India Chapter

pathways to deep decarbonization

2014 report

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SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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Preface

The Deep Decarbonization Pathways Project (DDPP) is a collaborative initiative, convened under the auspices of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), to understand and show how individual countries can transition to a low-carbon economy and how the world can meet the internationally agreed target of limiting the increase in global mean surface temperature to less than 2 degrees Celsius (°C). Achieving the 2°C limit will require that global net emissions of greenhouse gases (GHG) approach zero by the second half of the century. This will require a profound transformation of energy systems by mid-century through steep declines in carbon intensity in all sectors of the economy, a transition we call "deep decarbonization."

Currently, the DDPP comprises 15 Country Research Partners composed of leading researchers and research institutions from countries representing 70% of global GHG emissions and different stages of development. Each Country Research Partner has developed pathway analysis for deep decarbonization, taking into account national socio-economic conditions, development aspirations, infrastructure stocks, resource endowments, and other relevant factors. The pathways developed by Country Research Partners formed the basis of the DDPP 2014 report: Pathways to Deep Decarbonization, which was developed for the UN Secretary-General Ban Ki-moon in support of the Climate Leaders' Summit at the United Nations on September 23, 2014. The report can be viewed at deepdecarbonization.org along with all of the country-specific chapters.

This chapter provides a detailed look at a single Country Research Partner's pathway analysis. The focus of this analysis has been to identify technically feasible pathways that are consistent with the objective of limiting the rise in global temperatures below 2°C. In a second—later—stage the Country Research Partner will refine the analysis of the technical potential, and also take a broader perspective by quantifying costs and benefits, estimating national and international finance requirements, mapping out domestic and global policy frameworks, and considering in more detail how the twin objectives of development and deep decarbonization can be met. This comprehensive analysis will form the basis of a report that will be completed in the first half of 2015 and submitted to the French Government, host of the 21st Conference of the Parties (COP-21) of the United Nations Framework Convention on Climate Change (UNFCCC).

We hope that the analysis outlined in this report chapter, and the ongoing analytical work conducted by the Country Research Team, will support national discussions on how to achieve deep decarbonization. Above all, we hope that the findings will be helpful to the Parties of the UNFCCC as they craft a strong agreement on climate change mitigation at the COP-21 in Paris in December 2015.

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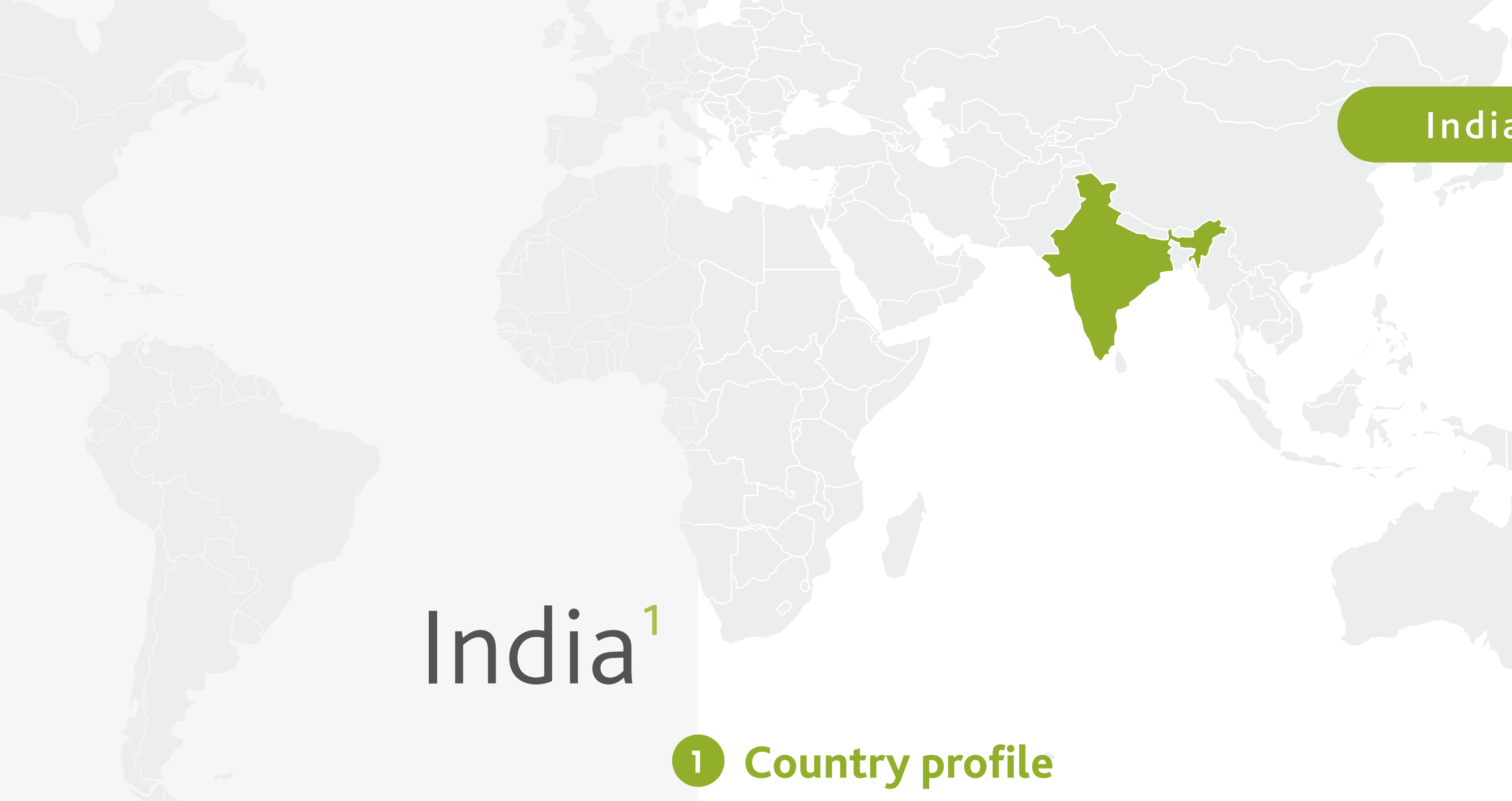

India[1]

1 Country profile

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1.1 The National Context for Deep Decarbonization and Sustainable Development

Development continues to remain the key consideration for India as a large section of its population still lacks access to basic infrastructure (roads, housing, education, and health care facilities) and clean and reliable energy forms. A significant proportion of households continue to use traditional fuels like firewood, dung, and crop residue for cooking, and about 400 million people do not have adequate access to electricity[2]. Further, while there has been significant progress on electrification of villages, it does not imply that all the houses in these villages actually have access to electricity. Furthermore, even those that do have access often have intermittent and unreliable power supply. Significant efforts need to be made towards providing farmers and businesses with better connectivity to markets, providing improved education, housing, adequate health care services, and social security across all segments of society. Given that large unmet demands continue to exist, it is clear that India faces a huge challenge of providing its people with higher and better level of services, infrastructure, and basic energy needs, while attempting to contain the associated environmental implications.

