2016).

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18 Comparison of GHG emissions from the energy and industry sectors in both countries only as compared to population. Source: IEA, World Bank and Authors' calculations.

Figure 4: GHG emissions projections from Energy –India and China[19]

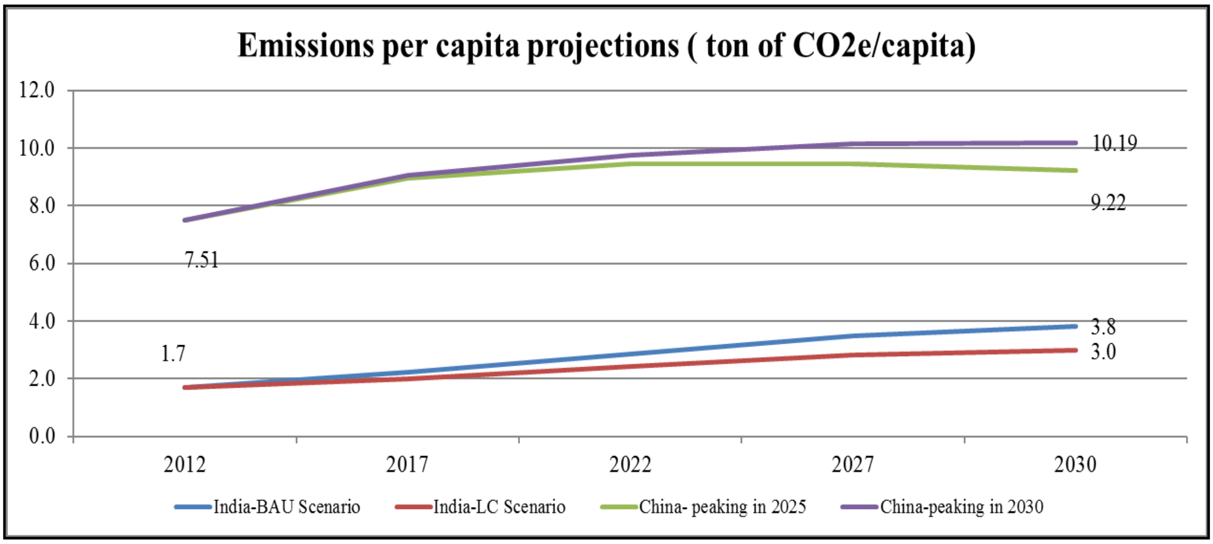

Figure 4 shows that India's current GHG emission per capita is much lower than that of China's, but as already mentioned, so too is India's per capita income. According to our projections, if China's GHG emissions were to peak at 2030 this would be at a level of around 10 tCO_2e per capita. In India's case, if the LC scenario is followed, then GHG emissions would peak around 2040 at around 5 tCO_2e per capita. Making reasonable assumptions about the likely growth rate until the time when GHG emissions peaks are expected (2030 in China and 2040 in India), it appears that China would have peaked its GHG emissions at around twice the income per capita as India. In other words, while India would peak later than China in pure time terms, it would actually peak GHG emissions much earlier in the development process than China. However, if the BAU scenario for India is followed, then GHG for India would be much higher and would not peak at all during the period up to 2047.

A comparison between India and China based on GHG emissions per unit of GDP also presents some interesting features about the nature of production in the two economies and the emissions efficiency of their growth. This is displayed in Figure 5.

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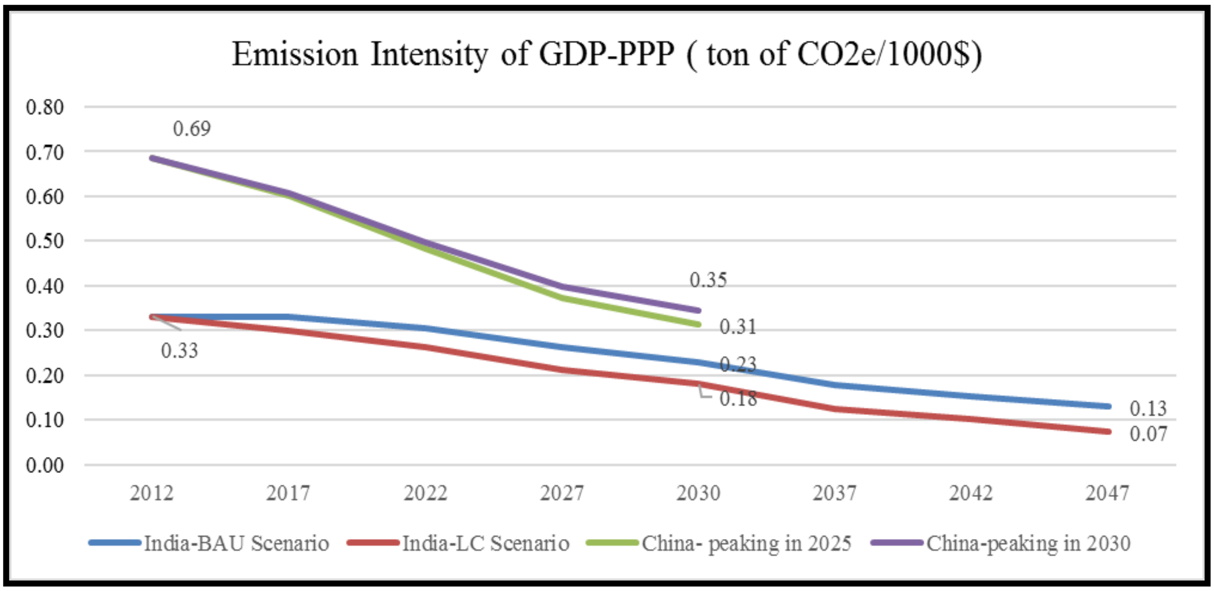
[19] See footnote 17.

Figure 5: Emission Intensity of GDP –India and China[20]



Note: GDP on PPP basis has been used to compare emission intensity of India and China.

Under both the BAU and the LC scenarios, India would see a reduction in the emissions intensity of GDP, though it would be much greater under the LC scenario. China's emissions intensity of GDP is much higher than India's at the start, because China's GDP is more dependent on fossil fuels. The emissions intensity of GDP in China is projected to fall more sharply than in India but it is expected to remain above the Indian level; during the projection period. We note that even at the end of the projection period, China's emissions intensity of GDP will be significantly higher than India's under both the BAU and the LC Scenario.

The results in Figure 4 and 5 present good news in the sense that growth in both China and India is likely to be less dependent on GHG emissions than in the past. However, the absolute levels of GHG emissions for both countries, will be much higher than today, and this has implications for the global carbon budget that need to be carefully considered.

If China and India were both to have per capita GHG emissions of approximately 5 tCO_2e per capita by 2040, an outcome broadly consistent (see Figure 4) with the BAU scenario for India and a continued sharp reduction for China, the total emissions of the two countries would amount to approximately 15 $GtCO_2e$ per annum. However, if the world has to transition to a 2^oC path, the total world carbon budget in 2040 would be approximately 20 $GtCO_2e$ per annum (or 2 tCO_2e per capita), with the requirement that it should decline further to reach net zero GHG emissions in the second half of the century (2050 – 2099). However, in this scenario this means that India and China would consume 75% of the global carbon budget by themselves, making the likelihood of meeting the global targets highly remote.

