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Quality of life for all: A sustainable development framework for India's climate policy reduces greenhouse gas emissions

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A R T I C L E I N F O

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A B S T R A C T

This study placed improving quality of life at the centre of India's national climate policy and asked what happens to greenhouse gas emissions with such an approach. In the lead up to the Paris climate agreement in 2015, countries determined their contributions based on their priorities, contexts, and capabilities and prepared their Intended Nationally Determined Contributions. Following the agreement, these became each country's Nationally Determined Contribution (NDC). Using bottom-up scenario analyses, the sectoral interventions modelled in this research demonstrate that it is possible to get close to achieving the country's NDC targets while improving quality of life at the same time. A comparison of a Business-As-Usual (BAU) and a sustainable development (SD) pathway leading up to 2030 reveals that improvements in a range of sustainable development conditions are possible. These include reduction in air pollution, savings in water and land use, and savings in materials and resource requirements. These changes occur along with a nearly 30% reduction of greenhouse gas emissions and a 25% reduction in primary energy compared with BAU. Emissions intensity in 2030 is reduced in the sustainable development pathway by 16% compared with that in 2012 and fossil-free sources are able to contribute to about a third of India's electricity.

Introduction

Development pathways and policies have direct implications for Greenhouse Gas (GHG) emissions and the ability to adapt to climate change impacts (Nakicenovic and Swart, 2000). Furthermore, major policy decisions and large-scale investments in the near term can foreclose options for the future by causing institutional as well as technological lock-in (Foxon, 2008). Still, development strategy and climate change mitigation sometimes appear to be at cross-purposes and have often been placed in different silos in research and policy circles. Nevertheless, there has also been an important strand of analysis focussing on the linkages between the two (Cohen et al., 1998; Robinson and Herbert, 2001; Winkler et al., 2002; Swart et al., 2003). In fact, at least since the Third Assessment Report of the IPCC (Intergovernmental Panel on Climate Change), the global scientific community has recommended a Sustainable Development (SD) framework as an effective strategy for addressing mitigation (Banuri et al., 2001). Furthermore, a SD framework could offer opportunities to pursue a climate policy that is attractive to stakeholders in different sectors (Robinson and Herbert, 2001; Robinson et al., 2006).

India has been an active player in multilateral negotiations on climate change. Being a large developing country with low per capita emissions, the country's emphasis for over two decades, especially in international climate forums, has been on the need for developing countries to have sufficient carbon space and the importance of reducing GHG emissions by Annex-1 (industrialised) countries (Dubash, 2011). India's domestic priorities have been to meet the basic needs of the population and provide energy services. There is also an urgent requirement to improve living conditions for the substantial population that lives in poverty. In India's Intended Nationally Determined Contribution, it is noted that the country "houses the largest proportion of global poor (30%), around 24% of the global population without access to electricity (304 million), about 30% of the global population relying on solid biomass for cooking and 92 million without access to safe drinking water" (Ministry of Environment Forest and Climate Change (MoEFCC), 2015).

The Fifth Assessment Report of the IPCC highlights the strong interlinkages between building mitigative and adaptive capacity and equitable and sustainable development. It is likely, therefore, that a SD

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Table 1
Interventions made in different sectors under the BAU and SD scenarios.

Interventions	BAU	Sustainable scenario
Agriculture		
Increase area under micro-irrigation schemes	Area under micro-irrigation increases from 1.5% of gross cropped area (~3 Mha) in 2012 to 6% (~13 Mha)	13% (~29 Mha) of gross cropped area under micro-irrigation
Water saving techniques for wheat and rice cultivation	Applied on 10% (~9 Mha) of gross cropped area of wheat and rice	Applied on 20% (~17 Mha) of gross cropped area of wheat and rice
Supplementing fertilisers with bio-fertilisers	10% (~3 Mt) of chemical fertiliser use supplemented	15% (~5 Mt) of chemical fertiliser use supplemented
Organic farming	Area certified as organic increases from 4% (~5 Mha) of total net cropped area in 2012 to 10% (~15 Mha)	20% of total net cropped area (~30 Mha) certified as organic
Tractor efficiency improvement from 2012	11% improvement in fuel efficiency from 4.5 l/h in 2012 to 4.0 l/h	18% improvement in fuel efficiency to 3.7 l/h
Increase in deployment of solar pumps, reduction in diesel pumps	5% penetration of solar pumping	15% penetration
Improvement in efficiency of pumps	10–15% improvement in input requirement of electric and diesel pumps	25–30% improvement in input requirement of electric and diesel pumps
Buildings		
Improvement in lighting efficiency	Residential: 30% LED penetration in point and linear lighting Commercial: 30% penetration of LEDs, 50% penetration of high-efficiency CFLs	Residential: 80% penetration of LEDs in point and 70% in linear lighting Commercial: 60% penetration of LEDs, 35% penetration of high-efficiency CFLs
Improvement in appliance efficiency	Residential: 5–20% penetration of highly efficient appliances Commercial: 30% penetration of highly efficient appliances	Residential: 50–60% penetration of highly efficient appliances Commercial: 60% penetration of highly efficient appliances
Improvement in building design and equipment controls	Up to 30% penetration over different types of urban residential buildings 10–20% penetration over commercial FSA	Up to 60% penetration over different types of urban residential buildings 40% penetration over commercial FSA
Setting Air Conditioner (AC) thermostat temperature higher by 2%	Not applied	13% savings in energy consumption of ACs
Solar Water Heating (SWH)	16 million m^2 of residential and 4 million m^2 of commercial FSA under SWH	48 million m^2 of residential and 12 million m^2 of commercial FSA under SWH
Using low-Global Warming Potential (GWP) coolants in refrigerators and ACs	85% penetration of R410-A in ACs 70% penetration of HFC- 134A in Refrigerators	35% penetration of R-32 and 23% penetration of R-290 33% penetration of HFC-600A
Increasing the FAR of Buildings	45% penetration of High-Rise Residential buildings (FAR-7)	60% penetration of High-Rise Buildings
Affordable Housing	Affordable Housing Gap met by 2030	Affordable Housing Gap met by 2022
Rainwater Harvesting (RWH)	10% of residential and 15% of commercial rooftop area utilised for RWH	25% of residential and 40% of commercial rooftop area utilised for RWH
Residential: Cooking		
Transition to ICS	25% of rural and 5% of urban households use ICS (58 million households)	36% of rural and no urban households use ICS (73 million households)
Improve PNG infrastructure with focus on domestic supply	23% (33 million) of urban households use PNG	35% (50 million) of urban households use PNG
Biogas plant implementation	4% (8 million) of rural households using biogas	8% (16 million) of rural households using biogas
Increased use of electric cooking access due to improved electricity access	2% of rural and 2% of urban households use electricity for cooking (7 million households)	6% of rural and 5% of urban households use electricity for cooking (19 million households)
Improve reach of LPG to rural areas	25% (51 million) of rural households use LPG as a primary cooking fuel	50% (101 million) of rural households use LPG as a primary cooking fuel
Industries		
Improving energy efficiency of industries	5–8% reduction in Specific Energy Consumption (SEC)	10–25% reduction in SEC
Process switching	Steel – Increase in Gas DRI (9%–12%) and COREX process (10%–12%) Aluminium – Shift to Pre-baked method (70%–75%) Fertilisers – Shift to Natural Gas Feedstock (80%)	Steel – Increase in Gas DRI (9%–12%) and COREX process (10%–14%) Aluminium – Shift to Scrap (20%–40%) Fertilisers – Shift to Natural Gas Feedstock (100%)
Higher recycling/use of scrap	15% scrap use in steel 20% scrap use in aluminium 43% recycled fibre use in paper 80% share of blended cement	33% scrap use in steel 40% scrap use in aluminium 65% recycled fibre use in paper 92% share of blended cement
Industrial wastewater treatment	Increasing secondary and tertiary treatment by 14% 10% methane recovery	Doubling secondary and tertiary treatment over 2012 30% methane recovery
Transport: Passenger (urban)		
(a) Shift to NMT (walking and cycling)	Reduction in NMT share from 30% in 2012 to 10% in 2030	Maintaining the share of NMT at 30% in 2030
(b) Development of compact cities	No compact city intervention, city sprawl trend continues	Compact city intervention reduces trip length by 20%
Increase in public transport share	Share reduces from the current 46% (road: 44%, rail: 2%) to about 33% (road: 29%, rail: 4%)	Public transport ~67% share (road: 61%, rail: 6%)
Promoting clean technologies [electric vehicles (EVs)]	Negligible EVs in 2012 to 2% of cars, 9% of 2 W and 3% of buses in 2030	4% of cars, 15% of 2 W and 5% of buses in 2030
Transport: Passenger (Non-urban)		
Increase the share of rail-based transport	Current shares (road: 83%, rail: 16%, air: 1%) change in BAU to road, 81%; rail, 18%; air, 1%	Increase in 2030 to 75% road share, 22% rail and 2% air
Increased public transport	Current bus share of 74% reduces to 62% in passenger kilometres travelled	About 71% share of buses in passenger kilometres travelled
Transport: Freight		
Increasing the share of freight transport by railways	61% road and 39% rail by 2030	50% rail and 50% road by 2030