India achieved a GDP growth rate of around 4.9%, 6% and 7.8% during 1981-1991, 1991-2001 and 2001-2011 respectively. While the last 3-4 years have seen a downturn in the GDP growth rate, the aspiration continues to be that of achieving a high growth rate over the next few decades in order to increase the overall level of per capita income and reduce poverty through inclusive growth that increases equity in income distribution.

1 This study does not reflect the views of the Indian Government or Indian industry

2 http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS

India is listed as the world's aggregatively third largest emitter of greenhouse gases based current annual emissions, but it is also the world's second largest country in terms of population and the third largest economy in purchasing power parity terms. India has the lowest current per-capita emissions among G20 countries, as well as the lowest per-capita historical responsibility reckoned from 1850 to 2011, among the same group. Further, the GHG intensity of India's economy is virtually at the median level among G20 countries, being well below that of many developed economies, including the United States, Australia, and Canada. With one-third of the world's poor in India and a Human Development Index (HDI) rank of 135, India would be faced with an excruciatingly difficult challenge in trying to follow the Illustrative Deep Decarbonization Path (DDP) identified in this report. However, the exploration of the purely technical potential of doing so may help prioritize national and international interventions that may facilitate the adoption of a mitigation trajectory.

In terms of the availability of energy resources, India's fossil fuel reserves are limited, with crude oil and natural gas reserves estimated at around 760 MT and around 1330 BCM respectively in 2012/13. Around half of the country's oil reserves and two-thirds of the natural gas reserves are offshore.[3] Moreover, much of India's proven coal reserves (estimated at 118 BT[4]) are not only of low quality but also inaccessible due of technological, geological, or economic factors.[5] According to recent estimates, India's extractable reserves are estimated to last for only about 30 years at current rates of production. At present India is largely dependent on fossil fuels, with coal accounting for around 54% of commercial energy use. With production of coking and non-coking coal remaining around 50 MT and 500 MT respectively and domestic production of crude oil and natural gas hovering around 40 MT and 50 BCM respectively during the last 4-5 years, the country's dependence on energy imports has increased. Oil imports accounted for 8% of current account deficit and approximately 30% of imports in 2010. In light of volatile and increasing fossil fuel prices, and trends of rising energy import dependency, concerns regarding energy security have increased. Continued fossil fuel use faces challenges in terms of long-term domestic availability and energy security considerations, as well as associated local and global environmental implications.

On the other hand, India is relatively well endowed with renewable energy resources. The estimated wind potential at 80 m hub height is around 500 GW while over 58% of the land receives global insolation of over 5 $kWh/m^2/day$. Large hydro is estimated to have a potential of 148 GW while small hydro has around 15 GW potential. Biomass to power has a potential of around 25 GW. The exact potential of other resources like geothermal, tidal, and offshore wind is uncertain, since not many reliable studies exist at present. While renewable energy resources have a relatively large potential in India, the share of renewables in total energy use is still small, due to several factors including the relatively high costs compared to fossil fuel options at present, uncertainty regarding on-ground efficiencies of some of the new technologies, stochasticity of supply, suitability across regions and applications, socio-economic considerations, and issues related to confidence in adoption of commercially less established technological options.

In planning ahead for future energy and infrastructure requirements, it is therefore in the country's interest to tap opportunities wherein it could transition to a reliance on energy sources and technologies that can provide a secure and sustainable development path for the future. In so doing, India can avoid locking itself into inefficient infrastructure and fuel choices that are import-intensive.

3 http://petroleum.nic.in/petstat.pdf

4 http://www.coal.nic.in/welcome.html

5 Batra and Chand 2011, *India's coal reserves are vastly over stated, is anyone listening ?*, TERI

1.2 GHG Emissions: Current Levels, Drivers and Past Trends

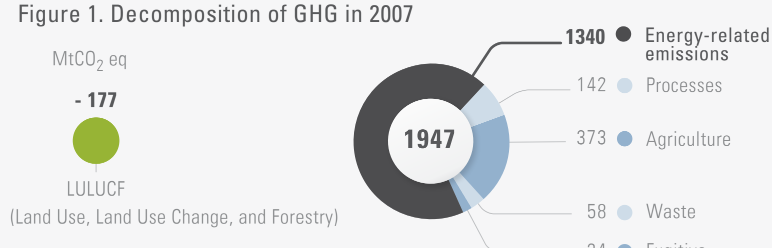
As indicated in Table 1 and depicted in Figure 1, energy and industrial process[6] related emissions together account for a majority of the total emissions, and the share of these has been increasing over time. Accordingly, in this study, we focus only on energy and industrial process-related emissions. As illustrated in Figure 2a and Figure 2b, India's CO_2 emissions have increased in total magnitude across all sectors, not only as a result of growth in economic activity and the consequent increase in overall energy requirements, but also the gradual move from traditional biomass fuels towards modern commercial fuels. Electricity generation[7] is the largest contributor to the total emissions followed by industry and transport. However, India's primary energy requirement per unit of GDP has been continuously decreasing due to efficiency improvements across sectors as well as structural changes in the economy. This can also be seen through the CO_2 emissions from fossil fuels, which have been increasing, relative to 1990 but at a decreasing rate in relation to GDP growth. Therefore, even though the total emissions are increasing, the economy has continuously been decarbonizing and becoming less energy intensive. Energy consumption in the industry sector, for example, increased at an annual average growth rate of only about 6% per year, although industrial production grew at about 9% per year, as a result of several energy efficiency measures that have been implemented across industry sub-sectors, as well as other shifts such as the pronounced increase in the use of fly ash instead of limestone in cement manufacturing.