20 Source: IEA Energy Outlook 2015, IMF and Authors' calculations (China's emission intensity data are available only until 2030 in line with their recent submissions to UNFCCC.

This further underlines the urgency for all countries to explore the possibility of accelerating the transition to a low-carbon path. It is especially important to avoid the lock-in of carbon intensive infrastructure, which may become stranded in future. As we have pointed out earlier, if industrialised countries really do manage a transition which brings their per capita consumption to the targeted level (2 tCO_2e per capita) for the globe as a whole by 2050 (an arbitrary benchmark since it will almost certainly be argued by developing countries that they should actually be lower than the average given their much larger capacity and their history of emissions) it will be because of technological breakthroughs which would also help developing countries such as India to reduce their GHG emissions.

IV. Other Co-Benefits of the LC. Scenario

In the previous section, we dealt with benefits from the LC scenario related to the reduction in emissions. However, the LC scenario also provides additional "co-benefits" which are sometimes not adequately appreciated but must be included in any serious cost-benefit analysis of making the low-carbon transition. These include aspects such as enhancing energy security, economising on water and improving local level environmental aspects (e.g. air pollution) which is increasingly imposing serious health costs. These benefits are potentially very large.

Energy security

In Table 2 we saw that India has a significant reliance on the import of primary fossil fuels for energy supply and this dependence is expected to increase sharply in the BAU. The import dependence in the LC scenario in each of the primary fuels is very different and is shown in Table 8.

Table 8: Import Dependence in LC scenario (% of primary energy supply)

		Units	**2012**	**2032**	**2047**
Coal	Consumption	Mtce	706	1,317	1,427
	Production	Mtce	582	1,152	1,157
	Import Dependence	%	**18%**	**13%**	**19%**
Oil	Consumption	Mtoe	166	295	294
	Production	Mtoe	38	49	59
	Import Dependence	%	**77%**	**77%**	**60%**
Gas	Consumption	Bcm	60	131	163
	Production	Bcm	48	69	128
	Import Dependence	%	**22%**	**47%**	**21%**
Overall	Consumption	Mtoe	609	1,142	1,445
	Production	Mtoe	421	799	1,272
	Import Dependence	Mtoe	**31%**	**30%**	**22%**

Note: Mtce is million tonnes of coal equivalent, Mtoe is million tonnes of oil equivalent and Bcm is billion cubic meters.

Comparing Table 8 with Table 2 we see that projected import dependence on coal in 2047 drops from 57% in the BAU to 19% in the LC scenario, and in the case of oil from 90% to 60%. If the LC scenario is followed the total import dependence of each of these fuels is reduced to 22%, which is actually lower than the 31% level in the base year 2012. This is clearly a desirable outcome from the point of view of energy security.

Economising on water use

Another potential benefit from transitioning to the LC pathway can be seen in the electricity-water linkages. India's per capita renewable fresh water availability was 1,130 m^3 per capita in 2013. This is half that of China (2,072 m^3/capita) and one ninth of that of the USA (8,904 m^3/capita), the two largest power producing nations from fossil fuels (World Bank, 2016b). Furthermore, the availability of water in India is likely to reduce to 753 m^3 per capita by 2027[21]. Since different energy sources require very different quantities of water, policies which reduce energy use and shift the composition of energy to less water using energy systems have strong economic benefits.

A study by Virginia Water Resource Research Centre compares the water consumption efficiency of various energy sources as indicated in Table 9 below (Younos et al, 2009).

Table 9: Water use efficiency for various electricity sources

Electricity Source	**Water consumption (litres per 1000 kWh of Energy)**
Hydroelectric	260
Solar thermal	2,970-3,500
Fossil-fuel thermal	14,280-28,400
Nuclear	31,000-74,900
Wind	0.004
Solar PV	0.110

Based on the projected electricity mix in India under the BAU and LC scenarios, coal is projected to be a dominant source of electricity generation in India in both the BAU and even the LC scenarios but much more so in the BAU. Since coal-based electricity generation is also a large user of water as compared to RE sources (see Table 9), and shift away from coal based generation helps in handling the water constraint. Nuclear power is also heavily demanding of water, but the absolute size of the additional nuclear capacity envisaged is much smaller than coal based generation.

Even if coal-based power plants deploy more water efficient technologies such as wet cooling[22], the additional capital cost of these systems is likely to increase the cost of

[21] Estimates from central water commission and population projections from IESS V.2.

[22] There are two kinds of water usage: consumption and withdrawal. Closed loop systems or Wet Cooling systems are not high on withdrawal but have higher consumption of water (approximately 3L of water/kWh of electricity is lost in closed loop technology). Further, a closed loop system is 40% more expensive in terms of capital costs than open loop technology and reduces the efficiency of the power plant by 2-5%.

production of coal-based electricity. If this is accompanied by the adoption of rational water pricing policy, which may well be necessary over a longer period, it will further increase the price of fossil-fuel electricity. This would strengthen the incentive to substitute solar PV and wind capacity for coal. Hydropower is clearly the source of energy which does not actually "consume" water but the scope for adding to hydro power potential is limited and is being fully explored in the LC scenario.

The need for close attention to water constraints is heightened by the fact that, in the absence of global action, climate change is likely to have a strongly negative effect on the availability of water, increasing its variability. Recently, generation from a 2300 MW power plant on the banks of river Ganges was shut down for the first time in 30 years following an unprecedented drop in water levels (Biswas, 2016). Such instances are likely to become more common because of climate change putting fossil-fuel based thermal capacity at a high risk.

Health benefits from lower air pollution

A low-carbon strategy can also bring important health benefits from the reduction in air pollution because of (a) lower use of coal in industry with a switch to electricity for heating and in furnaces; (b) a shift away from petrol and diesel in transport towards electric traction and biofuels; and (c) a shift in producing electricity away from fossil-fuel based generation to cleaner fuels, notably solar and wind. Unlike the benefits associated with climate change, which accrue to all countries, and therefore require global cooperation to determine some fair sharing of the burden of mitigation action, the benefits of reduced pollution are local, i.e. they accrue within the country. Efforts to mitigate pollution costs should not therefore be dependent on what other countries do.

The health problems posed by air pollution in India have now entered public consciousness in India, with the WHO reporting that thirteen of the 25 most polluted cities in the world are in India. We know that as growth proceeds, urbanisation will increase and if Indian cities are to be liveable, it is essential that the problem of air pollution is effectively tackled. A large part of the problem arises because of coal-based electricity generating plants near urban areas, diesel generating sets that are used by commercial and residential establishments in cities to deal with sudden power cuts by the utility, and of course the pollution from automobile exhausts, which is made worse by growing traffic congestion.

