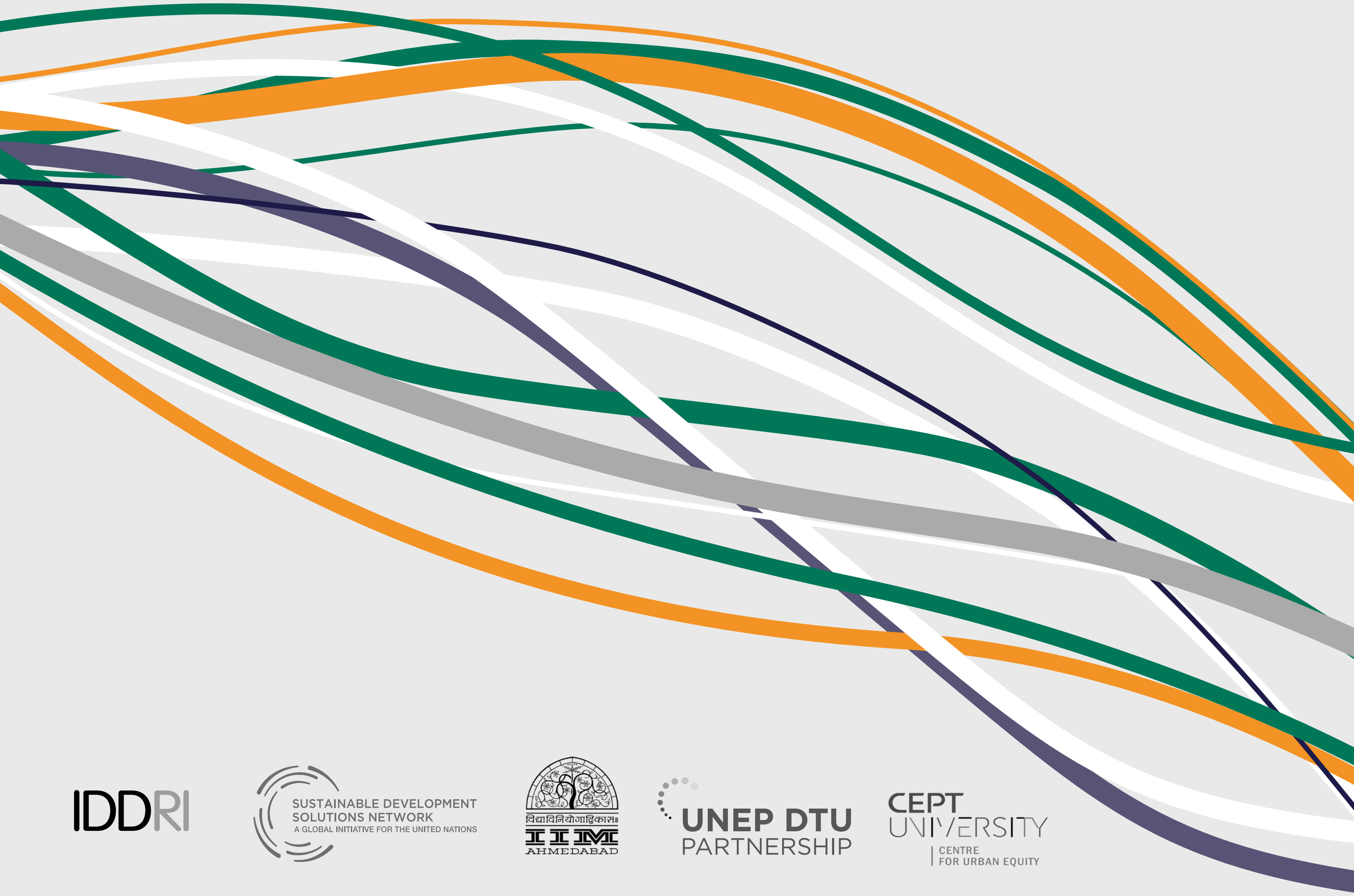
IN 2015 Report

pathways to deep decarbonization *in India*



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Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP), an initiative of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their energy systems by 2050 in order to achieve a low-carbon economy and significantly reduce the global risk of catastrophic climate change. Built upon a rigorous accounting of national circumstances, the DDPP defines transparent pathways supporting the decarbonization of energy systems while respecting the specifics of national political economy and the fulfillment of domestic development priorities. The project currently comprises 16 Country Research Teams, composed of leading research institutions from countries representing about 70% of global GHG emissions and at very different stages of development. These 16 countries are: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

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The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support of practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

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1 Introduction

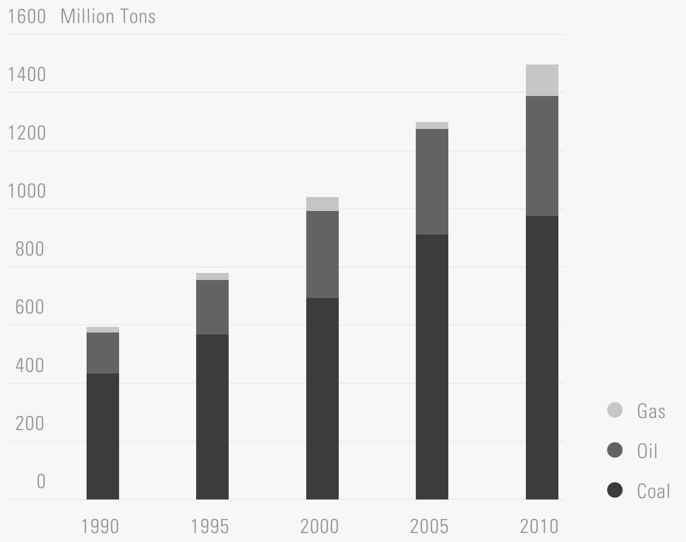
India has endorsed the long term UNFCCC target of limiting the increase in the global average surface temperature to 2°C above the preindustrial level. India made a voluntary commitment at COP15 in Copenhagen to reduce the emission intensity of GDP in the year 2020 by 20 to 25% below 2005 levels. India's National Action Plan on Climate Change (NAPCC)', released in June 2008 (GoI, 2008), includes eight national missions focused on mitigation, adaptation and knowledge (Table 1).

In early 2015, four additional missions were proposed by the Prime Minister's Council on Climate Change: a wind power and a waste to energy mission aimed to augment sustainable low carbon energy supply and a coastal health and hu-

Table 1 Missions of the National Action Plan on Climate Change

Sr. No.	National mission	Objectives	Concerned Ministry
Eight Approved Missions			
1.	National Solar Mission	Target of deploying 100,000 MW of grid connected solar power by 2022. To reduce the cost of solar power generation in the country through policies and large scale deployment goals; R & D and increase domestic production	Ministry of New and Renewable Energy
2.	National Mission for Enhanced Energy Efficiency	To unlock energy efficiency opportunities through market-based approaches	Ministry of Power
3.	National Mission on Sustainable Habitat	Extending the existing energy conservation building code Better urban planning and modal shift to public transport Recycling of material and urban waste management	Ministry of Urban Development
4.	National Water Mission	comprehensive water data base in public domain and assessment of impact of climate change on water resource; promotion of citizen and state action for water conservation, augmentation and preservation; focused attention to vulnerable areas including over-exploited areas; increasing water use efficiency by 20%, and Promotion of basin level integrated water resources management.	Ministry of Water Resources, River Development and Ganga Rejuvenation
5.	National Mission for Sustaining the Himalayan Ecosystem	Conservation of biodiversity, forest cover, and other ecological values in the Himalayan region, where glaciers are projected to recede To develop national capacity to regularly assess the health status of the Himalayan Ecosystem Enable organizations for policy-formulation and assist States in the Indian Himalayan Region for implementation of priority actions for sustainable development	Ministry of Science and Technology
6.	National Mission for a "Green India"	To increase forest/tree cover to the extent of 5 million hectares and improve quality of forest/tree cover on another 5 million hectares Enhance ecosystem services like carbon sequestration and storage, hydrological services and biodiversity and provisioning services Increase forest based livelihood income for about 3 m households	Ministry of Environment, Forests and Climate Change
7.	National Mission for Sustainable Agriculture	Promoting sustainable agriculture through adaptation measures focusing on; 'Improved crop seeds, livestock and fish cultures', 'Water Use Efficiency', 'Pest Management', 'Improved Farm Practices', 'Nutrient Management', 'Agricultural insurance', 'Credit support', 'Markets', 'Access to Information' and 'Livelihood diversification	Ministry of Agriculture
8.	National Mission on Strategic Knowledge for Climate Change	The plan envisions a new Climate Science Research Fund that supports activities like climate modelling, and increased international collaboration; it also encourages private sector initiatives to develop adaptation and mitigation technologies	Ministry of Science and Technology

Figure 1: CO_2 Emissions from Fossil Fuel Combustion (1990-2010)



man health mission aimed to enhance resilience and adaptive responses to climate change. The targets of these missions are being worked on and their formalization is awaited.

Overall, India's approach to climate change mitigation is based on delineating and implementing actions which are aligned to national sustainable development goals as well as to the globally agreed 2°C stabilization target. India's GHG emissions in 2007 were 1,727 million tons of CO_2e, 58% of which come from the energy sector (MoEF, 2010). Between 1994 and 2007, overall emissions grew at a rate of 3.3%, with the highest growth rate shown by the electricity sector followed by transport, residential and other energy sectors (ibid). Figure 1 shows the CO_2 Emissions from fuel combustion between 1990 and 2010.

2 Research Approach and Assessment Framework

2.1 Scenario Visions

The analysis in this report considers two scenarios, each representing a distinct 'Deep Decarbonization Pathway (DDP)' for India that corresponds to the global 2°C climate stabilization target. The scenarios span the period from 2010 to 2050. The scenarios and the analysis in this report are limited to the mitigation of CO_2 emissions from fossil energy use in India. The two scenario storylines differ in terms of underlying development perspectives as vividly articulated by Mahatma Gandhi:

"A technological society has two choices. First it can wait until catastrophic failures expose systemic deficiencies, distortion and self-deceptions… Secondly, a culture can provide social checks and balances to correct for systemic distortion prior to catastrophic failures."

The framing of scenarios captures, in the broad sense, two alternative perspectives:

1. A '*conventional deep decarbonization scenario*' (referred to as 'Conventional' throughout this report) that follows the forward-looking neoclassical economic framework that assumes existence of perfect markets dynamics. It finds the mix of mitigation actions in India that are aligned, via a common global carbon price trajectory, to cost-effective global mitigation actions to deliver the 2°C climate stabilization target. In reality though, the ideal market conditions are far from the real dynamics in the developing countries, like India, which are undergoing simultaneous socio-economic transitions in income, demography, urbanization, industrialization and institutions including the markets.
2. A '*sustainable deep decarbonization scenario*' (referred to as 'Sustainable' throughout this

report) that follows a 'development first' framework wherein the CO_2 mitigation actions are back-casted from the national sustainability goals set at the end-time horizon. The goals as well as the actions to achieve them are attuned at levels that are feasible as one gets closer to the present time. The iterative readjustment process takes into account the constraints and systemic imperfections while simultaneously shaping the development pathway and the emissions. The term 'development pathway' is used here is to represent the roadmap of actions that are aimed to simultaneously shape these transitions and thereby maximize the net total benefits. Scenarios can manifest in many shades, each shaping a distinct 'development pathway'. In this report we construct and analyze two scenarios to demonstrate the following: *first*, how will the two distinct national development visions, the corresponding socio-economic and environmental policies and the global mitigation target shape India's energy system and deliver alternate 'deep decarbonization pathways' for India? ii) how shall alternate 'deep decarbonization pathways' compare vis-a-vis national sustainable development goals such as sustainable energy for all (SE4ALL), energy security and clean air? and iii) how would the 'social value' of carbon differ across alternate scenario?

The scenarios are described next.

2.2 Scenario Architectures

Both scenarios presume that the global agreement to achieve 2°C stabilization is in place and that India is participating in the corresponding global mitigation effort following the principles of 'common but differentiated responsibility (CBDR) and respective capabilities' (UNFCCC Article 3.1), 'cost-effectiveness' (UNFCCC Article 3.3) and the 'right and the mandate to promote sustainable development' (UNFCCC Article 3.3). Recognizing that the mitigation efforts over the past two decades have lagged behind the set of cost-effective actions that optimally respond to the 2°C stabilization target and acknowledging that the global carbon budget available through the century to remain within this target has shrunk now to below a trillion tons of CO_2e, this report analyzes only the 'deep decarbonization pathways' for India. The report therefore does not assume the existence of a benchmark reference scenario of a world with unmitigated carbon emissions recognizing UN Secretary General Ban Ki-moon's exhortation that '.. *there is no "Plan B" for action as there is no* '*Planet B*' (UN News and Media, 2014[1]). Both the scenarios thus assume global and national commitment to the global 2°C stabilization target. The two Indian scenarios though differ in terms of alternate perspectives, ways and means by which India may participate in the global stabilization efforts. The storyline of the 'conventional' scenario presumes economic growth as the central development objective and perfect markets as the key institutions to influence the behavior of economic actors. The low carbon transition in this framing is achieved through the imposition, on the Indian economy, of a global carbon price corresponding to the global climate stabilization target. The framing of the 'sustainable' scenario aims to meet proposed targets of multiple sustainable development goals, including a national low carbon emission target, by the year 2050. The roadmap of actions is back-casted by iteratively adjusting the actions that deliver these targets cost-effectively. Figure 2.1 shows the underlying architecture of the DDP scenarios.

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[1] http://www.un.org/apps/news/story.asp?NewsID=48766#.VVL5LbeJh9A

2.3 Scenario Storylines

The alternate paradigms underlying the two scenarios (Figure 2.1) lead to two distinct storylines. Both scenarios agree on the aim to craft a deep decarbonization pathway for India that is aligned to the global climate stabilization target. The two storylines differ on the visions to craft India's future socio-economic architecture. The scenarios are assessed using a soft-linked integrated modeling system (described in section 2.4) which derives carbon prices from a global integrated assessment model. The national level analysis is carried out using a techno-economic model. The information on socio-economic drivers of a scenario is provided as exogenous input.

'Conventional' Scenario

This scenario assumes the existence of a universal carbon 'cap and trade' market and/or equal cross-border 'carbon tax' regime that follows the global cost-effective carbon price trajectory. An identical global carbon price (or tax) trajectory applies to India. For this scenario, the carbon price (see Table 2.1) is assumed to follow Lucas *et. al.* (2013). This scenario assumes the Indian economy to be market driven, whereas the social and environmental goals are viewed as 'external' to the in-situ market dynamics and are 'internalized' via the instruments that operate via the 'invisible hand' of the market.

India's long term energy demand and emissions trajectory will be largely influenced by the transitions it will go through – mainly in demography, income, urbanization, industrialization and governance. The key drivers of national socio-economic development, e.g. GDP, population and urbanization are specified exogenously (see Table 2.2). Population growth and urbanization, in the Conventional Scenario, are based on the UN median demographic forecast (UNPD, 2015). Population continues to grow, albeit at a declining rate even in the conventional scenario, through the coming decades and will reach 1620 million in 2050. The conventional scenario assumptions for GDP growth follow the expectations from the literature (GoI, 2006, OECD, 2012, Dhar and Shukla, 2014).

Figure 2.1: DDP Scenarios – Alternate Paradigms and Architectures

About a third of India's population now lives in urban areas. Urbanization is expected to rise through the coming decades and nearly half of India's population will reside in urban areas in 2050 (UNPD, 2015). Household size, incomes and consumption patterns vary in urban and rural areas. The form and pattern of urbanization will hence have significant influence on future energy use and emissions (Pathak et al., 2015). India, with its huge population, shall be transitioning to a middle income phase by mid-21st century. The conventional scenario is urban-centric. Its caricature of urban growth assumes self-organizing processes akin to a metaphorical *favela* regime (Jacoby, 2005). The organic urban growth dynamics shall lead to large cities with unevenly distributed income and high inequality, characterized by high energy and resources intensive life-styles by the upper income sections and resource poverty and unclean environment for the lower income groups. The conventional scenario will pay scant attention to sustainable rural development. This will sustain the use of local biomass energy resources and inefficient and unclean traditional combustion technologies by a sizable section of the rural population.

The conventional scenario assumes the availability of global technologies evolves in response to a global carbon price corresponding to the 2°C climate stabilization target. Due to the low response of demand-side technologies to a carbon price, behavioral lock-ins, high transaction costs and information asymmetry, the primary focus for the low carbon actions in the conventional scenario is on the supply-side of the primary and secondary (electricity) energy resources and technologies. In the case of electricity generation, the supply-side focus, depending upon national circumstances, may bring to the fore nuclear and carbon capture and storage (CCS) technologies as key options for deep decarbonization. The scenario storyline assumes government policies related to these technologies will internalize the aggregate external costs and risks associated with nuclear and CCS. Since India, has a sizable domestic endowment of coal, CCS appears as an energy security option besides being a low carbon option for electric power plants and high carbon intensive industries like steel and cement. The absolute and relative risks from these technologies need specific attention in the comparative assessment of scenarios.

The conventional scenario includes stated and intended government programs such as targets for solar energy and energy efficiency and policies to address air quality and energy security concerns. India's nuclear program was

Table 2.1 Global Carbon Price

	2020	2030	2040	2050
USD	40	60	80	130

Ref: Lucas et. al. (2013)

Table 2.2: GDP and Population

	2010	Conventional Scenario 2030	Sustainable Scenario 2030	Conventional Scenario 2050	Sustainable Scenario 2050
Population (million)	1206	1476	1434	1620	1509
Households (million)	247	365	356	502	473
GDP (Billion $)*	1397	6489	6002	25664	23007
GDP per capita GDP ($)	1158	4397	4186	15842	15247

constrained in the past on account of the restrictions on the access to global technology and fuels. As these constraints no longer exist, the conventional scenario assumes market competition to decide nuclear energy penetration and also assumes that the official safeguards internalize all the external costs and risks. The conventional scenario assumes commercial CCS technology to be available after a decade and uses existing, albeit highly uncertain, estimates of storage potential to develop supply curves of CCS technology.

Demand-side interventions such as energy efficiency technologies, building codes, fuel-economy standards for vehicles, and appliance standards, are introduced in the analysis via policies which are included as a part of exogenous assumptions.