Table 1. Distribution of GHG emissions by sector

	1994	2000	2007
Agriculture	29%	23%	19%
Waste	2%	4%	3%
Energy	62%	67%	71%
Industrial process	7%	6%	7%

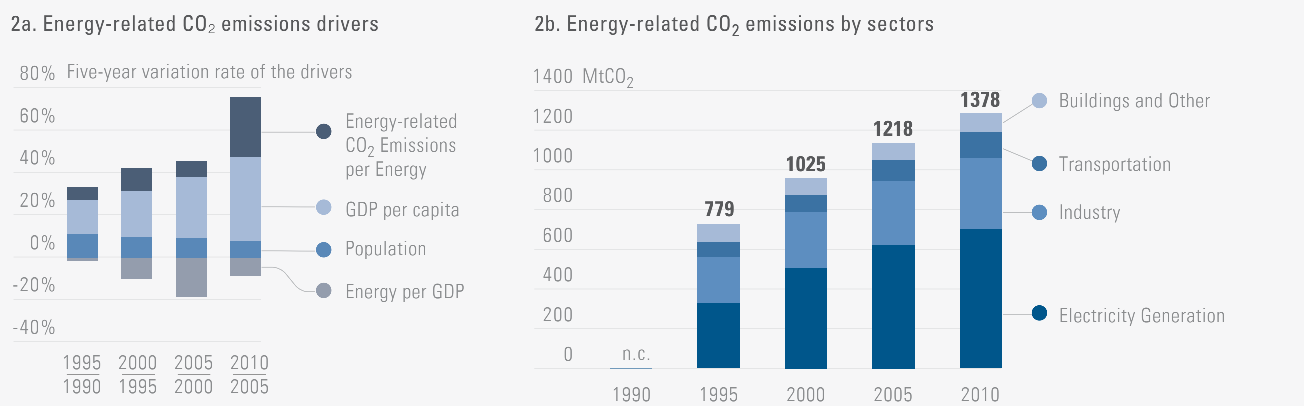
Source: India: Second national communication to the United Nations Framework Convention on Climate Change, pg 82, Ministry of Environment and Forest, Government of India, 2012

Figure 1. Decomposition of GHG in 2007



Source: India:
Second National Communication to the UNFCCC, MOEF, 2012

Figure 2. Decomposition of historical energy-related CO_2 Emissions, 1990 to 2010



6 Post 2000, emissions from the iron and steel sector are not reported under process emissions

7 India's emission inventory includes captive power plants within the electricity sector, while this study includes captive generation within the industry sector

2 National Pathways to Deep Decarbonization

2.1 Technological Options and Assumptions considered in the DDP for India

Using a set of largely common assumptions for all 15 participating project partners in the different countries, and some others, specific to the Indian study, the DDP results for India represent a set of possible outcomes in terms of a "what-if" analysis. The common assumptions relate to the time frames in which specific clean energy technologies would reach commercial viability, becoming competitive due to certain carbon prices and without considering any adverse implications for the country's GDP growth or income distribution across social classes. Although India is likely to face several barriers related to the actual capacity to absorb and deploy technologies rapidly and at large scales due to various limitations affecting its ability to undertake upfront investments, operational and maintenance costs, human and institutional capacities, and the wherewithal for build-up of associated infrastructure, at this stage the DDP assumes that the alternative options can be scaled up quickly across sectors, without including any socio-economic, infrastructural or financial barriers/constraints.

Table 2. Technology assumptions for the India DDP

Sector	Technology	Starting date of global deployment at scale – suggested assumptions for DDPP Country Research Partners [a]	Deployment date assumed for India DDP	Comments
Power	Advanced energy storage (CSP with 15 hour storage)	2030 – 2035	2035	Uptake by 2035. Solar achieves 20% of total capacity by 2050
	Nuclear Fast Breeder reactors	[b]	2035	We assume that India would progress with its 3 phased nuclear program. Thorium-based Fast Breeder Reactors (FBR) would be available at a commercial scale by 2035. By 2050 nuclear is 16% of total power generation capacity
	Wind offshore	[b]	2030	Offshore wind technology, which currently is in RD&D phase, is assumed to be commercially available post-2030
	Wind onshore and solar	[b]	Capacity already exists	Solar thermal with storage technology (15 hours storage) is assumed to be commercially available from 2035. Onshore wind technology at hub height of 80 m is assumed to be deployed post 2030
	Grid Technology	Available now	Available now	We assume the centralized grid becomes more reliable and uninterrupted power supply can be ensured such that industry could switch from captive power plants to grid based supply. Apart from strengthening and extension of the grid, we assume development and integration of smart grids and management of power systems to ensure balance of power and support the integration of renewables, at no additional cost, and without any barriers at this stage.
Transport	Global availability of long range EVs across all vehicle types	2020 – 2025	2035	Uptake from 2035 to 2040
	Third generation biofuels	2020 – 2025	2035	
Industry	Solar thermal based boilers	[b]	2035	Heavy industries are able to continue reducing their energy intensity further, though at lower rates, although many of these are already at world-best levels.

Notes: [a] See Chapter 5 of the full report for more details. [b] Starting date of global deployment at scale not specified in recommendations for DDPP Country Research Partners

The global technology assumptions considered across the study and the specific assumptions for India as considered in the DPP are listed in Table 2.

Additional assumptions that are included the DDP analysis are provided below:

1. Domestic natural gas production is assumed to reach 50 BCM by 2035 with commercialization of new discoveries.
2. Adequate infrastructure and compressed natural gas (CNG) supply network is assumed to be available across the country to support increased CNG use in the transport sector.
3. Hybrid and electric vehicles achieve significant penetration in servicing surface passenger demands post 2030, based on the assumption that electric vehicle technology would progress such that family size cars become cheaper and preferred options by 2030.
4. Heavy industries are able to continue reducing their energy intensity further, though at lower rates, although many of these are already at world-best levels.
5. People prefer more efficient appliances (such as efficient fans, air-conditioners, and LEDs), more efficient personalized vehicles and more efficient transport systems (use of public buses, metro, and non-motorized transport modes) enabling higher switch to these options.
6. Biodiesel plays a major role in the transport sector post 2030 with availability of third generation biofuels by then.
7. On the demand side, we assume significant improvements in appliance efficiencies, shifts towards green buildings, improvements in efficiencies of existing industrial processes, apart from including shifts towards alternative technologies and processes, and assuming a significant switch-over to more efficient transportation modes in both freight and passenger movement. These are envisaged at levels that are significantly beyond what the existing policies and measures can achieve.