The magnitude of the health costs involved are much larger than is generally realised. Some simple assumptions about a hypothetical country suffice to illustrate the problem. Let us assume that in this hypothetical country one in a thousand people die each year because of exposure to air pollution. We note in passing that this would be a plausible rough estimate for

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Exact estimate of the retrofitting costs of open-loop systems with closed loop systems are not available but they are likely to be more than the capital costs of closed loop systems alone. The Ministry of Environment and Forest has come up with a draft norm in 2015 that if accepted would require all power plants to replace systems with closed loop systems. The broader point however, remains that LC scenario will have a significantly lower water footprint as compared to that of BAU.

both India and China (Rhode and Muller, 2015). The next step in estimating costs is to ascribe a value to the loss of a life. This is inherently difficult because there is understandable moral hesitation on putting a monetary value on a human life. However, cost-benefit studies in health and transport do make such assumptions to determine the cost a society should be willing to bear to save a life (see for example WHO, 2005). It is common in such studies to value a life saved at 100 times the per capita GDP. On this basis, the loss of GDP from air pollution in our hypothetical country could be as high as (.001xN) 100 x (GDP/N), which works out to be 10% of GDP (N= total population). We can make different assumptions about the number of people per thousand who die because of air pollution, and also the multiple of per capita GDP at which a life is valued. For example, reducing the value of a life to say 20 times the per capita GDP would reduce the loss due to air pollution to 2% of GDP, but even this would justify incurring large costs to reduce air pollution, much larger than is being done today. A recent study by Ghude et al (2016) estimates that present day premature mortalities per annum in India due to air pollution, are approximately 570,000 people for fine particulate matter ($PM_{2.5}$) and 31,000 due to ozone exposure (O_3).[23].

The appropriate way of handling such externalities is to "price them" into the price of the polluting commodity. Pigou more than a hundred years ago, pointed out that activities that cause damage, such as air pollution, should be taxed to bring private costs and social costs into line and thus give appropriate incentives for avoiding pollution. This could be done by imposing taxes on fossil fuels so that the polluting activity is adequately discouraged. The resources generated in the process could be used to incentivise cleaner fuels and subsidise alternative less polluting systems, e.g. public transport. Linking the taxes with financing beneficial activity could not only help accelerate the transition but also help generate public support for the package.

The carbon tax needed to reflect the cost of climate change is estimated to be around US$70 per tonne of coal based on a fairly low-carbon price of US$35 per tonne CO_2. (A tonne of coal, when burnt, releases around 2 tCO_2 so the impact on the underlying coal price is roughly twice the price attributed to CO_2), However, as pointed out in IMF (2015) the costs on account of damage from air pollution could be much higher. Boyd et al (2016) suggest that the costs of coal due to local pollution could be as high as US$150 to 200 per tonne. These calculations are necessarily broad brush, and in any case the costs of local air pollution also depend on local circumstances. But they provide an idea of the level of taxation that is needed. We note in this context that India has a clean energy tax (cess) on coal of Rs 400 per tonne, but this equates to only about US$7 per tonne, much lower than suggested by the estimates reported above. Besides, it is currently imposed only on coal and not on petroleum-based fuels.

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23 The study assumes the value of a life in India at USD 1.1 million in 2011.based on the estimated value of a life for the EU of $3 million in 2005. This is scaled it down by the ratio of the GDP per capita of India and the EU and further adjusted this increase in GDP per capita and in inflation from the base year 2005. This yields a much higher total cost as a percentage of GDP. We do not endorse this estimate but cite it only to show that perceptions of the cost of air pollution are gradually building up in India.

Imposing a tax which effectively increases the price of coal threefold could increase the price of coal-based electricity from around Rs 3/kWh to Rs 7/kWh. At this price, solar electricity, with all its additional balancing costs, could be cheaper than conventional electricity. It is difficult to imagine any government raising the price of a key energy source as much as the estimates above would suggest, but at the same time the social costs are not imaginary costs; the pollution costs are real and the damage to the lives and livelihoods of the population cannot be ignored. More work is needed to refine these estimates for Indian conditions and use them to build a consensus on the need for carbon or pollution taxes which close the gap between economic costs and social costs.

V. Investments and Costs of Transition to the LC Scenario

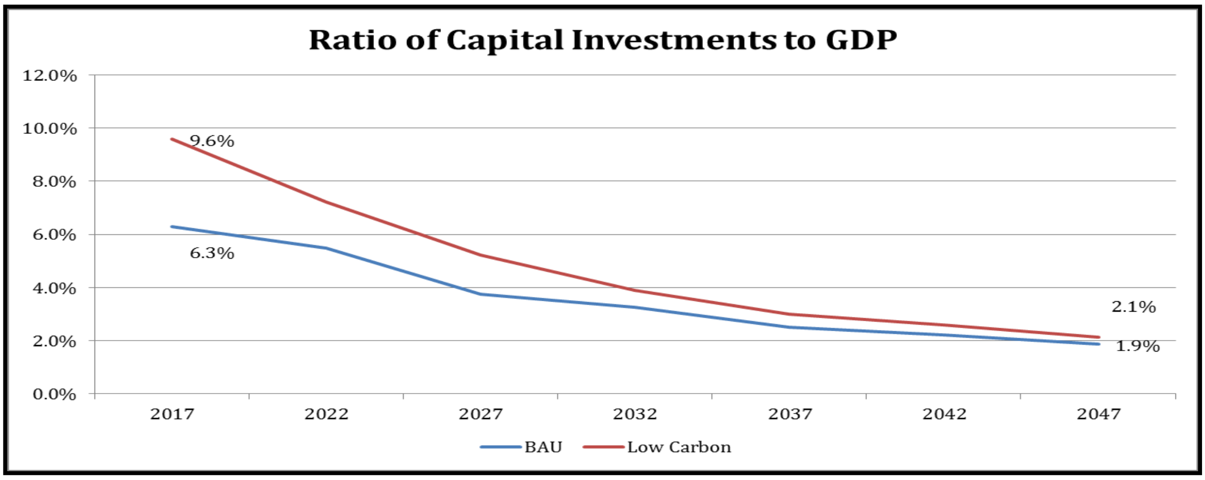
We now turn to examine briefly the additional investment and costs involved in moving from the BAU to the LC scenario. This is an inherently difficult exercise because of the uncertainty about how technologies will evolve over the next three decades. However, the IESS calculator has built in some assumptions about costs associated with the specific changes envisaged (capital costs, operating costs and fuel costs) based on discussions with experts, and a literature review.

The IESS calculator provides three different cost scenarios: a high-cost scenario, which is based on the assumption that costs will remain at present levels, a low-cost scenario which implies that costs of newer technologies which save energy and which allow exploitation of greener energy options will fall in line with the rate of decline observed in the past, and finally a mid-point of the two (see Appendix A for details). We have adopted the mid-point option in discussing cost issues in this section, though we think this may be too pessimistic since it is very likely that costs will fall faster than in the past, if the whole world is determined to take action.

