Quality of Life for All:

A Sustainable Development Framework for India's Climate Policy

Technical Report

CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

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Executive Summary

India and other countries are expected to submit their Intended Nationally Determined Contributions (INDCs) for the Conference of Parties (COP-21) in December 2015. Keeping in mind the expectation that India will experience severe impacts from global warming and the fact that a large proportion of people still require basic needs and energy services, CSTEP conducted a study examining two scenarios for India's development by 2030: policy or Business as Usual (BAU) and Sustainable Development (SD) or quality of life.

The study builds on the India Energy Security Scenarios (IESS) 2047 tool developed by NITI Aayog by adding a 'quality of life' dimension to the energy and emissions pathways.

Impact of SD pathway on energy and emissions

When we considered improvements in quality of life using SD indicators such as fresh water, clean air, food security and energy services, we found that greenhouse gas emissions were reduced by close to 30% and energy use by 25% compared to BAU. The SD pathway reduced emissions intensity by 16% compared to 2012 and fossil free sources contributed to about a third of our electricity.

Renewable Energy (RE) generation and reduction in Transmission and Distribution losses offer significant scope for emission reductions in the power sector under an SD scenario. Industries and buildings also contribute to substantial reductions over BAU.

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

Impact of SD pathway on quality of life and sustainability metrics

Ambient air pollution reduces by 30% on average, on account of increased use of public transport, improved energy efficiency in industry, increase in RE generation and more stringent pollution control measures in thermal power plants. Aggressive penetration of modern cooking fuels more than halves the morbidity due to a reduction in indoor air pollution from traditional cooking.

Significant water savings are possible by rationalising water tariffs for large consumers, better water accounting practices, mandating green buildings by-laws, ensuring investment in the agricultural sector to improve water-use efficiencies and switching to RE generation options.

A switch to alternate materials in building and industry sectors and change in agricultural fertiliser practices can significantly reduce the material and resource requirement and improve soil health.

Therefore, we recommend that India make a commitment to a quality of life pathway for its INDC.

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List of Acronyms

AAP	Ambient Air Pollution
BAU	Business-as-Usual
BCM	Billion Cubic Meter
BEE	Bureau of Energy Efficiency
BPKM	Billion Passenger Kilometre
CAGR	Compounded Annual Growth Rate
CFL	Compact Fluorescent Lamp
CO	Carbon Monoxide
CO_2e	Carbon Dioxide Equivalent
COP	Conference of Parties
CPCB	Central Pollution Control Board
DALYs	Disability Adjusted Life Years
DRI	Direct Reduced Iron
EFOM	Energy Flow Optimization Model
ESP	Electrostatic Precipitate
EV	Electric Vehicle
FAR	Floor Area Ratio
FGD	Flue Gas Desulphurisers
FSA	Floor Space Area
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
GW	Gigawatt
GWP	Global Warming Potential
IAP	Indoor Air Pollution
ICS	Improved Cook Stoves
IESS	India Energy Security Scenarios
INDC	Intended Nationally Determined Contribution
INR	Indian Rupee
LPG	Liquefied Petroleum Gas
MCM	Million Cubic Metres
Mha	Million Hectares
Mt	Million Tons
MTPA	Million Tons Per Annum
NAPCC	National Action Plan on Climate Change
NMT	Non-motorised Transport
PM2.5	Particulate Matter
PNG	Piped Natural Gas
RWH	Rainwater Harvesting
SD	Sustainable Development
SEC	Specific Energy Consumption
SO2	Sulphur Dioxide
SPM	Suspended Particulate Matter
SWH	Solar Water Heater
T&D	Transmission and Distribution
TPES	Total Primary Energy Supply
TPP	Thermal Power Plant
TWh	Terawatt-hours
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds

A. Introduction

This study by CSTEP proposes an analytical framework to view India's growth and emissions trajectory through a 'people's lens'. The objective of this study is to examine a scenario in which we improve air quality, enhance availability of fresh water, provide cleaner cooking fuels, enhance energy services, promote efficiency in use of resources and facilitate food security. If we developed along a path that improved quality of life, what would be the implications for various sectors and for greenhouse gas emissions by 2030?

We argue that the central tenet of India's climate strategy should be the commitment towards a Quality of Life or Sustainable Development (SD) paradigm, rather than narrowly focussing on emissions. The results suggest that such an approach can also reduce the intensity of GHG emissions and provide strategic opportunities for India's development path and climate policy.

B. Framework and Approach

The study builds on the India Energy Security Scenarios (IESS) 2047, a tool developed by NITI Aayog to evaluate the energy demand and supply scenario of various sectors such as agriculture, buildings, industries, power and transport. A bottom-up energy system model (TIMES- The Integrated MARKAL EFOM System) is used to examine several combinations of technology and policy options based on constrained optimisation (1). This ensures that the SD pathway is strictly relevant to national and international contexts. *Figure 1* provides a diagrammatic representation of TIMES.

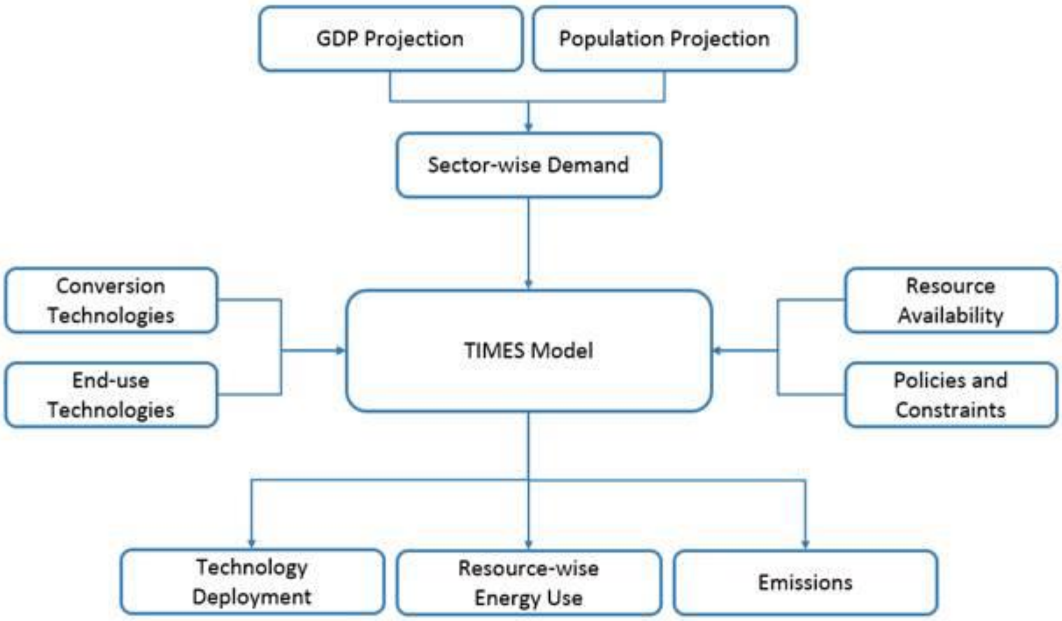

Figure 1: Representation of the India-Multi Region TIMES Model

In order for India to transition to a SD pathway, we outline the key sustainability challenges that need to be managed by identifying the following:

1) Drivers: Macroeconomic factors determining growth in demand for resource consuming goods and services

2) Pressures: Key sustainability challenges in the sector and sustainability indicators to measure the state of resource use or impact

3) Response: Interventions that reduce the pressure state of the indicators.

Figure 2 illustrates the approach followed by this study.

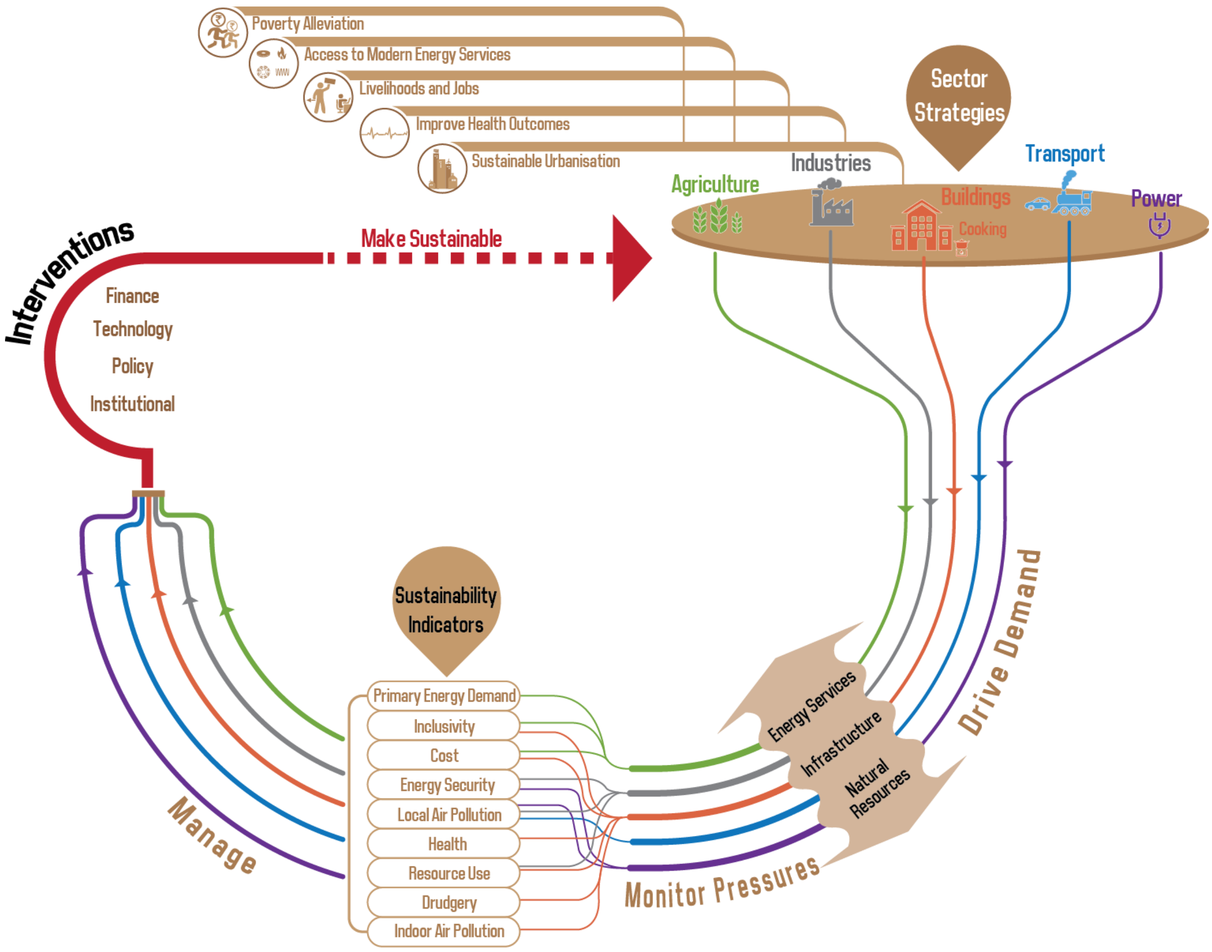

Figure 2: Approach to the Study

Two scenarios are constructed to compare the implications of Business-as-Usual (BAU) activities in various sectors versus an SD scenario that aims to significantly improve factors associated with improving the living conditions for people. Sector-wise details of data, assumptions and interventions examined in the two scenarios are available in the Appendix section.