Sustainable Scenario

This scenario represents an alternate world view of development in India as compared to the market -efficiency centered perspective of the Conventional Scenario. Its storyline follows the 'sustainability' rationale, akin to the IPCC SRES B1 global scenario (IPCC, 2000). This scenario takes an integral view of the social, economic and environmental goals as in the 'inclusive green growth' paradigm (World Bank, 2012) with a view to decouple national economic growth from a highly resource intensive and environmentally inferior conventional path. The sustainable scenario aims at creating a 'low carbon society' (Kainuma et al., 2012) as opposed to the conventional paradigm which at best aims to construct a 'low carbon economy'

Compared to the conventional scenario, the sustainable scenario assumes measures such as higher investments in education and health, which lead to lower fertility rates (Dreze & Murthy, 2001) and therefore lower population (Table 2.2).

The sustainable scenario assumes policies, programs and actions that are aligned to deliver economic, social and environmental goals so as to maximize net total benefits and meet multiple national objectives. The scenario assumes the proactive introduction of a variety of measures that enhance technology innovation and deployment, improve governance and promote sustainable behavior. An assortment of policy instruments include a 3R (reduce, reuse, recycle) approach towards dematerialization and resource efficiency; targeted policies to enhance human development indicators such as those influencing demography and urbanization, land use and urban planning, sustainable infrastructure choices and the existence of global technology transfer and financial mechanisms to support low carbon actions.

The sustainable scenario also assumes a strong push for using India's large renewable energy potential (GoI, 2015) (Table 2.3) and developing sustainable low carbon regional energy architectures via cooperation among South-Asian nations (Shukla & Dhar, 2009) for energy and electricity trade and the effective use of shared water and forest resources. Elements that decouple the key sustainable development goals and low carbon target from economic growth are thus anticipated in the scenario storyline.

The urbanization and regional development story in the sustainable scenario is very different from the conventional one. This scenario assumes policies that support small and medium-sized urban settlements which can generate employment for the growing labor force and lead to higher economic growth and balanced development (Kundu, 2011). The rate of urbanization is the same for both scenarios. The sustainable scenario assumes a more homogenous distribution of urban population compared to the top-heavy approach in the conventional scenario, where urban population will be concentrated in and around the million plus cities forming large city regions. Policies aimed at supporting small cities, towns and large rural centers will enable growth in these cities and improve the quality of life (Chandrashekhar and Sharma, 2014). The introduction of such policies in the sustainable scenario is assumed to result in evenly distributed urban population in small and medium cities. This will also facilitate better implementation of low carbon mobility plans, providing infrastructure and improving green cover resulting in improved quality of life. The sustainability scenario also takes into consideration a series of sustainability actions implemented in urban areas including e.g. municipal sector responses like solid waste (and sewage) to energy, efficient electric motors, increasing green cover, groundwater recharge and efficient municipal services including street-lighting.

In the sustainable scenario, sizable investments are made to gain non-economic benefits from social and environmental sectors. The GDP is lower in the Sustainable scenario, by around 10% vs. the Conventional scenario in 2050, as the focus is on the quality of growth. The scenario assumes increased government spending on health, education, equitable development and environmental quality. Per capita income in the sustainable scenario is about 5% lower than in the conventional scenario, but since a sustainable world delivers other social and environmental benefits, the overall welfare shall be higher.

In India, like in all emerging nations, huge investments are committed to build new energy infrastructure, buildings, vehicles and appliances and energy intensive industrial products. The key is to prevent technological and behavioral lock-ins by driving an early shift towards lower emissions pathways. In the sustainable scenario this is achieved by implementing near-term measures like investment in efficient infrastructure and technology shifts such as using wires to transmit electricity from mine-mouth power stations rather than transporting coal to distant power stations (Shukla et. al., 2009), instituting high energy efficiency standards for energy intensive industries, early implementation of demand-side measures such as technical efficiency, reduction of heat losses, behavioral shifts such as wearing ‘cool biz’ apparel (Tan, 2008; Holroyd, 2008), incentives to leapfrog by replacing less durable devices like tube lights by LED lamps, etc. Like the conventional DDP scenario, the

Table 2.3: Potentials of Technologies for India

Technology	Technical Potential (GW)	Reference/s
Solar PV	748 GW	GoI (2015)
Solar CSP	1700 GW	Purohit et al. (2013)
Wind	748 GW	Gomathinaygam (2014)
Biomass	23 GW**	MNRE (2015)a
Small Hydro (<25 MW capacity)	20 GW	MNRE (2015)b
Waste to Energy	2,780 MW by 2050	GoI, (2014)e
CCS	105 Gt 572 Gt 47-48 Gt (good quality) 142.5 Gt (High) 63 Gt (Intermediate) 45 Gt (Low)	Dooley et al. (2005) Singh (2013) Holloway et al. (2009) Viebahn et al. (2014)

Wind power density greater than 200 W/sq. m at 80 m hub-height with 2% land availability in potential areas for setting up wind farms @ 9 MW/sq. km

*** Including cogeneration*

sustainable DDP also assumes that India's mitigation actions correspond to a globally cost-effective 2°C climate stabilization regime. However, the sustainable scenario has many interventions which lower carbon emissions. This can be interpreted in two different ways. *First*, the application of an identical global carbon price trajectory over India, as in the conventional scenario, can result in lower emissions in the sustainable scenario. India can sell the emissions saved in the sustainable scenario and use the carbon revenues to partly pay for the additional costs of some sustainability measures.

Second, if we allow the sustainable scenario to emit same cumulative emissions from 2015 to 2050 as in the conventional DDP scenario, then the shadow price of carbon mitigation in the sustainable DDP scenario would be what can be alternatively called as 'social value of carbon'.

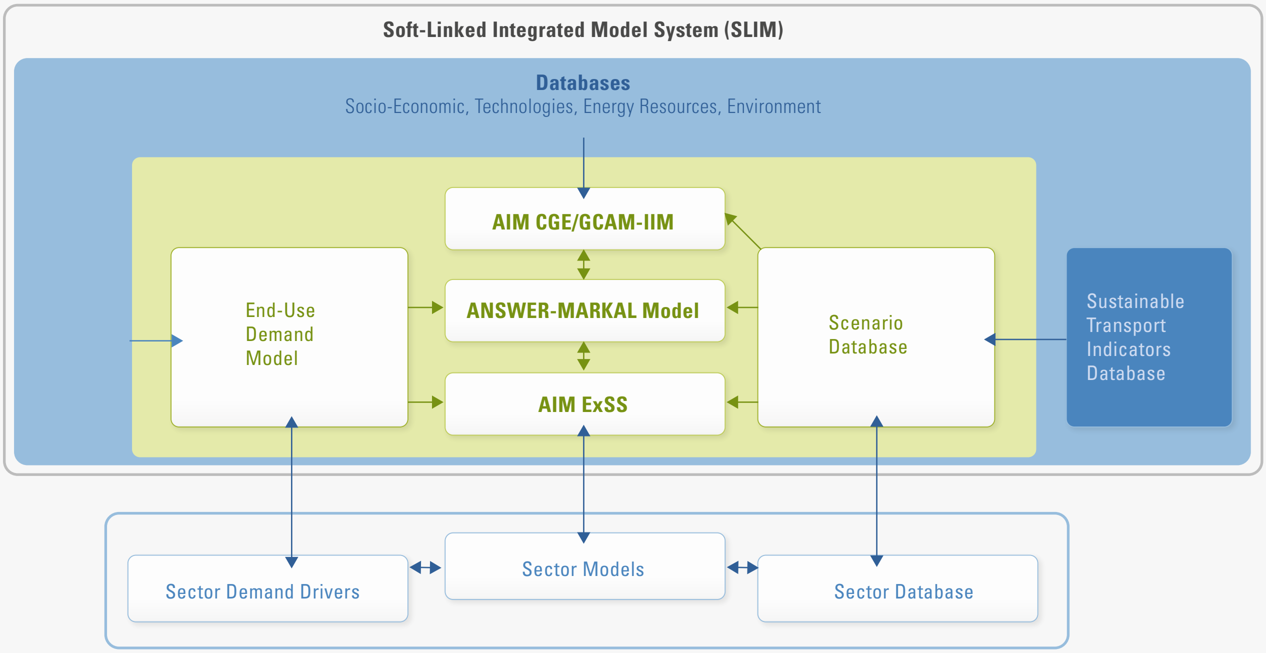
2.4 Model and Modeling Framework

Model

Long-term scenario assessments of national energy and environment policies involve answering varied questions of interest to the policymakers. The diversity of national circumstances and specificities of contexts, e.g. regional hierarchy or sector specificity, calls for finding specific answers to each question. The model choice therefore needs to follow a 'horses for courses' approach. We use a soft-linked integrated modeling system (Shukla et. al, 2015) which includes various models with exogenous mechanisms to intermittently introduce key information across the models.

Soft-linking of models is a practical strategy adapted to assess a given scenario on both top down and bottom up models. Figure 2.2 shows a stylized sketch of a soft-linked modeling system (SLIM) used for assessing the DDP scenarios.

Figure 2.2: Soft-Linked Integrated Model System(SLIM)



The macro-economic consistency between the models runs of different models is ensured, for a specific scenario assessment, by making the key drivers of a scenario (e.g. GDP, population) and other exogenous data comparable across each linked model. Typically, output data from a model is passed as an input to another model belonging to a different hierarchy. The shared data helps to modify the output from the recipient model. For example, the GDP loss resulting from a carbon tax regime which is assessed endogenously by the top-down model can then be used to alter the exogenous GDP inputs or the end-use demands provided as the input to the bottom-up model (Shukla et. al., 2008). The altered results of the bottom-up model, e.g. technology shares, are then passed on to the top-down model. The iterations are done by passing information exogenously and sequentially across the models.

Thus, while the mathematical architectures of the models are not hard-linked, the models are soft-linked through information exchange. A shortcoming of this approach is that it does not ensure theoretically consistency and full convergence of the results of the integrated model system. Its key advantage is the simplicity of using models which follow different paradigms and operate at different hierarchies and thereby receive deeper policy insights with less complexity of modeling.

SLIMS used for the scenarios assessment includes a Global CGE model which computes the global carbon price for a 2°C stabilization scenario. In the case of DDP, we use the carbon price from a global macroeconomic assessment reported in Lucas et al. (2013). The bottom up analysis is done using the ANSWER-MARKAL model (Noblesoft Systems, 2007), MARKAL is an energy system model which optimizes energy system costs for a scenario while maintaining consistency with system constraints such as energy supply, demand, investment, technology potentials and emissions (Loulou et al., 2004). The MARKAL database includes a rich characterization of energy supply and demand-side technologies and fuels. The ANSWER MARKAL model framework has been used extensively for scenarios assessment for India (Shukla et. al., 2008; Shukla et. al., 2009; Dhar & Shukla, 2015).

Modeling Framework

The "Delhi Declaration" of the UNFCCC COP8 in 2002 formally recognized the net economic, social and environmental benefits from aligning climate change and sustainable development actions. Sustainable development is shown to be an eminent framework for aligning development policies on a climate friendly track (Halsanæs and Shukla, 2007). Whereas significant opportunities for gaining multiple development and climate benefits exist, especially in developing countries, these have to be netted through policies and programs that align the development and climate agendas.

We use a back-casting framework (Shukla et al., 2015), a preferred modeling assessment approach, for scenarios assessment aiming to align national development goals with a global climate target like 2°C stabilization. It is a normative approach which permits modelers to construct desirable futures and specify upfront certain targets and then delineate alternate pathways to attain these targets (IPCC, 2001). We take long-term national development objectives as benchmarks guiding the model dynamics and use SLIMS framework to delineate the roadmap of actions to achieve the national goals. Back-casting exercises are suitable to internalize sustainability benefits within a global carbon price to assess the 'social value of carbon' (Shukla et. al., 2008) for a nation. The back-casting approach does not aim to produce blueprints; it rather points to the relative feasibility and the social, environmental, and political implications of different development and climate futures on the assumption of a clear relationship between goal setting and policy planning (Dreborg, 1996).

3 DDP Scenarios Assessment

The scenarios framing in this report differs compared to the traditional low carbon scenario assessments which is benchmarked vis-à-vis a 'business-as-usual (BAU)' type reference scenario. The two scenarios for India assessed in this report are both low carbon scenarios. Each assumes India's cost-effective participation in the global deep decarbonization corresponding to a 2°C temperature stabilization during the 21st century. The scenarios differ, as discussed in Section 2, in terms of their approach towards socio-economic development strategies in India. This section presents the comparative modeling assessment results of the two scenarios.

The focus of the scenarios assessment is on the evolution of India's energy system under deep decarbonization commitments. Scenarios are compared in terms of primary and final energy mix, emission from the energy system, electricity generation capacity additions and related costs. The comparative assessment also includes energy demand from the residential, commercial, transportation, industry and agriculture sectors.

3.1 Overall Energy and CO_2

The primary energy supply reported in this study follows the IEA accounting format for renewables like solar, hydro and wind and therefore a transformation efficiency of 100% is considered. The transformation efficiency in the case of nuclear is also 100%

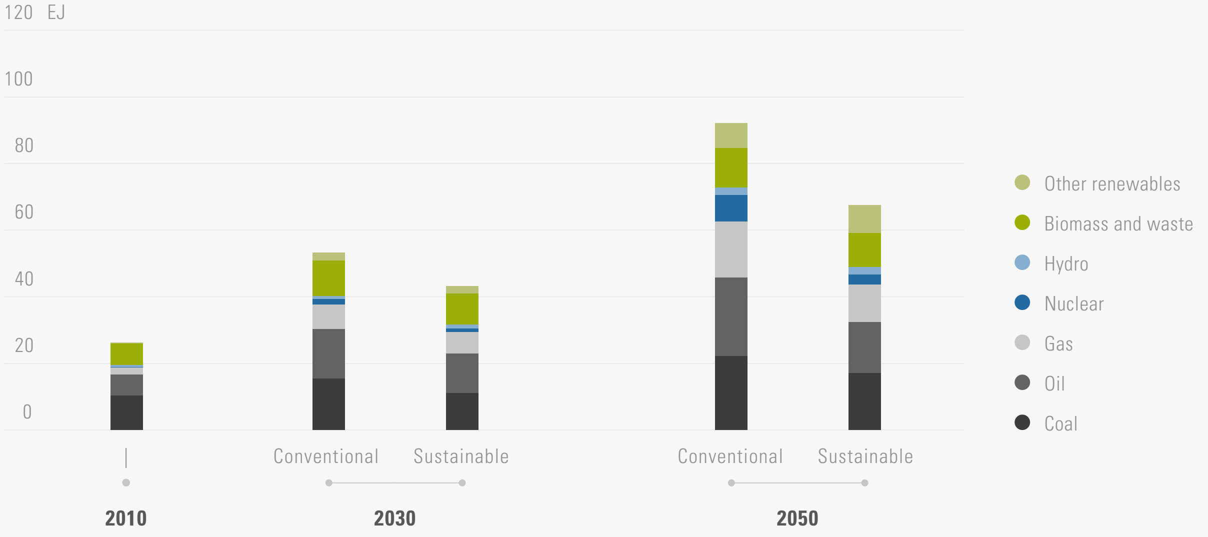
Primary Energy Supply

Figure 3.1 shows primary energy supply for the two scenarios.

In the conventional scenario: i) primary energy supply in 2050 is 3.9 times higher compared to 2010, ii) dependence on fossil fuels continues, though the share of fossil fuels declines, iii) the fossil fuel mix shifts towards natural gas, iv) the contribution of renewables in primary energy rises to twenty percent and that of nuclear to six percent in 2050. .

In the Sustainable scenario, i) primary energy supply in 2050 is nearly a quarter (i.e. 24 EJ)

Figure 3.1: Primary Energy Supply



below that in the conventional scenario, ii) dependence on fossil fuels declines compared to the conventional scenario, iii) renewables contribute nearly a third of primary energy and nuclear contributes three percent in 2050.

Both scenarios show a strong decoupling between economic growth and energy use. Energy intensity of GDP reduces from 12.96 TJ/million USD in 2010 to 3.08 TJ/million USD in 2050 in the conventional scenario. The sustainable scenario shows even stronger decoupling with the energy intensity declining to 2.53 TJ/million USD in 2050.

Final Energy Demand

Figure 3.2 shows final energy demand for the two scenarios.

In the conventional scenario, final energy demand increases 4.3 times between 2010 and 2050, a growth that is higher than that of primary energy. This is partly due to the enhanced role of nuclear and renewables (Figure 3.2), which are assumed to have a transformation efficiency standard of 100%. The higher transformation efficiency in the refining and power generation using fossil fuels is responsible for the remainder. The final energy mix shows a transition towards electricity, as 27% of final energy demand is met by electricity by 2050.

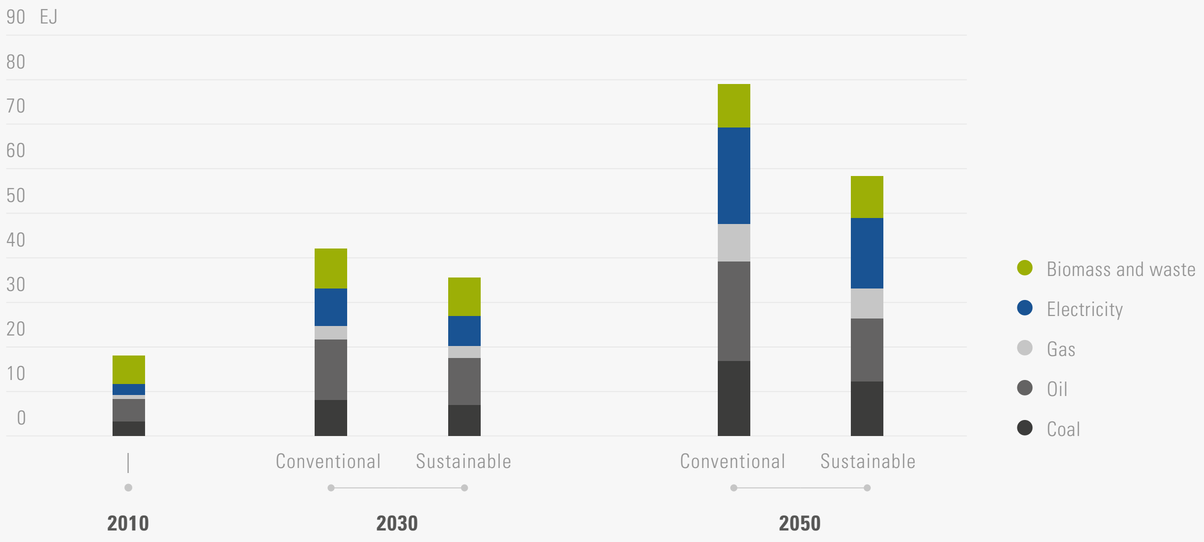
In the sustainable scenario strategies such as reduce, reuse and recycle bring down final energy demand, which by 2050 is lower by 20.7 EJ, i.e. a quarter of the final energy demand of the conventional scenario. The final energy fuel mix gets more diversified, similarly to the conventional scenario.