Capital Costs

Figure 6 shows the total capital investment in the sectors where the LC scenario envisages specific parameter changes. The blue line shows the investment cost in these sectors in the BAU and the red line shows the investment costs in the same sectors in the LC scenario. The total capital investments involved in the LC scenario are significantly higher, by about 3% of GDP initially, than in the BAU scenario, but the difference starts to narrow down thereafter, declining steeply as the costs of the low-carbon technologies come down and eventually converge with that of BAU pathway. For the period as a whole, the additional costs are around 1.75 % of GDP higher than in the BAU.

Figure 6: Total Capital Investment in LC Scenario



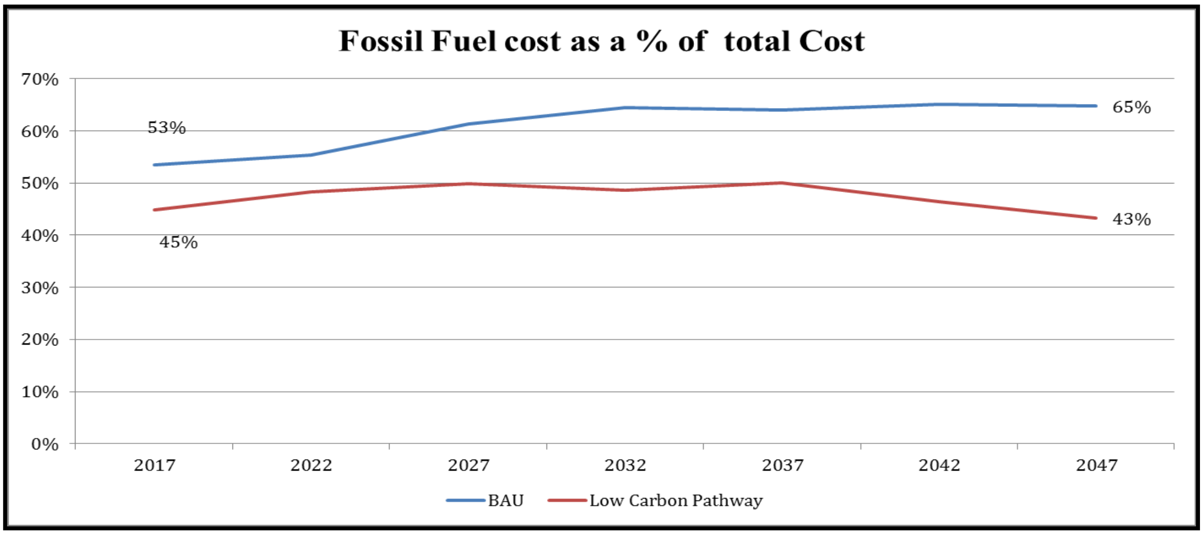
If the total investment capacity of the economy is constrained, the additional investment costs of the LC scenario will involve a diversion from productive investment in other sectors, and to that extent, the overall GDP growth rate may be a little lower. The calculator does not endogenously determine the impact on growth, but it is reasonable to think that a reduction in investment of 1.75% GDP might reduce the growth rate by about 0.4 %. However, this could be offset by measures to achieve higher growth in productivity, so as to maintain the growth target at 7.4%. While there are additional costs which could reduce the rate of growth, this outcome has to be weighed against the strong co-benefits such as greater energy security, conservation of scarce water and better health due to lower air pollution, all of which are real benefits to be offset against costs. Some of the benefits, e.g. conserving water and also reducing the burden of ill health, also show up in GDP though the impact is not easily quantified.

In considering the impact on growth we must also keep in mind that new low carbon technologies will (i) have lower operating costs in the future, (ii) carry strong benefits (including reduced pollution) beyond GDP, (iii) trigger strong discovery and learning-by-doing and further technological change (Aghion et al, 2012). If we bring in these important effects then future growth over the medium term need not be adversely affected, indeed it could even be increased.

Fuel Costs

Figure 7 shows the IESS estimate of fossil-fuel costs as a percentage of total costs. As we would expect, the curve for the alternative low-carbon pathway is consistently below the curve for the BAU because the dependence on fossil fuels is lower. A positive feature of the low-carbon pathway is therefore that fuel costs will be lower as percentage of total fuel costs.

Figure 7: Fuel Cost as a percentage of Total Costs



The net picture in terms of additional costs/savings in the LC scenario compared with the BAU during the period 2012 - 2047 is shown in Table 10 There is a potential saving of US$8.8 trillion in the reduction of the use of fossil fuels because of the shift to renewables. There is also a saving of about US$1.9 trillion in transport because the low-carbon scenario embodies an eventual reduction of transport demand by 48% because of better transport planning leading to a reduction in the vehicle stock and also in infrastructure costs. This saving is offset to some extent by the higher capital costs of electric vehicles but these are also expected to decline over time. There are costs in other areas as shown in Table 10 below. We note however that the savings in fuel costs are based on the relatively high prices of oil that prevailed in 2013 and they would be lower at currently prevailing prices.

Table 10: Incremental Cumulative Costs of LC Scenario over the BAU

Sector	**Additional Costs/(Savings) USD Billion**
Fossil Fuels	(8,776)
Bio-energy	1,227
Electricity	325
Buildings	486
Transport	(1,932)
Industry	245
Others	52
Total	(8,371)

The net effect over the 35 year period (without any discounting) is a saving of about US$8.3 trillion Since the capital costs will be incurred in the earlier years, whereas the fuel savings will materialise only in the later years, comparison of the cost and benefits should be based on discounting over time. If a discount rate of 6% is applied, the net savings are considerably reduced to a present discounted value of US$ 1.8 trillion. This is the present discounted value of net savings over a 35 year period and amount to just under 1% of GDP per year.

The shift to a low-carbon pathway will require additional investments worth US$2.1 trillion from now to 2047, out of which about US$325 billion will have to be made in the electricity sector alone. These upfront costs will be offset by savings on fossil fuels in later years. However, much of the savings in fossil fuel costs are in industry and transport sectors.

Potential consequences for the costs of electricity

The implications of a low carbon strategy for electricity pricing is in many ways a critical factor in determining the acceptability of the strategy. It is easy to understand that any government would be unwilling to accept an option which involved raising the price of electricity but it has to be accepted that in all probability the "real cost" of electricity would be higher in the LC scenario. Table 11 shows that the real cost of electricity in the BAU increases from the present level of Rs 3.2/kWh (Planning Commission, 2014b) to Rs 5.3/kWh because of the increasing proportion of renewables in the BAU over time. In the LC scenario, the proportion of renewables is much higher, and the real cost of electricity increases further to Rs 5.9/kWh. This estimate takes into account the reduction in the costs of renewable energy built into the cost projections in the calculator, though we note that the final outcome could be better, depending on the pace of technological change.

The ability of the power sector to absorb the large increase in renewable capacity involved in the LC scenario, depends critically upon (a) power producers being allowed to charge economically viable electricity tariffs that will cover the financing costs of the investments involved and (b) being sufficiently efficient in operating the distribution segment to fully realise the revenues made possible by the tariffs prescribed.