C. Sector-wise Drivers and Challenges

In order to meet its aspirations for improving the quality of life of its people, India can envision a development trajectory that is *inclusive, equitable and sustainable*. This hinges on its ability to support agriculture through effective policies, enable urban services for a growing population[1], make use of emerging technologies for better innovation and efficiency and provide dignified livelihoods. In addition, ensuring an improved quality of life *for all* would entail enabling access to clean air, natural and material resources, and other public services. Various policy documents have ambitiously targeted a minimum growth rate of 8 % in GDP. Such aspirations imply significant increase in the demand for resources and energy. The following section presents the key drivers for growth in service demands in key sectors along with current and anticipated challenges.

Agriculture

Globally, India is amongst the top producers of agricultural produce and about half of the total workforce is employed in this sector (2). Agriculture accounted for 11% of the country's exports in FY 2013 and the share of GDP from the sector was 14%. This has declined about 1% per annum since FY 2000 (2). Despite this, agriculture will remain important to ensure domestic food security, provide livelihoods to millions, provide industrial raw material and contribute to India's exports.

Agriculture accounted for about 85-90% (650 BCM-700 BCM) of the water consumption in 2012 (3). Both water and electricity for pumping are provided free or at heavily subsidised prices in most states. Thus, there is little incentive for farmers to improve their consumption, resulting in highly inefficient electricity and water usage. Agriculture accounts for about 18% of the total electricity consumption (153 TWh in FY 13) (4); this is as high as 30% in some states. Pumping demands are expected to grow at a Compounded Annual Growth Rate (CAGR) of about 5-6% p.a. till 2030 (5). The sector also accounts for about 13% of the country's diesel consumption, mainly used in tractors and diesel pump-sets (6). Currently only 5% of farming households own tractors, and the tractor density is 16 tractors per 1,000 hectares which is lower than the world average of 19 tractors per 1,000 hectares. Some estimates suggest that the numerous government initiatives introduced to improve agricultural production will lead to increased mechanisation and tractor stocks will grow rapidly (7).

India uses 144 kg/ha of fertiliser compared to the world average of 107 kg/ha. The larger agricultural states use between 200-270 kg/ha (7). While agricultural productivity has benefitted with the introduction of fertilisers, over-application or poorly timed application of chemical fertilisers and pesticides has adversely impacted water quality leading to detrimental effect on flora and fauna. With the slow uptake of organic fertilisers, increasing use of chemical fertiliser could continue to adversely affect soil nutrient levels.

Among the biggest challenges in the coming decades are water supply constraints with a high dependence on groundwater, which is depleting in many agriculture-dependent states, low productivity and poor soil health due to the overuse of chemical fertilisers.

Policy Drivers – There are a number of policies put in place to promote integrated agricultural development. Some key schemes that could promote sustainable farming include:

1. Integrated agricultural schemes: National Mission for Sustainable Agriculture

[1] With a decadal population growth rate of 17.6%, India is expected to overtake China as the most populous country by 2030 and will support nearly 18% of the world population (12)

2. Energy schemes: Agriculture Demand Side Management (AgDSM) and central and state solar pumping schemes such as Surya Raitha in Karnataka
3. Irrigation schemes: National Mission on Micro Irrigation and Rashtriya Krishi Vikas Yojana
4. Nutrient management schemes: Integrated Nutrient Management, central and state specific schemes for organic farming such as those in Sikkim, Kerala and Andhra Pradesh.

Industries

The industry sector has been a key driver of India's economy post-independence. It has grown at 6.45% in the post liberalisation era and employs 105 million people. It has a 27% share in GDP and 23% share in employment. In the period 2005-10, shrinking manufacturing sector employment has contributed to reduced overall job growth (8).

India's per capita consumption of key industrial outputs remains very low compared to global averages. Infrastructure demand from transport, housing and energy sectors and consumption demand driven by rising per capita incomes will be key drivers of growth in the industrial sector output and employment, leading to multiplier effects in the economy. To realise the targets of National Manufacturing Policy, we estimate that most sectors such as cement, steel, aluminium, paper and chlor-alkali will likely grow at 6-8% per annum till 2030. Fertiliser and textile sectors are likely to grow at slower rates.

To realise this growth, the sector will need to avoid resource constraints and remain competitive with global manufacturing, especially China. India's known reserves of iron ore, bauxite, limestone, etc. are at less than fifty years (9). The sector is one of the highest consumers of energy, demanding almost 1400 TWh in 2012.

As energy input costs vary from one-fifth to one-third for key industrial sectors, this has direct bearing on manufacturing competitiveness. Key industries such as iron and steel still grapple with inefficiency in energy use, while the fertiliser industry has not yet been able to shift to efficient feedstock completely. India has one of the most efficient cement industries in the world, though their consumption is 50% higher than the Best Available Technologies (BAT). Significant scope for energy efficiency exists in smaller industries such as paper and textiles.

Further, industries contribute almost a quarter to national emissions with steel and cement accounting for over half of industrial emissions (10). As in the case of energy efficiency, fuel raw material and process switching can not only reduce emissions, but also improve industrial profitability.

In addition to GHG emissions, air pollution from SO_2, NO_x and particulates during fuel production and combustion are more immediate fallouts of industrial expansion. Air pollution norms for industries have neither been uniform nor effective.

Industries also account for 5% of India's water demand. Absence of proper water accounting and rationalised pricing policies have resulted in inefficient water-use in the sector. This also applies to industrial wastewater (IWW) generated, especially from the CPCB's 17 Red Category industries. Rivers, lakes and underground water tables polluted with IWW carry high concentrations of metal, dissolved solids and nitrates (11).

Policy Drivers – The key existing policy and regulatory provisions tracked for this sector include:

- Make in India Initiative

- National Manufacturing Policy
- Sector Specific Policies- National Steel and Mineral Policies
- Perform Achieve and Trade (PAT) mechanism under National Mission for Enhanced Energy Efficiency (NMEEE)

Buildings

The buildings sector comprises urban and rural housing and commercial real estate. The latter includes non-commercial built up areas such as offices, hospitals, retail outlets, educational institutions etc. Based on the latest census, the number of urban and rural households in 2012 is calculated as 87 million and 189 million respectively[2] (12). Floor-Space Area (FSA) under residential buildings in 2012 was 13,470 sq. meters and has been growing at a rate of 4.4% per annum. Commercial FSA has been growing at 6.4 % per annum owing to the high growth of 8.6% in the services sector since 2000-01 (13).

The buildings sector consumed 240 TWh of electricity in 2012. This represents 31% of the total electricity consumption by all sectors. Residential and commercial sectors contributed 22% and 9% respectively to this demand. This yields an Energy Utilisation Index (EUI) of residential and commercial buildings as 13.53 kWh/sq. m/ year and 82.13 kWh/ sq. m/ year respectively. Between 2006 and 2013 the residential electricity demand grew at 9% and commercial at 10% per annum (14).

The challenge to secure electricity access to the building sector will only get more daunting in future as the intensity of energy use is likely to witness high growth owing to increased air-conditioning demand. Demand for space cooling has been growing at 20-25% per annum (15), and the sales of room air conditioners by 16% from 2005 (16)[3].

Apart from electricity, the residential sector uses other fuel sources such as kerosene for lighting that adversely impacts indoor air quality and poses significant health problems (17). Access to electricity for lighting remains particularly low at 55% in rural households and 67% for India (12). Kerosene consumption for lighting in India is estimated at 9 TWh in 2012 (18). While CFL has emerged as the most popular choice for energy efficient lighting in India, there are challenges in its disposal owing to the presence of toxic mercury.

Another major challenge for the government is to deliver on the affordable housing promise. The National Housing Board estimates a deficit of 44 million houses in rural and 19 million houses in urban areas (19). Together this constitutes 1.87 billion sq. meter of floor-space that requires to be built over the next 7 years to be able to fulfil the 'housing for all' promise.

Several reports have contended that at least half of the constructed floor-space for buildings will come up between 2015 and 2030. This has profound impact on material and indirect energy requirement in the construction sector.

Buildings also constitute a significant demand for water for construction and operations. One-sixth of the world's fresh water withdrawals are accounted for by building construction (20). Household water demand in India is around 112 litres per capita per day (lpcd) (21) and buildings account for approximately 8% of total water demand. Competing water demand from industry, electricity generation and agriculture sectors and falling water availability in future

[2] These are based on average household sizes of 5.00 and 4.41 for rural and urban areas respectively

[3] Lawrence Berkley National Laboratory (LBNL) estimates that household ACs will contribute almost 150 GW to peak demand by 2030 (8).

may make it very difficult to meet the water demand from buildings at current rates of consumption, which is likely to increase to 134 lpcd by 2030 (21).

The Indian urbanisation story paints a stressful picture. A report Indian Institute of Human Settlements indicates that while in 2011 there were over 833 million people in 0.64 million villages, there were only about 8,000 urban centres housing 377 million Indians. The 100 largest cities in India account for 43% of the GDP and 16% of the population on only 0.24% of the land area. At the same time, built-up densities have been reducing for core areas in the largest cities (22). Our calculations show the land- footprint from urban dwellings and commercial establishments at around 2.72 billion sq. meters currently. Owing to competing use of land and ever increasing population densities in urban areas, land footprint of buildings will have a bearing on both the supply and prices.

Policy Drivers – The key existing policy and regulatory provisions tracked for this sector include:

- Lighting and Appliance Efficiency (DSM Based Efficient Lighting Programme (DELP), Standards and Labelling (S&L) and Super-Efficient Equipment Programme (SEEP))
- Provisions for Green Buildings and Overall Design Efficiency-(Energy Conservation Building Code (ECBC) of Bureau of Energy Efficiency (BEE), Green Rating for Indian Habitat (GRIHA) of The Energy Resources Institute (TERI) and Leadership in Energy and Environmental Design of India Green Building Council(IGBC))
- Affordable Housing and Smart Cities Programmes
- Rural Electrification Programmes (Deendayal Upadhyay Gram Jyoti Yojana (DDUGJY, Remote Village Electrification Programme (RVEP), etc.