2.2 Illustrative Deep Decarbonization Pathway

2.2.1 High-level characterization

In terms of socio-economic framing, the illustrative DDP envisaged for India in this exercise respects the need for increased energy supply to enable the country to achieve rapid economic growth leading to higher per capita incomes over time. This coupled with an increase in percentage share of industry in GDP, thus ensuring increasing employment, would make the growth trajectory more inclusive. In the past the value added from agriculture has been declining, but the proportion of people dependent on agriculture has either stayed constant or has only marginally decreased. Population, technological change, and GDP are the main drivers of growth. Population is assumed to increase at an annual average rate of 1%, resulting in a population of 1751 million by 2050 (with urban population having a share of 39% by 2050). GDP is envisaged to grow at an annual average rate of about 7% with the share of industry in GDP assumed to increase from 19% in 2010 to 34% by 2050.

Improved access to modern energy forms, especially to the poorer sections of society has been included by assuming 100% electrification of households by 2020; however, the lowest income category households are still assumed to be able to fulfill only their most basic energy needs and not achieve levels of appliance ownership or electricity consumption which India's middle class is able to afford today. The DDP also envisages that the share of traditional biomass use decreases as access to modern energy forms such as LPG for cooking increases.

On the supply side, the illustrative DDP scenario is not a result of an optimization modeling exercise based on cost minimization, but rather a visualization of the maximum levels to which alternative supply options could be harnessed if these options were globally available at commercially viable costs and at large scales of deployment. It is assumed

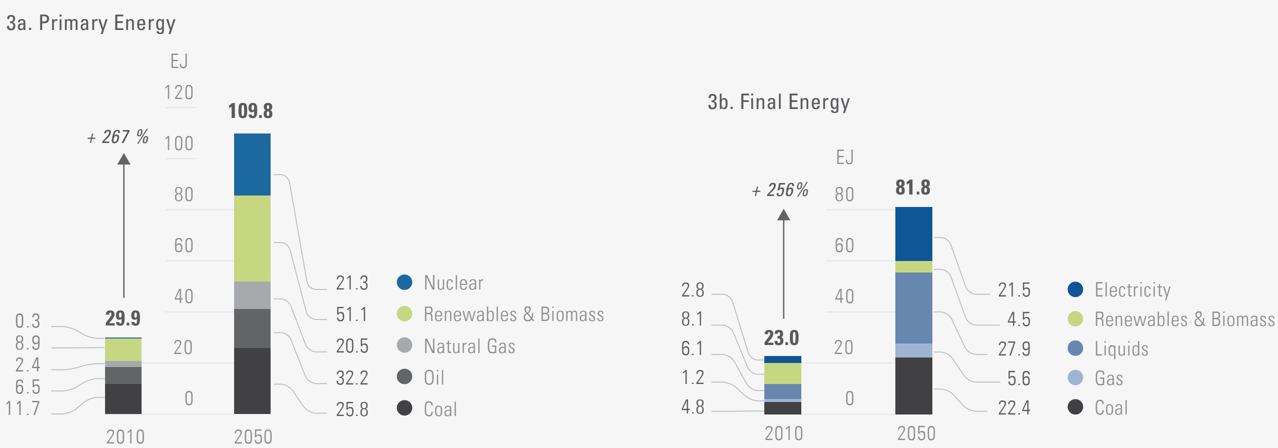
that the share of electricity based energy increases across sectors, with most of this increase being based on grid-connected renewables and nuclear. Moreover, several options that are also of interest from an energy security point of view in India have been included to their maximum limits based on expert-based judgment of the technically feasible potentials. Similarly, efficient technological options that could enhance India's energy security and bring in higher environmental sustainability are also pushed to their limits across the demand sectors.
Although, energy efficiency is envisaged to play a major role across sectors, and this dampens sharp increases in final energy requirements across sectors, both primary and final energy demands still increase nearly 4-fold between 2010 and 2050 as indicated in Figure 3. Figure 4a illustrates the overall picture of the Indian economy relative to 2010 levels. An analysis of the DDP indicates that India's per capita income would increase decade on decade (relative to 2010 levels), at a decreasing rate. The primary energy per unit GDP is decreasing, implying reduction in energy intensity of GDP over time, due to energy efficiency improvements as well as structural changes in the economy. Growth in fossil energy based CO_2 emissions per units of energy decreases over time, indicating that final energy is becoming cleaner and dependence on fossil fuels is decreasing. This DDP therefore assumes that not only is the GDP growth achieved more efficiently

Table 3. Development Indicators and Energy Service Demand Drivers

		2010	2020	2030	2040	2050
Population [Millions]		1,201	1,370	1,523	1,651	1,751
GDP per capita [B$/capita]		1092	2364	5119	9997	17890
Electrification rate		73%	100%	100%	100%	100%
Sectoral share in GDP	Agriculture	16%	13%	10%	8%	6%
	Industry	19%	20%	20%	26%	34%
	Services	65%	68%	70%	66%	60%

Note: Numbers are actually for 2011-2051 but represented in this document as 2010-2050 to ensure consistency with other country chapters and analysis

Figure 3. Energy Pathways, by source



(with lesser energy), but the energy portfolio also shifts towards cleaner fuels. In absolute terms (Figure 4b) total emissions decline after 2040 based on the DDP envisaged in this chapter, indicating that if the country were able to make massive and rapid enough strides to bring in zero carbon fuel options into the energy mix and undertake large efficiency improvements across the energy chain, emissions could peak and possibly bend downwards Three of the key areas that lend themselves to significant decarbonization in case of India as indicated by the DDP envisaged in this exercise are energy efficiency, decarbonization of the electricity sector, and fuel-switching in the transportation sector. The DDP visualized for India results in an emission level of 1.44 tons CO_2 per capita in 2010, and 2.48 tons CO_2 per capita in 2050.

Energy efficiency as envisaged in the DDP plays a key role in the Indian economy and cuts across sectors. It is important to note that the energy demand curves in the end-use consuming sectors may not reflect a stabilization or a downturn by 2050 due to India's development needs; however, energy efficiency is included at extremely ambitious levels across all the sectors, playing a crucial role in containing the rapid increase in the country's final energy requirements by 2050 despite the aspirations of better lifestyles and improved access to basic amenities, energy and infrastructure. With the efficiency improvements envisaged in the DDP, energy intensity reduces by 78% from 27MJ per $ of GDP in 2010 to 6 MJ per $ of GDP in 2050.