Table 11: Average Cost of Electricity (INR/kWh) in the BAU and LC Scenario

	2017		2032		2047	
	BAU	LC	BAU	LC	BAU	LC
Capacity Charge	1.1	2.0	2.5	3.2	2.9	4.2
O&M Cost	0.5	0.6	0.6	0.6	0.6	0.7
Fuel Cost	1.8	1.3	1.7	1.2	1.8	1.1
Total Cost	3.4	3.9	4.8	5.1	5.3	5.9
Share of RE	9%	13%	18%	22%	27%	43%

Note: INR/kWh is Indian Rupees per kilowatt-hour

Any projection that involved raising the cost of electricity would meet political resistance, but this only highlights the dilemma that politicians face. The only way to push the system to use more green energy without passing on higher costs, is to find resources to subsidise the transition. That would be unlikely to be fiscally manageable. However, green energy is not really more expensive than, say, coal based energy if coal is priced properly. The work of the IMF (2015) has shown that, if coal were priced properly for its pollution and its carbon emissions, it would be much more costly than its current cost of approximately $50 per tonne, and coal-fired electricity would already be much more expensive than, say, solar. That would be true even if the carbon price were zero, since the costs of pollution from coal are so high (see discussion at end of section IV above).

Looking ahead it is possible that solar power may become competitive even without pollution and carbon pricing. Costs of solar power in India are already falling faster than anticipated, with prices coming in at 4.63 INR/kWh for a 500 MW dollar PV project in Andhra Pradesh, while 10 other bids were below 5 INR/kWh (Jai, 2015). This is within the current range of coal tariffs (3 – 5 INR/kWh). If prices continue to fall, it is projected that solar could be 10% cheaper than coal power by 2020 and fall even further by 2025 with prices of INR 4.20 per kWh and INR 3.58 per kWh respectively (KPMG, 2015). While these prices do not reflect the balancing costs of integrating RE, these lower costs would be at grid parity and have the potential to incentivise other more dispersed electricity generation options (e.g. rooftop solar PV). When these are combined with flexibility options (e.g. battery storage) the costs of solar power could be cheaper than grid-power between 2020 and 2025 (KPMG, 2015). If this happens, the switch to green sources of power could potentially lower the costs of electricity in India and these sources would compete effectively with coal. They would be very significantly cheaper if pollution or carbon taxes are introduced.

VI. Orchestrating Policy Change

In this section we focus on how the transition to the low-carbon path can be achieved, assuming that aggregate social cost-benefit analysis justifies making the switch. It is clear that the transition cannot be achieved by adjusting one or two key policy instruments. The LC scenario is based on changing about 17 parameter values in eight energy using sectors (Boxes 1 to 8) combined with action on the supply side as summarised in Table 7. What this means is that the realisation of the LC scenario will require multiple interventions. Appendix 2, provides an illustrative list of these interventions that would have to be deployed to support the changes envisaged in each area. A special challenge is that these interventions fall in the domain of different levels of government. Some of the actions would have to be taken by the central government, others by the state government, and some even by local governments.

The detailed design of the specific policy interventions will depend upon particular circumstances, and could also vary across states. It is beyond the scope of this paper to explore these issues in depth, but some general points that are relevant are highlighted below.

Energy pricing and taxes

Energy pricing has a critical role to play in transitioning to a low carbon growth path and it also poses politically difficult choices. We are more likely to become energy efficient, if energy prices are set at levels that incentivise energy efficiency. As a first step therefore, energy subsidies on fossil fuels should be eschewed and these fuels should be priced at its full economic cost. If particular target groups require support, that could be better delivered as a straight cash transfer to identified eligible beneficiaries which is now practical since Aadhar, the unique ID system based on bio metric identification, has been put in place. In the case of electricity or piped gas, the same effect could be achieved by having a first slab of consumption at an affordable price, with subsequent slabs attracting higher prices thus cross subsidising the concessionally priced first slab.

Ideally, all countries should also go beyond covering full economic cost of generation and delivery, and impose taxes on fossil fuels which ensure that the price paid by the consumer internalises the social costs of burning fossil fuels. Unfortunately, although this "polluter pays" principle is well established in theory, and is even enshrined in policy statements, governments find it very difficult to apply it in practice. Perhaps a more determined effort needs to be made to explain to the public that the taxes are being imposed to discourage activities that otherwise impose a high social cost, and also that the revenue earned will be used to support the shift to less polluting alternatives which benefit the general public. However, this is easier said than done, though we note that it is perhaps easier to make this case when fossil fuel prices are low as they are at present. We would emphasise that it is not necessary to make large adjustments suddenly. Announcing a system of annual adjustments to achieve the objective of internalising social costs could achieve a substantial transition in a defined period of time. India's clean energy cess on coal needs to be recalibrated at a higher level and a similar cess imposed on petroleum products reflecting the carbon content. In the case of petroleum products, especially petrol, indirect taxes are already quite high. These taxes need to be made comparable with indirect taxes on other inputs and a separate clean energy cess imposed, which is not integrated into the normal chain of value added taxation with rebates allowed against the taxes due on the final product.

An argument often advanced against introducing pollution and carbon taxes is that it will make domestic production uncompetitive internationally unless all countries follow suit. To the extent that this is true, it presents a classic case where international cooperation, especially by the developed countries and the larger developing countries, would be a key determinant for broader action. However, OECD has recently demonstrated that such competitiveness effects are generally very limited relative to the other determinants of the patterns of trade (see also The Stern Review, 2007 and Kozluk and Timiliotis, 2016).

An alternative to carbon taxes is a cap and trade system focussing on capping emissions. This is being used in many countries. China, is implementing a countrywide cap and trade scheme, while the U.S. administration is attempting to implement a plan to limit emissions from coal-fired power stations although this particular initiative has been challenged in the courts. Some US cities and states have taken strong action. Other examples include the introduction of carbon taxes in South Africa, Mexico and Chile. In total almost 40 countries are already using or planning to implement carbon pricing in the near future (World Bank, 2016a). India is currently working with a voluntary Perform Achieve and Trade (PAT) system to limit emissions in selected industries. It is necessary to benchmark what is being done in India against practice elsewhere.

The role of regulation

While energy pricing and associated tax policy can provide strong price-based incentives to move towards energy efficiency, non-price measures also have a large role to play. Examples are, regulations mandating the compulsory phasing out of incandescent light bulbs, establishing higher fuel-efficiency standards for automobiles, controlling the level of exhausts from three-wheeled auto-rickshaws, setting energy-efficient building standards and enforcing them, insisting on super-thermal technology for all future power stations and introducing higher standards for automotive fuels that would make them less polluting. All these could help trigger change, though they will also impose higher costs.

Regulatory action can work in tandem with price incentives. For example, an announcement of the intention to force all inner-city taxis and buses to be electric from some given date in the future could be coupled with tax incentives, or other special programmes, to facilitate the switch. However, it is important that such incentives are not suddenly withdrawn. Normally, tax exemptions are not much liked in Finance Ministries, but sudden changes in incentives are unfair to investors entering the area in the belief the incentives will continue. Resistance to tax incentives by the fiscal authorities will be lower if they are clearly understood to be part of a package of additional taxation on fossil fuels, which generates tax revenues offsetting the revenue loss from the incentive.