Electricity

Figures 3.3 and 3.4 show the mix of electricity generation and electric power capacity for the two scenarios.

Electricity generation rises seven fold between 2010 and 2050 due to the increased reach of electricity infrastructure and end-user preference for electricity as a cleaner, convenient and readily available energy resource. The rising penetration of electrical devices offers opportunities for decarbonizing energy since the electricity supply sector is more flexible to using

Figure 3.2: Final Energy



low carbon energy resources and technologies. Coal is currently the mainstay of electricity generation in India, but both scenarios show a limited growth in coal based power generation. The share of coal power generation declines by 2030 and coal based power plants account for only a quarter of total generation in the conventional scenario, down from two-thirds in 2010. The decline is even greater in the sustainable scenario. Nuclear power bridges the gap created in base load generation due to the decline of coal. Nuclear electricity generation increases in both scenarios, however its share is significantly higher in the conventional scenario.

The ambitious renewable energy targets of the government are responsible for an early increase in renewable power in both scenarios. Renewable energy makes up 58% of electricity generation capacity in 2050 in the conventional scenario and 71% in the sustainable scenario. In the short term (i.e. until 2030), renewable capacity is pre-dominantly a mix of hydro, wind, solar and biomass. Post 2030, solar power capacity dominates the mix. In the sustainable scenario the share of solar within renewables is even higher. Nuclear capacity increases rapidly in the conventional scenario to 350 GW by 2050 as an alternative to coal for base load power capacity. Coal based capacity however starts making a reentry post 2030 in combination with CCS as an option for low carbon electricity. In the sustainable scenario nuclear capacity grows relatively slower to 120 GW by 2050 since the overall demand for electricity is 30% lower, and the scenario assumes greater policy support for renewables.

CO_2 Emissions

CO_2 emissions increase in both scenarios despite a high carbon price (Table 2.1) in the conventional scenario. In the Sustainable Scenario however, a deeper decarbonization can be achieved through sustainability oriented policies which reduce energy demand and support low carbon energy resources and technologies. Thus, the sustainable scenario has CO_2 emissions which are 33% lower than in the conventional scenario in 2050. In both DDP scenarios for India, the *per capita CO_2 emissions*[2] remain low - at 1.95 t CO_2

Figure 3.3: Electric Generation

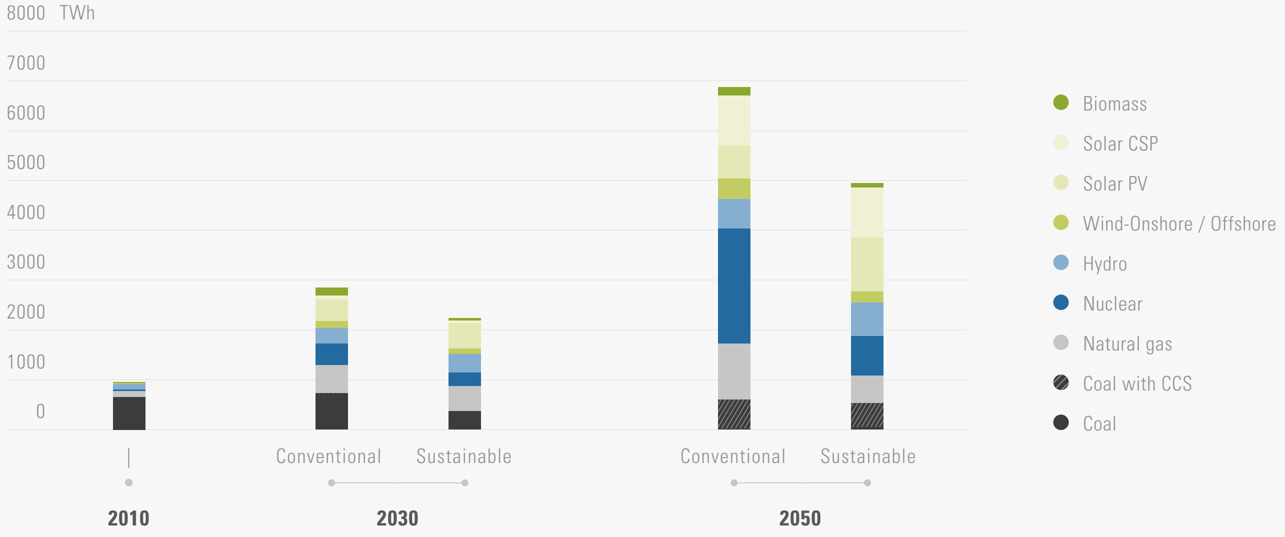
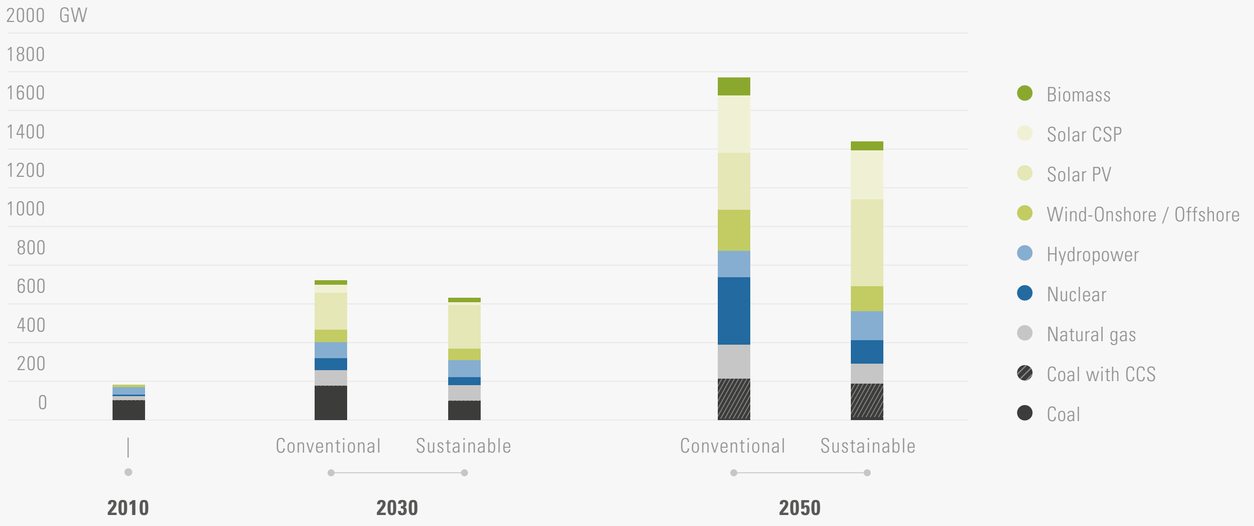


Figure 3.4: Electric Generation Capacity



in the conventional and around 1.4 tCO_2 in the sustainable scenario and just marginally higher than 1.24 t CO_2 per capita in 2010 (Table 3.1). A key factor for achieving low emissions is the significant decarbonization of electricity, which happens quickly in both scenarios. The CO_2 intensity of electricity reduces from 771 g CO_2 per KWH in 2010 to 56 g CO_2 per KWH in the sustainable scenario and 66 g CO_2 per KWH in the conventional scenario by 2050. The decarbonization of electricity gains importance with time since the share of electricity in final energy increases from 14% in 2010 to 27% in 2050 in both scenarios. The decarbonization of electricity is mainly due to substitution of coal by nuclear and renewables and using CCS along with coal. Deep decarbonization manifests in the strong decoupling between economic growth and energy use and this is true for both scenarios. The energy intensity of the economy declines from 13 TJ per Million US dollars in 2010 to 3.1 TJ per Million US dollars in 2050 in the conventional scenario and 2.5 TJ per Million US dollars in the sustainable Scenario (Table 3.1). The per capita final energy use, which is a low 0.36 toe in 2010, will increase in both scenarios and reach 0.92 toe in the sustainable scenario as compared to 1.16 toe in the conventional scenario.

Table 3.1: Energy and CO_2 Indicators

	2010	2030 Conventional	2030 Sustainable	2050 Conventional	2050 Sustainable
Total CO_2 (Million Tons)	1497	2810	2138	3157	2108
Primary Energy Supply (EJ)	25.9	53.1	43.2	91.7	67.3
Energy Intensity (TJ/M$)	13.0	6.5	5.9	3.1	2.5
CO_2 intensity (tCO_2/TJ)	82.7	66.7	60.1	40.0	36.1
CO_2 intensity (tCO_2/1000 US$)	1.07	0.43	0.36	0.12	0.09
CO_2 per capita (tCO_2/capita)	1.24	1.9	1.49	1.95	1.4

[2] The per capita CO_2 emissions are only from energy use

Coal has been the largest contributor to energy related CO_2 emissions in India. Deep decarbonization shall lower emissions from coal but emissions from oil and gas will continue to grow (Figure 3.5). Emissions from coal are reduced due to the diffusion of carbon capture and storage (CCS) in the power generation, cement and steel sectors. CCS becomes economically viable at sites with high storage potential and low transportation and sequestration costs such as depleted oil and gas wells. The scenarios assessment in this report used information from literature and experts to map CO_2 storage sites, their potentials and identification of low cost and high prospective storage locations where industries with large emissions can be located in bunches.

The estimates of geological storage potential of CO_2 in India vary in the literature depending on the methodology and sources considered. Estimates of the theoretical storage potential in basalt formations and saline aquifers vary widely and range from 105 GT (Dooley et al. 2005), to 143 GT (Holloway et al 2009) and up to 572 GT (Singh et al. 2006; Singh 2013). Three scenarios of theoretical CO_2 storage capacity in India by Viebahn et al. (2014) estimates the storage potential in oil and gas fields to range from 2 to 4.5 GT and from 43 to 138 GT in aquifers. The CO_2 storage capacity used in Table 3.2 is much below even the lowest good quality estimate of 45 GT by Viebahn et al (2014). This leaves sizable potential available for CO_2 storage post-2050 in the ongoing and new coal power capacity and coal using industries.

For coal power generation between 2030 and 2050 the entire CCS option is assumed to be available. The main enabler for CCS is the carbon price, which increases steadily and reaches US $ 130 per ton CO_2 by 2050 (Table 2.1). The cumulative CO_2 sequestered is much higher in the conventional scenario (Table 3.2) on account of a higher overall demand for energy. The supply of low cost CCS storage, which can be made available in depleted oil and gas wells and also coal mines has been limited to around 5 billion tCO_2 (Holloway et. al., 2009); beyond this level, the supply curve is steep owing to uncertainty

Figure 3.5: CO_2 Emissions

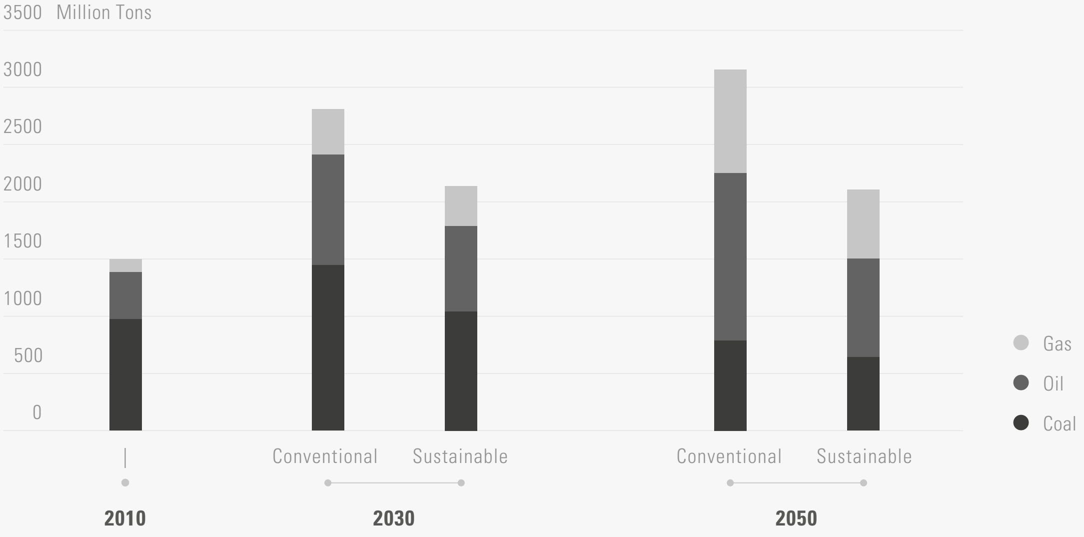


Table 3.2: Carbon sequestsered by CCS (Million Ton CO_2)

	2030		2050	
	Conventional	Sustainable	Conventional	Sustainable
Power Generation	6.7	7.5	473.6	409.5
Steel	4.3	0	831.7	564.1
Cumulative CO_2 Sequestered by CCS: 2010 – 2050			9929	7099

in the availability of storage and in the ability to marry large point sources with CCS storages (Garg & Shukla, 2009).

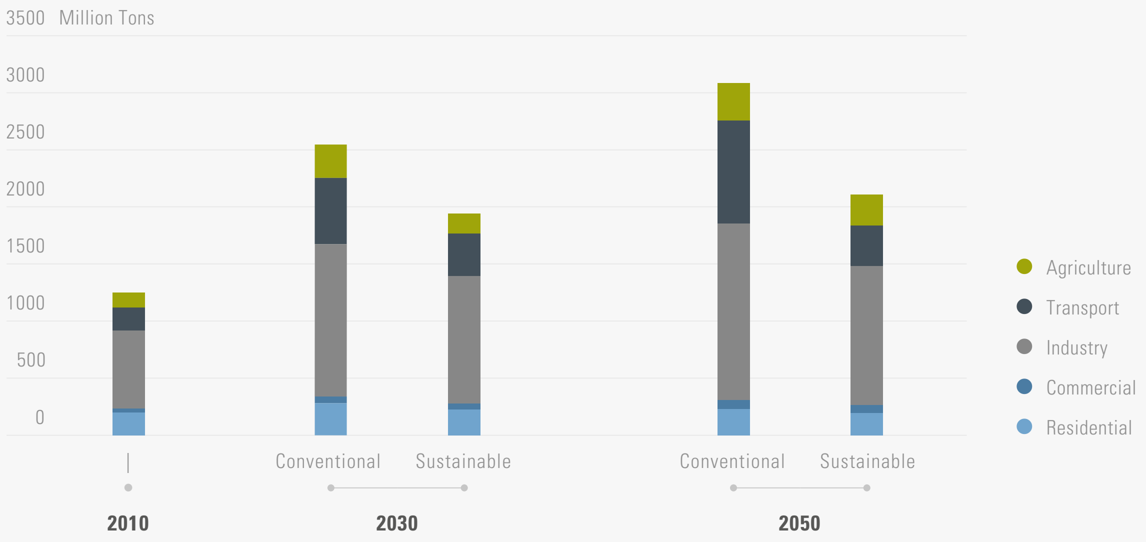
3.2 Energy Demand and CO_2 Emissions by Sectors

This section presents energy and CO_2 emissions from the energy end-use sector. CO_2 emissions from the electricity sector are apportioned to the sectors in proportion to their electricity consumption. The electricity sector is the largest contributor to CO_2emissions. It accounted for more than half of energy related CO_2 emissions in 2010. In both decarbonization scenarios, emissions from electricity decrease significantly over time. In the conventional and sustainable scenarios, CO_2 emissions from the electricity sector are 14.5 % and 13.2% respectively of the 2050 total . In both decarbonization scenarios industry dominates in the share of CO_2 emissions (Figure 3.6). the transport sector emerges as the second largest contributor as the share of transport emissions goes up by 4.5 times by 2050 over 2010 levels in the conventional scenario.

Industry

The industry sector is a significant contributor to India's GDP. Rising urbanization, demand for residential and commercial buildings and construction of infrastructure are the key drivers of the demand for steel, cement, aluminium and

Figure 3.6: CO_2 Emissions by Sector



other energy intensive products. The final energy demand from industry in the Conventional Scenario will go up six times in 2050 relative to 2010. Energy demand from industry, however, is 22% lower in the sustainable scenario compared to the conventional scenario (Figure 3.7), due to targeted interventions in the transport and building sectors (see Section 4). The energy intensity of industry declines from 483.6 toe per million US dollars in 2010 to 137.5 toe per million US dollars in 2050 in the conventional scenario and 121.2 toe per million US dollars in the sustainable scenario.

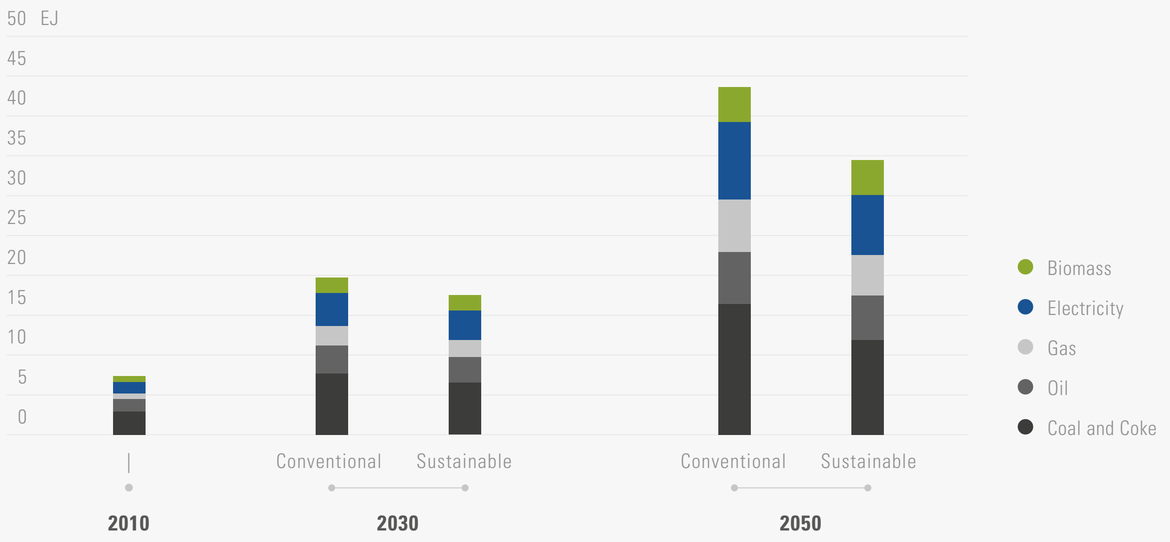
A second factor for decarbonizing industry is the changing fuel mix which reduces the CO_2 intensity of energy use in both scenarios - from 3.92 tCO_2 per toe in 2010 to 1.49 tCO_2 per toe in the conventional scenario and 1.48 tCO_2 per toe in the sustainable scenario in 2050. The fuel mix shifts away from coal and the share of coal drops from 40% of the total mix in 2010 to 38% in 2050 in the conventional scenario and 35%in the sustainable scenario. Coal use in the steel and cement sector is also combined with CCS, which further reduces CO_2 emissions from coal. The other explanation for the reduced CO_2 intensity of energy is the increased role of gas in the fuel mix. The rising share of electricity also contributes, as electricity itself gets increasingly decarbonized.