(continued on next page)

Table 1 (*continued*)

Interventions	BAU	Sustainable scenario
Electricity Supply		
Reduce air emissions (SO_x, NO_x, $PM_{2.5}$)	No restrictions on air pollution	SO_2 & $PM_{2.5}$ emissions restricted to 40% of BAU
Reduce water use in thermal plants through (a) closed cooling and (b) fuel mix change	No restrictions or water standards	Reduce water use in power sector by 40% of BAU
Import dependence	Domestic Coal Mining Capacity at 1500 MTPA	Domestic Coal Mining Capacity at 1500 MTPA
Increase in access to electricity	75% of household access to electric lighting in rural areas in 2030	100% access to lighting in rural areas

approach will not only serve to reduce the rate of emissions growth, but could potentially also enable coping strategies for improving climate resilience (Fleurbaey et al., 2014). This is critical given that South Asia is expected to experience severe impacts from climate change, and India, with its large population, diverse ecological zones and long coastline, is especially vulnerable (IPCC, 2014a). Adverse effects are anticipated through changing patterns of the monsoons, heat waves, droughts, floods and rising seas (Ministry of Environment and Forest, 2012). All these impacts in turn adversely affect various sectors including agriculture, economic development, water resources and livelihoods. Improvements to the living conditions of millions of Indians require investments in development programmes and infrastructure in various segments of the economy including energy and industry. The accompanying rise in incomes and lifestyle patterns will likely lead to an increase in GHG emissions in the absence of mitigating measures.

While India's per capita GHG emissions are less than 2 tonnes (CO_2eq) and well below average global values, the country needs to develop along a low-carbon pathway owing to the challenge of a limited carbon budget and the need to peak global emissions within the next few years (IPCC, 2014b). Moreover, India is a party to the international agreement on achieving Sustainable Development Goals (SDGs), which means sustainability will have to be mainstreamed into its development and climate policies.

It is within this larger context of climate change and SD, the well-recognised linkages between them and the development challenges that India faces that the researchers in this study decided to use a different approach — one that places sustainable development and quality of life at the centre of India's climate strategy. In adopting such a framework, we have initiated early steps broadly similar to the Sustainable Development Policies and Measures (SD-PAMs) approach for India and are asking what the implications of a SD agenda would be for GHG emissions (Winkler et al., 2002). In a significant departure from conventional SD-PAMs studies, we have also paid special attention to providing access to modern energy services, implying an increase in emissions in some sectors, to the vast numbers of people in India who are currently deprived.

India has poor quality of life indicators and it is in the country's interest to improve them (World Bank, 2016). Most previous studies on India's climate policy primarily concentrated on reducing energy and emissions intensities across sectors without placing quality of life at the centre of the analysis (The World Bank, 2011; Das et al., 2013; Parikh et al., 2014b). These studies generally estimate the development benefits or co-benefits from mitigation action. Similar to studies carried out by Shukla et al., 2008 and Shukla and Chaturvedi, 2013, this research flips the question, by placing SD at the centre of India's climate strategy and asks what should be done to reduce air pollution, improve freshwater availability, enhance energy services, promote efficiency in resource-use, provide cleaner cooking fuels and facilitate food security. Second, when such an approach is adopted, with affordable low-emissions technology choices, what does it do for the country's GHG emissions and energy intensity?

We identified critical conditions that were required for improving quality of life such as clean air, freshwater, food security and access to clean cooking fuels. Specific interventions were identified in the six main energy-related sectors that were studied.

Under these circumstances, involving multiple domestic and international pressures, in order to transition over the long term to a low-carbon inclusive pathway, India may find it useful to begin with a few SD objectives and examine the linkages and potential for reducing GHG emissions in a SD framework. If this preliminary approach shows promise, a future transition to development paths that are more stringent in their emissions could be considered (Winkler et al., 2002).

Methodology

The research conducted examined two scenarios for India's development leading up to 2030: Business-As-Usual (BAU) and SD or quality of life scenario. Since India and many other countries set 2030 as the target year for their intended nationally determined contributions, this study selected 2030 as the end year of its scenarios. The base year used in this study was 2012, which is the latest year for which revised official statistics were available to calibrate the energy balance when the study was carried out. Two scenarios leading up to 2030 were examined.

The BAU scenario assumes that government schemes and policies for different sectors (described in the Supplementary materials) will be continued. These are, however, not explicitly focused on SD. Moreover, the scenario acknowledges that some targets have been missed in the past, especially the ones on access to basic services and those that improve quality of life owing to a variety of reasons. Gestation lags are also seen in a variety of progressive schemes on Renewable Energy (RE) and energy efficiency, where the expected returns are lower owing to technological, regulatory, political and behavioural factors involved. The BAU scenario has been constructed with these aspects in mind.