As indicated in Figure 4 and Figure 5, with the introduction of renewables and nuclear based

Figure 5. Energy-related CO_2 Emissions Pathway, by Sector, 2010 to 2050

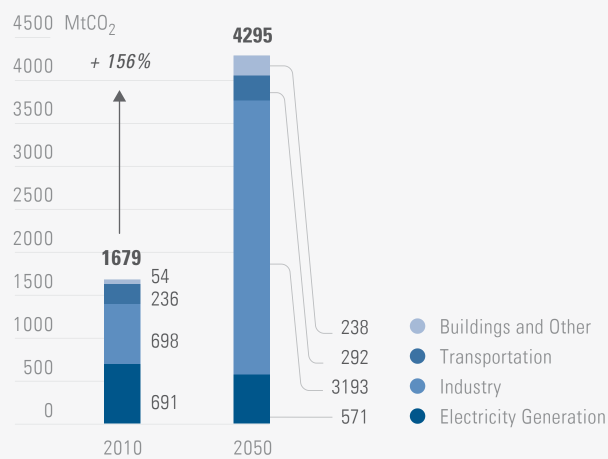
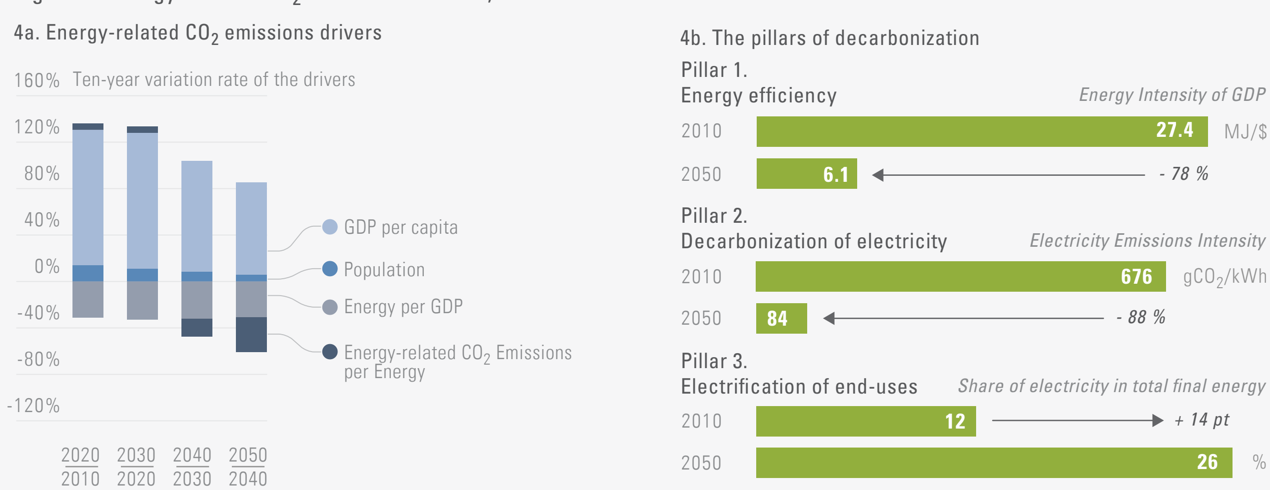


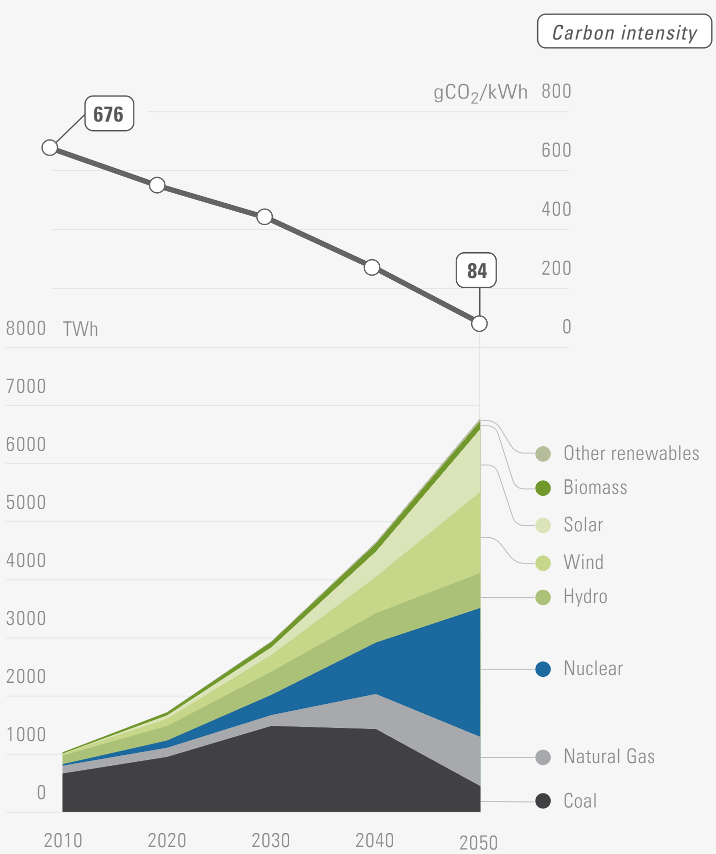
Figure 4. Energy-related CO_2 Emissions Drivers, 2010 to 2050



generation at the assumed levels the electricity generation sector makes major contributions to the DDP.

In terms of electrification of the economy, the share of electricity in total final energy increases from 12% to 26% during 2010-2050, on account of the shift towards centralized electricity from captive generation (reducing captive generation from 14% at present to just about 5% by 2050 contingent on greater reliability as assumed for the grid) in the industry sector, significant shifts towards electric motorized vehicles and electric rail based movement, and significant increase in the penetration and use of electrical appliances in the residential and commercial sectors.

Figure 6. Energy Supply Pathway for Electricity Generation, by Source



2.2.2 Sectoral characterization

Different sectors and options vary in terms of the mitigation and the degree of flexibility they offer in the short and longer terms.

For example, the industry sector illustrates limited flexibility in the shorter term with emissions increasing by around 70%, while the last ten years of the analysis period visualizes prospects for much larger transformations of processes and fuel switching abilities, leading to only 20% increase in emission. Similarly, the electricity generation sector has limited degrees of freedom in the next decade and therefore results in an 85% increase in emissions during this period, compared to a 55% decline in emissions during 2040-2050 if the levels of zero carbon options could actually be commercially available and deployed at large scales as envisaged in the DDP. The gestation time associated with planning and implementing much of the energy and infrastructure requirements for the country's development path is an important dimension that would affect the actual uptake of the options. However, for this exercise, at this stage we assume that the country is not limited by such barriers and do not analyze these limits in detail.