Cooking

India accounts for the world's largest population (850 million) that rely on traditional biomass to meet their cooking needs (12). Of the households that use traditional biomass, 63% also collected their own fuel (23). Women and children spend up to 2-3 hours a day in collection activities. Estimates suggest that each year around 875,000 people in India die from Indoor Air Pollution (IAP) from traditional cooking. Globally, around 17 million Disability Adjusted Life Years (DALYs) are lost owing to diseases caused by IAP, women and children being most susceptible (23). Further, black carbon or soot emissions from traditional stoves contributes to the Asian brown cloud phenomenon that has impacts ranging from disrupting regional monsoons to exacerbating retreat of the Himalayan-Tibetan glaciers (24).

Liquefied Petroleum Gas (LPG), the main alternative to biomass for households, has been subsidised for over 30 years and has penetrated well in urban markets (65% in 2011 – a 12% increase since 2001) (25). With increasing urbanisation and monetisation of activities especially in urban middle to high-income households, demand for commercially procured meals could grow fourfold in urban areas. As of now, 88% of the commercial cooking sector also relies primarily on LPG. Piped Natural Gas (PNG) is being considered in major cities for enabling both commercial and residential use (13). However, import dependence and supply uncertainty along with high upfront cost of infrastructure could pose constraints for large scale deployment. Recent market advances with electricity based cook stoves could also enable increased use of this technology.

In rural areas, access to LPG is still less than 15%. Policies for improving access have largely been fuel subsidy based, implying a subsidy outlay of INR 48,362 crores in FY 14. Reforms are underway for improved targeting of the subsidy via Direct Benefit Transfer (DBT) to poorer households and improving last mile services (25). Yet, challenges in accessing modern fuels in remote areas and altering community behaviour[4] will likely mean that biomass will continue to be a significant fuel source, especially in rural areas. Technologies targeted at effectively using this biomass for rural communities such as improved cook stoves (ICS)[5] and biogas are used in less than 4% of Indian households owing to poorly implemented programmes and marketability challenges (23).

Policy Drivers – The key policies that are in place to promote access to cleaner cooking are:

- Unnat Chulha Abhiyan
- National Biogas and Manure Management Programme (NBMMP)
- Rajiv Gandhi Gramin LPG Vitrak Yojana (RGGLVY)
- DBT for LPG consumers

Transport

The transport sector comprises passenger and freight services. In recent decades, growing urbanisation and per capita income has driven the demand for passenger transport and vehicle ownership. Rising demand for commodities such as coal and iron ores, iron and steel and other material resources for industrial growth has implied an increase in the demand for freight services. The transport sector accounts for about 70% of the country's diesel usage (48 Million Metric Tonnes (MMT) in 2012) and 99% of the country's petrol usage (15.68 MMT) (6).

India's passenger transport demand was about 7,000 Billion Passenger Kilometre (BPKM) in 2012 (18), having grown 2.5 times since 2001. This is likely to double by 2030. In India, road is the principal mode for passenger transport, meeting over 80% of the demand. The share of urban transport is about 11%; the remaining is attributed to inter-city and rural travel.

The stock of passenger vehicles (two-wheelers and cars) stood at 132 Million in 2012 (26). In major cities public transport serves about 31% of the demand in 2011 (27). Most cities are planned primarily for motorised road-based passenger transport resulting in poor walkability. Rapid rates of motorisation have led to a reduction in peak hour speed (15 -25km/hr) in most major cities, indicating severe congestion. Congestion implies increase in idling time of vehicles, thereby an increase in fuel and travel costs.

According to the World Health Organization, nearly a third of the top 100 most polluted cities in the world are in India (28)[6]. Fuel standards improvements can reduce emissions but are progressing slowly; Delhi is among a handful of cities to have adopted the BS IV standard (BS V norms are in the pipeline). Poor ambient air quality adversely affects health of city dwellers; chronic respiratory diseases and morbidity in cities are on the rise.

Improving integration of public transport and other modes has proved challenging as cities are sprawling to adjoining rural areas. Interventions such as compact mixed-use development for city planning have the potential to facilitate shorter trip lengths and fuel conservation, but have not been explored. In rural areas, the share of non-motorised transport is declining, but fuel inefficiency of vehicles and poor fuel standards have emerged as major concerns.

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[4] Several communities engage in 'stacking' of fuel, i.e. using multiple options including traditional biomass simultaneously or as secondary options for cooking

[5] ICS can improve thermal efficiency of traditional biomass use from 10-15% to about 30-40% and also reduce emissions due to reduced fuel requirements

[6] PM2.5 emission concentration levels have been consistently recorded in violation of National Ambient Air Pollution Standards (NAAQS) in majority of the cities and NOx emission concentrations are on a steady rise.

The aggregate freight traffic was about 1.4 trillion tonnes kilometres in 2012 and is estimated to increase five-fold by 2030. Road transport constitutes about 60% of the total freight traffic, followed by rail (38%). Studies have revealed a loss of INR 240 billion annually due to congestion and poor vehicular mileage in freight transport (29). Railways are being considered an important alternative for improving fuel efficiency and alleviating road congestion. Railway freight movement was about 1,008 million tonnes in 2012-13, increasing at a CAGR of 3-4% since 2008 (30); progress on announced capacity expansion plans and institutional and regulatory changes to improve competitiveness will determine its ability to meet demand.

Policy Drivers – The main policies influencing transport sector are:

- Passenger transport:
  - National Urban Transport Policy - To ensure safe, affordable, quick, comfortable, reliable and sustainable access
  - National Electric Mobility Mission Plan - Enhancing national energy security and mitigate the adverse impact of vehicle emissions on environment
  - Auto fuel policy
- Freight transport: Dedicated freight corridor – to increase share of freight transport by rail and reduce unit cost of transportation

Power

Power sector will be a key enabler for India's growth and improving quality of life. Of the total electricity sales in FY 2012, industry sector accounted for the largest share (45%), followed by domestic (22%) and agriculture (17.3%). Demand from domestic and agriculture sectors has increased at a much faster pace compared to other sectors since 1970, growing with CAGR of 9.44% and 8.43% respectively (4). In 2012-13, India had about 209 GW of grid-connected capacity and about 45-50 GW of industrial captive installations (4).

The Indian government aspires for 24X7 access to electricity for the entire population. Even with the national grid reaching 97% (31) of rural villages, about 25% of the population still lacks access to electricity (32). Further, the energy and peak deficits on restricted demand in India were at 90 TWh and 15 GW in 2012 (33).

Coal has been the dominant source of electricity, accounting for approximately 56% of all installed capacity and 67% of generation. At present, coal fired plants that are under 'permitted' or 'under construction' stage account for an additional 150 GW. Several projects (~ 220 GW) have also been announced or are in the pre-permit development stages; realisation rates have been low due to challenges in coal linkages, and land and water availability (34). All new installed capacity is projected to be from supercritical or ultra-super critical technology.

About 2 GW of nuclear power was added in the last decade, and 20 GW is in the pipeline (35). While about 40 GW is in the proposed stage, its development is subject to site availability, public acceptance and the pace of reprocessing capacity expansion for the Fast Breeder Reactor (FBR) programme. The 24 GW of installed gas capacity installed is running at 20-25% Plant Load Factors (PLF) due to lack of domestic gas availability[7] (36).

Financial constraints of state power utilities have led to slow pace of improvements in transmission and distribution (T&D) efficiency. T&D losses are at about 27%; much higher than the world average of about 9-10% (37). Majority of non-technical losses are attributed to illegal

[7] Costs of Imported (Regassified) LNG are considered prohibitive

tapping of lines and faulty electric meters. Feeder segregation for non-agricultural consumers in rural areas has enabled identifying areas with high transmission losses. The government has set a target of reducing T&D losses to about 14% by 2022.

High reliance on thermal power plants also has implications for environmental sustainability. At present India has regulations imposed only on the emission of Particulate Matter (PM). However, there are no regulations for SO_2 and NO_X and it is estimated that 80,000 and 115,000 people die annually from pollution exposure from TPPs (38). In the absence of proper emissions and monitoring norms for power plants, TPPs are unlikely to invest in technologies that reduce these emissions.

The electricity sector withdrew about 22.3 billion cubic metres (BCM) of fresh water, which is equal to over half of India's total domestic water requirement (39). Indian TPPs with closed cooling systems currently consume about 5-6 m^3 per mega-watt hour of generation. In comparison, China and US plants report water consumption of half this amount. Breach of ash dykes is common and a number of water bodies are reported to be polluted with fly ash. The mandate for 100% fly ash utilisation in coal-fired plants has not been enforced effectively.

The government has recently announced a target of 175 GW of installed RE capacity by 2021-22. Of this, 100 GW is planned from solar, 60 GW from wind, 10 GW from biomass and 5 GW from small hydro power projects (40). This could imply about 20% share in generation in 2020-21. Such high levels of RE penetration in the electricity mix will have implications for distribution utilities, evacuation infrastructure, resources (land and water) as well as affordability to end-users. The pace of RE deployment will be dictated by how actively the barriers are tackled, most notably the delayed clearances, lack of evacuation facilities, problems with land acquisition, lack of robust site assessments, and high financing costs.

Policy Drivers – The main policy and regulatory drivers for the power sector are:

- Deendayal Upadhyaya Gram Jyoti Yojana
- Restructured Accelerated Power Development and Reforms
- National Solar Mission
- National Mission for Enhanced Energy Efficiency
- 24/ 7 Electricity Access
- RE capacity targets and policy instruments (Accelerated Depreciation, Generation-based Incentive, Viability Gap Funding) announced by Government of India.
- National Mines and Mineral Policy
- State-level Renewable Purchase Obligations (RPO) and schemes on electricity access and energy efficiency
- CEA regulations on water-use for TPPs
- MoEF/ CPCB regulations on Fly Ash Disposal and local pollutant emissions from TPPs

D. Key Findings

This section outlines the key findings for sustainability across the BAU and SD scenarios for 2030.

Energy Demand

The total energy demand in 2012 was 4,696 TWh, of which the residential sector contributed 45% followed by industry at 29%. *Figure 3* shows that in BAU (2030), the demand is likely to more than double to 10,693 TWh with the industrial share increasing to 43% on account of robust manufacturing sector growth. Residential demand reduces on account of provision of cleaner cooking fuels and technologies with better efficiencies. Commercial sector grows at 12% primarily due to high growth in floor-space and high penetration of air-conditioners.