The SD scenario considers some of these targets, especially the ones on equity and access, as realisable. Achieving these targets has implications for the energy system as a whole. Moreover, there are aspects of resource-use (raw materials, water, land, etc.) and pollution that have a more direct and immediate bearing on the quality of life of citizens, as opposed to GHG emissions. Therefore, the SD scenario is designed to bring all these dynamics into perspective and provide insights for GHG implications for the NDCs. The SD scenario, in addition, is explicit about making interventions in various energy-related sectors to improve quality of life and, on the whole, reduce the harmful effects on ecosystems, humans and biodiversity.

The study therefore concentrated on specific key social, environmental and economic dimensions of sustainability and examined six main energy-related sectors for India from 2012 until 2030. The sustainability indicators considered included savings in water, reduction of air pollution and recycling materials for efficient use of material resources. Table 1 lists the interventions made in different sectors under the BAU and SD scenarios.

In order to transition to a SD pathway, key sustainability challenges need to be managed by identifying specific drivers (macroeconomic factors determining growth in demand of goods and services), pressures (key sustainability challenges in the sector and the associated sustainability indicators) and the responses (interventions that reduce the pressure of the indicators). (See Fig. 1).

The TIMES (The Integrated MARKAL EFOM System) is a cost-optimisation modelling platform developed to compute dynamic partial

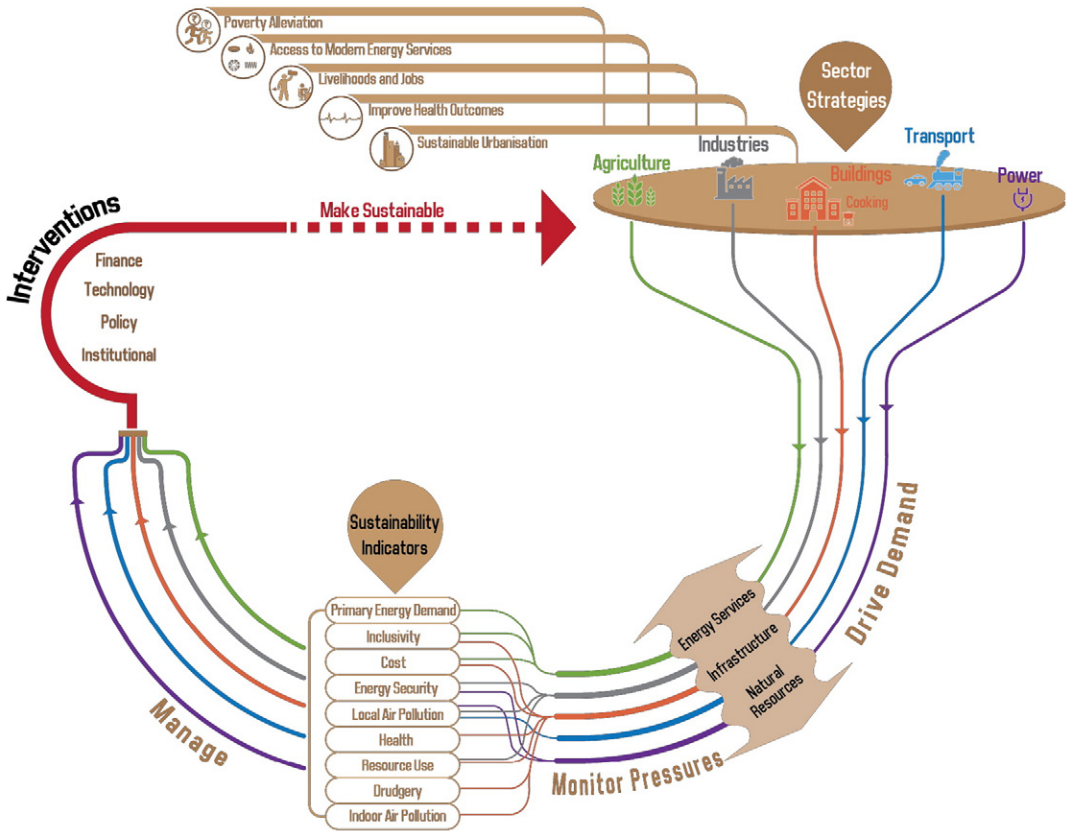

Fig. 1. Approach to the research.

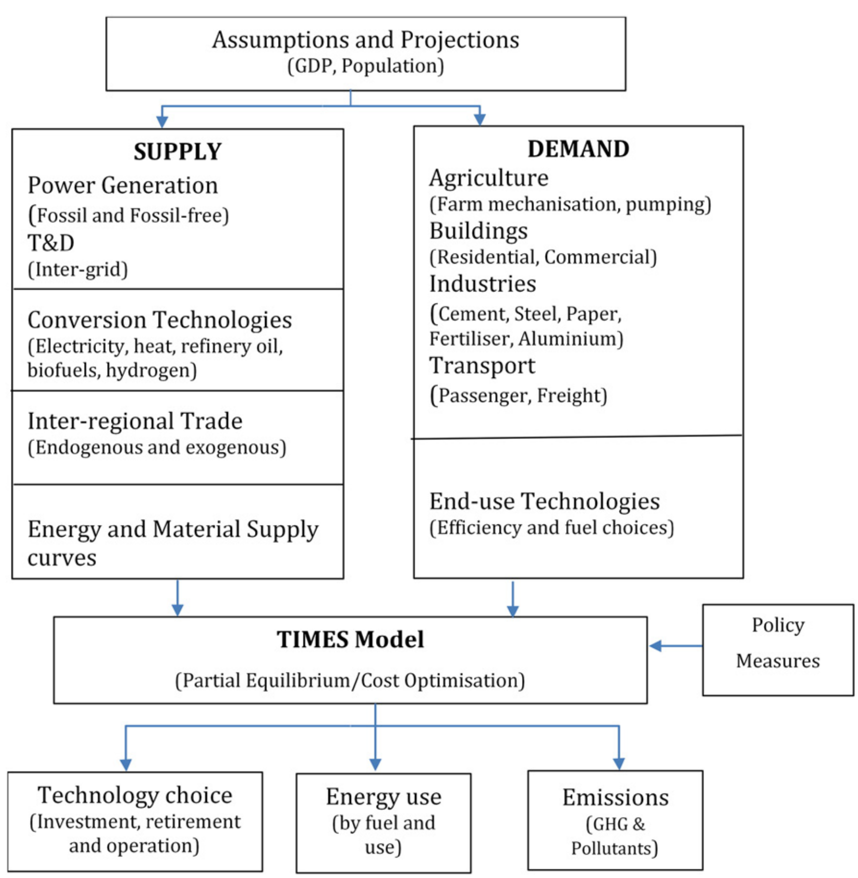

Fig. 2. Representation of the IMRT model architecture.