Electricity Generation

While India has a high technical potential for renewables and the government has been encouraging generation based on renewables by offering various incentives, costs of these technologies are still not competitive, and in some cases technologies also need to mature and improve further to instill higher confidence and ensure uptake at larger scales. Coal based power generation remains the most economical option for India, and because of this the current and planned generation capacity continues to be coal based.

For the DDP we assume a significant investments would be made in RD&D in renewable energy technologies globally to create a rapid improvement in technology. As a result we envision the scaling up of renewable based capacity more than ten-times the current levels by 2050, thus increasing the share of renewable generation from 5% to 39%. Further, we also assume large scale deployment of fast breeder reactors (FBR) based on thorium after 2030 such that the contribution of nuclear power increases from 3% to 33% from 2010 to 2050.

Although India continues to face large demand-supply gaps as a result of which any power generated (even if inefficiently) is important for the country, in the DDP we assume fossil-based plants would shut down after the end of their current economic life. We also assume that the country would have a much more strengthened, integrated, and reliable grid that makes it possible for industry to rely solely on centralized electricity rather than captive power. With the changes envisaged, the carbon intensity of electricity generation falls dramatically from 676 gCO_2 per kWh in 2010 to 84 gCO_2 per kWh in 2050 as shown in Figure 6.

Industry Sector

The DDP incorporates several assumptions specific to the industry sector, which are detailed below:

- As much as 30% of the steel production in 2040 can be produced with electricity using scrap steel.
- Share of blended cement can increase from 76% in 2010 to 93% in 2050.
- All new cement production capacity would be based on state-of-the-art technology.
- Efficiency of the fertilizer sector is assumed to improve further by 2% although it is already near the highest achievable efficiency levels per unit. The few old and inefficient units that exist are assumed to retire by 2030, and use of naphtha as a feedstock is also discontinued beyond 2020.
- Paper industry moves towards the efficient RCF process based on waste and 40% of the total paper production in 2050 is from waste based process.
- We assume that MSME units would be able to decrease their energy intensity about 1% per year, although this is a very optimistic decline and contingent on several factors like availability of finance for these enterprises, and handholding them to understand the new technologies or processes (as MSMEs are small, unorganized, and disaggregated).
- The DDP also envisages that industry will reduce the use of captive power plants from about 14% in 2010 to 5% in 2050.

Accordingly, based on the assumption that energy intensity reductions would continue across industry sub-sectors albeit at varying rates, industrial energy use in the DDP scenario increases at only 2% while industrial production grows at around 9% between 2040 and 2050.

As Figure 7 illustrates, the carbon intensity of fuel for the industry sector decreases and stabilizes post 2030 – as much of the potential that was relatively easy to tap in terms of efficiency improvements in the large sectors and units has already moved towards higher efficiencies, and because rapid and massive scale-ups across MSMEs is difficult to envisage in the near-term. Further, as big industries like iron and steel electrify, the decarbonization potential gets captured in the electricity generation sector as opposed to industry sector. The carbon intensity curve however, by no means reflects a soft path for the country, because given the massive development and infrastructural growth requirements, industrial production needs to increase massively as well, and cannot be compromised.

Agriculture sector

The pressure to enhance agricultural productivity in India emanates from the fact that net cropped area has saturated while the country needs to provide higher and better quality of nutrition to a growing population. Apart from the concerns of food security, about 51%[8] of India's population depends

8 National Sample Survey Organization, the 66th round

directly or indirectly on agriculture. Bringing in a larger share of the agricultural land under irrigation and mechanization is therefore important while making efforts to decarbonize the sector.

The DDP considers the following options to decarbonize this sector:

- The efficiency of the stock of tractors improves significantly, coming close to the most efficient tractors today.
- Inefficient power tillers get phased out by 2015 and all new capacity is efficient.
- Diesel pump-sets start are phased out after 2020, and are completely phased out by 2040 being replaced by electric pump sets.

Transport Sector

With the envisaged growth in socio-economic indicators, India's mobility needs are projected to increase 4.5 times for passenger movement, and 13 times for freight movement between 2010 and 2050. Past trends show a rapid increase in the use of personalized vehicles and a decreasing share of rail based movement in both passenger and freight transport, as well as of public transport in cities. However, in the DDP we visualize the possibility of being able to put in place adequate state-of-the-art infrastructure, and enable a higher penetration of public transportation, and rail based movement, apart from including continuous improvements in vehicle efficiencies. Moreover, we also optimistically assume that mobility needs can be reduced to a small extent by moving to compact cities that would be set up during the process of urbanization and development in the coming decades.

Apart from more efficient transportation modes, several fuel switching options are also included in the DDP. These include:

- Substitution from petroleum products towards CNG, electricity and biofuels.
- Increase in the blend of biodiesel through uptake of third generation biofuels.[9]
- Almost all 2-wheelers could become electric by 2050.
- Electric cars could comprise 50% of the total passenger car stock in 2050.
- Decline in share of railways in both passenger and freight movement is assumed to be arrested such that by 2050 railways retain a share of 17%.
- Increased electrification of railways (60% of passenger movement and 80% in freight by 2050).

Accordingly, the DDP indicates that by 2050, the carbon intensity of passenger transport and freight movement decrease by 75% and 86% of the 2010 levels respectively. The carbon intensity of the transport sector as a whole decreases from 68.4 to 13.0 gCO_2/MJ as shown in 7b. This reduction is attributable to the introduction of electric vehicles and biofuels after 2030, along with continual improvement in fleet efficiencies, modal shifts towards rail, and electrification of railways.

Residential Sector

In the residential sector we assume higher penetration of clean and efficient fuels and technologies that on the one hand provide access to modern forms of energy, and on the other try to contain the energy consumption levels and emissions from usage of such fuels. In 2010, about 12% and 65% of the rural and urban households respectively were using LPG, which is assumed to increase to 35% and 88% of the rural and urban households respectively by 2050. While a significant population is still envisaged to continue using traditional fuels, the DDP envisages that they would be able to transition towards efficient cookstoves by 2050. Many lower income households that are electrified begin using a variety of electrical appliances, but not all of the population is expected to be able to afford all types of appliances and move to the most efficient options.