Residential Buildings

The assessment for the building sectors considers only the operational energy demand and associated carbon emissions from buildings. The embedded energy in building construction materials is accounted for in the industry sector.

Cooking, lighting, space cooling and other domestic appliances are the major drivers of end-use energy demand in residential buildings in India. Demand and fuel sources for residential energy use vary between urban and rural areas. Energy resources used by urban and rural households include electricity, piped natural gas (PNG or simply gas), liquefied petroleum gas (LPG), kerosene, firewood, crop residue, animal dung and solar energy. Energy demand for cooking in urban areas is largely met through LPG, with low-income populations using kerosene and

Figure 3.7: Energy demand in Industry

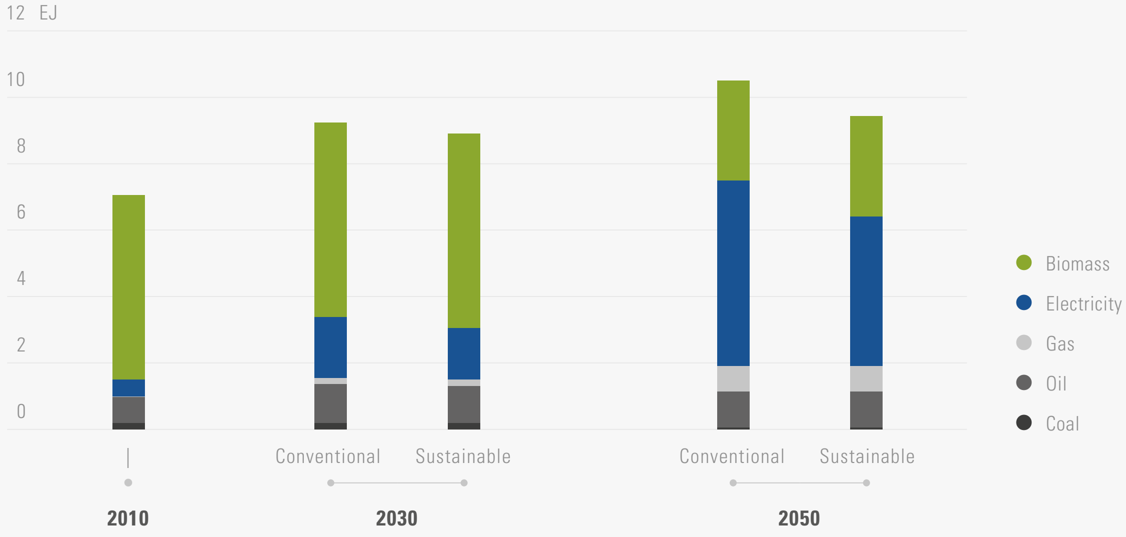


biomass. Rural households still depend predominantly on traditional biomass for cooking. Electricity is preferred for lighting. Kerosene is used as a gap filing fuel. It is used for cooking in areas facing shortage of traditional fuels or access to LPG. It is also used for lighting during electricity shortages or by those who lack access to electricity. In recent years, there has been a significant increase in the penetration of clean energy sources including gas, LPG and electricity. A sizable chink of the population, however, lacks access to cleaner energy resources. In 2011, three fourths of rural households used biomass for cooking compared to 15% of urban households (NSSO, 2013).

Growth of population, urbanization and household income are the key drivers of demand for residential floor space, space cooling and household appliances. Final energy demand from residential buildings will increase from 7 EJ in 2010 to 10.5 EJ in 2050 in the conventional scenario (Figure 3.8). An important transition in the residential sector is the decline in the share of traditional biomass. The fuel mix shifts away from traditional biomass to gas and electricity. This change in fuel mix reduces indoor and local air pollution but increases the carbon intensity of residential energy, assuming traditional biomass supply as sustainable and therefore having no CO_2 incidence. The CO_2 intensity of energy use declines nearly equally in both scenarios from 3.92 tCO_2 per toe in 2010 to 1.49 tCO_2 per toe in 2050. The higher share of electricity also contributes to the decrease in energy intensity as electricity gets increasingly decarbonized in both scenarios. The sustainable scenario also assumes building construction practices that optimize natural ventilation and cooling, therefore reducing energy demand. In addition, a greater policy push for energy efficient appliances and sustainable behavior contributes to lower end use demand in the sustainable scenario compared to the conventional scenario.

The sustainable scenario assumes that the supply of clean and affordable energy will be prioritized and that related goals will be embedded in national and regional policies and plans. As a result, access to housing and clean fuels, especially among

Figure 3.8: Energy Demand in Residential Buildings



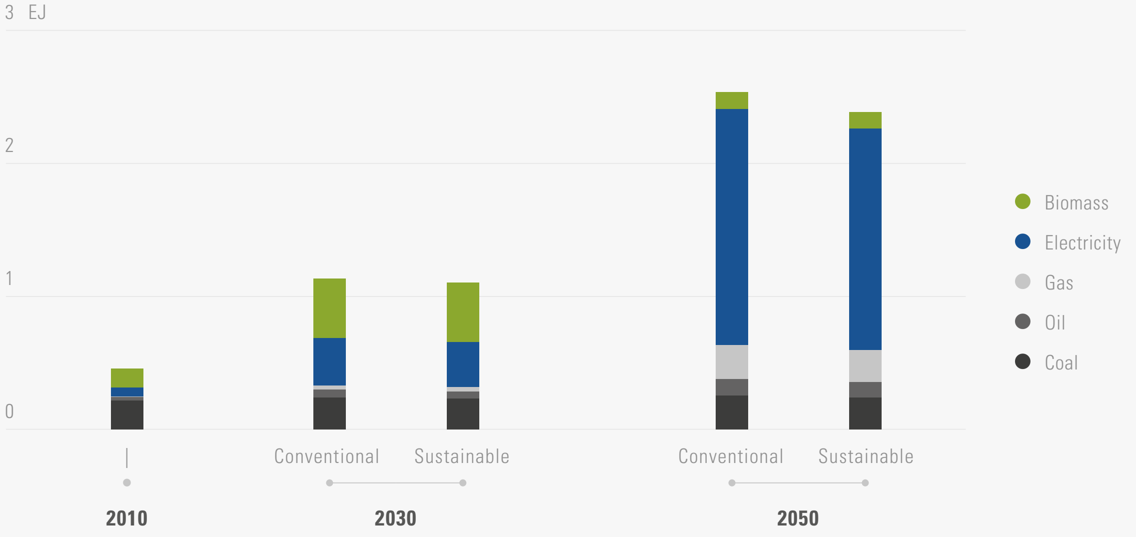
peri-urban and rural households is greater in the sustainable scenario. These reduce dependence on kerosene and biomass and enhance efficiency of energy use and reduce indoor air pollution for low income households. The sustainable scenario is differentiated from the conventional scenario by: i) higher access to cleaner fuels for households, ii) building design and construction practices that reduce energy consumption, and iii) sustainable behavior towards adopting energy conservation practices. These result in a 15% lower energy demand from residential buildings in 2050 in the sustainable scenario compared to the conventional scenario (Figure 3.8).

Commercial Buildings

Services are delivered by government, non-government and commercial entities. The term commercial buildings include buildings used for providing all services. These include government buildings, schools, hospitals and other institutions along with commercial offices, retail outlets, malls, hotels, restaurants etc. Commercial built up area in India in 2010 was 659 million square meters (Kumar et al., 2010). There is a significant range in energy intensity in commercial spaces based on type, size, and location.

The trends show a rising contribution of the service sector to national GDP. Future trends show an increase in commercial floor area driven by the rising service sector and an increase in energy intensity per unit floor area due to greater use of lighting, cooling and appliances which enhance comfort as well as productivity (Chaturvedi et al., 2012). In the conventional scenario, there is a fourfold increase in energy consumption in commercial buildings from 2010 to 2050. The share of biomass in rural commercial spaces like local food processing and eateries increases till 2030, however it declines post-2030 as access to electricity and LPG increases in rural areas. The sustainable scenario assumes higher penetration of buildings compliant with energy efficiency standards in line with the national Energy Conservation Building Code (ECBC) (BEE, 2015). End use demand, especially for lighting and space cooling, will drive up the energy demand in both scenarios. Stricter implementation of building

Figure 3.9: Energy Demand in Commercial Buildings



codes and a stronger push for energy efficient appliances in the sustainable scenario results in a 5% reduction of energy demand in commercial buildings compared to the conventional scenario in 2050 (Figure 3.9).

Transport

The transport sector is the second highest CO_2 emitting sector after industry. Propelled by the growth of the economy, urbanization and industrialization, transport energy demand will rise rapidly through the next several decades (Figure 3.6). In the conventional scenario, transport energy demand increases from 2.6 EJ to 15.3 EJ (Figure 3.10), a 5.8 fold increase between 2010 and 2050.

The shift towards gas, electricity and bio fuels helps reduce CO_2 intensity of transport energy use from 3.17 tCO_2 per toe in 2010 to 2.50 tCO_2 per toe in 2050 in the conventional scenario. Compared to the conventional scenario, the sustainable scenario assumes an even greater policy push that at first aims to reduce transport demand (e.g., by better land-use planning, promotion of non-motorized transport in cities and practices like working from home), then shift demand to more efficient modes (e.g., from private vehicles to public transport), improve vehicle efficiency (stricter application of fuel economy standards) and promote alternative fuels (e.g. bio-fuels) and vehicles (e.g. electric vehicles). These policies achieve a reduction of the share of transport sector CO_2 emissions in 2050 to 16% in the sustainable scenario compared to 28% in the conventional scenario. Energy demand in the sustainable scenario in 2050 would be 8.1 EJ by 2050, only a three-fold increase over transport energy use in 2010.

Agriculture

The structure of energy use in the agriculture sector has changed significantly in recent years moving from animal power towards greater mechanization. This has led to a significant increase in energy consumption. Between 1970 and 2010, the share of fossil energy use by the agriculture sector doubled. Land constraints and rising demand for agro-commodities portends an intensifi-

Figure 3.10: Energy Demand in Transport

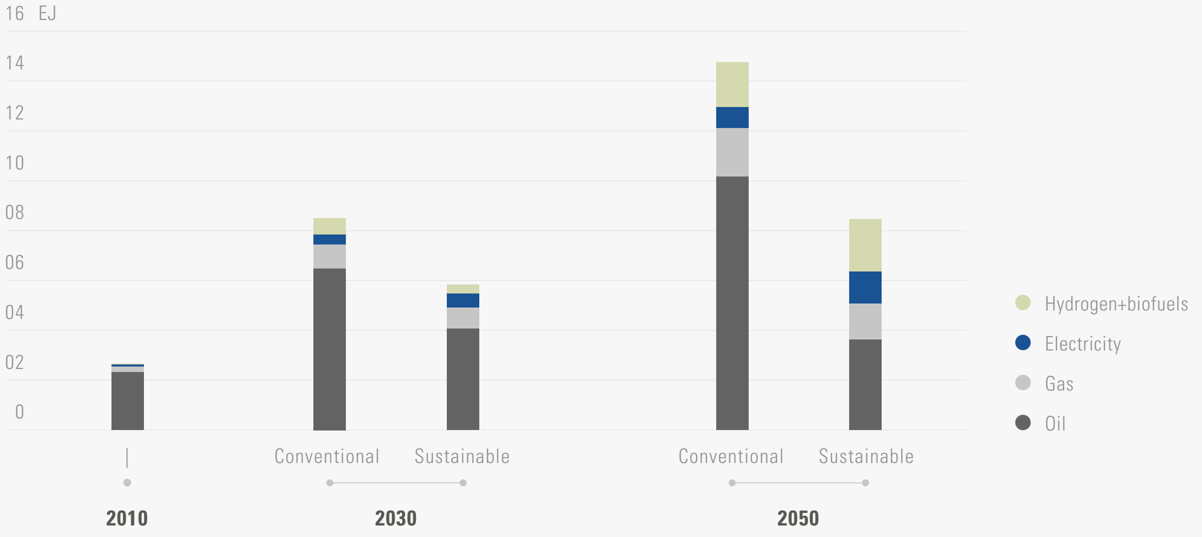
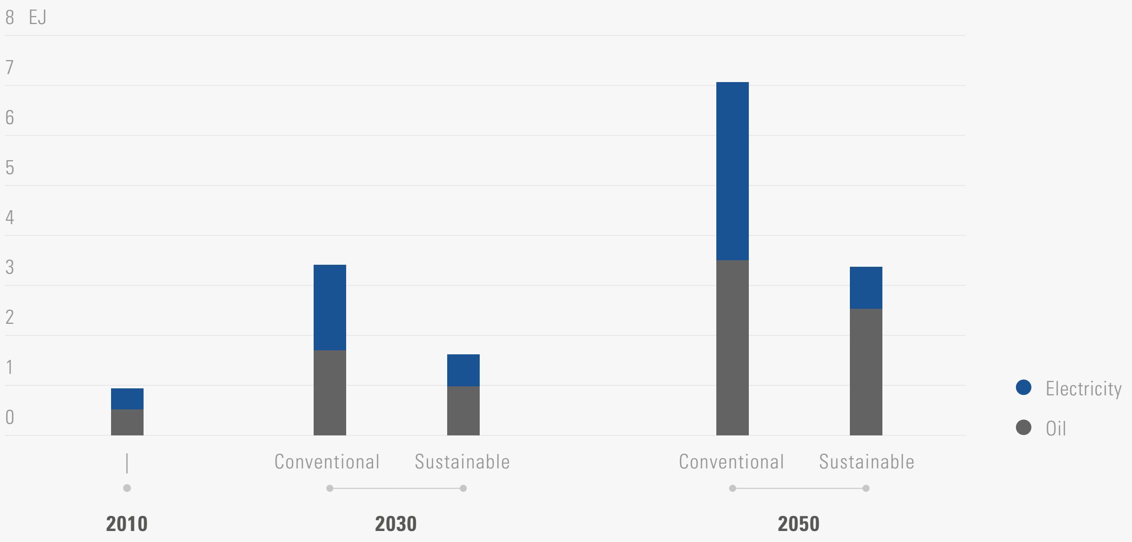


Figure 3.11: Energy Demand in Agriculture



cation of agriculture requiring greater direct energy inputs in future. The net sown area, which was 140 million ha (MoSPI, 2014) in 2014, is expected to remain same till 2050, but greater mechanization and irrigation shall drive energy demand with continued dependency on oil and electricity. The conventional scenario assumes enhanced efficiency of irrigation pump-sets and farm machinery. However, it also considers a decline in water table due to unsustainable water use. In the conventional scenario, energy demand from agriculture increases seven-fold (Figure 3.11). The sustainable scenario, in addition to energy efficiency measures, assumes improved faster implementation of farming practices such as the use of scientific assessment of fertilizer dosages, organic farming, soil enriching, cropping in line with agro climatic conditions, conservation tilling and drip irrigation (see Uprety et. al., 2012 for a detailed description). As a result, energy use by the agriculture sector in the sustainable scenario is only half that of the conventional scenario in 2050.

4 Deep Decarbonization Policy Landscapes

Energy is associated with all human activities. National energy systems can be decarbonized by reorienting national development actions or direct alteration of energy-centric actions. This report outlines two 'Deep Decarbonization Pathways'; a 'conventional' pathway shaped by energy market centric policies and a 'sustainable' pathway that centers on development policies. This section presents a comparative picture of the two scenarios over a time horizon spanning 2010 to 2050. The assessment shows, for each scenario, the implications of scenario specific policies on sectoral energy demand, energy supply, investments in power plants, environmental indicators, energy security risks and the social value of carbon.

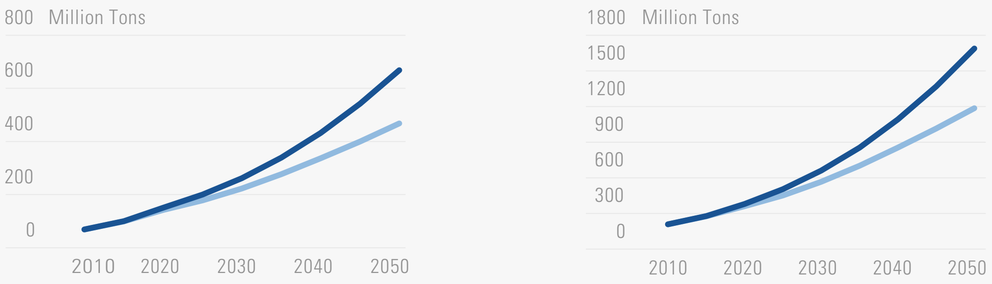
4.1 End use Demand-side Policies

A mixture of policies reduce final demand for energy across end-use sectors in the sustainability scenario. These policies include instituting measures like 3R, which reduce end-use demand but not necessarily consumer's utility from the consumption of targeted goods or services. Demand side measures are implemented through participative governance and coordinating institutions, which reduces the transaction costs of executing demand-side interventions. In the sustainable scenario, aggregate final consumption is significantly lower due to a lower population (Table 2.2); however on a per capita basis demand is lower in the sustainable scenario due to a range of actions targeting technological change and behavioral change in line with the scenario storyline. Sector specific drivers also influence demand for industry sub-sectors. For instance, demand for steel and cement is influenced largely by the dynamics of the buildings sector. The subsections below outline the impacts of demand side policies on deep decarbonization in both scenarios.