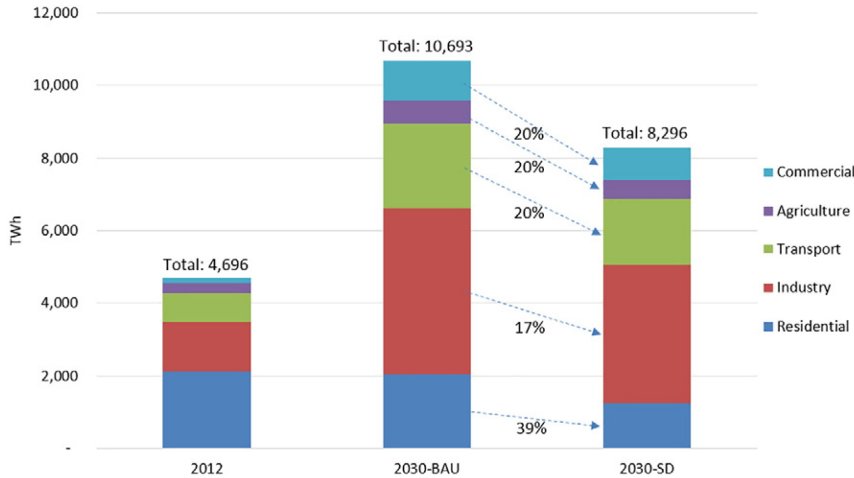

Fig. 3. Final energy demand in the BAU and SD scenarios.

equilibrium on the energy-environment system. Several combinations of technology and policy options can be examined under least cost optimisation with granular behavioural rules and constraints (Loulou et al., 2005). This approach allows us to analyse the systemic and environmental implications of India's development aspirations under a consistent framework, drawing out the inter-sectoral consequences of specific interventions. Structurally, it consists of primary energy supply curves, energy transformation sector (refineries, hydrogen etc.), power sector (supply) to ensure sustained provision of electricity to end-users, and end-use demands from four key sectors - agriculture, buildings, industries and transport (Kypreos et al., 2008; Labriet et al., 2012; Amorim et al., 2014).

The India Multi Regional TIMES model (IMRT) presented in this study is distinctive in taking a hybrid approach, where the power sector is formulated as an optimization model while the end-use sectors follow an accounting framework. Fig. 2 represents the modelling architecture for the India Multi-Region TIMES (IMRT) model. The power sector is based on detailed plant level operational data published by Central Electricity Authority (CEA), installed capacities for both existing and proposed units and inter-state electricity transmission data from Power System Operation Corporation Limited (POSOCO). Spatio-temporal location-specific data are also embedded into the model, in addition to a 72-slice load curve based on hourly data, to establish transmission and distribution linkages within the system. Furthermore, renewable energy resources (solar, wind and biomass) are characterised and mapped using endogenous inter-grid exchange data, exogenous fuel prices, solar and wind resource assessment.

All the end-use demands from agriculture, buildings, industries and transport sector are modelled using IESS methodology that considers four trajectories of energy requirement. This approach generates four detailed demand scenarios (least, determined, aggressive and heroic) defined by IESS.[1] Other resources such as land, water and material use were considered in respective sectors using definitive trends from literature and informed assumptions from experts. We believe that an accounting approach is more suitable for end-use sectors in developing countries like India, where many economic agents are unable to make energy choices based on cost optimization. Using an optimization approach will need intricate constraints on the system, especially in the short and medium term.

The BAU scenario was calibrated with IESS' Level 2 (Determined Effort) and Level 3 (Aggressive Effort) based on historical achievement in various sectors and consultations with a number of experts and policy practitioners as regards the likely policy-as-usual trajectory for India.

In the SD scenario, we have not explicitly modelled affordability in terms of its run-through effects on the energy economy. Early penetration of electricity and access to modern cooking services and public transport have been exogenously assumed. On the other hand, solar and wind targets were not exogenously plugged into the model. Instead, the coal power capacity was capped based on the stated targets on coal production. In addition, all the relevant cost curves for each resource used in generation were employed to estimate the likely achievement period of 'grid-parity'. This approach allowed the model to choose dynamically from various fossil-free alternatives such as solar, wind, biomass, nuclear and hydro.

The scenarios are designed by taking into account a 6.5% projected annual growth rate of the economy until 2030.[2] The population for 2030 is assumed to be 1476 million.[3]

The data and assumptions used for this study for each of the sectors were obtained from various published materials, and through consultations with, government bodies and other public and private institutions. These are provided in greater detail in the Supplementary Material.

Results

Energy demand and supply

The total final energy demand in 2012 was 4696 TWh, of which the residential sector contributed 45% followed by industry at 29%. Fig. 3 shows that in BAU (2030), the demand is likely to more than double to 10,693 TWh, with the industry share reaching 43% due to robust manufacturing sector growth. Residential demand reduces on account of provisions for cleaner cooking fuels and technologies with improved efficiencies. The commercial sector grows at 12% mainly due to high growth in floor space and high penetration of air conditioners.

The SD scenario demonstrates that over 22% of the BAU energy demand can be avoided through various interventions (refer Table 1) across sectors. The energy demand therefore grows in a manner that significantly alleviates pressures on the energy sector. Most sectors

[1] This framework builds on the Indian Energy Security Scenarios (IESS) 2047, an energy pathways calculator developed by NITI (National Institute for Transforming India) Aayog. The inputs to IESS 2047 were provided by a number of leading think-tank institutions (including CSTEP) and verified by ministries and official sources.

[2] The Expert Group Report on Low Carbon Inclusive Growth (Parikh et al., 2014a) estimated 7.03% and 6.87% CAGR between 2007 and 2030 in a baseline and a low-carbon scenario, respectively, using a multi-sectoral, dynamic optimisation macroeconomic model. We adjust the base year for constant prices to the (then) official base year (2004–05) and the growth horizon to 2012–30. The result (~6.5% growth rate) compares well with international studies(International Energy Agency, 2011).

[3] With a decadal population growth rate of 17.6%, India is expected to overtake China as the most populous country by 2030 and will support nearly 18% of the world population (General, 2012).

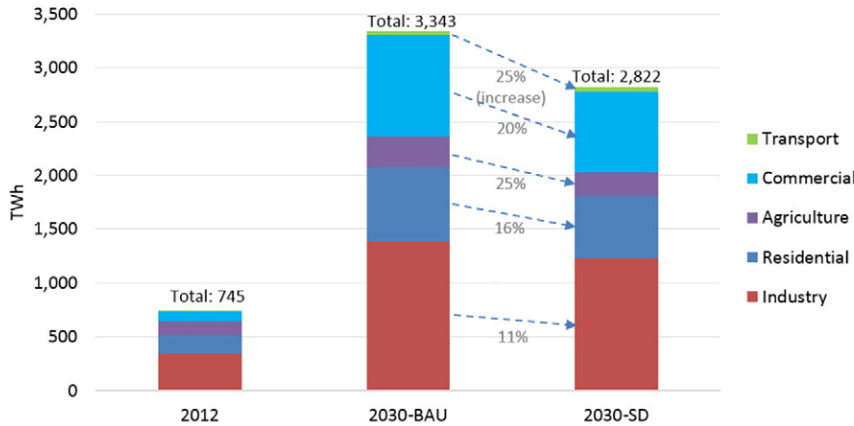

Fig. 4. Electricity demand in the BAU and SD scenarios.

decrease their demand by about 20%, except the residential sector where aggressive penetration of modern cooking technologies and efficient appliances leads to about a 40% reduction in energy demand.