9 Assuming a land availability of 30,000 km^2 for algal based biofuels

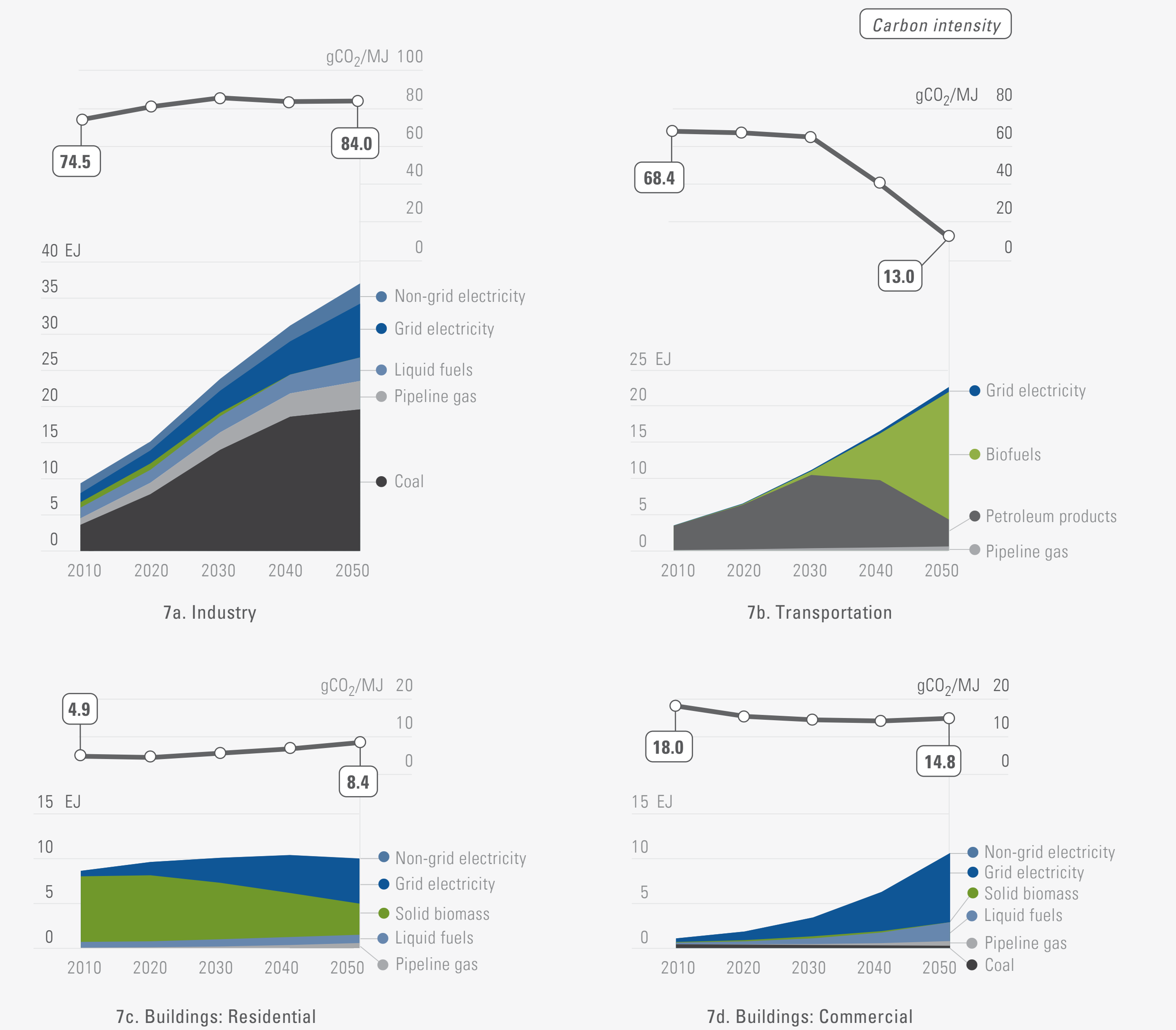
The DDP includes the following:

- Increased penetration of efficient (labeled) appliances for all income classes.
- 100% penetration of efficient appliances, 50% penetration of clean cook stoves, and 90% penetration of LED lighting in both rural and urban areas.

Commercial Sector

Growth in energy requirements in the commercial sector is inevitable as the country develops, and there is growth in the hospitality sector, commercial buildings, shops, public services like lighting, sewage, etc. Growth in the commercial sector is also of importance at the structural level as

Figure 7. Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



growth in services helps strengthen the economy, and is generally associated with lower energy intensity than the manufacturing sector.

The DDP includes the following:

- A 5% reduction in the energy performance index every five years for air conditioned buildings.
- Penetration of energy efficient, green rating for Integrated Habitat Assessment (GRIHA) certified buildings in new built area increases sharply from 2010 levels of 1% to 50% penetration in 2050.
- Additionally, penetration of efficient appliances such as air conditioners, lighting systems, etc. increases rapidly in the commercial sector.

The emissions intensity of the sector as a result of these assumptions in the DDP falls from 18.0 to 14.8 gCO_2/MJ.

2.3 Alternative Pathways and Additional Measures

In this phase of this exercise we have delineated the implications of one particular deep decarbonization pathway. However, alternative pathways could internalize other technological options were these to be economically attractive and desirable for deployment in the time period under consideration. Further, alternative socio-economic trajectories could also be envisaged. A faster growth path with inclusive development and transformational infrastructural growth in a shorter time period providing society with improved living standards, better quality and levels of housing, education, healthcare, and public transportation, could, for example, simultaneously envisage higher capabilities to absorb new technologies and processes, and adopt more innovative options for mitigation as well.

However, given that this stage of this study involved a purely technical analysis, it is important to revisit the timings and levels of introduction of various alternative options based on an explicit assessment of the economic costs and their implications for GDP growth, infrastructural barriers, socio-economic preference structures, and affordability considerations, etc.

It is however important to note that progress along any of the envisaged trajectories would be contingent on several factors including the costs, timing, and scale at which alternative options mature and get deployed at large scales globally. Accordingly, while envisaging alternative DDPs can be meaningful to visualize the choices and their broad implications, these cannot be seen as robust pathways that countries can be pressurize into following, especially if there are possible conflicts with development priorities, GDP growth, and capacities or capabilities of individual countries.

2.4 Challenges and Enabling Conditions

India's challenges in making a transition towards the DDP envisaged are several and significant.