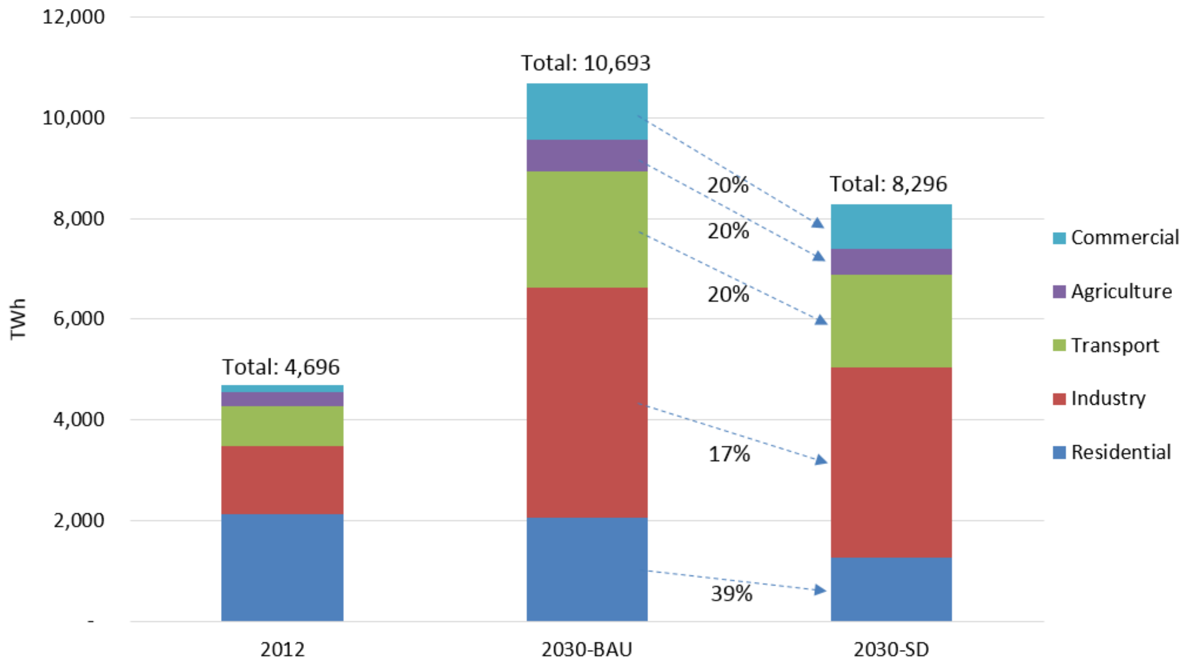


Figure 3: Final Energy Demand

The SD scenario indicates that over 22% of the BAU energy demand can be avoided through various interventions (refer to Appendix 1) across sectors. Energy demand thus grows in a manner that significantly alleviates pressures on the energy sector. Most sectors decrease their demand by about 20%, except the residential sector where aggressive penetration of modern cooking technologies and efficient appliances leads to about 40% reduction in energy demand.

Figure 4 shows the electricity demand, which grows from 745 TWh in 2012 to 3,343 TWh in 2030 in the BAU scenario (at 9% CAGR). Industry remains the chief consumer of electricity (including captive generation).

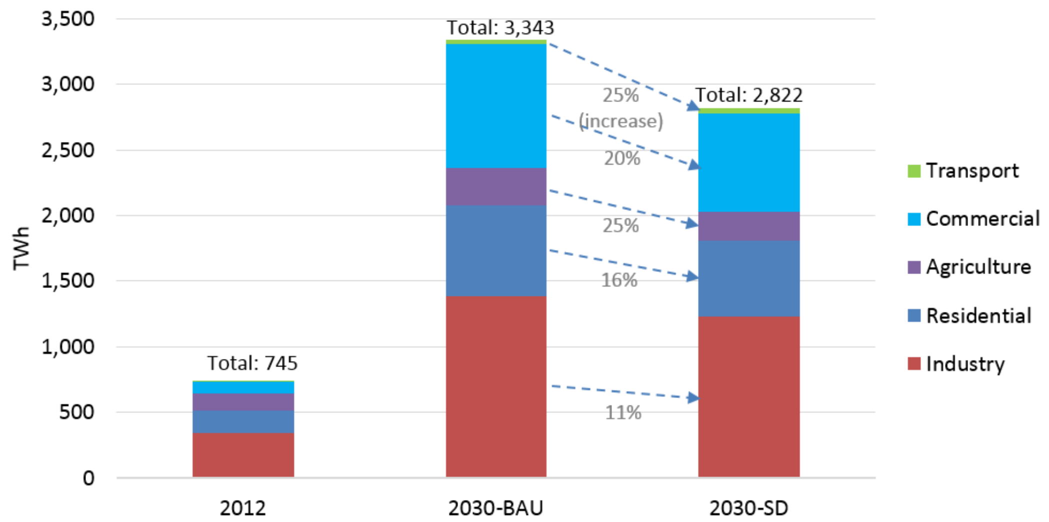


Figure 4: Electricity Demand

In the SD scenario, improved energy efficiency can reduce electricity demand by 521 TWh, or 16% compared to BAU. The transport sector's electricity consumption is likely to increase owing to higher penetration of Electric Vehicles (EVs).

Energy Supply

In the BAU scenario, Total Primary Energy Supply (TPES) grows almost three-fold from 6,355 TWh in 2012 to 17,538 TWh in 2030 (6% CAGR). TIMES model ensures that all energy demand is met based on technology, policy and resource constraints in the most cost-effective manner. Accordingly, the share of coal supplying this energy increases from 39% in 2012 to 62% in 2030. Based on the recent government announcements 1,500 MTPA of domestic coal mining capacity is assumed to be achieved by 2030.

The BAU scenario has 7% share of fossil-free energy that includes nuclear, hydro, wind, solar, and biomass used for electricity generation. Although a significant portion of biomass is procured commercially by households for cooking and heating applications, this is not considered as clean energy due to its negative effects on health.

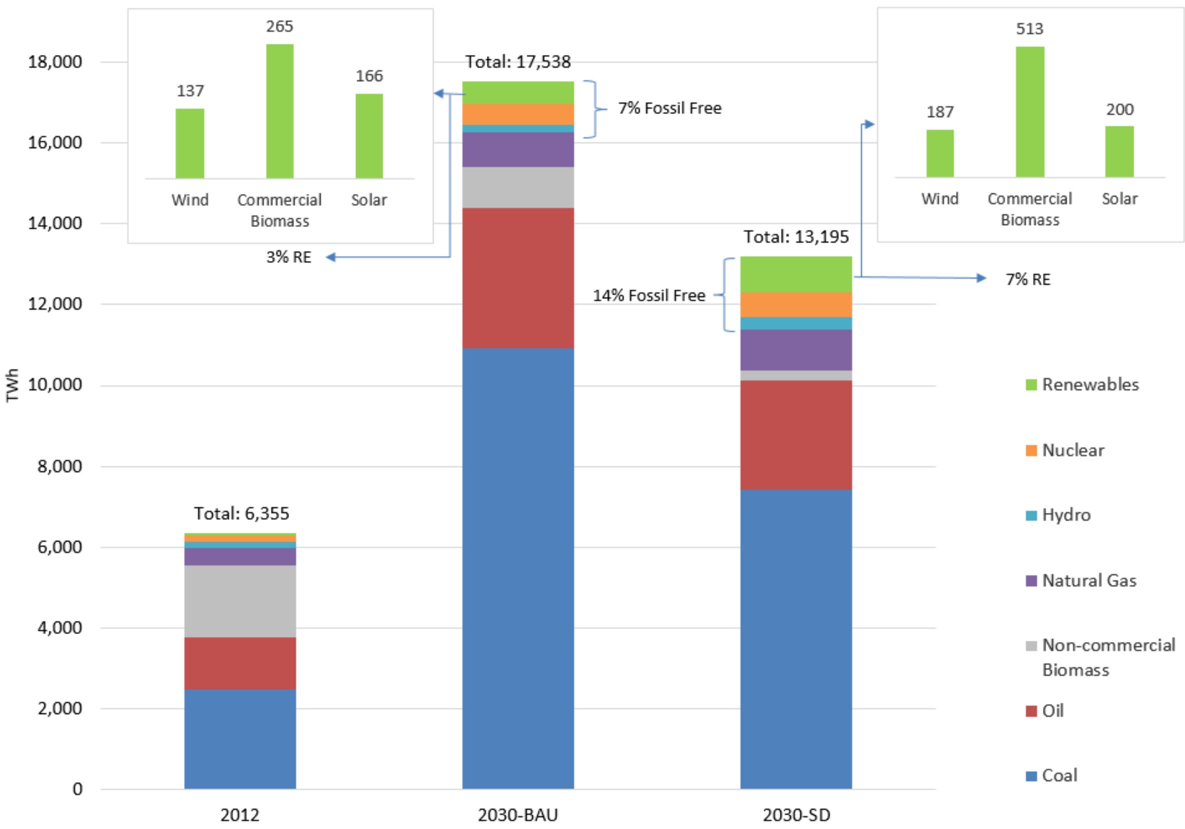


Figure 5: Total Primary Energy Supply

In the SD scenario, TPES reduces by 4,343 TWh (25%) compared to BAU owing to increased efficiency in energy use and in electricity transmission and distribution (T&D). The shift towards RE across agriculture, industry and electricity sectors results in the share of fossil-free energy doubling to 14% compared to BAU.

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

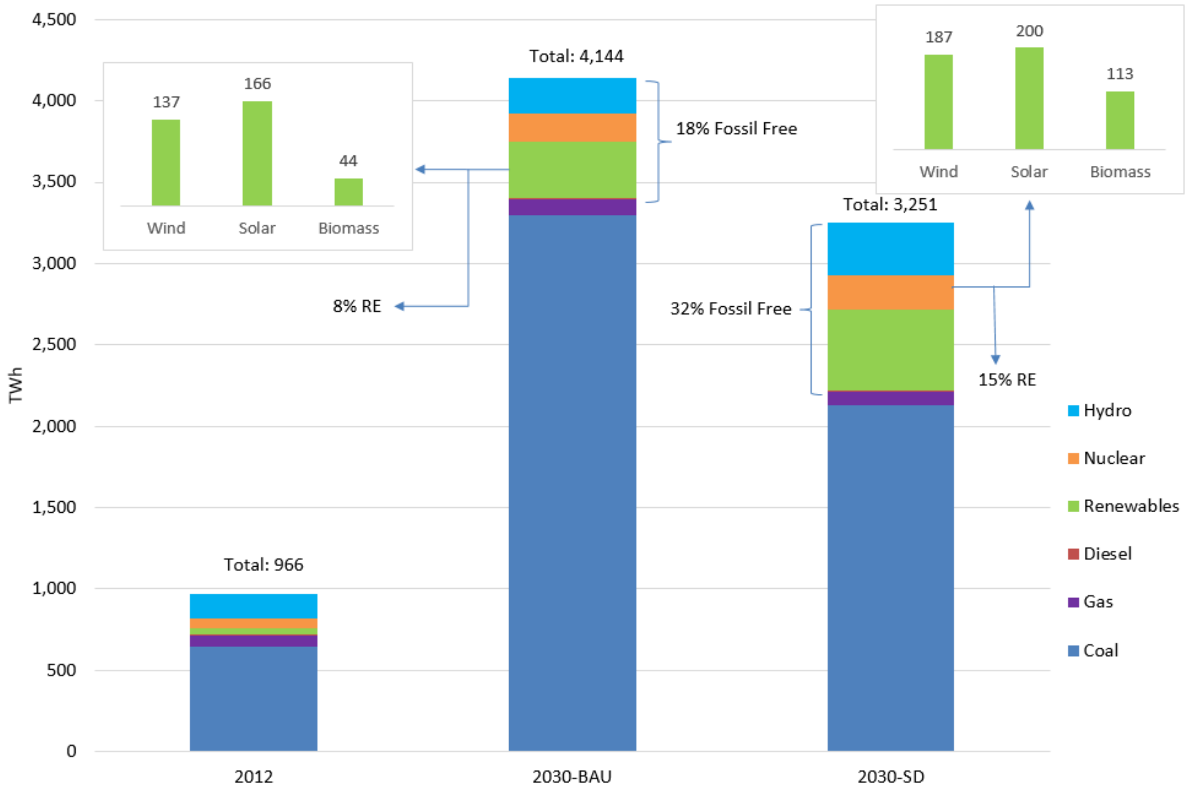


Figure 6: Fuel wise Electricity Generation

Electricity generation requirements reduce in the SD scenario by 893 TWh (27%). Figure 4 shows that 521 TWh of this reduction is on account of improved energy efficiency in demand sectors. Approximately 100 TWh is imported from neighbouring countries in the SD scenario. The balance of 272 TWh savings is due to aggressive T&D loss reductions across the country. While coal remains the primary source of supply, its contribution reduces to 66% of net generation in the SD scenario. Almost a third of electricity is supplied by fossil-free sources, and renewables contribute significantly (15%) to electricity supply.