Fig. 4 shows that the electricity demand grows from 745 TWh in 2012 to 3343 TWh in 2030 in the BAU scenario (at 9% CAGR). Industry remains the chief consumer of electricity in 2030 in both scenarios.

In the BAU scenario, Total Primary Energy Supply (TPES) grows almost three-fold from 6355 TWh in 2012 to 17,538 TWh in 2030 (6% CAGR) (see Fig. 5). The share of coal supplying this energy increases from 39% in 2012 to 62% in 2030. Based on the Indian government's announcements (Buckley, 2015), 1500 MTPA of domestic coal mining capacity is assumed as being achieved by 2030.

The BAU scenario has a 7% share of fossil-free 'clean' energy, which includes nuclear, hydro, wind, solar and biomass used for electricity generation, but excludes non-commercial biomass. Households procure a significant portion of biomass for cooking and heating applications, but this is not considered clean energy due to its deleterious effects on health. In the SD scenario, however, TPES reduces by 4343 TWh (25%) compared with BAU owing to increased efficiency in energy use and electricity T&D. The shift towards RE across the agriculture, industry and electricity sectors results in the share of fossil-free energy doubling to 14% compared with that in BAU.

Fig. 6. shows that the net electricity generation will need to grow over four times to accommodate the growing electricity demand in the BAU scenario. Reliance on coal-based electricity will increase from 70% in 2012 to 80% by 2030, despite the doubling of the share of renewables in the mix.

Electricity generation (Fig. 6.) requirements reduce by 893 TWh (27%) in the SD scenario. Fig. 4 shows that 521 TWh of this reduction is on account of demand management. In the SD scenario, about 100 TWh of electricity is imported from neighbouring countries. The remaining 272 TWh savings is due to aggressive T&D loss reductions across the country. This study finds that in the case of India, coal remains the primary source of supply. Yet its contribution to the fuel mix can be reduced to 66% of the net generation in the SD scenario (Fig. 6).

Almost a third of the electricity is supplied by fossil-free sources and renewables contribute significantly (15%) to electricity supply. Fig. 7 provides the implications of the electricity generation scenarios on the installed capacity, which will need to increase from 251 GW in 2012 to 819 GW in 2030 in the BAU scenario. Renewables will

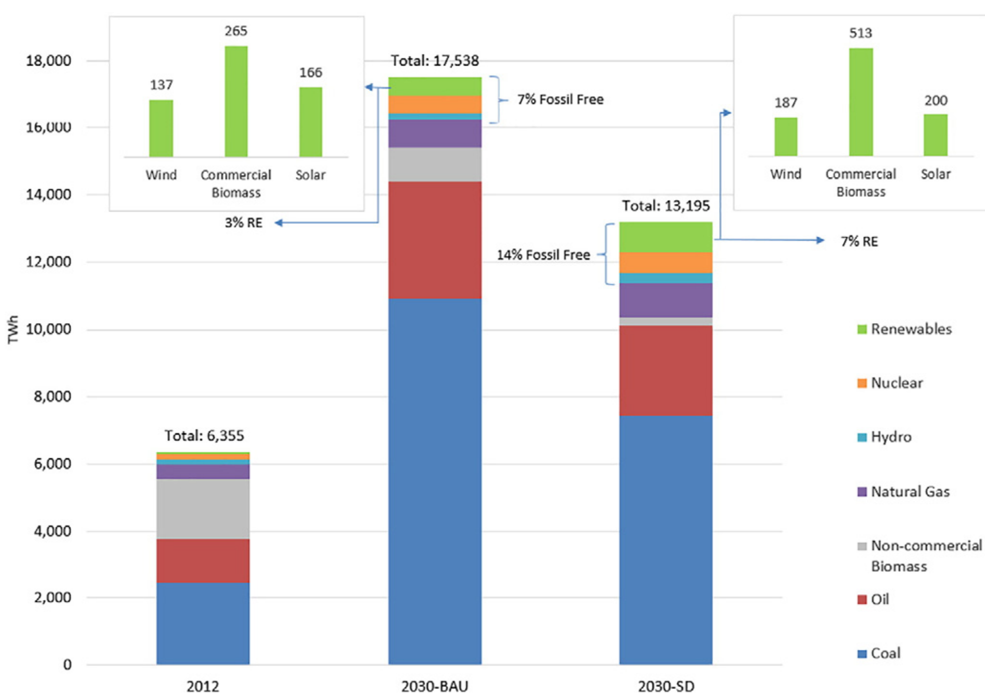

Fig. 5. Total primary energy supply in the BAU and SD scenarios.

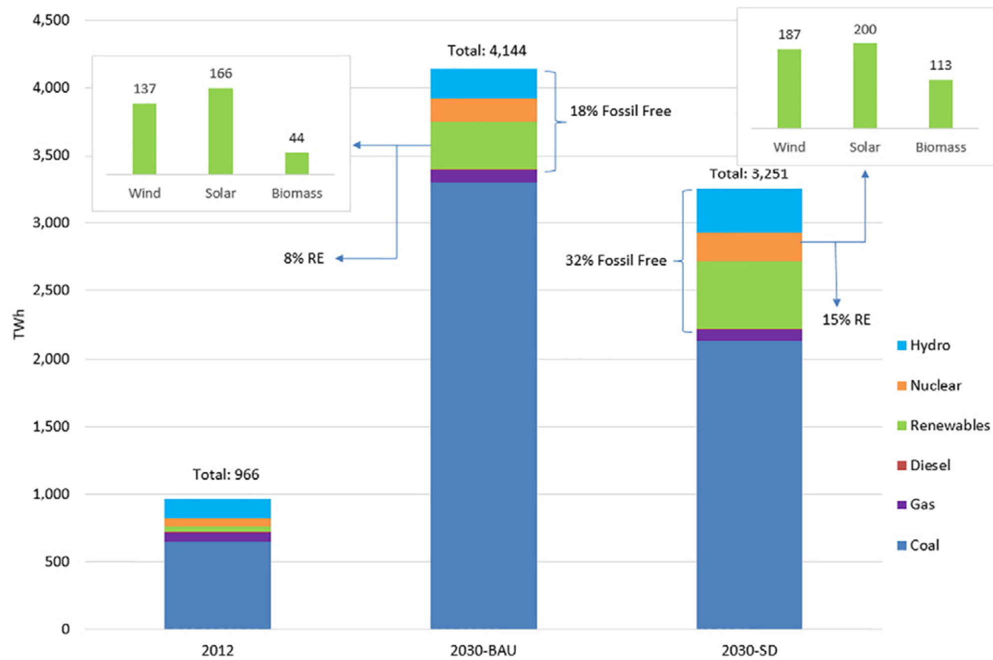

Fig. 6. Fuel-wise electricity generation in the BAU and SD scenarios.

contribute 180 GW in BAU. In the SD scenario, the installed capacity reduces by 25 GW; most notably, 112 GW of coal capacity is avoided. In contrast, the installed capacity of renewables increases by 61 GW in this scenario.