Industry

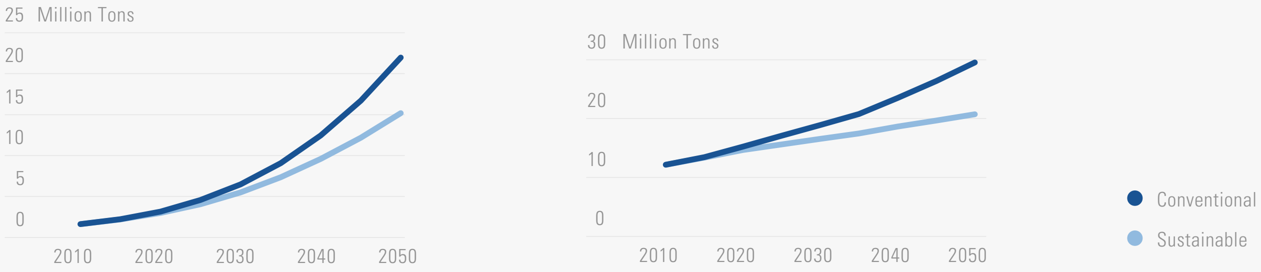
The energy intensity (toe per unit of GDP) of industry shows a downward trend (Section 3.2.1) in both decarbonization scenarios. A large part of the decline can be attributed to efficiency measures within energy intensive industries and to a lesser extent to the transformation of the industry mix from primary to secondary and tertiary commodities e.g., from steel to more value added products. Key energy and emissions intensive industries in India include iron and steel, cement, fertilizer, aluminium, chemicals, and paper (MoEF & CC, 2015). The Government of India has, in recent years, announced market oriented policies and measures aimed at increasing the energy efficiency of industries. The Perform, Achieve & Trade (PAT) scheme under the

Figure 4.1: End use Demand in Industry Sectors



a. Steel Demand

b. Cement Demand



c. Aluminium Demand

d. Fertilizer Demand

Mission on Enhanced Energy Efficiency (NMEEE) aims at enhancing energy efficiency in seven energy intensive industry sectors and the power sector through trading of energy savings certificates (MoEF&CC, 2015). Other reforms include initiatives to improve the performance of the supply chain including improved availability of coal, better transport infrastructure, and capacity enhancement of coal washeries. These aside, a myriad energy conservation programmes, energy efficiency standards and guidelines have also been announced by the Government of India and state governments.

Energy demand from energy intensive industries like steel and cement is also a function of the demand for energy intensive products. The demand for energy intensive industrial products e.g., steel and cement is influenced by transitions in the building and transport sectors. Buildings account for energy and emissions embedded in construction materials as well as the operational energy used during their lifetime. In the sustainable scenario, lower population and urbanization patterns that promote compact and walkable cities lead to lower floor area and lower demand for transportation (Dhar & Shukla, 2015). Reduced demand for space and transportation help bring down the demand for steel and cement (Figure 4.1 a & b). The sustainable scenario also envisages sustainable building construction with lower embedded energy. Sustainable building materials can reduce 52% of total embedded energy and 45% of total embedded CO_2 (Shams et al., 2011). Higher acceptance and use of low-energy materials, use of local materials and resources, mixing fly ash in cement, recycling of industrial waste and reuse of construction wastes in the sustainable scenario bring down the demand for conventional building construction materials- mainly steel, cement and bricks. India is an important producer and consumer of aluminum globally and a significant growth of aluminium demand is expected in future (Figure 4.1c). Demand in the sustainable scenario however is 31% lower compared to the conventional scenario in 2050 (Figure 4.1c) on account of policies promoting higher recycling rates of aluminium scrap and the sustainable use of aluminium in other sectors.

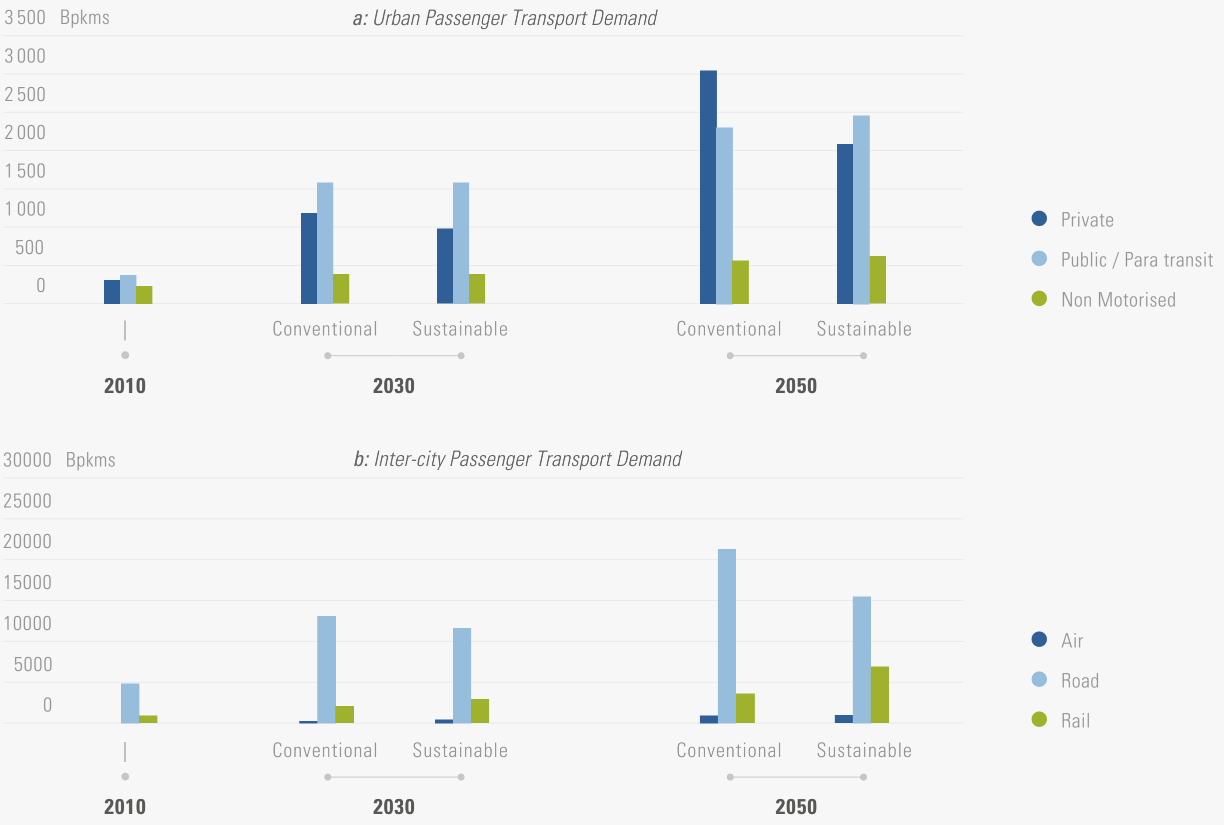
The fertilizer industry in India is a major contributor of greenhouse gas emissions (MoEF & CC, 2015). Growing population and rising incomes would increase demand for food, which in the conventional scenario is expected to increase the demand for fertilizers (Figure 4.1d). The sustainable scenario, besides a lower population, also assumes better farming practices including higher use of organic fertilizer, crop rotation and agricultural practices that conserve soil nutrients. As a result, fertilizer demand in the sustainable scenario is 30% lower than in the conventional scenario.

Transport

Transport is a rapidly growing end-use sector and accounts for around 32% of India's oil supply and contributes to 12.45% of energy-related GHG emissions (MoEF&CC, 2015). Driven by rising population, income and urbanization, India's energy demand from transport is projected to increase six-fold in 2050 from 2010 levels. This has a significant impact on key national sustainable development indicators like energy security and air pollution. Transport decisions interface with several other development policy areas, e.g. planning, energy, environment, technologies, development and finance. Transport decisions have inherent long-term lock-ins lasting through several decades. Policymaking in the transport sector needs a long-term perspective and concurrent attention to a multitude of development goals. National transport policies are crafted keeping an eye on the diversity of transport demand and the appropriate mix of modes, technologies, fuels and corresponding infrastructure. The transport system architecture varies at national and subnational levels and so do policy interventions.

Sustainable transport is the focus of several policies at the national and subnational level. The National Urban Transport Policy (NUTP) (MoUD, 2006), the National Policy on Biofuels (NPB) (MNRE, 2009), and the policy on electric vehicles (GoI, 2012) support clean and sustainable transport in India. Intercity transportation, where railways have lost ground to road transport, is witnessing initiatives such as dedicated rail freight corridors (Pangotra & Shukla, 2012) and development of high-speed rail links between cities for passenger transport. The 2014 NUTP provides an overall policy framework for integrated urban and transport planning and promoting non-motorized transport and public transport projects related to bus rapid transit and metro in cities. The 2009 NPB has focused on blending targets for ethanol in petrol and bio-diesel in diesel and is not feedstock specific and includes second generation biofuels using crop waste. It has achieved limited success with ethanol though Jatropha-based biodiesel has not gone beyond pilots since production costs are higher than purchase prices specified by the government (Purohit & Fischer, 2014). The National Electric Mobility Mission Plan (NEMMP) announced in early 2013 projects 6 to 7 million electric vehicles (EVs) on the road by 2020 (GoI, 2012)a.

Figure 4.2: Passenger Transport Demand



The sustainable deep decarbonization scenario assumes a faster implementation of policies related to urban transport, intercity rail, bio fuels and electric mobility. In cities this means faster implementation of mass transit systems including Metros and BRTS, improved infrastructure for non-motorized modes and integration between modes. This will facilitate a shift away from private motorized transport and increase the share of public transport and non-motorized transport in cities (Figure 4.2a). Integration of urban transport with city development plans and vertical integration of local and national plans will bring simultaneous benefits of reduced GHG emissions, improved mobility and better air quality (Pathak and Shukla, (2015). Better urban planning and strengthening of public transport is expected to bring down demand for urban passenger travel in the sustainable scenario by over 10% compared to the conventional scenario in 2050 (Dhar and Shukla, 2015). Current trends in intercity transport point to an increasing share of road and air and a declining share of rail. The efficiency of all modes improves in both scenarios. The sustainable scenario builds on the premise of targeted investments in railway infrastructure including the early introduction of high speed rail corridors. This will facilitate the shift towards rail, which explains the fact that the share of rail in total intercity transport demand doubles in 2050 in the sustainable scenario compared to the conventional scenario (Figure 4.2b) (Dhar and Shukla, 2015).

Buildings

The building sector in India is expected to undergo a major transition in the coming decades driven by an increase in population, urbanization and personal incomes. In residential areas this will be due to: 1. Demand for new residential floor space due to an increase in population and a decrease in household size, 2. Construction of housing to accommodate low income populations that will transit from informal housing (kutcha) to formal (pucca) houses, 3. Higher demand for floor space due to an increase in income among high income groups 4. Demolition and replacement of buildings, 5. Change in construction practices, and 6. Increase in energy intensity with increase in end-use demands, and especially space cooling. Given these expected transitions, both the embedded and operational energy demand from the building sector shall increase significantly in the future.

Per capita floor space in India is significantly lower than in developed countries and some developing countries. In 2010, average residential per capita floor space in urban areas was 10.9 square meters (sq. m) and 8.8 sq m in rural areas (NSSO, 2013). Floor space consumption varies significantly among different income classes. In 2010, average per capita floor space in the high income group in urban areas was 20 sq. m., five times that of the lowest income group. Residential floor space in India will continue to remain low in 2050 as compared to developed countries. Indian cities have relatively high densities. As population increases in cities, land supply in urban areas will be further constrained. In the conventional scenario, floor space consumption grows across all income groups; however, affluent households consume higher residential floor space, especially in urban areas.

Housing policies under the Ministry of Housing & Urban Poverty Alleviation are aimed to promote inclusive and sustainable development of habitats in the country by ensuring equitable supply of land, shelter and services at affordable prices across all income groups. Recently the government has announced an initiative to achieve Housing for all by 2022.[3] The initiative proposes building 20 million houses by 2022. This will include slum housing and affordable

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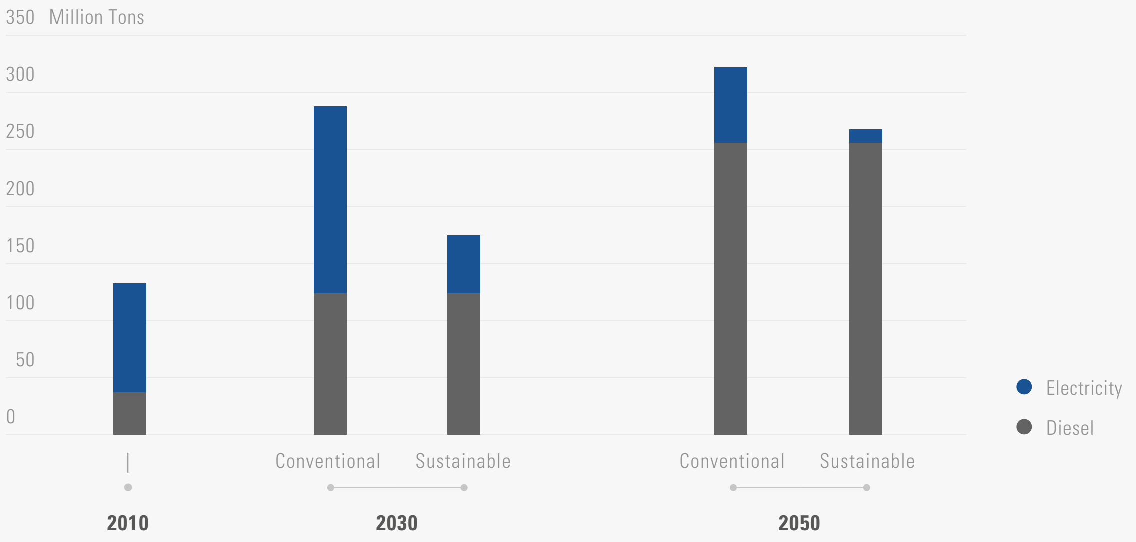
[3] http://pib.nic.in/newsite/PrintRelease.aspx?relid=114840 Accessed on May 3, 2015

housing for the lower socio-economic group in metros, small towns and urban areas. A Mission on Low Cost Affordable Housing is proposed to facilitate this. Financial support will include incentives on home loans and schemes to incentivize development of low cost housing. The sustainable scenario assumes the realization of the above targets and a more equitable distribution of residential built-up areas compared to the conventional scenario. Overall, residential floor space consumption is lower in the sustainable scenario compared to the conventional scenario due to lower population. Construction of affordable housing through public private partnerships and other financing mechanisms, bringing slums within the formal housing systems, and ensuring access to basic services for the urban poor are already outlined as objectives in current housing policies (MHUPA, 2015). The sustainable scenario envisages a more aggressive push on targets and faster implementation for ensuring housing and basic services to all sections of society. The floor area per capita is a little lower in the sustainable scenario, since distribution across income groups is considered to be more equitable. This would however require policies beyond those currently envisaged that discourage high per capita floor areas at high income levels. In addition, since the overall population is lower than in the conventional scenario, the floor area requirements are 5% lower in 2050 in the sustainable scenario.

Agriculture

Agriculture in India is due to witness a major transformation over the coming decades. The agriculture sector operates in two interfacing spheres; one is modern and market driven, while the other endures traditional production relations. The conventional and sustainable scenario storylines for the agriculture sector have distinct policy architectures for transforming the two spheres at different speeds and styles. The conventional scenario story assumes the sector to be rapidly transformed by market forces and sustainable scenario story assumes the sector to be primarily transformed by sustainability driv-

Figure 4.3: CO_2 Emissions from Agriculture



en policies while using markets for economic efficiency. This policy dichotomy keeps an eye on social goals such as employment, since the agriculture and allied sectors account for 18% of GDP and employ 50% of the work force (GoI, 2015). Electricity and diesel are the two main energy resources consumed by agricultural activities. Irrigation pumps and post-harvesting implements like thrashers use electricity. Diesel irrigation pumps exist in areas with uncertain electricity supply. Farming and transport equipment like tractors use diesel.

In the conventional scenario, market oriented policies drive mechanization, which leads to rapid rise in energy use in agriculture (Figure 3.11) despite the improved energy efficiency of irrigation pumps and other implements. In the sustainable scenario, sustainable agriculture policies alter farm practices and reduce the demand for water and other agro-inputs. These, together with improved technology efficiency, lead to a lower rate of growth in energy demand (Figure 3.11). Steep decarbonization of electricity in both scenarios keeps down the growth of CO_2 emissions from electricity (Table 4.1) but emissions from diesel rise at a higher rate in both scenarios due to the inability to stem CO_2 emissions during combustion (Figure 4.3). In the sustainable scenario aggregate energy use is lower compared to the conventional scenario. However, as the share of diesel in total energy is higher in the sustainable scenario, the emissions from the two scenarios differ only marginally in 2050 compared to the difference in energy use. Hence, targeting oil emissions from agriculture implements will be a robust policy choice.

4.2 Energy Supply Policies and Investments

The energy supply in both deep decarbonization scenarios gets increasingly diversified with low carbon resources and technologies progressively substituting coal and oil (Figure 3.1). The rising share of gas, nuclear and renewables reduce the CO_2 intensity of energy substantially (Table 3.1). A sizable reduction happens in the electricity sector and since the electricity share in final energy demand keep rising over time, the electricity sector becomes central to cleaning the energy supply. In both decarbonization scenarios the CO_2 intensity of electricity declines steeply from a high of 771 g per kwh in 2010 to near zero CO_2 content in 2050 (Table 4.1).

Renewable energy is a key pillar for decarbonizing electricity in both scenarios. Recognizing renewable resources and technologies as the robust options in any future energy system in India, the government has announced ambitious targets for renewable energy. Of the total installed electricity capacity of 243 GW in 2014, the share of renewable energy sources, including traditional biomass, was 12 per cent. Through a series of initiatives, the government has announced ambitious capacity targets of 100 GW for solar and 60 GW for wind power to be installed by 2022. These short-term targets would prevent long-term lock-ins into fossil based power system. The solar target includes 40% capacity through rooftop PV, which would also prompt decentralized applications to remote locations without access to electricity.

These renewable power capacity targets are supported by substantial financial incentives. Both

Table 4.1: CO_2 Intensity of Electricity Generation (grams CO_2/KWH)

	2010	2020	2030	2040	2050
Conventional	771	641	319	121	66
Sustainable	771	558	254	102	56

scenarios assume these short-term targets will be achieved and that the financial support to renewable energy, including for R&D, will sustain in the long-run. In the conventional scenario, apart from national policies, the global carbon price expectation is the main driver of renewables capacity additions raising the share of renewable electricity generation to 34% in 2050 compared to 4% in 2010 (Figure 4.3). In the sustainable scenario, renewable capacity is driven at first by policies to meet sustainability goals like energy security and air pollution and only secondarily by the global carbon price. Renewable energy takes up nearly half of the total electric generation capacity in the sustainable scenario (Figure 4.3). The lower electricity demand in the sustainable scenario, however, will result in lower financial commitments compared with the conventional scenario.