1. The first and foremost consideration for India is that the country's development should not be compromised and people should be better off in terms of per capita incomes, employment opportunities, access to basic services and infrastructure. Since India's basic development needs themselves require significant investment, accelerated development is envisaged to need even faster growth and significantly larger levels of investment.
2. Even though the DDP scenario for India assumes declining global costs for technologies, there would be massive infrastructural related costs to enable to technologies to be absorbed. It is therefore important to ensure adequate flow of finance to developing countries to support uptake of higher cost alternatives in the near term.
3. The challenge with regard to technologies is multi-faceted. Several technologies exist globally but are not economically competitive yet and/or are associated with uncertainties surrounding their actual performance and ef-

ficiencies on the ground. Moreover, some technologies assumed in India's DDP are still in the R&D phase (e.g. 3rd generation biofuels) and not implemented at commercial scales. There are likely to be challenges in scaling up new options such as solar thermal technology where the issue of intermittency related with renewables needs to be addressed. With the levels of future electricity transmission requirements and a greater share of power being generated by renewables, there is a strong need to not only develop adequate transmission and distribution capacity in the grid, but also to further manage and strengthen the grid to be able to handle the additional loads. Moving towards smart grids that can handle renewables based generation, and balance the loads in the system is also necessary. Further, there is need for in-depth mapping of resource potentials, and assessment of the actual usable potentials based on availability of land, water, etc. for energy generation and supply.

4. It will be a great challenge to diffuse existing clean and efficient technologies at large scales to bring down their costs rapidly and demonstrate their performance efficiencies to build investor/user confidence in all regions and countries. There needs to be a global collaborative R&D effort on technology, with sharing of benefits across all countries, including by way of sharing of intellectual property rights and/or other means of concessional technology transfer, not only for technologies that are not yet in the commercial domain (e.g. third generation biofuels), but also for technologies that are already implemented to further enhance confidence in their application and efficiencies, and reduce their costs. Much greater international and regional co-operation is required towards this end.
5. Capacity related challenges are also significant for India. The diversity in economic profiles and industrial units makes it important to identify alternative options for all user groups. For example, India has several MSMEs that use a wide mix of fuels and processes and for which standardized technologies used in larger scale manufacturing units may not be applicable or viable. The MSME sector plays an important role in the economy as it contributes 8% of GDP and employs close to 70 million people.[10] There are about 40 million MSMEs units operating on a small scale, accounting for between 30% and 40% of the industry energy consumption. Accordingly, the challenge is to improve the efficiencies in these units without threatening their competitiveness. Identifying the best technological solutions for the diverse user groups and hand-holding smaller enterprises to make the transition towards efficient and clean operations through awareness programs, developing adequate skill sets, helping small units to undertake higher upfront investments (through grants/soft loans and other international mechanisms), and demonstrating a suite of possible transition options across industrial clusters would be required. Similarly, given that clean energy access and affordability is key in India's DDP, options that can be envisaged to work among the relatively better-off urban user groups may not be a possibility among the lowest income classes. While we must recognize that removing poverty and enabling greater equity in incomes is one of the greatest enablers to making clean energy transitions, other than attempting to work towards a rapid, high, and inclusive economic growth path for the country, there is a need to simultaneously push clean technology solutions in the interim to the poor sections of society as well. For example,

10 Annual report of the Ministry of MSME, http://msme.gov.in/WriteReadData/DocumentFile/ANNUALREPORT-MSME-2012-13P.pdf

in case of cooking, efficient and improved biomass cook stoves should be promoted for rural households that have access to biomass and are unable to afford modern energy fuels. Another important aspect in terms of capacity development relates to the gearing up of education and training programs towards development of skill sets and knowledge base that would be required for future technologies and systems likely to be part of a DDP.

6. Further, issues of resource scarcity and prioritization of competing uses is important. For example, while India seems to have abundant renewable resources, issues with regard to availability of land for energy generation purposes as compared to other competing uses are a potential challenge.

2.5 Near-Term Priorities

In the short term, energy efficiency can play a key role in India. Several "win-win" options exist, that could be tapped immediately.

In residential and commercial buildings, there exists significant scope to reduce energy use, in case of both existing as well as new construction. CFLs (compact fluorescent lamps) and LED (light-emitting diodes) based lighting can bring in significantly higher efficiency levels than conventional light bulbs. Similarly, energy-efficient appliances (such as refrigerators and air conditioners) have a large potential to save energy. Updating of appliance energy norms and building energy codes, energy labelling, and rationalising energy pricing could help encourage a move towards higher levels of efficiency in these sectors.

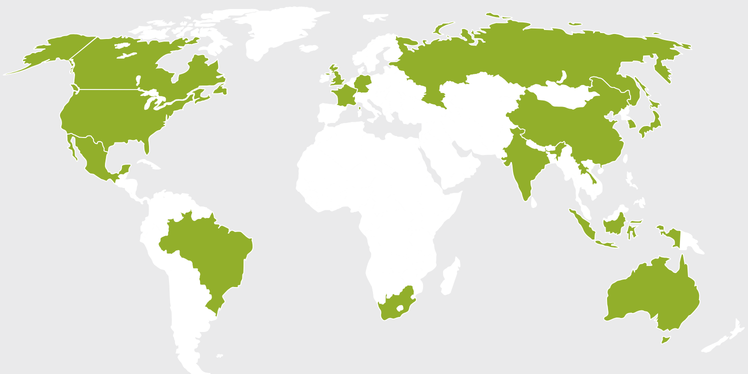
Enhanced and improved public transportation in both large and medium cities and towns could contribute significantly to increased energy efficiencies in passenger movement. Similarly, diverting a larger share of freight movement to rail from road by developing dedicated freight corridors and improving rail based connectivity to demand centers could create efficiencies in freight transportation.

Energy saving opportunities exist in the industry sector and could be tapped by establishing and further strengthening the existing energy performance standards for various equipment/appliances like pumps, compressors, fans, air-conditioning, etc.

Given that fossil based power generation would need to continue to play a significant role at least in the next two decades, establishing the commercial viability of ultra-super critical boilers under Indian conditions and focusing on advanced gas based generation technologies can help contribute towards improving the efficiency of the electricity generation sector.

Rational energy pricing that promotes competition and reduces distortions such that consumers are provided the correct price signals for making efficient energy choices needs to be adopted. This can be achieved by designing effective and transparent subsidies, delivered at end of supply chain to facilitate energy access by the genuinely needy, while ensuring efficient use of resources.

Finally, while this study assumes that alternative technologies would mature and be deployed at economically attractive costs globally so as to be able to make significant future inroads into the country's energy mix, much higher levels of investment are required even in the immediate short term, focused on R&D and deployment at the global level, if rapid and large scale progress on these technological fronts is desired.



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