Figure 7 provides the implications of the electricity generation scenarios on installed capacity. Installed capacity will need to increase from 251 GW in 2012 to 819 GW in 2030 in the BAU scenario. Renewables will contribute 180 GW in BAU.

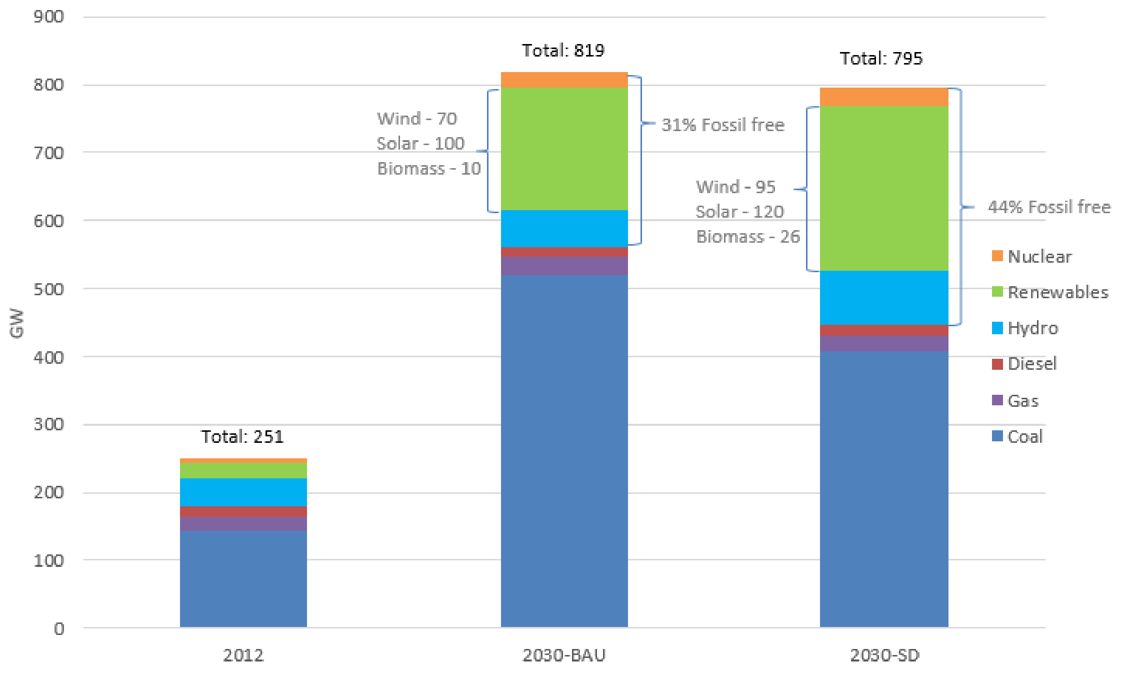


Figure 7: Installed Capacity

In the SD scenario the installed capacity reduces by 25 GW; most notably 112 GW of coal capacity is avoided. Installed capacity of renewables increases by 61 GW.

Import Dependence

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

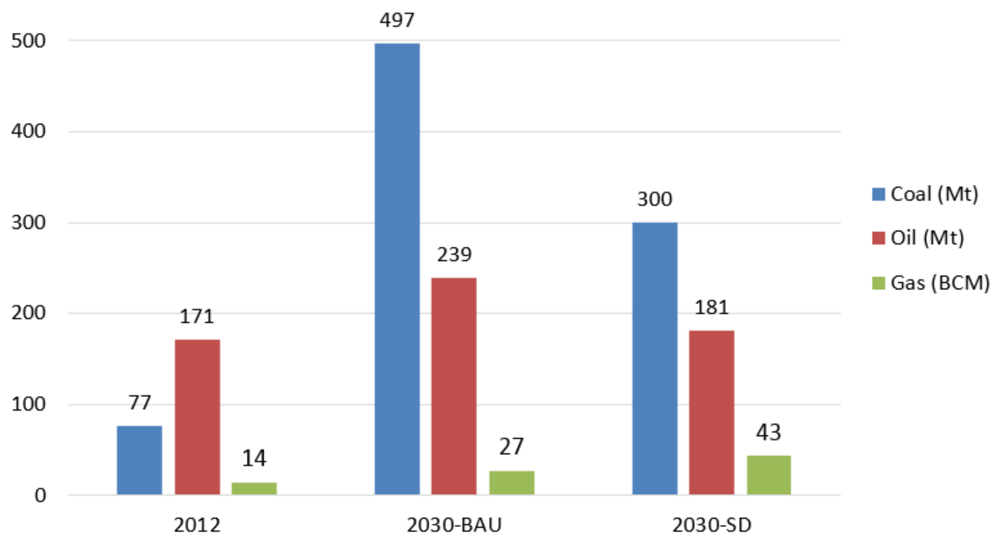


Figure 8: Energy Imports

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

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

Air Pollution

Figure 9 provides ambient air pollution from combustion of fossil fuels in industrial, transport and electricity generation sectors. The pollution is represented as annual loads of Suspended Particulate Matter (SPM), Oxides of Nitrogen (NO_x), Sulphur Dioxide (SO_2), Carbon Monoxide (CO) and Volatile Organic Compounds (VOC). In the BAU scenario, these emissions almost double from 2012 due to enhanced activity in these sectors, and limited efforts at improving energy efficiency, pollution control and switching to cleaner fuels.

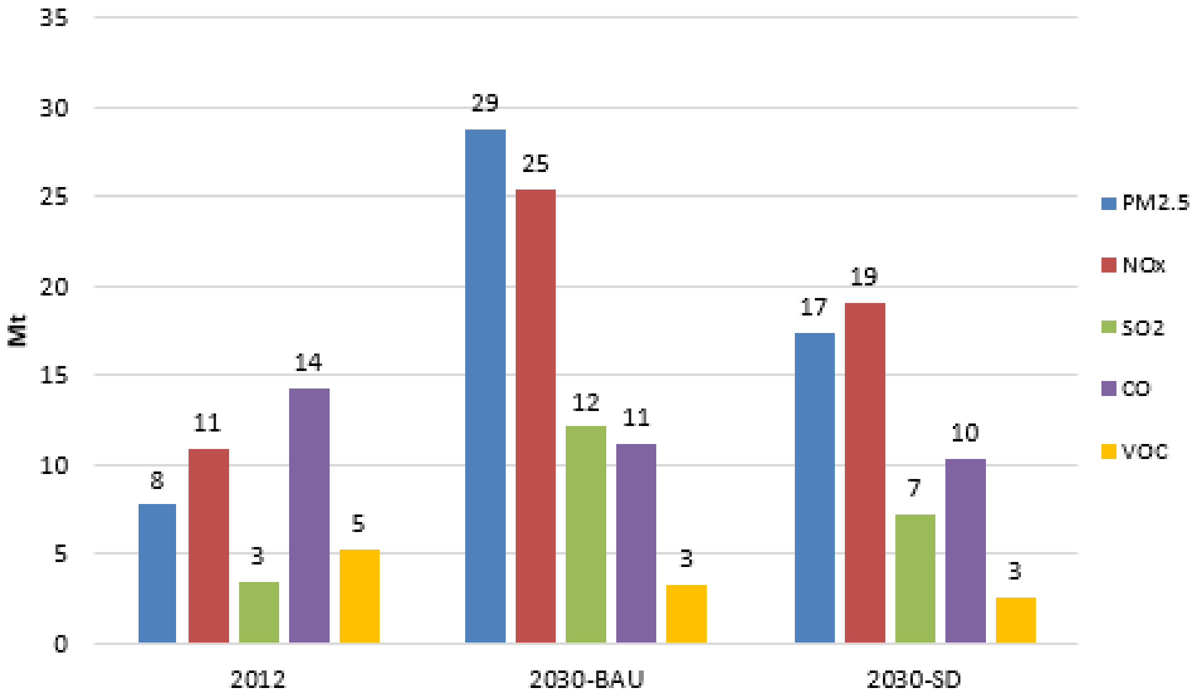


Figure 9: Ambient Air Pollution

In the SD scenario, air pollution reduces by 30% on average due to reduced vehicular activity through promotion of non-motorised transport and public transport, process upgradation and improved energy efficiency in industry, higher RE penetration in electricity and pollution control measures in Thermal Power Plants (TPPs). Electrostatic bag filters, flue gas desulphurisers and Low NO_x burners are key interventions in thermal power plants that reduce PM, SO_2 and NO_x emissions by 10% in the SD scenario at an additional 10-15% of capital costs of these plants.

Indoor Air Pollution (IAP) from traditional cooking fuels in households is a premier contributor to mortality and morbidity in India. Improving access to cleaner cooking fuels and technologies can significantly mitigate these impacts. The onus of collecting fuel wood for cooking disproportionately falls on women and children. This also makes them vulnerable to back injuries and limb deformation, and prevents them from engaging in other useful activities such as education and income generation. Figure 10 provides a summary of these outcomes in the two scenarios.