The second pillar of decarbonization of electricity is nuclear power. The share of nuclear generation capacity increases from 3% in 2010 to 34% by 2050 in the conventional scenario but only up to 16% in the sustainable scenario (Figure 4.4). The negative perception about the hazards from nuclear plants is still very high. Until recently, there were restrictions on India for importing fuel and technologies. The lack of clarity on the extent of liability has contributed to high uncertainty about capital and operating costs (Chaturvedi et. al., 2015). Under the conventional scenario, the share of nuclear is high (Figure 4.4) for two reasons. First, the high carbon price makes nuclear competitive vis-à-vis coal power plants despite the higher initial capital costs of nuclear capacity. Second, high demand for electricity in the conventional scenario makes nuclear competitive against more expensive renewable alternatives. In the sustainable scenario, lower electricity demand and higher risk aversion lead to relatively lower demand for nuclear power (Figure 4.4).

In the conventional scenario, 480 GW of new capacity are added between 2010 and 2050. In the sustainable scenario, new capacity additions are 20% lower than in the conventional scenario (Figure 4.5a).

The capital investments required to sustain the necessary levels of electricity generation capacity

Figure 4.4: Share of Nuclear and Renewables in Electricity Generation

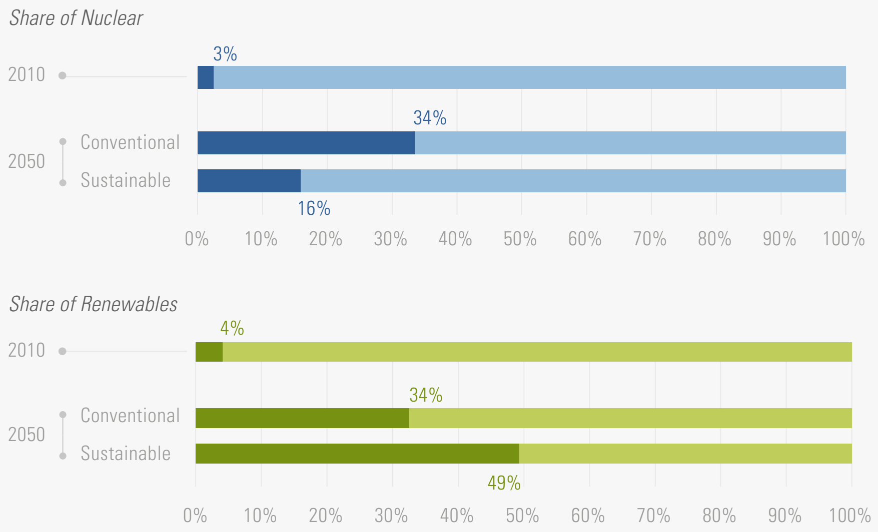
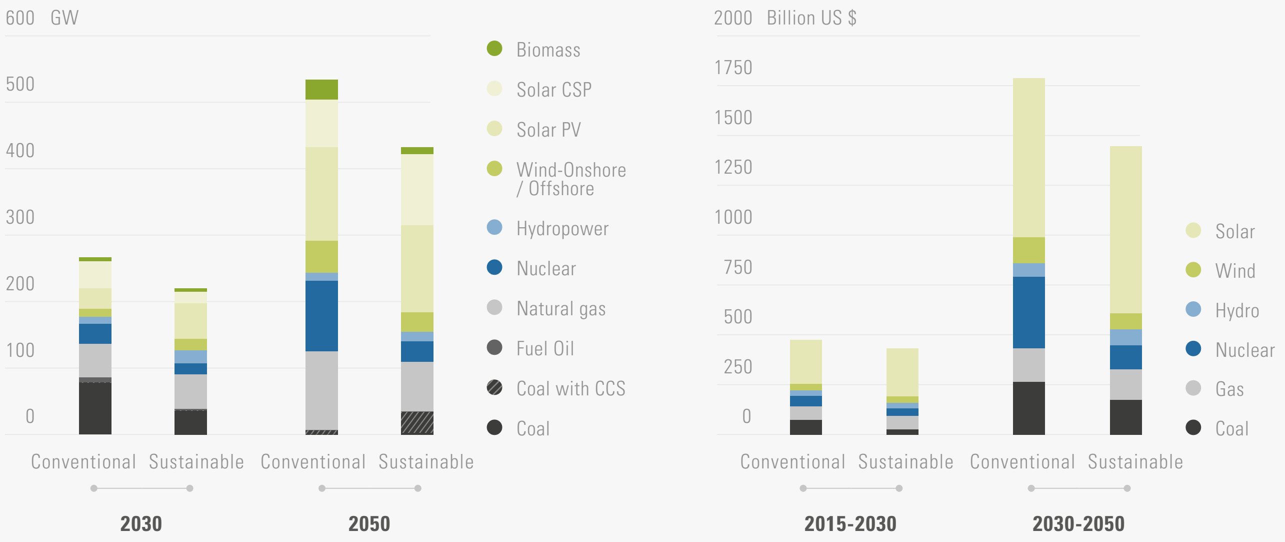


Figure 4.5 a: Electric Generation Capacity Additions and Replacements

4.5 b: Investments in Electricity Generation



are shown in Figure 4.5b Capacity additions of fossil based generation are lower compared to nuclear and renewables in both scenarios. In the conventional scenario, annual investments would increase from USD 25 billion per year between 2030 and 2050 to nearly USD 90 billion tons (Figure 4.5b). This would include a cumulative investment of USD 400 billion until 2050 in nuclear power capacity and over USD 1180 billion in renewable power capacity. The investment in power capacity is 17% lower in the sustainable scenario with over 60% of the total investments directed towards renewable capacity.

4.3 Sustainable Development Benefits

Climate change mitigation can deliver several co-benefits (co-costs and risks). Below is a comparative assessment of the two scenarios for co-benefits vis-a-vis two sustainability indicators - energy security and air quality. The aggregate co-benefits are assessed using the concept of 'social value of carbon' which is defined in the present context as the optimal trajectory for the shadow price of carbon in the sustainable scenario that would achieve the same cumulative emission as in the conventional scenario.

Air Pollution

On the national policy landscape, air pollution mitigation policies preceded the decarbonization agenda. The Government of India instituted numerous policies for fossil linked air pollution. Two focal areas of air pollution policies have been: i) vehicle technology and fuel improvement aimed to meet urban air quality standards, and ii) control of air pollutants from coal burning in industry and plants generating electricity. In the wake of rapidly rising fossil energy consumption, this conventional air control policymaking approach succeeded, albeit partially, to abate air pollution but contributed little to carbon dioxide emissions mitigation. Currently, Indian cities experience very high levels of air pollution (WHO, 2014) which is leading to serious health impacts. PM 2.5 is one of the key local pollutants and is associated with severe health risks. The transport sector accounts for 30%-50% of PM 2.5 emissions (Guttikunda & Mohan, 2014).

Evidently, decarbonization and air pollution abatement actions are naturally linked since they both originate from fossil fuel combustion. The current policy focus on sustainable development goals and the climate stabilization target have created an opportunity to align actions on both fronts. The analysis of such a sustainable deep decarbonization pathway shows that the same level of CO_2 emissions as in the conventional scenario can be achieved with sizable air pollution reductions by aligning sustainable development and deep decarbonization actions.

Sustainability actions deliver these conjoint benefits by reducing end-use demand, shifting consumption to cleaner modes and technologies and raising the ratio of clean energy in the energy supply-mix. Conventional approaches to air pollution focus on end-of-the-pipe technology and fuel related interventions like catalytic converters in vehicles or desulfurization equipment in the case of coal combustion in industry. The levers of air pollution control in the sustainable scenario are very different compared to the conventional track. For instance, the key mitigation actions in road transport would include urban design and planning to reduce travel, investments in infrastructure that facilitate modal shift to public transport and non-motorized transport and support for innovations and the development of alternative technologies (e.g. electric vehicles and energy storage devices). The implementation of targeted demand reduction measures can potentially reduce travel demand in the sustainable scenario by half compared to the conventional scenario in 2050. Lower travel demand translates into reduced energy demand and lower travel time. In addition, market based incentives for cleaner low carbon fuels like natural gas and bio-fuels deliver sizable CO_2 emissions mitigation as well as mitigation of $PM_{2.5}$ (Figure 4.6a).

SO_2 emissions in India come mainly from industry and power generation. Conventionally, SO_2 emission mitigation relies on the shift away from coal towards low carbon sources. Advanced technologies, dematerialization, recycling and sustainable behavior differenti-

Figure 4.6 a: PM2.5 Emissions from Road Transport

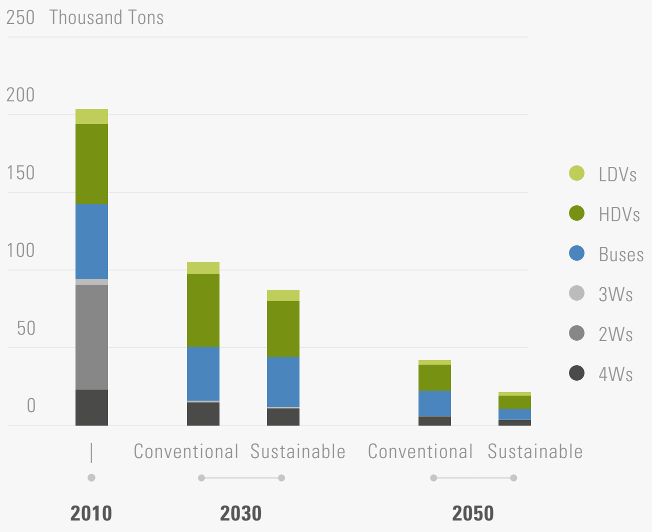
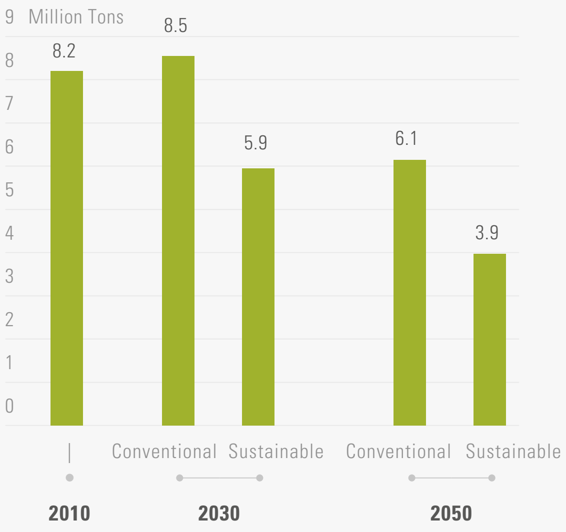


Figure 4.6 b: SO_2 Emissions from Energy



ate the demand for industrial products in the sustainable scenario from the conventional scenario. The fuel mix shifts to cleaner fuels. A simultaneous implementation of targeted environmental policies including desulphurization of coal, process efficiency, emission norms, and cleaner fuels is assumed. The sustainable scenario therefore delivers higher SO_2 reductions compared to the conventional deep decarbonization scenario (Figure 4.6b).

The analysis of 'Deep Decarbonization Scenarios' for India shows that 1. Both decarbonization scenarios make a positive contribution to air pollution mitigation in the long run, 2. Compared to the conventional 'climate centric' deep decarbonization approach, the sustainable scenario will deliver substantial air quality benefits 3. The benefits are greater when deep decarbonization measures and air pollution mitigation measures are crafted to align with the national sustainable development goals.

Energy Security

Energy resource endowments, technology stocks and demand for energy vary across nations. India is endowed with sizeable coal resources, as well as good solar and wind energy potential. India, though, lacks in oil and gas. Our assessment of future energy demand under a deep decarbonization pathway (DDP) shows rising imports of oil and gas in India. Over 80% of the country's oil demand is currently met through imports and by 2050 a significant proportion of the country's primary energy shall come from imports. This raises concerns vis-a-vis the four dimensions of energy security (Kruyt, 2009), namely the availability, accessibility, affordability and acceptability of energy.

Our analysis of two deep decarbonization pathways for India, each following distinct development paradigms but targeting an identical CO_2 emissions budget from now to the year 2050, results in very different energy security risk profiles.

Figure 4.7 a: Energy Security Index (NEID)

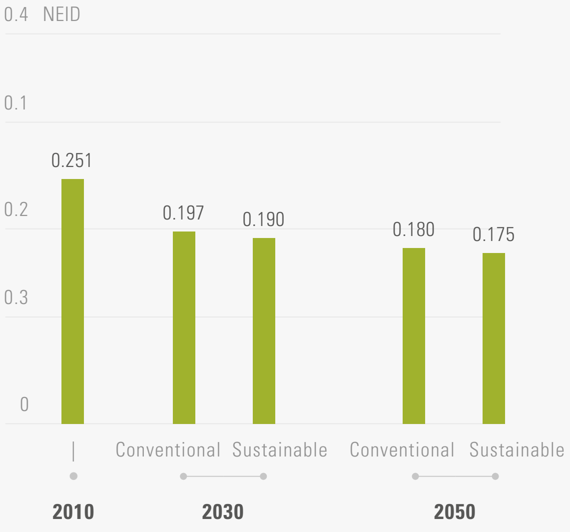
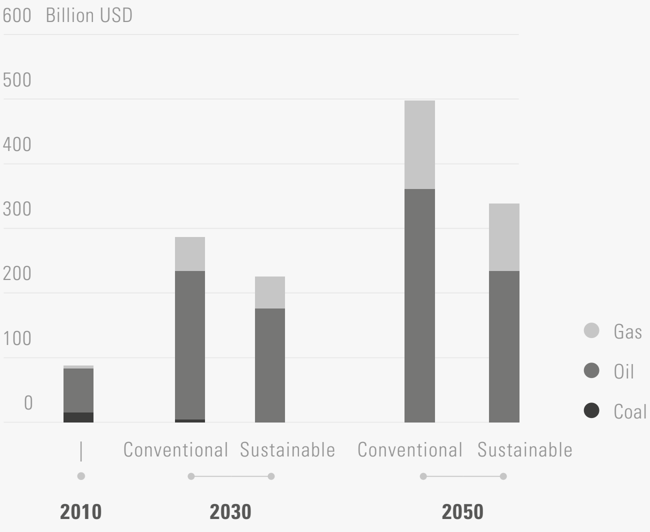


Figure 4.7 b: Value of Energy Imports



Note: Energy Security index shows the Net Energy Import Dependence (NEID).
The modified Shannon index shows diversity and import dependence. Lower value indicates higher security of supply.
Reference: Kruyt et al., 2009. The analysis includes fossil energy forms.

The 'conventional' climate-centric decarbonization approach delivers mitigation by altering the energy supply mix with enhanced investments in renewable, nuclear and CCS technologies. The alternate 'sustainable' approach aligns decarbonization and sustainable development actions. It, at first, focuses on demand-side technological and behavioral interventions which significantly reduce end-use demands and eventually uses low carbon energy supply options to the extent needed to keep cumulative CO_2 emissions within the budget.

The diversity of fuel in both scenarios increases with time and the fuel-mix shifts towards lower carbon content. The lower end-use demand in the sustainable DDP results in a higher percentage of domestic renewable energy contribution. The sustainable DDP therefore fares better, compared to the conventional DDP, on the energy security indices: a) Net Energy Import Dependence (Figure 4.7a and b) Total value of fuel imports which are 30% lower in 2050 in the sustainable DDP (Figure 4.7b).

The energy mix in the conventional DDP has higher nuclear and CCS shares. Risks associated with these technologies would require to be mitigated. Both DDPs have high renewable electricity content and would require mitigating risks associated with the stability of transmission grid. The energy security benefits from nuclear and renewables will accrue, provided these technologies are indigenized. A DDP, implemented with actions aligned with domestic sustainability goals, *can improve the resilience of national economies to international conditions*.

Social Value of Carbon

The two scenarios - conventional and sustainable - achieve the same carbon goal but differ in their base construct. The conceptual bifurcation underlying the two scenarios is the treatment of the '*social cost (or value) of carbon*'. The conventional scenario takes as an exogenous input a 'global carbon price' trajectory through 2050. This carbon price trajectory is obtained from the global integrated modeling assessment that targets a 2°C stabilization under a perfect global carbon market. For the conventional scenario, this global carbon price trajectory is the *social cost of carbon*. In the sustainable scenario, the assessment assumes that the carbon budget for India, from now to 2050, is the same as the cumulative emissions in the conventional scenario. The two scenarios are thus *equivalent in terms of carbon budget*. In the sustainable scenario, the *shadow price of carbon* corresponding to the carbon budget constraint appears as the surrogate for the social cost of carbon.

The sustainable scenario storyline assumes a multitude of local, bottom-up and sectoral policies aimed at various goals and/or targets like SDGs, share of renewable energy, air quality standards, energy access and energy efficiency. The policy mix is articulated vis-à-vis opportunities that help

Figure 4.8: Social Value of Carbon

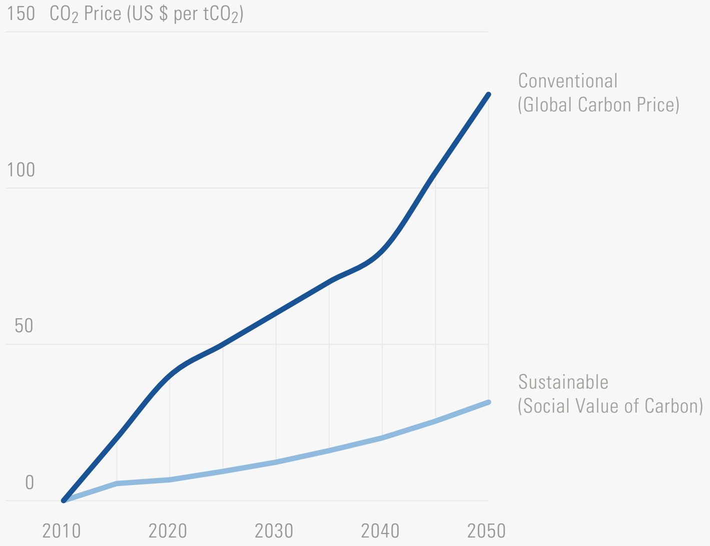


Table 4.2: Revenues from carbon saved in Sustainable vs. Conventional Scenario

	2020	2030	2040	2050
CO_2 saved (Million tCO_2)	370.6	671.8	918.9	1049.4
Revenue from CO_2saved (Bn US $ 2010)	16.6	45.1	82.3	152.9
Revenue as % of GDP	0.6%	0.8%	0.8%	0.7%

meeting sustainable development goals while delivering deep emissions cuts. Prominent among these are the choice of urban form, investment in low carbon infrastructure, energy efficient building codes, fuel-economy standards, air quality standards, waste recovery mandates, water conservation policies, regional agreements for sharing rivers and energy infrastructure, and the wise use of common property resources. The effect of policies, programs and projects are introduced in the model assessment via exogenously computed alterations in model input parameters. The conventional scenario misses these opportunities as the carbon price does not provide an adequate anchor for pulling these options.