Import dependence

Fig. 8 provides the fossil fuels imported in 2012, and in 2030 in the BAU and SD scenarios. Coal imports increase by 6.5 times, oil by 1.5 times and gas imports double by 2030 in the BAU scenario. Securing supplies of fossil fuels amidst competing demand from other nations, price volatilities and geopolitical uncertainties will prove to be key challenges going forward.

Coal imports reduce by 40% and oil by 24%, but gas imports increase by 58% in the SD scenario compared with BAU. The reduction in coal and oil can primarily be attributed to reduced coal- based electricity generation; modal shift and compact city interventions (that reduce the share of motorised demand and average trip lengths in passenger transport); and a shift to rail-based freight movement, including process shifts, improved energy efficiency and alternate raw material use in industries. The increase in natural gas may be attributed to meeting clean cooking demands, a shift to entirely gas-based nitrogenous fertiliser production, increased gas-based production of sponge iron and enhanced CNG use in transport.

It is necessary to improve natural gas availability commensurately for the applications mentioned above, especially given the investments proposed in providing for the distribution infrastructure that is required for natural gas.

Air pollution

Ambient air pollution has been identified in both the scenarios from the combustion of fossil fuels in the industry, transport and electricity generation sectors. The pollution is estimated as annual loads of

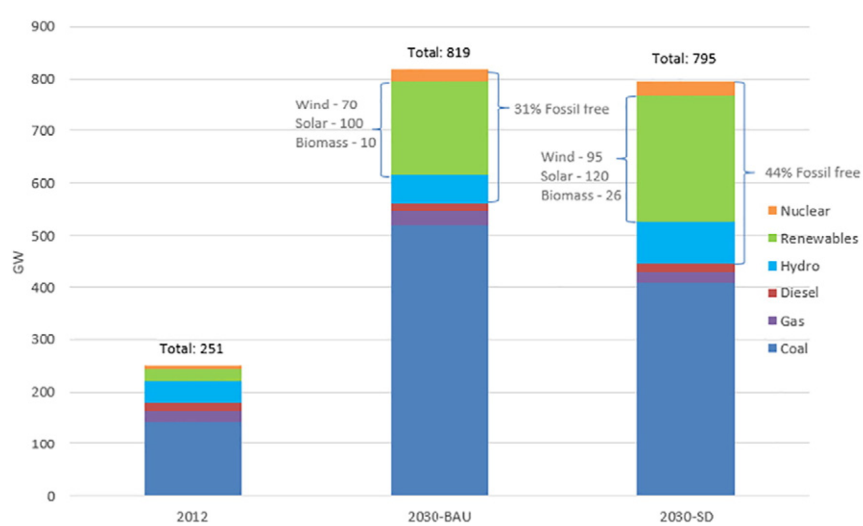

Fig. 7. Installed capacity in the BAU and SD scenarios.

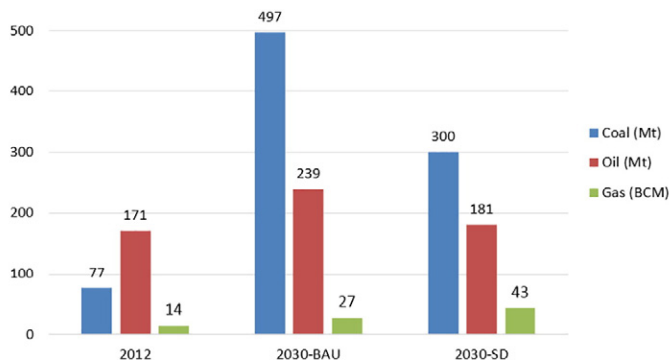

Fig. 8. Energy imports.

Suspended Particulate Matter (SPM), NOx, SO_2, Carbon Monoxide (CO) and Volatile Organic Compounds (VOC). In the BAU scenario, these emissions almost double from 2012 due to enhanced activity in these sectors along with limited efforts at improving energy efficiency, pollution control and switching to cleaner fuels.

In the SD scenario, air pollution reduces by 30% on average due to reduced vehicular activity through promotion of NMT and public transport, process upgradation and improved energy efficiency in industry, and higher RE penetration of electricity and pollution control measures in TPPs. Electrostatic bag filters, flue gas desulphurisers and low-NOx burners are key interventions in TPPs that reduce PM, SO2 and NOx emissions by 10% in the SD scenario at an additional 10–15% of the capital costs of these plants. Details are provided in Supplementary materials.

IAP from traditional cooking fuels in households is a premier contributor to mortality and morbidity in India (Smith, 2013). Improving access to cleaner cooking fuels and technologies can significantly mitigate these impacts. The onus of collecting fuel wood for cooking falls disproportionately on women and children. This also makes them vulnerable to back injuries and limb deformation, thus preventing them from engaging in other beneficial activities such as education and income generation.

While there is progress in providing clean cooking fuels and technologies in the BAU scenario, leading to a reduction in the indoor emissions of black carbon, CO and organic carbon, this effort is increased significantly in the SD scenario. This is due to aggressive penetration of LPG in rural and PNG in urban sectors, which more than halves the harmful effects associated with traditional cooking fuels. Mortality in the SD scenario reduces by more than half in 2030 and morbidity is halved over the same time period. Drudgery (hours devoted to collecting fuelwood) reduces by about 63% in the 2030 SD scenario compared with BAU. Details can be seen in Supplementary materials.

Land

Extraction of metals and minerals causes significant damage to land and water bodies and threatens ecosystems and livelihoods (Bhushan, 2010; Giegrich et al., 2013). The SD scenario envisages a shift towards alternate materials that reduce land footprint and the consequent waste generated from mining activities. Table 2 gives the land footprint from mining in 2012 and in the BAU and SD scenarios in hectares.

Increasing the Floor Area Ratio (FAR) of urban residential buildings and commercial establishments (refer Appendix II in Supplementary Material for details) and increasing the penetration of high-rise housing can reduce the land footprint of urban buildings from 10,489 million sq. m in BAU to 7316 million sq. m in SD. This implies a savings of 43% or 3173 million sq. m. of land in the SD scenario.

Table 2
Land footprint from mining (hectares).

	2012	2030—BAU	2030—SD	Saving
Coal	13,259	41,438	29,407	29%
Limestone	2819	9613	7872	18%
Bauxite	57	201	158	21%
Iron Ore	1198	4463	3308	26%
Total	17,332	55,715	40,745	27%

Water

Various estimates have shown that rising water demands from the agriculture, industry and building sectors are likely to cause a severe stress on water resources in the future. The Ministry of Water Resources has indicated utilisable water of 1123 BCM against an estimated demand of 843 BCM by 2025 (Ministry of Water Resources, 2011). Other studies have, however, projected a demand of over 1000 BCM by 2025 (The 2030 Water Resources Group, 2009). Further, 17% of the population will face absolute water scarcity, with only 1235 cm^3 per capita availability in 2050 (Amarasinghe et al., 2007).