Role of public investment

Public investment has a major role to play in facilitating the transition to the LC scenario. The shift from road to rail transportation in freight, and from air transportation to railways, are both critical for the transition and they can only happen if the railway sector is suitably strengthened and modernised. While some of this could be done through public private partnership, it will also involve a substantial increase in public investment. Much the same is true for urban transport within the cities which requires major investment in metros and also in the bus transport system, with the two together operating in a much more interchangeable way.

Co-operation across different levels of government

An important feature of the multiple intervention points indicated in Appendix 3 is that they fall in the domains of different levels of government. For example, technical standards for appliances and fuels are mainly in the hands of the central government, but state governments control building standards. Public transport is expected to see a major change in our low-carbon scenario with the share of public transport[24] increasing from 42% in the BAU to 79% in the low-carbon scenario. The responsibility for providing a reliable public transport system rests with both the state and the local governments but fuel-pricing policy, which can discourage reliance on personalised transport, falls in the realm of the central government. Urban land planning is again a responsibility divided between state governments and local bodies. Appendix 2 provides many other examples of such divided responsibilities. One of the challenges of devising a workable structure of policy intervention is to ensure a collectively effective effort.

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[24] Inclusive of intra-city and inter -city public transport

Some of the areas where collaboration across agencies is necessary might not be immediately evident. For example, women are unlikely to switch from personal vehicles to public transport if feel public transport is not sufficiently safe in evening hours. Greater and more effective security measures in the "last mile" areas around public transport stops are therefore important and this is in the domain of the police.

Clarity in policy

Experience in both developed and developing countries shows that policy uncertainty, or lack of consistency and clarity, can be a major disincentive to private investment. This is vitally important if the investments needed to achieve the transformation to a low-carbon pathway have to rely heavily on private investment. Private investment needs both clarity and also some assurance that policies will not be change suddenly in a manner which would adversely affect the investor. Since multiple levels of government are often involved, there is need careful coordination of policy, with a clear enunciation of national and state level policies, which can provide direction for local policy decisions.

Clarity and consistency of policy will also help to bring down the cost of capital especially when investments are expected to be in production over a long period. There is also much that can be done by the financial sector to bring down the cost of capital. Multilateral development banks (MDBs) and national development banks can play an important role here for a number of reasons. First, their presence in a deal gives confidence to investors. Second, they can provide a wide variety of instruments to manage and share risk, ranging from loans, to political risk guarantees, to different forms of equity (Bhattacharya et al, 2015). Third, they can be trusted convenors who are much more likely to bring co-investors together than a private agent. Fourth, they can develop strong specialist shields in key areas (and such as the EBRD and UK Green Investment Bank on energy efficiency and renewables).

Lowering the cost of capital is particularly important in supporting renewable energy investment, which generally has large upfront capital costs. A stable, investment environment is a key element in lowering the cost of capital, while offering security to investors is essential. A variety of mechanisms could be relevant here, including clear procedures for competitive bidding, providing feed-in tariffs or mandatory RE targets for utilities. While India has pursued competitive bidding for large-scale RE projects, it could also be worth investigating feed-in tariffs for medium scale projects, or net-metering systems for small scale projects. A combination of sound and stable policies and financial sector innovation and reform could be very powerful in both scaling up investment and making it low-carbon.

Link to strategy for urbanisation

A strategy for climate change must be closely coordinated with the strategy for managing urbanisation in the coming decades. About 65% of India's GDP is currently produced in urban areas and this percentage is likely to increase strongly over the next two decades. The urban share of the population is also increasing sharply, and is likely to reach at least 60% by

2047, and possibly as high as 65% if the definition of urban is brought in line with international norms.

The relationship between urbanisation and climate change in India has been brought out in the 2015 ICRIER study, prepared jointly with the Global Commission on the Economy and Climate, in its work on the New Climate Economy[25]. The study focuses on the energy sector, agriculture and land use, and cities. It emphasises the importance of controlling urban sprawl, managing congestion and drastically reducing air pollution. Experience from around the world shows that it is possible and desirable to manage all three together but strong clear strategies are required. Public transport, careful city planning and control of vehicle emissions would all be central elements. These would require a step change in the quality of city administration and planning in India, which will in turn require support from states and the centre.

VII. Conclusions

The main conclusions that flow from this paper can now be summarised.

(i) It is quite clear that high growth based on BAU assumptions will produce an outcome which is not environmentally sustainable. India is very likely to achieve the targets indicated in the INDCs, but we know that even if all INDCs are implemented, the world will fall short of limiting global warming to no more than 2ºC above pre industrial levels. Hopefully, stronger action by industrialised countries, including the provision of appropriate financial and technical support, will be taken in the years ahead and this will encourage developing countries to strengthen their efforts.

(ii) The LC scenario explored in the paper suggests that India can improve the trajectory of GHG emissions very substantially. This requires taking strong action to reduce the energy intensity of GDP in many sectors and also to shift the composition of energy supply towards green sources. Although this scenario still leaves per capita emissions level in 2047 at a high level in the context of global carbon constraints, it does demonstrate that India could peak GHG emissions before the mid-century point if there is a global concerted effort to achieve ambitious goals.

(iii) Although public attention focuses heavily on green energy sources, almost 86 % of the reduction in emissions in our low-carbon scenario comes from action on the demand side to improve energy efficiency and only 14% from the supply side. This is partly because the technologies in use, and the systems we have, are much less energy efficient than is now possible. This highlights the importance of supporting the development and deployment of energy-saving technologies, encouraging behaviour change amongst consumers, and supporting and creating the systems for sustainability in grid networks, public transport, urban areas and others.

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[25] www.newclimateeconomy.report/India

(iv) Although no single policy intervention will achieve the structural changes needed to move to the low-carbon scenario, energy pricing is critical. Prices of fossil fuels should be set at levels which not only avoid subsidies, but ideally also to reflect social costs associated with fossil fuels. This will incentivise savings in the use of these fuels and encourage shift to greener energy. The revenues earned from taxes that penalize fossil fuels could be used to encourage energy-saving technologies, foster R&D on clean energy, or support the building of sustainable infrastructure programmes, and also protect the poor. Clearly, the extent to which countries will be willing to proceed with carbon taxes will depend upon global, national and local leadership. In the case of carbon pricing to reflect the impact on climate change, a global move in this direction would encourage individual countries to take similar action. Individual countries are unlikely to act in isolation for fear of becoming uncompetitive even if this fear is greatly exaggerated.

(v) Rational energy pricing can be supported by regulatory measures that can help to push towards more energy-efficient technologies and less polluting systems. Well-designed regulation, with clarity about policy in the longer term, supported by a rational approach to energy pricing and policy can make a big difference. It will create an environment which develops confidence and encourages investment.