The sustainable scenario has a much lower social cost of carbon (Figure 4.8) compared to the conventional scenario, since incremental investments in actions aimed to achieve sustainability targets in most cases also generate lower carbon emissions. The conjoint benefits of targeted sustainability programs are sizable, especially in developing countries, due to pre-existing market distortions, weak institutions, uneven socio-economic development and geo-political risks. The incremental costs of sustainability programs are offset in a sustainable world by lower social costs and reduced risks, including from nuclear technologies. This is a basic justification for a targets approach. The gap in the social value of carbon between conventional and sustainable scenarios is a proxy for the conjoint benefits of sustainability actions. In general, deep decarbonization pathways enhance risks from higher use of nuclear and CCS. But in the sustainable scenario, primary energy demand is substantially lower and therefore so is the need for high risk technologies.

The social value of carbon in the sustainable scenario can be interpreted in another way. India, for instance, can follow its own sustainability targets and also participate in the global carbon market, thus facing a global carbon price which is identical to that in the conventional scenario. In this case, the carbon budget in the sustainable scenario would be underutilized and the excess emissions credits can be monetized at the prevailing global carbon price. The carbon revenues generated can be sizable and can amount to 0.7% of India's GDP (Table 4.2). This revenue can partly offset the costs of decarbonization actions.

5 Conclusions and High Level Messages

Meaning of 'deep decarbonization' in India

India's climate change policymaking has preferred a 'development–centric' approach which sought to align climate change and development actions. But past policies were framed within a short-time horizon and undecided on long-term emissions targets. This prevented the adoption of policy solutions that could trigger cost-effective near-term actions and prevent long-term lock-ins into high carbon pathways. The uncertainty about global decarbonization targets is now reduced due to the general acceptance by all nations of the 2°C stabilization target and the assessment in the IPCC AR5 Synthesis report (IPCC, 2014) of the corresponding global emissions budget of 1 trillion tons of CO_2e for the period 2012-2100. This emissions budget is the global deep decarbonization target. This report assumes India's deep decarbonization to be the result of global and national policies that lead to India's 'cost-effective' participation in a global deep decarbonization regime while enabling national economic development to proceed in a sustainable manner. Global finance and technology transfer mechanisms are assumed to be in place.

'Deep decarbonization' scenarios and modeling framework

Two deep decabonization scenarios for India are framed for this assessment. The scenarios follow contrasting policy frameworks (Figure 2.1) – one ('conventional') following a forward looking neoclassical economics framework that assumes perfect market conditions aiming to delineate a cost-effective mix of mitigation actions; and the other (sustainable) following the development-centric framework which back-casts actions that deliver multiple national sustainability goals besides decarbonization. The assessment includes only CO_2 emissions from energy combustion and a time horizon spanning through 2050. A soft-linked integrated modeling system (Figure 2.2) that includes multiple models is used for the scenarios assessment. An exogenous mechanism is used to intermittently transfer key information across models, e.g. plugging a global carbon price generated by the global model into the national energy model. Scenario modeling follows a forward looking assessment for the conventional scenario and a back-casting framework in the sustainable scenario.

It is feasible to deep decarbonize Indian economy

The scenario assessment (Section 3) shows that it is feasible to deeply decarbonize the Indian economy by using known technologies and primary energy resources (Figures 3.1). However, strategies for deep decarbonization vary depending on national development perspectives and policies. The assessment of two deep decarbonization scenarios with different underlying development perspectives show that a carbon price or emissions targets lead to more energy efficient demand and supply-side technologies and enhance the use of renewable energy resources. These are the most robust carbon mitigation options and they also deliver additional benefits vis-à-vis air pollution.

Higher nuclear and CCS capacity development raises safety concerns. Estimates of CCS potential in India are quite uncertain. However our assessment shows that the CO_2 storage capacity needed till 2050 (Table 3.2) falls within the estimated estimate for good quality storage (Table 2.3). The rising global carbon price, which is projected to reach US$ 130 in 2050, would be adequate to lead to economical deployment of fair quality storage sites. In case the risks related to CCS were found to be excessive, our deep decarbonization scenarios have room to spare for increased renewable energy potential. Alternatively, the nuclear option exists, albeit with its own risks.

Electricity is the key sector for decarbonization

Final energy demand would shift in a big way towards electricity. Most current energy-related CO_2 emissions are attributable to electricity generation. Electricity generation is flexible in terms of its use of primary energy resources (Figures 3.3. and 3.4) and therefore readily amenable to decarbonization through a change in primary energy mix. Electricity generation gets deeply decarbonized in both scenarios (Table 4.1) as the generation mix shifts towards nuclear and renewable power technologies (Figure 4.4) and coal power plants with CCS. In the sustainable scenario the combination of lower electricity demand and decarbonized electricity contribute sizably to the decarbonization of the entire national energy system.

It is desirable to align deep decarbonization and sustainability goals

The sustainable scenario shows that aligning deep decarbonization and sustainability goals is an effective strategy to address energy related external costs and risks. Sustainability driven actions and programs like 3R, city planning, building design and materials substitution deliver a sizable reduction in primary energy demand (Figure 3.1). The sustainable scenario story reduces the use of risky and contentious energy supply-side options like nuclear and CCS. Besides, actions driven by sustainability goals help reduce air pollution levels (Figure 4.6) and reduce energy security risks (Figure 4.7), since India will have to meet most oil and gas demand though imports.

Early actions are vital to shape long-term deep carbonization pathway

The DDP scenario assessments show that cost-effective deep decarbonization calls for early implementation of technologies and the related investments in infrastructure. Energy demand and supply technologies require special infrastructure, e.g. sizable solar and wind penetration would require smart grid interface, electric vehicles need charging stations, CCS needs pipelines for CO_2 transport and nuclear needs waste disposal infrastructure. Investments and policies are needed upfront to create an early supply of energy infrastructure prior to the readiness of the technologies they support.

India will transition from low to medium income over the coming decades. This is the period during which major investments in infrastructure will need to happen. Government policies driving near-term infrastructure choices will shape long-term carbon emissions pathways. Therefore it is essential to prevent long-term lock-ins into high carbon emissions options such as conventional coal power.

The energy technology mix differs in the two scenarios but technologies like energy efficiency and renewable energy are common to both. The Government of India has announced ambitious targets and policies to support renewable energy and energy efficiency. The DDP scenario assessments show that deep decarbonization will however still require some amounts of coal and nuclear. Urgent government actions would be needed for stopping the unmitigated use of coal in new coal fired power stations, initiate geological survey to assess CO_2 storage potential, investment in and incentivize CCS pilot plants to assess the costs and risks of CCS technology and develop a roadmap for nuclear power based on full cost including the liability to cover risks. The sustainable scenario assessment shows the wisdom of early deployment of sustainable energy technologies. It allows time and reduces the scale of risky technologies like nuclear or CCS.

Deep decarbonization needs technology transfer and incremental investments

Deep decarbonization will entail substantial changes in energy supply and demand technologies. Intellectual property rights of low carbon technologies, e.g. nuclear, CCS, smart grid etc., are owned by private companies mostly based in developed nations. Early technology deployment would require technology transfer agreements and royalty payments. This would increase costs for the national energy system. The Government of India already subsidizes cleaner primary energy (e.g. LPG) and electricity for rural consumers to enhance clean energy access as a part of the Indian commitment to global SE4all and Sustainable Development Goals (SDGs). The increased cost of low carbon energy will add to the subsidy burden but would reduce air pollution loads (Figure 4.6).

Global carbon finance mechanisms have to date lacked adequate funding to support technology transfers and the incremental costs of low carbon energy resources and technologies. The Kyoto protocol's financial mechanisms could not generate a carbon price that was adequate to generate an early pull for low carbon technologies. The DDP scenario assessments show that early deep decarbonization would need the scaling up of finance and the institution of a technology transfer mechanism at the international level to support sustainable energy transformation at the national level and reduce the associated energy sector investments (Figure 4.5b).

Decarbonization policies should be sector specific

Energy demand is met by different technologies, infrastructure and primary energy resources for each sector. Deep decarbonization generally happens by enhancing efficiency of demand-side technologies and altering the energy mix. Industry is the highest CO_2 emitting sector. The DDP scenario assessment shows a very high potential for improvement in energy intensive industries, like steel and cement, which consume coal. Large plant sizes also make these sectors amenable for the use of CCS. In the sustainable scenario policy measures in other sectors, e.g. the choice of low carbon building materials and 3R measures, potentially reduce energy demand by 20 % for the industry sector in 2050 (Figure 3.7).

India's building sector will remain on a high growth trajectory for a long time driven by income, urbanization and service sector growth. The declining share of traditional biomass in rural cooking (Figure 3.8) will increase the carbon content of energy demand as carbon neutral biomass is replaced by LPG. The increasing penetration of efficient electrical appliances in residential and commercial buildings (Figure 3.8 & 3.9) will drive electricity demand, but a decarbonized electricity supply will deeply decarbonize the sector. Key policies in this sector aim at penetration of state-of-the-art devices (e.g. LED lamps) and appliances serving high energy demand during peak hours (e.g. space cooling). The focus on this sector in India is evident from the implementation of building codes mandated by the Bureau of Energy efficiency (BEE).

The transport sector is the second highest emitting sector after industry. Despite the emergence of clean technologies (e.g. electric vehicles), oil driven vehicles are expected to persist (Figure 3.10) in India albeit with a declining share in a deeply decarbonizing world. The rapid growth and rising share of inter-city passenger (Figure 4.2) and freight road transport due to the slow pace of railway infrastructure supply is the key driver of increased oil use in transport. Hydrogen and biofuel powered vehicles, especially in the sustainable scenario, offer credible alternatives to decarbonize the sector. An important message from the scenario assessment is that sustainability measures have the potential to reduce transport energy demand (Figure 3.10) by 44% in 2050.

Energy demand in agriculture is currently very low but rising rapidly and will grow seven fold under the conventional scenario from 2010 to 2050 (Figure 3.11), due to increased mechanization and resource intensive farming practices. Sustainable farming practices reduce demand for agro-inputs. This sizably reduces electricity demand, but not the demand for oil for farm implements. Decarbonization of agriculture therefore should focus on the efficiency of agriculture implements.

Cities are important centers of low carbon actions

The two DDP scenarios assume different rates and approaches towards urbanization. India's urbanization rate is currently 32%; this will rise to about 50% in the conventional and 55% in the sustainable scenario. Cities' policies for land-use, buildings, public transport, waste utilization, air quality, water recycling and other urban services vitally influence the demand for materials, vehicles and energy.

Alternate urbanization scenarios make a big difference to energy demand and emissions. The conventional scenario assumes cities to be built by self-organizing processes driven by markets. This process leads to the formation of large cities with sparse hinterland. The sustainable scenario is more interventionist and expects planned small and medium cities that integrate land use and transportation planning, efficient municipal services and infrastructure, sustainable waste management and the adoption of building regulations and measures to influence behavior. The urban scenario storylines, when quantified in modeling assessments, show that compared to the conventional urban scenario, the sustainable urban scenario would deliver vast gains vis-à-vis low carbon and sustainability goals.

This recognition has prompted the Government of India to implement a National Mission on Sustainable Habitat (Table 1.1) which focuses exclusively on the creation of sustainable low carbon cities. The recent 'Smart city' initiative (MoUD, 2014) envisages sustainable and inclusive development through comprehensive planning and development in select cities that can be replicable in other urban areas. These initiatives would deliver lower carbon emissions and sustainability benefits can accrue if these initiatives are broadened with intercity and urban-rural interfaces.

Low carbon rural development needs special attention

India's current rural population is eight hundred million. In 2050, rural India will still have the same population size. Traditional biomass is the main fuel used by most rural households. Clean energy access in rural areas is a key goal under the UN's SE4All initiative. The supply of clean and affordable energy is essential for the welfare of a vast rural population.

Rural areas lack efficient labor, commodity and financial markets. The conventional scenario seeks commercialization of rural energy, which cannot succeed under incomplete markets. The sustainable scenario can facilitate commercialization of clean energy in the near-term through public investments complemented by strategies to improve affordability through financial reforms, including targeted subsidies, micro-financing to spread upfront costs, and other innovative mechanisms.

Clean commercial energy options (e.g. LPG) run into a contradiction vis-à-vis the low carbon goal since they emit CO_2, whereas sustainably grown traditional biomass is carbon neutral. Rural areas can use the two complementary policies; one facilitating clean commercial energy and the other supporting technologies that deliver clean energy while using local biomass such as firewood, agro-waste and animal dung as feedstock. There is a long history of Government supported programs such as IREP (Integrated Rural Energy Programme) and local capacity exists to convert traditional biomass fuels into clean and zero carbon energy. The assumption of a revitalization of such programmes under a sustainable scenario leads to sizable gains vis-à-vis SE4All and low carbon goals.

Innovative carbon finance instruments are vital

Deep decarbonization entails an energy transition that also necessitates upfront investments. Our assessment of investment needs for the expansion of electric generation capacity shows that a cumulative investment of USD 2.2 trillion is needed between 2015 and 2050 in the conventional scenario and USD 1.8 trillion in the sustainable scenario (Figure 4.5). Most investment is allocated to solar technologies. Early penetration of these technologies is therefore vital, but this will require technological and financial transfers. This calls for a cooperative regime involving global and regional cooperation. International climate finance has a role to play in bridging the gap to cover incremental cost.

In order to compete with fossil based sources in the near-term, renewable energy technologies will require support through government policies, including subsidies. Adapting new technologies and infrastructure shall also require the transfer of technologies and capacity building. While climate finance and technology related instruments do exist, the quantum of finance needed for decarbonization shall be substantially higher compared to present allocations. The climate agreement expected in Paris in 2015 should bridge this investment gap and also bring forth explicit institutional arrangements that overcome the barriers to the transfer of low carbon technologies to developing countries.

It is important to create a domestic industry for low carbon technologies

India will be a large market for low carbon businesses. The scale of the domestic market can be a launching pad for Indian businesses to become global players in emerging areas of low carbon technologies, infrastructure and services. Domestic markets are vital for technology innovations, learning and domain specific adaptations. Large scale renewables like solar and wind, and clean and energy efficient demand-side technologies like electric vehicles and appliances offer huge market to launch a global scale domestic industry. Creating a domestic industry for contentious technologies like nuclear and CCS would require clarity and direct government involvement, at least in the near-term, to ensure public interests as well to cover private risks. The domestic industry can operate in partnership with global technology businesses. The information technology and financial services sectors can take advantage of new opportunities which are opening up to support low carbon markets. There are vast opportunities to create a domestic industry to serve the low carbon transition in rural areas and in the agricultural sector. The landscape of the sustainable scenario shows a vast spectrum of technologies, infrastructure and services where the localization of global industry can help meeting sustainability goals.

Regional cooperation is vital for deep decarbonization

Achieving deep decarbonization in developing regions at an affordable cost requires looking beyond direct carbon reduction measures. South-Asia is a fast developing region. It lacks a unified energy market which can generate win-win opportunities for all nations in the region. A regional energy cooperation initiative to develop Himalayan hydro potential, a natural gas pipeline to north India from the middle-east via Pakistan or central Asia via Afghanistan and gas imports from Bangladesh to India's north-eastern states have the potential to substitute coal in the region and mitigate sizable CO_2 and air pollutants compared to the sole alternative of using coal.

The Social value of carbon is an appropriate instrument to assess deep decarbonization investments

The two DDP scenarios use the same carbon budget but differ in their base construct. The sustainable scenario storyline assumes a multitude of local, bottom-up and sectoral policies aimed at achieving a suite of SDGs as well as decarbonization. The conventional scenario misses these opportunities as the carbon price is inadequate to make these options competitive vis-à-vis unclean fossil energy. Most incremental investments in sustainability actions also reduce carbon emissions. The conjoint benefits of targeted sustainability programs are sizable, especially in developing countries, due to pre-existing market distortions. The incremental costs of sustainability programs are offset by lower social costs and reduced risks. The shadow price of carbon corresponding to the carbon budget constraint is therefore lower (Figure 4.8) than the global carbon price. This shadow price in the sustainable scenario is the *social value of carbon* and the gap between the social value of carbon and the carbon price is a proxy for conjoint benefits of sustainability actions.

The social value of carbon has an alternative interpretation. India can follow its own sustainability path and also trade emissions rights at the prevailing global carbon price. In this case, India will be left with excess emissions credits from the emissions budget. These excess credits can be monetized at the prevailing global carbon price. Modeling assessment shows that the revenues generated would amount to 0.7% of India's GDP in 2050. These revenues can partly pay back the additional economic costs of sustainable actions or partly offset the economic loss from decarbonization actions.

The most significant lessons one can learn from the assessment of two different DDP scenarios are that sustainable actions lead to a gradual transformation of energy system, have less dependence on high risk technologies and carry a lower social value of carbon. Economists have argued on which instruments deliver an *equal carbon price* across nations as the prime goal of negotiations. The heterogeneity and distortions in the global economic system in general and energy markets in particular show that national policymakers would do better by agreeing on an achievable and desirable '*social value of carbon*' as a target and declare it upfront to evaluate investments and the choice of projects. Global carbon finance would deliver more and better results by pegging to the nationally agreed *social value of carbon* rather than the elusive carbon price in a perfect world.