Table 3 highlights the effects of different sustainability interventions across various sectors on the availability of water. Enhanced micro-irrigation provision, alternate wetting and drying for rice cultivation, and appropriate measurement of soil moisture can enable significant water savings from agriculture. In the industrial sector, enhanced wastewater recovery and reduced mining requirements in the SD scenario generate savings of water that can be recycled into industrial processes or contribute to groundwater recharge. Leaching of wastewater from industries and ash dykes can significantly pollute freshwater bodies and contaminate water tables. Closed water-cooling systems in TPPs consume up to 4 m^3 per MWh of electricity generated. Dry handling of

Table 3
Water impacts of sustainability interventions (million cubic metres).

Water Sectors	2030—BAU	2030—SD	Improvement
Industrial wastewater recovery	2700	4724	74%
Rooftop rainwater harvesting	748	2016	169%
Water savings in agriculture	69,000	146,000	111%
Water demand from TPPs	9209	6519	29%
Water footprint from mining	25,967	18,669	28%

Table 4
Raw material requirements for select industries.

Industry	Raw material	Validity (years)	Raw material requirement (Mt)			
			2012	2030—BAU	2030—SD	Saving
TPPs/Industries	Coal		430	1658	1176	29%
Steel	Iron Ore	29	120	446	331	26%
Cement	Limestone	35	282	961	787	18%
Aluminium	Bauxite	46	6	20	16	21%
Paper	Wood		6	17	10	39%
	Trees (million nos.)		12	36	22	39%

Table 5
Alternate material requirements.

Industry	Alternate material	Alternate material requirement (Mt)			
		2012	2030—BAU	2030—SD	Increase
Steel	Scrap steel	13	53	130	147%
Cement	Fly ash	45	162	240	48%
	Blast furnace slag	6	28	40	44%
Aluminium	Scrap aluminium	0.3	1	2	100%
Paper	Recycled paper	4	7	9	21%

Table 6
Material requirements for buildings.

Materials (units)	2012	2030—BAU	2030—SD	Saving
Bricks (billion)	1222	13,387	13,848	−3%
Cement (Mt)	106	1215	1276	−5%
Steel (Mt)	11	126	123	2%
Coarse aggregate (MCM)	211	2412	2261	6%
Brick aggregate (MCM)	48	565	588	−4%
Timber (MCM)	13	146	134	8%
Lime (Mt)	7	80	70	13%
Surkhi (MCM)	22	261	218	16%
Bitumen (kt)	890	10,263	8984	12%
Glass (million m^2)	39	448	406	9%
Primer (million lit.)	43	494	449	9%
Paint (million lit.)	67	774	699	10%

Table 7
Waste generated from mining.

Raw material	Waste generated (Mt)			
	2012	2030—BAU	2030—SD	Saving
Coal	1945	6080	4315	29%
Limestone	295	1006	824	18%
Bauxite	3	12	10	21%
Iron Ore	112	416	308	26%

Electrostatic Precipitate (ESP) and concentrating the ash slurry can significantly reduce the water requirement from TPPs. Dry cooling towers can also reduce the water demand for cooling, with an increase of 15% over the capital costs of the power plants.

The key levers to achieving these water savings are rationalising water tariffs for large consumers, better water accounting practices, mandating green buildings in building by-laws, investment in improving agricultural water-use efficiencies and switching to RE generation options.

Waste and material use

A key indicator in the SD scenario is resource demand or the goods and resources required for development activities. In agriculture, excessive application of chemical fertilisers and a lack of organic manure are leading to nutrient deficiencies and a reduction of organic carbon in the soil. This reduces soil health, water retention, microbial activities, soil aeration and nutrient retention, leading to a reduction in agricultural productivity. Thus, integrated nutrient practises that include appropriate use of organic manure as well as bio-fertilisers are important to improving the nutrient balance in soils. In the SD scenario, fertiliser consumption reduces by 21% compared with that in the BAU scenario, resulting in 99 kg/ha of fertiliser consumption in SD compared with 122 kg/ha in BAU.

Table 4 provides the raw material requirements for various industries in the BAU and SD scenarios and the years until expiry of known reserves based on current rates of extraction. In the industrial sector, this reduction in primary raw material demand in the SD scenario implies an increased demand for substitute materials. This is provided in Table 5.

Overcoming the gap in affordable housing and catering to the increased demand for housing and commercial buildings will impact the demand for construction material. Studies have indicated how vertical expansion leads to an overall reduction in material requirements. Table 6 presents the cumulative material requirements in the BAU and SD scenarios, with the difference attributable to a greater vertical expansion of building floor space in the SD scenario.

Bricks, cement and steel are the major contributors to cost and, therefore, offer the most significant potential for cost savings through recycling and use of alternate materials. Green buildings can further reduce the demand for these materials by up to 25% by proper utilisation of construction waste (Town and Country Planning Organisation, 2008).

Waste generation

Mining activities are responsible for generating waste that affects land, water bodies and water tables. Table 7 gives an account of the waste generated from mining activities in 2012 and the BAU and SD scenarios.

Use of alternate materials such as fly ash in Portland Pozzolana Cement brings benefits to TPPs in terms of reduced resource requirement for fly ash ponds. Fly ash disposal accounts for 35% of the land (18 ha/Mt. ash generated) and 40% of the water (ash: water = 1:10) requirement in TPPs where ash is handled in wet form. Fly ash utilisation from cement in TPPs increases from 34% in BAU to 75% in SD. For reference, in 2012–13 the cement industry used about 25% of the fly ash generated (Table 5).

The increased uptake of Light-Emitting Diode (LED) lighting in the SD scenario leads to a displacement of the CFL stock, which also checks mercury accumulation. Each CFL contains 5–6 mg of mercury. Based on the difference in cumulative CFL retirements between the BAU and SD

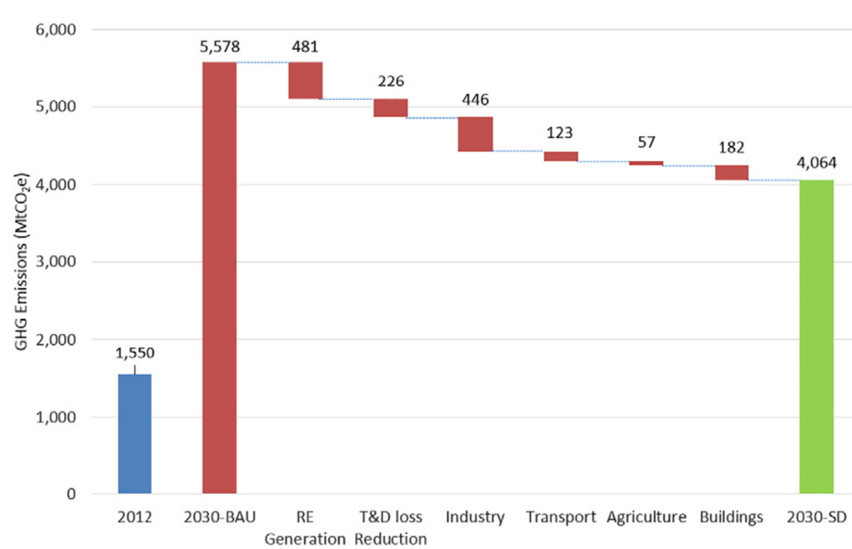

Fig. 9. Emissions in the BAU and SD pathways.