(vi) The policy instruments that have been identified in this paper are wide ranging and do not all fall in the domain of the same level of government. Some of them fall in the domain of the central government while others are in the domain of the state government or municipal corporations. The effectiveness of policy therefore depends upon how well action can be coordinated across these different levels. This is difficult enough even within the same level of government since ministries often act as silos.

(vii) While India's GHG emissions per capita are likely to peak between 4 and 5 tCO_2e, it is possible for India to do better depending upon the technological changes that occur over this period in areas as diverse as energy technologies, biotechnology and electric vehicles. There are likely to be increasing opportunities for energy efficiency throughout the Indian economy, driving further possible GHG emissions reductions. These opportunities will need to be supported by a strong commitment politically within India, both at the central government and state government level, to transition to a more sustainable growth path. This needs to be supported by public awareness and mobilisation of opinion in favour of policies which deal effectively with the social cost of pollution arising from the burning of fossil fuels.

(viii) Many of the policy interventions needed to transition to the LC scenario are precisely the ones that have to be used if we are to make urbanisation sustainable. The rapid rate of growth of GDP assumed in both scenarios, which should be the objective of government policy, will be possible only if India's urban areas provide a congenial environment to live, work and invest. Cities where people can move, breathe and be productive require a sensible strategy for urban transport planning, urban land-use planning, provision of rational structure for housing for the expected influx into the cities, and urban building regulation for sustainability and efficiency. Paradoxically, India has the "late comers advantage" that the existing urban infrastructure is not only well below global standards, it is also below India's own expectations and much of it is expected to be replaced. It has been estimated that 70% of the commercial buildings that will be needed by 2030 have yet to be built. This provides an opportunity to leap-frog by incorporating into the new buildings the higher standards of sustainability that are now feasible.

Finally, we wish to emphasize that the elements of the transition described here are not a final blueprint for action. They are only an attempt to show that there are multiple areas in which action is possible, which taken together, could make a very big difference. However, the action required needs to be explained to the public, and a conscious effort made to build as wide a consensus as possible. Global action in these areas will help build a momentum for change as each country learns from the experience of other countries how it is possible to grow and to overcome poverty, while preserving the environment both locally and also globally.

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Appendix

Appendix 1: The India Energy Security Scenarios (IESS) Calculator

The quantitative projections presented in this paper are based on the IESS Version 2 calculator recently released into the public domain[26]. The IESS V2 is a further development of the earlier IESS Version 1, which was developed by the erstwhile Planning Commission. Version 2 has the advantage of allowing some assessments of the cost of making the transition.

The IESS is not an economic model. It does not consist of a set of equations describing the relationship between a number of inter related macroeconomic and sectoral variables, with the solution of the equations providing an internally consistent solution for all these variables. The calculator is essentially a tool that can be used to explore the implications of different levels of "effort" that can be made in selected sectors to move towards more energy efficient outcomes and make alternative assumptions about different levels of supply of alternative energy sources. These options on the demand and supply side have been derived from extensive discussions with sector experts and are fed into the calculator to see what the resulting energy pathway would look like in terms of the degree of import dependence and the level of emissions.

The first step in using the calculator is to choose an exogenous assumption about growth, based on what is independently felt to be feasible. The macro economic feasibility of this growth assumption is not tested in the calculator. The calculator only uses the growth assumption to generate some features of structural change over time, including in various dimensions, which have an impact of total energy use such as per capita passenger transport demand, per capita residential space, per capita steel use etc.

Table A shows the projected levels of these elements for the years 2032 and 2047 assuming an average growth rate of GDP of 7.4 % per year (explained in section II). These projected levels can be compared with global averages in 2011 reported in the table. The comparison reveals that India begins at levels of per capita activities, and therefore energy use, that are well below the world average and a substantial increase in energy use is therefore unavoidable.

[26] Available form: http://indiaenergy.gov.in/

Table A: Indicators Showing Growth of Major Energy Using Activities per person

Indicator	2012	2032	World Average (2011)	Change 2012-2032	2047	Change (2012-20447)
Per Capita Incomes (2012, USD) at 7.4% Growth	1,440	5,253	12,600[27]	3.6	12,583	8.7%
Urbanization	30%	42%	52%[28]	1.4	51%	1.7%
Household Occupancy (persons per household)	4.9	4.3	N.A	0.9	3.8	0.8%
Per Capita Passenger Transport Demand (pkm)	5,992	13490	8222	2.3	18420	3.1%
Per Capita Freight Transport Demand (ton-km)	1375	5270	12166	3.8	8710	6.3%
Per Capita Residential Building Space (m2)	10.8	22.8	28.4	2.1	32.9	3.0%
Per Capita Commercial Building Space (m2)	0.6	1.9	9.25	3.2	5.9	9.8%
Per Capita Cement Use (Kg)	190	407	520	2.1	611	3.2%
Per Capita Steel Use (kg)	66	253	260	3.8	384	5.8%
Car Ownership (per 1000 population)	9	41	121	4.5	70	7.8%

The expansion in energy-using activities indicated in Table A is combined with projected energy requirements per unit that correspond with our BAU scenario and are summarised in Table B.

Table B: Improvement in Energy Efficiency[29]

	Units	2012	2032	2047	CAGR
Passenger Transport	kgoe/1000-pkm	6.7	8.1	8.9	0.7%
Freight Transport	kgoe/1000-tkm	18.4	15.6	14.1	-0.8%
Industry-Steel	kgoe/ton of Steel	636.1	583.4	551	-0.4%
Industry-cement	kgoe/ton of Cement	87.0	78.6	75	-0.4%
Residential Buildings	kgoe/m^2	1.2	2.1	2.2	2%
Commercial Buildings	kgoe/m^2	10.7	8	6.6	-1.3%

Note: pkm represents passenger-kilometer; tkm represents tonne-kilometre; kgoe represents kilograms of oil equivalent.

These projections incorporate some improvements in energy efficiency. However, it is worth noting that whereas energy use per unit declines in 4 of the 6 activities listed in Table B

27 http://www.indexmundi.com/world/gdp_per_capita_(ppp).html

28 http://tool.globalcalculator.org/gc-lever-description-v23.html?id=2/en

29 Specific energy consumption (SEC) numbers cannot be derived for telecom, cooking and agriculture as the methodology followed in those cases is a top down modelling approach. However, some energy efficiency improvements in those sectors have been built into the projections as assumptions.

above, it increases in the case of passenger transport and also residential buildings. This is because of the changing structure within each of these categories. In the case of passenger transport, there is a marginal shift in favour of rail, which is more energy efficient, but this is more than offset by the growth of private cars from 14% of total passenger-kilometres demanded in 2012 to 19% in 2047. In the case of residential buildings, the sharp increase expected in air-conditioning penetration is expected to swamp the restraining impact of greater energy efficiency of air-conditioning units and other home appliances. The situation is quite different in the case of commercial buildings where energy efficiency per unit is expected to improve because of penetration of high efficiency HVAC systems and changes in materials, techniques and technology for energy management.