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Abbreviations

BAU	Business-as-Usual
Bpkm	Billion Passenger Kilometres
BTkm	Billion Ton kilometers
CCS	Carbon Capture and Storage
CSP	Concentrated Solar Power
CO_2	Carbon dioxide
DDP	Deep Decarbonization Pathways
ECBC	Energy Conservation Building Code
EJ	Exa joules
EV	Electric Vehicles
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GoI	Government of India
Gt	Giga tonne
GW	Gigawatt
HDV	Heavy Duty Vehicle
kWh	Kilowatt-hour
LDV	Light-duty Vehicle
LPG	Liquefied Petroleum Gas
MoEF	Ministry of Environment and Forests
MT	Million tons
NAPCC	National Action Plan for Climate Change
NEMMP	National Electric Mobility Mission Plan
NMT	Non-motorized transport
NPB	National Policy on Biofuels
NUTP	National Urban Transport Policy
PM2.5	Particulate Matter, size 2.5 mm
PV	Photovoltaic
SO_2	Sulphur dioxide
Sq. m.	Square Meters
Toe	Tonnes of oil equivalent
TWH	Terawatt hours
USD	US Dollars
2W	Two-Wheelers
3W	Three-Wheelers
4W	Four-Wheelers

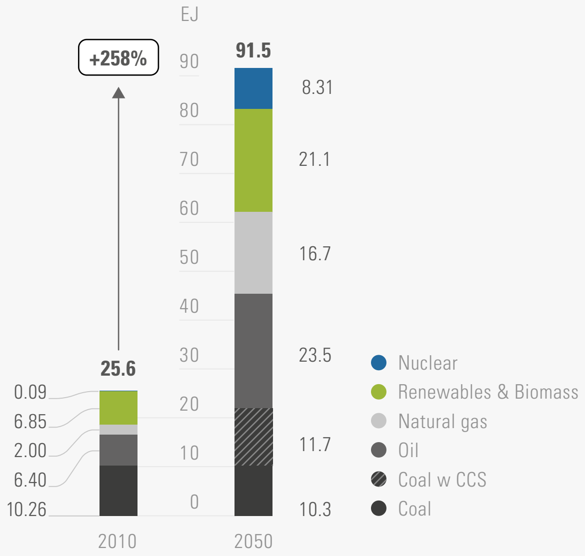
Standardized DDPP graphics for India scenarios

IN - Conventional

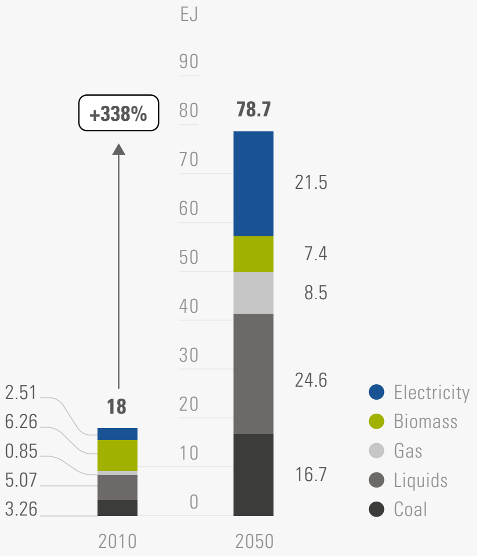
IN - Sustainable

IN - Conventional

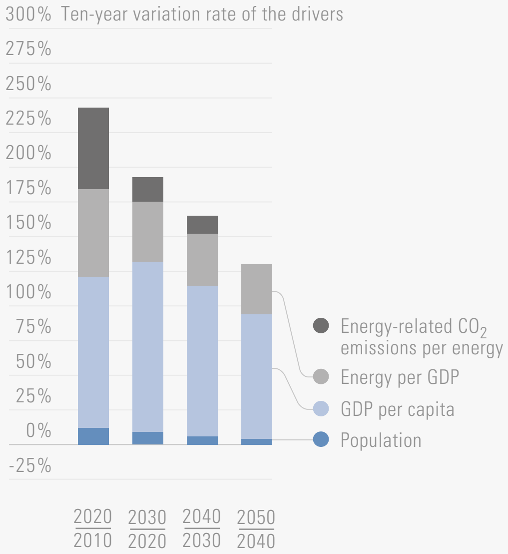
Energy Pathways, Primary Energy by source



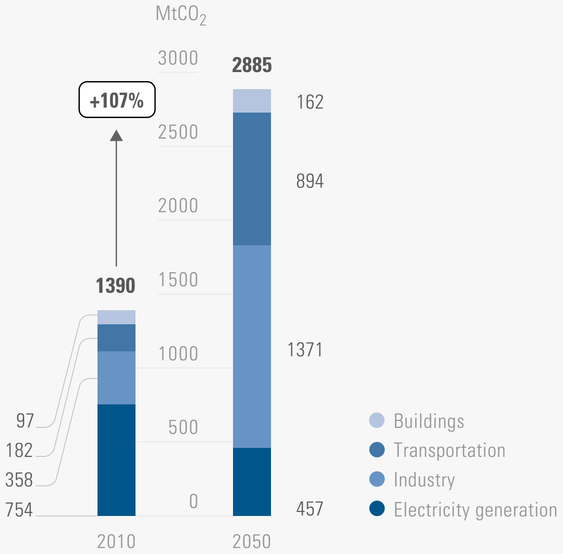
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

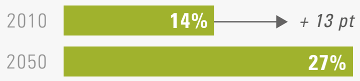
Energy efficiency

Energy Intensity of GDP, MJ/$

Decarbonization of electricity

Electricity Emissions Intensity, gCO_2/kWh

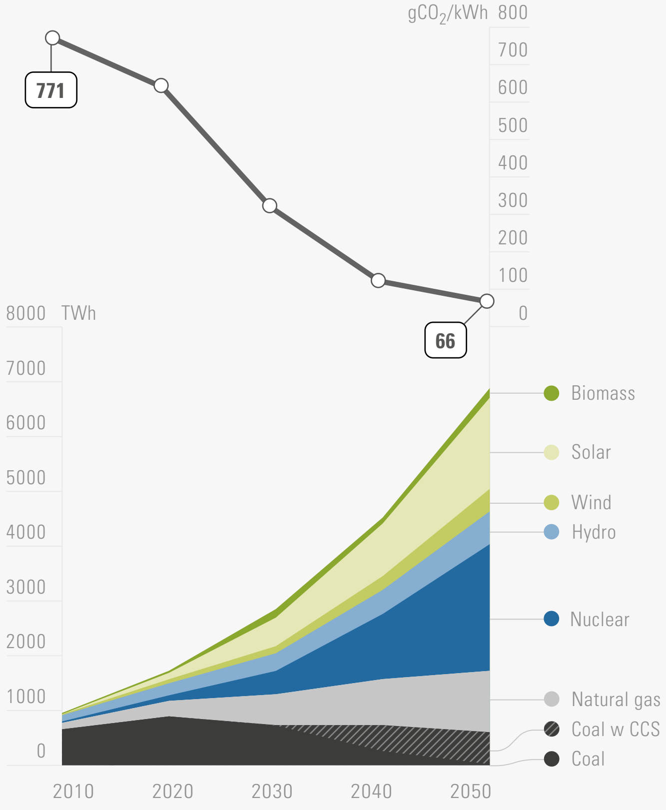
Electrification of end-uses



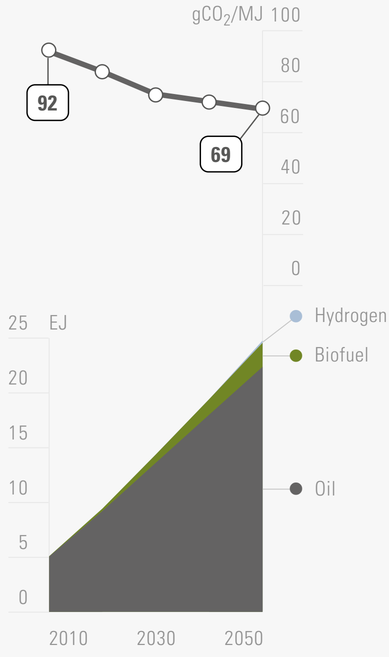
Share of electricity in total final energy, %

Energy Supply Pathways, by Resource

Carbon intensity

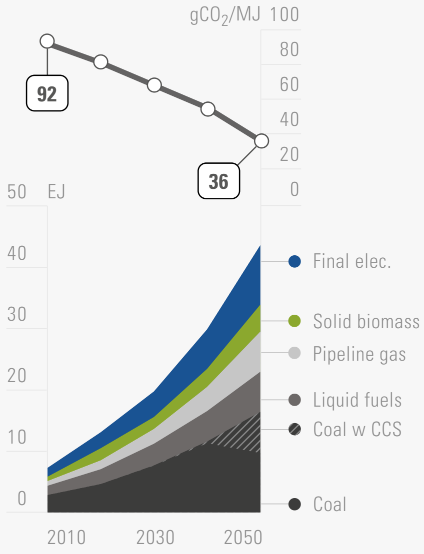


Electricity

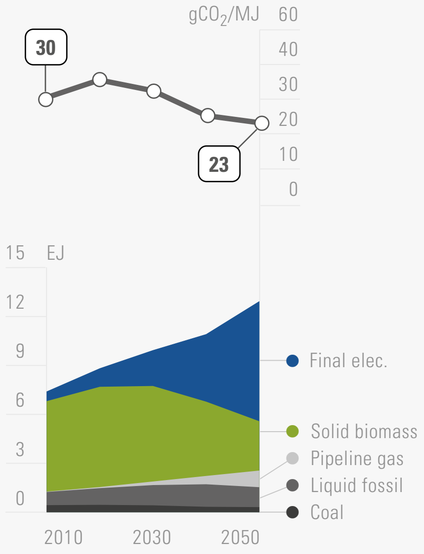


Liquid Fuels

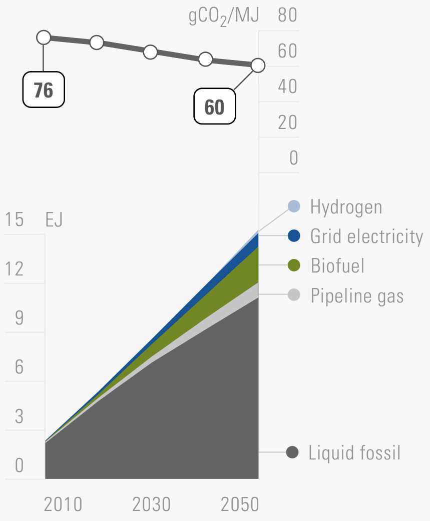
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



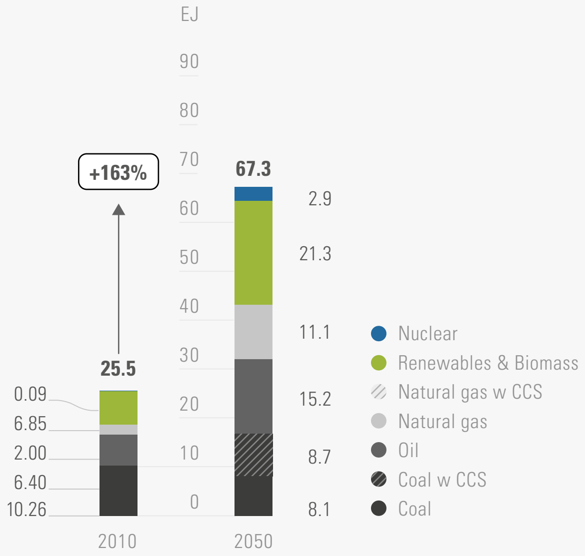
Buildings



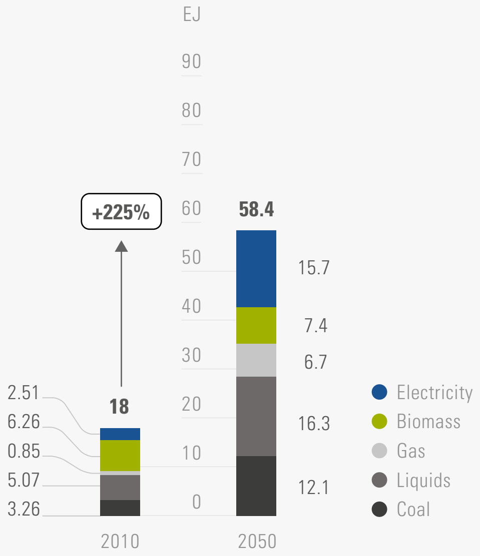
Transportation

IN - Sustainable

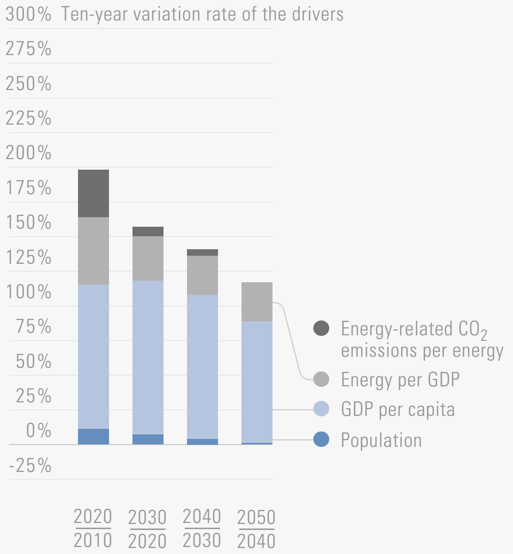
Energy Pathways, Primary Energy by source



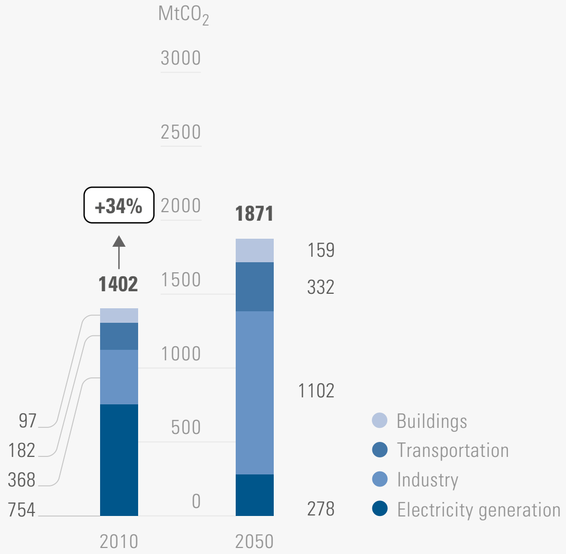
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



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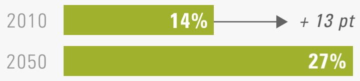
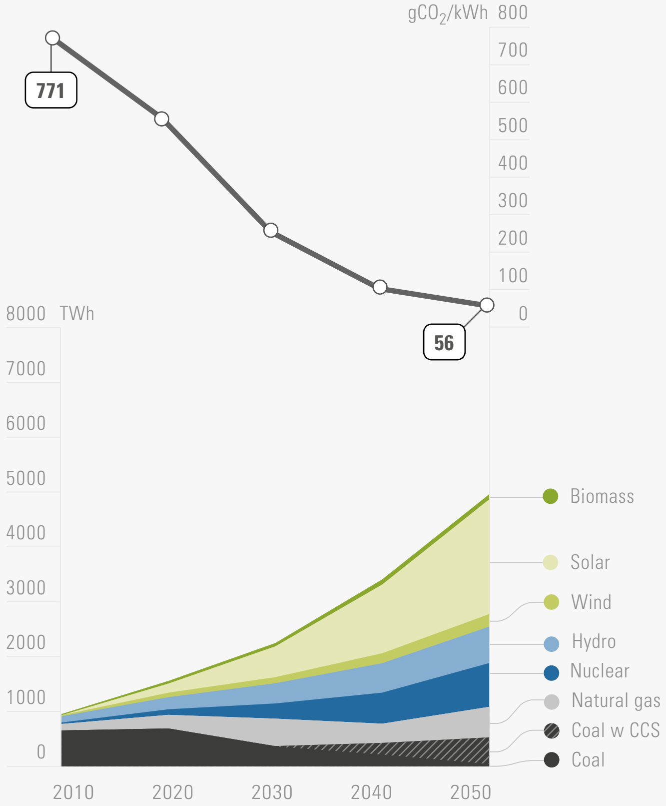


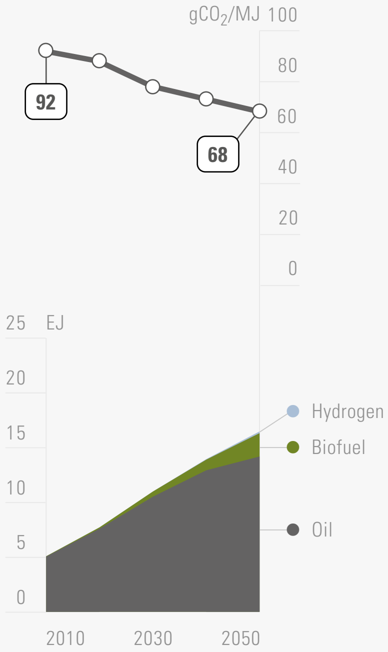
Share of electricity in total final energy, %

Energy Supply Pathways, by Resource

Carbon intensity

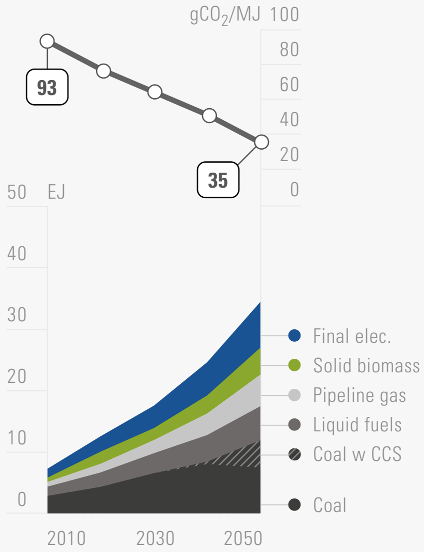


Electricity

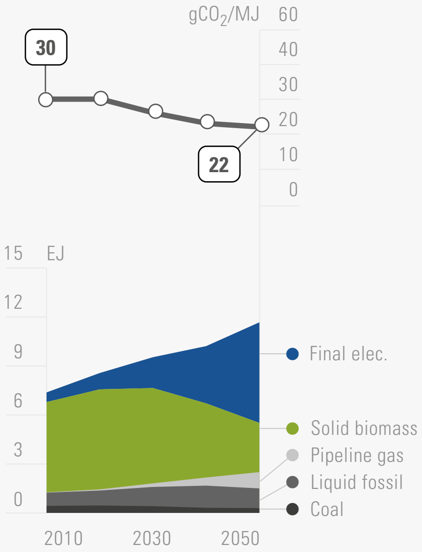


Liquid Fuels

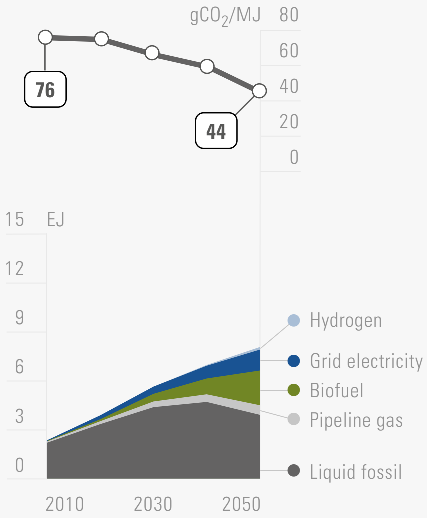
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



Buildings



Transportation