Table 8
Costs of SD vs BAU scenario.

Costs	Difference over BAU
Investment	2%
Operation and Maintenance	−23%
Fuel	−28%

scenarios, we estimate that around 10–12 t of mercury waste will be avoided in the SD scenario.

Emissions

Fig. 9 demonstrates how different sectors contribute to emissions reduction in the SD scenario in contrast with the BAU scenario. RE generation, the industrial sector, T&D loss reduction, and the residential and transport sectors contribute the most to emissions reductions in the SD pathway.

The final energy intensity reduces from 0.12 kWh/INR in 2012 to 0.11 kWh/INR in 2030 in the BAU scenario (11% decrease). In comparison, the SD scenario shows a much deeper reduction to 0.08kWh/INR (33% decrease), reflecting system-wide energy efficiency and some structural changes.

In concentrating on improvements to the quality of life using SD indicators, this study finds that GHG emissions were reduced by close to 30% in 2030 over 2012 and primary energy use was reduced by 25% in the SD scenario compared with BAU (see Fig. 5).

The emissions intensity (GHG emissions per unit of GDP) rises in the BAU scenario by about 16%. In contrast, emissions intensity decreases by 16% in the SD scenario primarily because fossil-free sources are able to contribute to about a third of India's electricity.

RE generation and reduction in T&D losses offer significant scope for emission reductions in the power sector under the SD scenario. Industries and buildings also contribute to substantial reductions over BAU.

A significant increase in the demand of imported fuels is likely under the BAU scenario (6.5 times increase in imported coal), which could threaten energy security in case of price volatilities and geopolitical uncertainty. Interventions to reduce service demands, improve energy efficiency and switch to cleaner fuels under the SD scenario can reduce the demand for imported coal and oil by 40% and 24%, respectively, and increase gas imports by 58%.

Costs of an SD pathway

The SD pathway assumes that ambitious socioeconomic targets are achieved within the stipulated time frames with primary emphasis on sustainable development. The economic costs associated with these activities include penetration and replacement of new technologies and infrastructure. These are captured in our database and used by TIMES to derive optimal system configurations under different constraints. TIMES provides total scenario costs as well as costs by technology type. Table 8 shows the change in SD costs over the BAU scenario.

The SD and BAU scenario costs constitute 16% and 19% of the GDP in 2030, respectively.

It is important to note that the above costs are indicative and not firm due to the exclusion of the following:

1) Certain infrastructure investments, such as expansion of gas distribution, freight corridors, railways and metro, etc.
2) Costs related to shifting behavioural patterns, such as publicity and propaganda costs, financing of public provisioning schemes, etc.
3) Regulatory and policy implementation costs, while not usually captured in macro-level energy or economic models, often constitute an important factor for the success of the schemes.
4) Costs of various externalities, including changes in morbidity and mortality resulting from reduced air pollution, the ecosystem services associated with organic agriculture, reduced use of water and widespread access to energy services.

The different costs and means of raising finance have a substantial overall economic impact. TIMES is a partial equilibrium optimisation model that treats macroeconomic demands (and therefore, growth) as exogenous, so the multiplier effects on the economy are not captured.

In comparison, the Low Carbon Inclusive Growth (LCIG) strategies report uses a macro model to show that the GDP growth rate is lower by 16 percentage points and GDP by 3.3% in the LCIG scenario versus the baseline scenario (Parikh et al., 2014a). This points to the critical role of means of implementation (finance, technology, capacity building). It also suggests that a low-middle-income country like India would require support from the industrialised world to transition to a low carbon pathway while ensuring that the other developmental goals are not compromised in the process.

Conclusions and policy implications

The interventions proposed in Table 1 result in a 16% emissions intensity reduction compared with 2012 levels (or about 27–30% relative to 2005 levels). This is based on a combination of 33% reduction in energy intensity and 14% contribution from fossil-free sources to energy supply between 2012 and 2030. About one-third (32%) of the electricity generation is from fossil-free sources by 2030. Note that this study does not consider fugitive emissions, process emissions from industries other than cement, steel and aluminium, and non-energy emissions from agriculture, forestry and other land-use sectors.

In its NDC, India has offered to reduce its GHG emissions intensity by about 33–35% below 2005 levels by 2030; this is equivalent to about a 21% reduction relative to 2012 levels by 2030 (based on estimates from (Ministry of Environment Forest and Climate Change (MoEFCC), 2015). India includes additional afforestation and tree cover in its NDC to achieve annual savings of 2.5–3 billion tonnes of CO_2 equivalent by 2030.

One key insight from this study for India's NDC is that setting a trajectory along a SD pathway could come close to meeting the country's international climate commitment while improving the quality of life of millions. The SD pathway demonstrates how various factors affecting quality of life – such as access to electricity services and clean cooking fuels, reduced natural resource extraction and associated impacts, reduced import dependence and waste generation – can be addressed while at the same time decreasing the rate of growth of the overall energy production and use in the economy.

A SD pathway abates ambient air pollution by 30% on average, on account of increased use of public transport, improved energy efficiency in industries, increased RE generation and more stringent pollution control measures in TPPs. Aggressive penetration of modern cooking fuels more than halves the morbidity due to a reduction in IAP from traditional cooking.

Significant water savings are possible by rationalising water tariffs for large consumers, better water accounting practices, mandating green buildings by-laws, ensuring investment in the agricultural sector to improve water-use efficiencies and switching to RE generation options. A shift to alternate materials in the building and industry sectors and a change in agricultural fertiliser practices can significantly reduce the material and resource requirement and improve soil health.

It must be noted that the interventions proposed in this study are not drastic. While the proposed interventions have been ambitious, this ambition is rooted in today's socioeconomic and political contexts and is consistent with the UN Sustainable Development Goals.

Based on the Paris Agreement of 2015, there will be a need to ratchet up targets for emissions reductions in the subsequent commitment periods. India, with its large and diverse society and its democratic traditions, will be able to increase future commitments and make transformational changes to its economy to attain these only if living standards improve for everyone. Without this, we are likely to witness a further split between the economies of the poor and rich within the country.

Clearly, further reductions may include the deployment of disruptive technologies in key sectors and policies to encourage less consumptive lifestyles while vigorously protecting ecosystem services.

India's long coastline, numerous ecological zones, high reliance on monsoons for agriculture, high dependence on agriculture and ecosystems for livelihoods and worsening groundwater levels all combine to make climate variability and climate change very challenging circumstances for the country. By emphasising quality of life and the inclusive provision of services over emissions reductions per se, this study's approach strengthens opportunities for building resilience, so that the country can adapt to future climate changes.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.esd.2017.04.003.

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