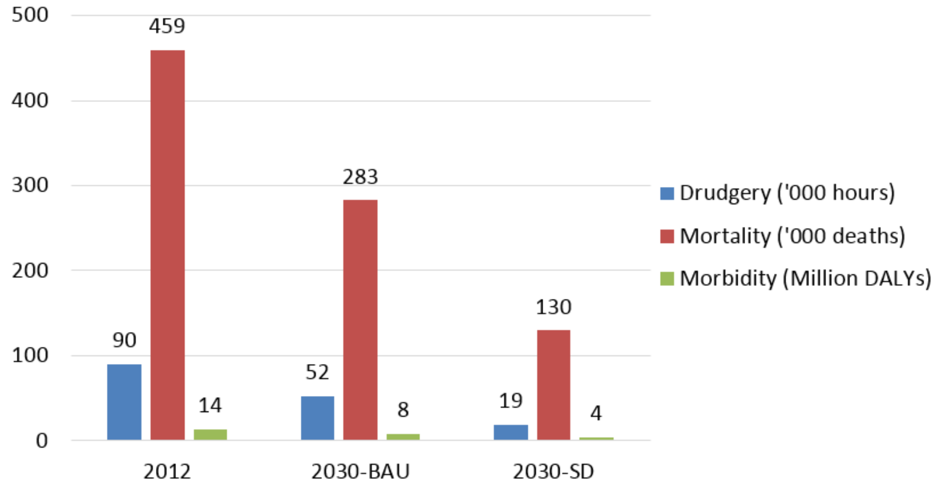


Figure 10: Drudgery, Deaths and DALYs due to Household Cooking

While there is progress in providing clean cooking fuels and technologies in the BAU scenario, (leading to reduction in indoor emissions of black carbon, carbon monoxide and organic carbon), this effort is increased significantly in SD scenario. This is due to aggressive penetration of LPG in rural and PNG in urban sectors, which more than halves the negative impacts associated with traditional cooking fuels.

Land

Extraction of metals and minerals is known to cause significant damage to land and water bodies. This threatens ecosystems and livelihoods relying on this mineral rich land for their subsistence. The SD scenario envisages a shift towards alternate materials that reduce land footprint and the consequent waste generated from mining activities. Table 1 gives the land footprint from mining in 2012 and BAU and SD scenarios in hectares

Table 1: Land Footprint from mining (hectares)

	2012	**2030-BAU**	**2030-SD**	**Saving**
Coal	13,259	41,438	29,407	29%
Limestone	2,819	9,613	7,872	18%
Bauxite	57	201	158	21%
Iron Ore	1,198	4,463	3,308	26%
Total	17,332	55,715	40,745	27%

Improving Floor Area Ratio (FAR) of urban residential buildings and commercial establishments and increasing the penetration of high-rise housing can reduce the land footprint of urban buildings from 10, 489 million sq. m. in BAU to 7, 316 million sq. m. in SD. This implies a saving of 43% or 3,173 million sq. m. in the SD scenario.

Water

Various estimates have shown that rising water demands from agriculture, industry and building sectors are likely to cause severe stress on water resources in the future. Ministry of

Water Resources has indicated utilisable water of 1,123 BCM against an estimated demand of 710 BCM by 2025. Other studies have projected over 1,000 BCM of demand by 2025. Further, 17% of the population will face absolute water scarcity, with only 1,235 cm^3 per capita availability in 2050.

Table 2 highlights the water impact of various sustainability interventions across sectors. Enhanced micro irrigation provision, alternate wetting and drying for rice cultivation and appropriate measurement of soil moisture can enable significant water savings from agriculture. In the industrial sector, enhanced waste water recovery and reduced mining requirements in the SD scenario generate savings of water that can be recycled into industrial processes or contribute to groundwater recharge. Leaching of waste water from industries and ash dykes can significantly pollute fresh water bodies and contaminate water tables. Closed water cooling systems in thermal power plants consume up to $4m^3$ per MWh of electricity generated. Dry handling of Electrostatic Precipitate (ESP) and concentrating the ash slurry can significantly reduce the water requirement from TPPs. Dry cooling towers can also reduce water demand for cooling with an increase in 15% over capital costs of power plants.

Table 2: Water Impacts of Sustainability Interventions (MCM)

Water Sectors	2030-BAU	2030-SD	Improvement
Industrial Waste Water Recovery	2,700	4,724	74%
Rooftop Rainwater Harvesting	748	2,016	169%
Water Savings in Agriculture	69,000	146,000	111%
Water Demand from TPPs	9,209	6,519	29%
Water Footprint from Mining	25,967	18,669	28%

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

Waste and Material Use

A key indicator in the SD scenario is how much goods and resources are demanded for development activities. In agriculture, imbalanced application of chemical fertiliser and lack of organic manure is leading to nutrient deficiency and reduction of organic carbon in the soil. This negatively affects soil health, water retention, microbial activities, soil aeration and nutrient retention, leading to reduced agricultural productivity. Thus, integrated nutrient practises such as proportionately higher application of organic manure as well as bio-fertilisers are important to improve the nutrient balance in soils. In the SD scenario, fertiliser consumption reduces by 21% compared to the BAU scenario, resulting in 99 kg/ha of fertiliser consumption in SD compared to 122 kg/ha in BAU.

TPPs and industries such as, iron and steel, cement, aluminium and paper rely on materials that are financially and environmentally costly to extract. Moreover, there is a finite life for the known raw material reserves at current rates of extraction, beyond which it may become very challenging to secure their supplies. Table 5 provides the raw material requirements for various industries in the BAU and SD scenarios and the years until expiry of known reserves (validity) based on current rates of extraction.

Table 3: Raw Material Requirements for Select Industries

Industry	Raw Material	Validity (years)	Raw Material Requirement (Mt)			
			2012	2030-BAU	2030-SD	Saving
TPPs/Industries	Coal		430	1,658	1,176	29%
Steel	Iron Ore	29	120	446	331	26%
Cement	Limestone	35	282	961	787	18%
Aluminium	Bauxite	46	6	20	16	21%
Paper	Wood		6	17	10	39%
	Trees (million nos.)		12	36	22	39%

In the industrial sector, this reduction in primary raw material demand in the SD scenario implies an increased demand for substitute materials. This is provided in Table 4.

Table 4: Alternate Material Requirements

Industry	Alternate Material	Alternate Material Requirement (Mt)			
		2012	2030-BAU	2030-SD	Increase
Steel	Scrap Steel	13	53	130	147%
Cement	Fly Ash	45	162	240	48%
	Blast Furnace Slag	6	28	40	44%
Aluminium	Scrap Aluminium	0.3	1	2	100%
Paper	Recycled Paper	4	7	9	21%

Overcoming the gap in affordable housing and catering to increased demand for housing and commercial buildings will have profound impact on construction material requirements. Studies have indicated how vertical expansion leads to overall reduction in material requirements. Table 5 presents the cumulative material requirements in the BAU and SD scenarios, with the difference attributable to a greater vertical expansion of building floor-space in the SD scenario.

Table 5: Material Requirements for Buildings

Materials (units)	2012	2030-BAU	2030-SD	Saving
Bricks (Billion)	1,222	13,387	13,848	-3%
Cement (Mt)	106	1,215	1,276	-5%
Steel (Mt)	11	126	123	2%
Coarse aggregate (MCM)	211	2,412	2,261	6%
Brick aggregate (MCM)	48	565	588	-4%
Timber (MCM)	13	146	134	8%
Lime (Mt)	7	80	70	13%
Surkhi (MCM)	22	261	218	16%
Bitumen (kt)	890	10,263	8,984	12%
Glass (million m^2)	39	448	406	9%
Primer (million lit.)	43	494	449	9%
Paint (million lit.)	67	774	699	10%

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

Waste Generation

Mining activities are responsible for generating waste that affects land, and water bodies and tables. Table 6 accounts for the waste generated from mining activities in 2012 and BAU and SD scenarios.

Table 6: Waste Generated from Mining

Raw Material	Waste Generated (Mt)			
	2012	2030-BAU	2030-SD	Saving
Coal	1,945	6,080	4,315	29%
Limestone	295	1,006	824	18%
Bauxite	3	12	10	21%
Iron Ore	112	416	308	26%

Use of alternate materials such as fly ash in Portland Pozzolana Cement brings benefits to TPPs in terms of reduced resource requirement for fly ash ponds. Fly ash disposal accounts for 35% of the land (18 ha/Mt ash generated) and 40% (Ash: Water=1:10) requirement in TPPs where ash is handled in wet form. Fly ash utilisation in TTPs increases from 34% in BAU to 75% in SD (Table 4).

The increased uptake of Light Emitting Diode (LED) lighting in the SD scenario leads to Compact Fluorescent Lamp (CFL) stock displacement, which also checks mercury accumulation. Each CFL contains 5-6 milligram of mercury. Based on the difference in cumulative CFL retirements between BAU and SD scenario we estimate that around 10-12 tonnes of mercury waste will be avoided in the SD scenario.