Based on these structural changes, the calculator generates a total demand for energy from eight different energy-using sectors: passenger transport, freight transport, residential buildings, commercial buildings, industry, agriculture, telecommunications and cooking. In each of these sectors, the calculator provide four alternative choices reflecting greater or less effort at achieving energy efficiency. The different levels of effort are pre-determined in the calculator and the user can choose the level of effort in each case, ranging from level 1 (less effort) to level 4 (most effort). We have adopted level 1 for Transport and level 2 for other demand sectors as representing the BAU scenario. We have adopted level 4 on the demand side in all sectors to represent the LC scenario. On the supply side, we have assumed levels 2 for BAU, and levels 3 for Solar PV and 4 for bio-energy under the LC scenario. Coal supply goes to level 2.

An important improvement in the more recent IESS V.2, over the earlier IESS V.1, is that the web tool indicates the cost of moving from one level to another in terms of the total investment needed as a percentage of GDP. We have adopted these costs for the purpose of our analysis.

Appendix 2: Areas of Action and Policy Interventions for a Low-Carbon Alternative

	Area of Intervention	Policy Interventions	Level of Government
A.	**Energy Efficiency in Buildings**	1. Mandatory Energy Efficient Building Design 2. Implementing Energy Efficiency in New Buildings and Retrofits in old buildings 3. Pricing of electricity to reflect costs and incentivize savings. 4. Setting mandatory energy efficiency standards for energy appliances. 5. Encouraging rooftop SPV connections which can feedback into the grid. 6. Introducing time of use electric metering to incentivize energy savings in peak hours. 7. Tax Incentives for expenditure on retrofits and for installation of rooftop SPV. 8. Financial incentives for manufacturers of Energy Efficient Appliances. 9. Provision of more testing and certification labs for standard with relevant technology upgrades and capacity building.	City & State Government. Central and State Government. Central Govt for pricing of coal and State Electricity Commission for pricing of electricity. Central Government. State Electricity Distribution Companies. State Electricity Regulatory Commissions. Central Government. Central Government Central Government.

	Area of Intervention	Policy Interventions	Level of Government
B.	**Sustainable Urban Transport Solutions**	1. Sensible Land Use Planning in Cities 2. Urban property laws (sale and rental) which facilitate mobility 3. Ensuring provision of reliable and good quality bus 4. Provision of metros in large cities 5. Rational planning of roads with features such as BRT, footpaths, cycle-ways, etc. 6. Institution of disincentive parking charges in congested areas to discourage parking of private Vehicles. 7. Differential taxation on buses and cars to incentivize public transport. 8. Imposition of "Congestion Charges" to allow private vehicle in congested areas. 9. Improved fuel efficiency standards 10. Maintaining fuel price differentials which discourage private transport, i.e., petrol prices higher than diesel prices with a high tax ab initio on diesel powered cars. 11. Incentivizing electric vehicles and hybrid vehicles through differential taxation and preferential depreciation rates. 12. Increasing last mile connectivity of public transport through feeder buses, in economically backward areas to prevent concentration of slums near urban cores. 13. Introduction of smart transport infrastructure and smart traffic management to facilitate scale up of smart electric vehicles /driverless cars in future. 14. Support for IT ecosystem/Entrepreneurship for smart transport management and car sharing.	City Planning Authorities Central & State Govt. City Government & Road transport corporations. City Corporations City Government City Government State & Central Government City Government Central Government Central Government Central Government City Transport Corporations City Government and Central Government Central Government.
C	**Sustainable Freight Transport Solutions**	1. Dedicated Freight Corridors and Integrated Logistic Planning. 2. Shifting freight to Rail. 3. Tariff Rationalisation in Rail based Freight 4. Fuel efficiency standards in Trucks 5. Efficiency in Railways wagons with higher axle loads and increased speeds. 6. Privatisation of Rail Freight	Central Government Central Government Central Government Central Government Central Government Central Government

	Area of Intervention	Policy Interventions	Level of Government
D.	**Efficiency interventions in Industry**	1. Rationalization of fossil fuel pricing in the long term. 2. Pricing of carbon, water and health externalities on the Industrial products 3. Availability of 24x7 quality grid electricity for Industry to facilitate switch from coal based captive generation. 4. Setting up of more aggressive PAT targets for increasing energy efficiency 5. Facilitation of transfer of low-carbon and energy efficiency technologies for steel and cement from Annex-1 to Annex 2 countries 6. Creation and augmentation of ecosystem of recycling and reuse of finished products	Central Government. Central Government Central Government & State Electricity Distribution companies. Central Government. Central Government. Central Government.
E.	**Minimizing Energy Use in Cooking and penetration of clean fuels**	1. Availability of Piped Natural Gas Infrastructure in tier-2 and tier-3 cities. 2. Availability of a robust LPG distribution infrastructure in rural areas 3. R&D Support and market incentives for usage of Clean Biomass Cook stoves 4. State of the art testing, monitoring and certification centers for cook-stoves in India	Central Government Central Government Central Government Central Government
F.	**Energy Efficiency in Agriculture**	1. Availability of 24x7 metered and quality of grid electricity in Rural Areas. 2. Segregation of feeders from agriculture/ domestic consumption. 3. Financial incentives for the purchase of Solar based irrigation pumps. 4. Fast track support for rain-fed irrigation areas through techniques such as watershed management program to minimize water use and consequently energy use. 5. Support for Micro-irrigation programs to minimize water and energy use.	State Government and central government. State Government and central government. State Government, Nodal Agencies of the MNRE. Ministry of Water Resources.
G.	**Increasing RE Penetration in electricity generation in the Grid to 45% (Solar 401 GW, Wind 290 GW)**	1. Priority sector lending status for RE 2. Financial Incentives-Interest Rate Subsidies, Low Cost International Loans. 3. Mandatory adherence for RPO and Solar RPO targets by states. 4. Financial and Regulatory support for Balance of System (BOS) manufacturers. 5. Provision of Net Metering and Solar Buy back tariff policy for Solar Rooftop by States. 6. Pricing of externalities on fossil fuels.	Central Government. Central Government. State Government. Central & State Government. State Government & City Authorities. Central & State Government

	Area of Intervention	Policy Interventions	Level of Government
H.	**Increasing Bio Energy in transport to 15%**	1. Financial support for research and development of second generation and advanced bio-fuel feedstock. 2. Long term blending policy and emissions standards. 3. Long term pricing policy for Bio-fuels	Department of Science and Technology/ Agriculture. Ministry of Road Transport. Ministry of Petroleum.
I.	**Reducing T&D losses to 7.2% by 2047**	1. Upgradation of sub-transmission/distribution grid infrastructure and digitization of substations. 2. Advanced metering Infrastructure (AMI) deployment by utilities. 3. Deployment of HVDC lines for long distance transmission.	State Utilities/Central Govt. State Utilities Ministry of Power
J.	**Deployment of Energy Storage**	1. Time of Day pricing of grid based electricity. 2. Net Metering Support for Domestic Consumers. 3. Support for localization for storage.	Ministry of Power/State Govt. State Government. Central Government.

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