Water Saving

111%

Reduction in Diesel Demand

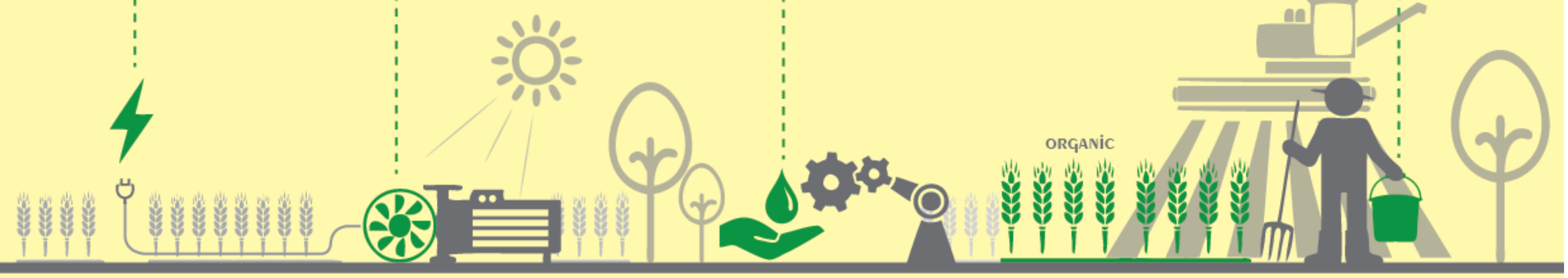
15%

Reduction in Chemical Fertiliser

18%

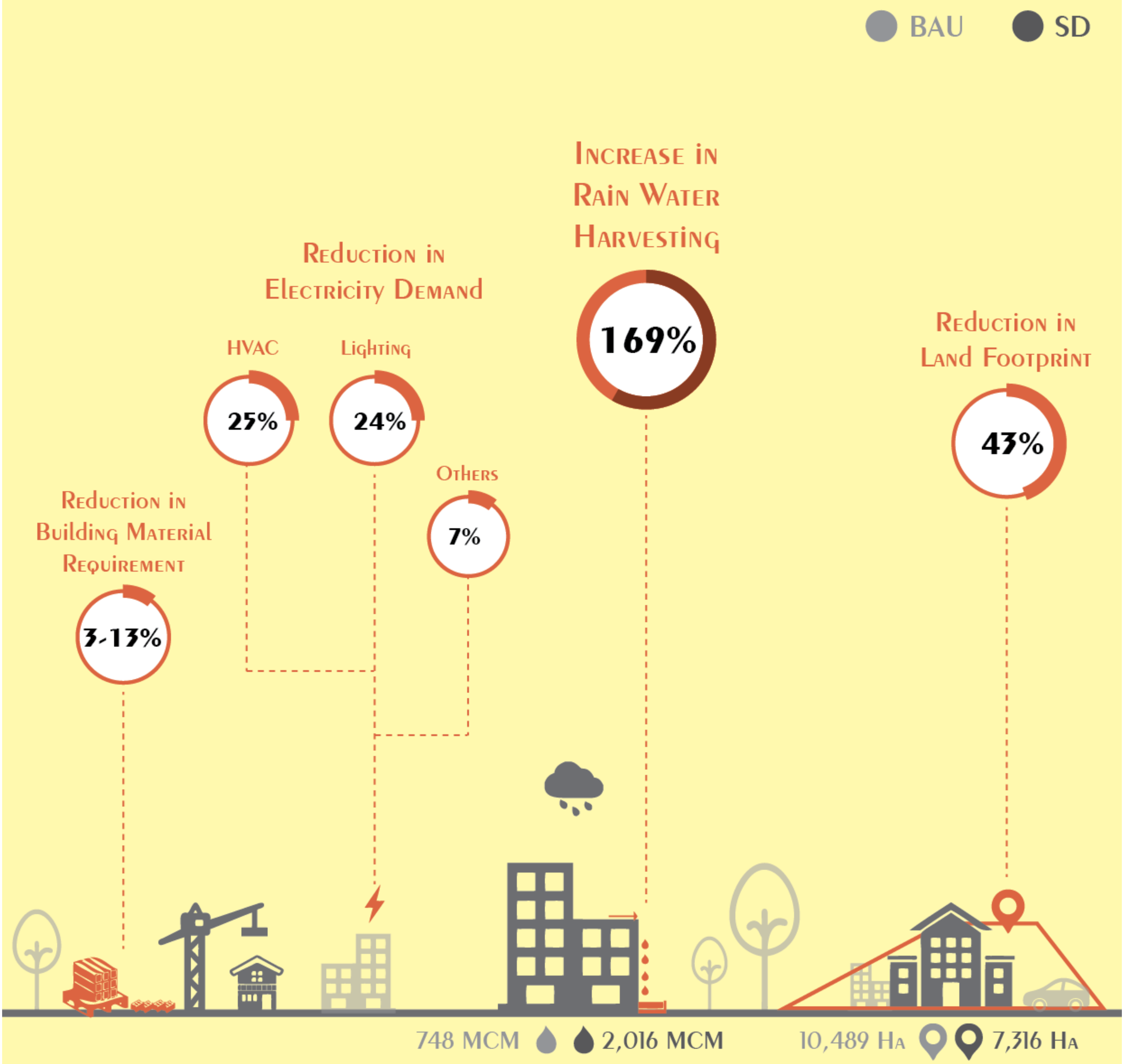
Reduction in Electricity Demand

24%

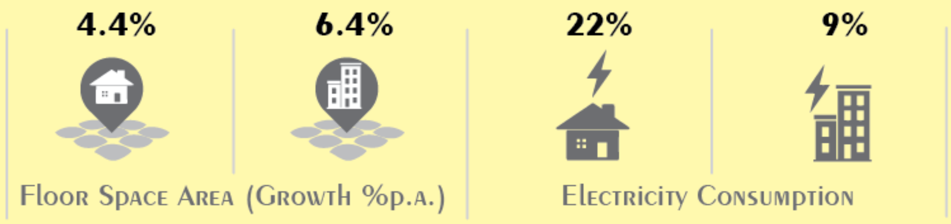


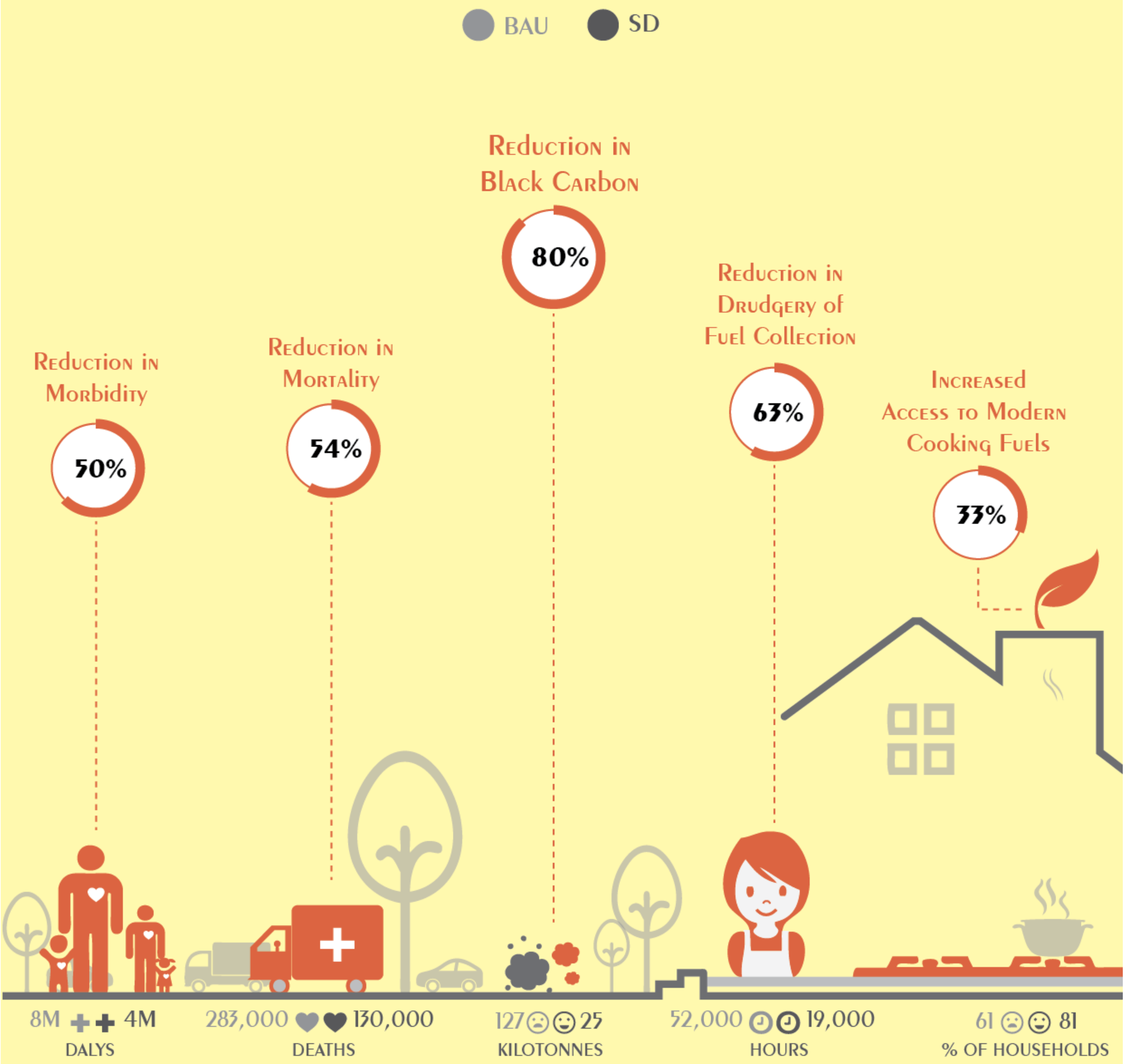
Agriculture

Water Use	Land Use	Employment	GDP	Electricity Use	Diesel Use
85 - 90%	40%	53%	12%	17%	13%


BAU
SD
Increase in Rain Water Harvesting
169%
Reduction in Electricity Demand
HVAC
25%
Lighting
24%
Others
7%
Reduction in Land Footprint
43%
Reduction in Building Material Requirement
3-13%
748 MCM
2,016 MCM
10,489 Ha
7,316 Ha

Buildings

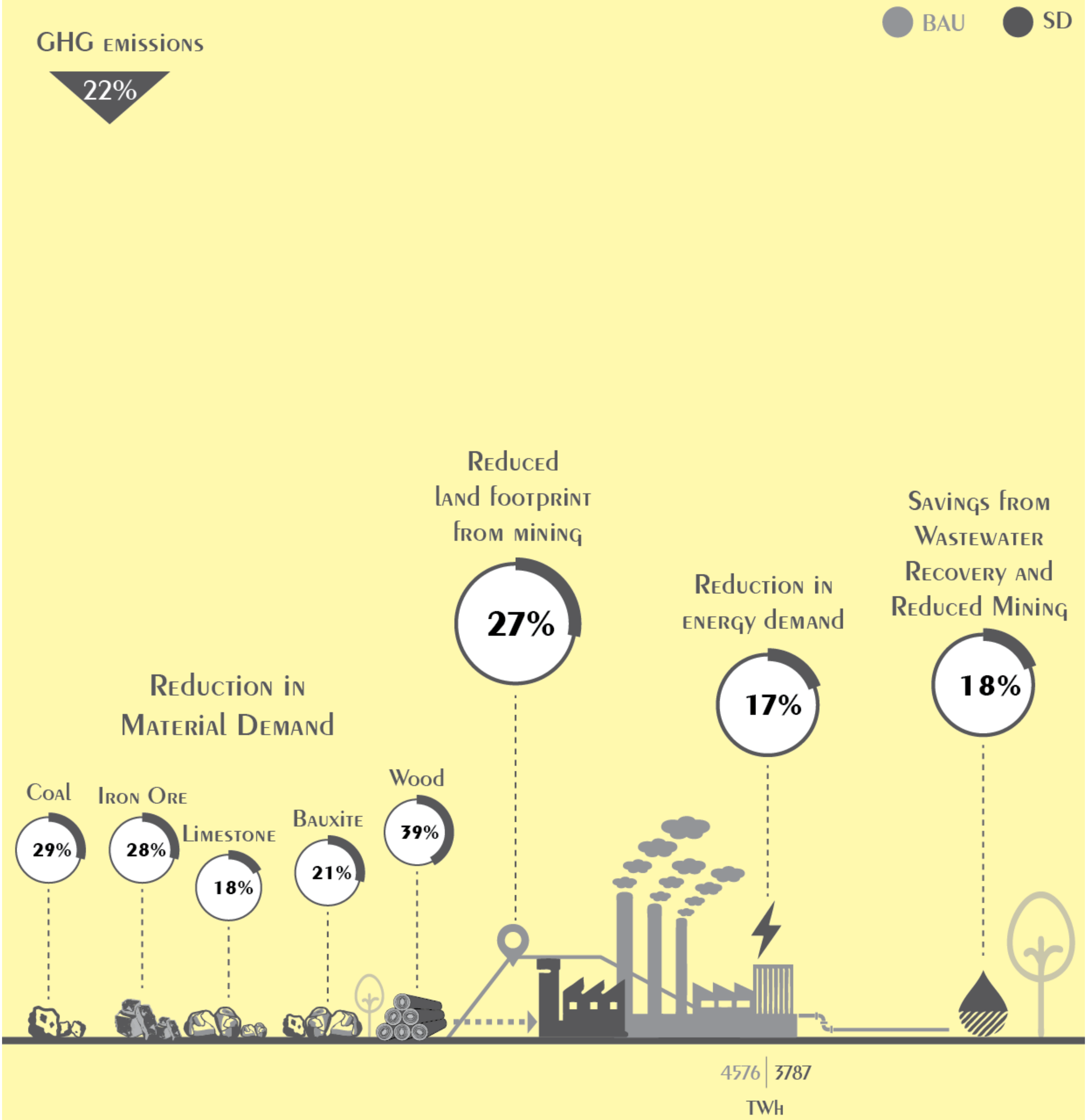

4.4%
6.4%
22%
9%
Floor Space Area (Growth %p.a.)
Electricity Consumption



BAU
SD
Reduction in Black Carbon
80%
Reduction in Drudgery of Fuel Collection
63%
Reduction in Morbidity
50%
Reduction in Mortality
54%
Increased Access to Modern Cooking Fuels
33%
8M 4M
DALYS
283,000 130,000
DEATHS
127 25
KILOTONNES
52,000 19,000
HOURS
61 81
% OF HOUSEHOLDS

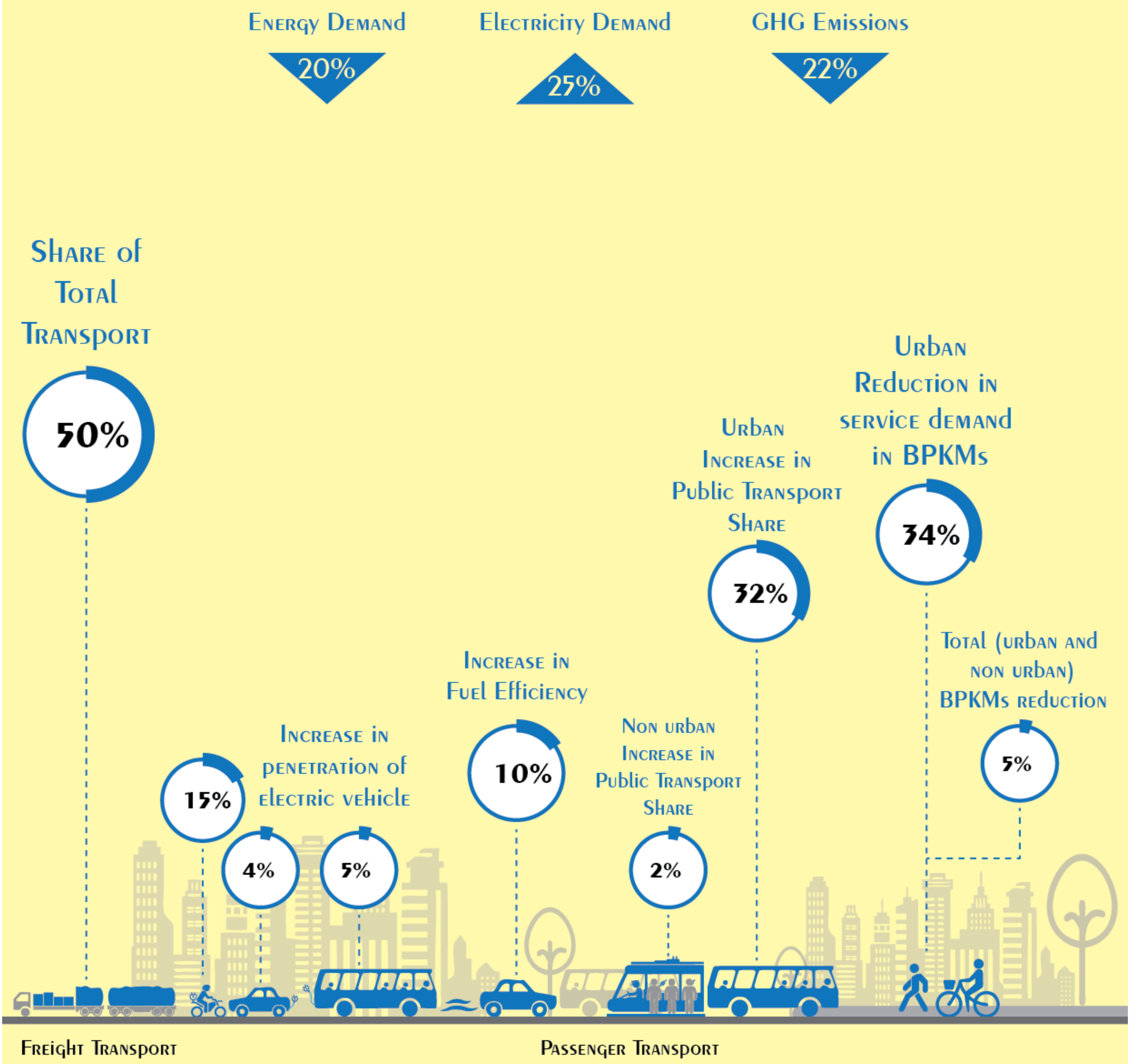
Cooking

60 - 70%
Collect own Biomass
90%
Cook & Collect Biomass
1 - 2 Hours per day
Fuel Collection
5,00,000 - 9,00,000
Deaths per year



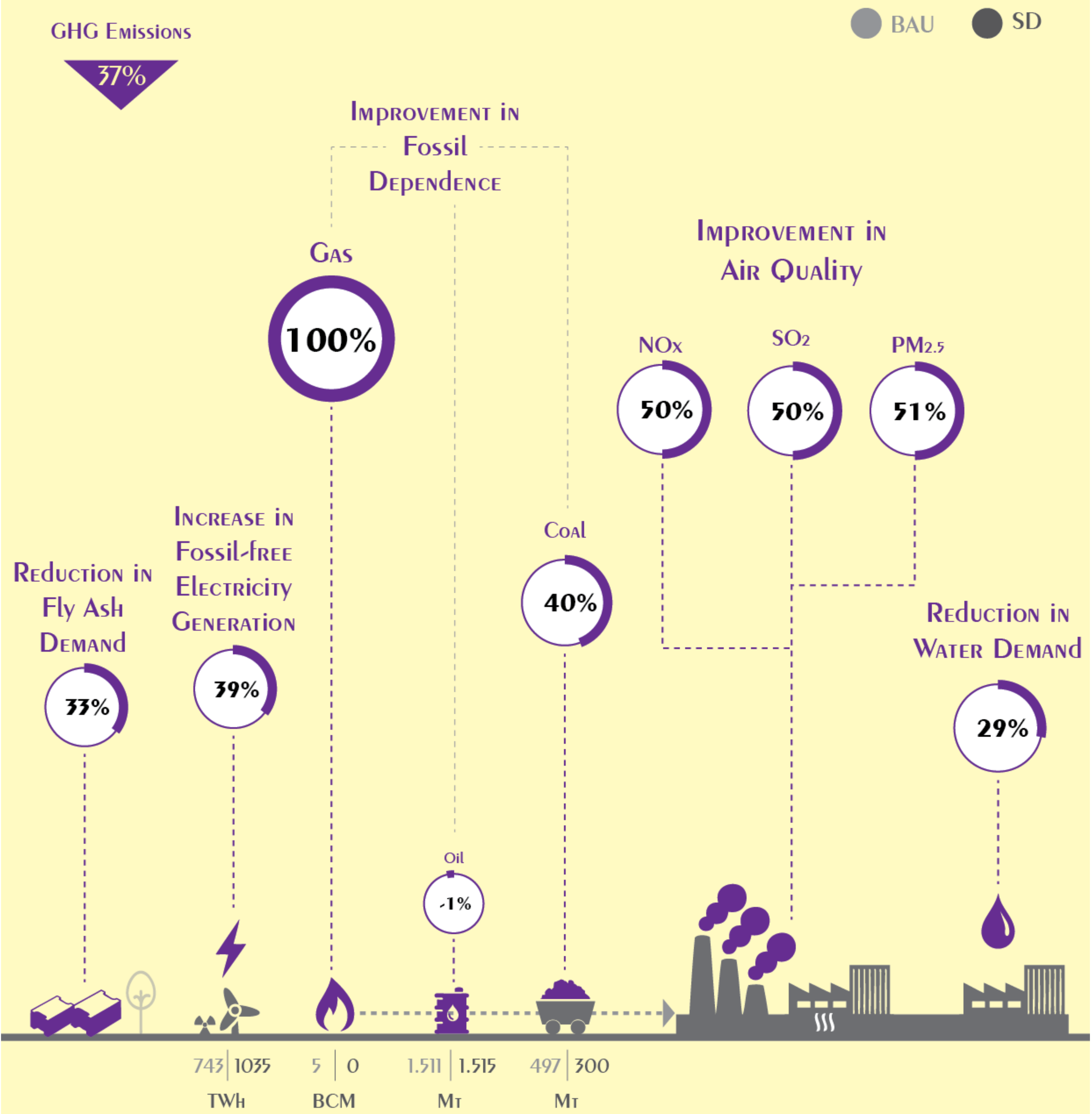
Industries

Growth	GDP	Iron and Steel	Cement
6.45%	27%	31.50%	28.47%


Energy Demand
20%
Electricity Demand
25%
GHG Emissions
22%
Share of Total Transport
50%
15%
Increase in penetration of electric vehicle
4%
5%
Increase in Fuel Efficiency
10%
Non urban Increase in Public Transport Share
2%
Urban Increase in Public Transport Share
32%
Urban Reduction in service demand in BPKMs
34%
Total (urban and non urban) BPKMs reduction
5%
Freight Transport
Passenger Transport

Transport


7K
BPKM
1.4K
BTKM
49,500
premature deaths
(2010)



Power

Coal	Gas	Nuclear	Hydro	Renewables
112 GW	18.4 GW	4.7 GW	40 GW	24.5 GW

E. Implications for India's INDC

The key insight for India's INDC is in terms of GHG emissions reduction along an SD pathway that significantly improves quality of life. Figure 11 demonstrates how different sectors contribute to emission reduction in SD scenario versus the BAU. RE generation, industrial sector, T&D loss reduction, and residential and transport sectors contribute the most to emissions reductions in the SD pathway. The interventions described in the Appendix 1 provide the necessary guidelines towards achieving these emission reductions.

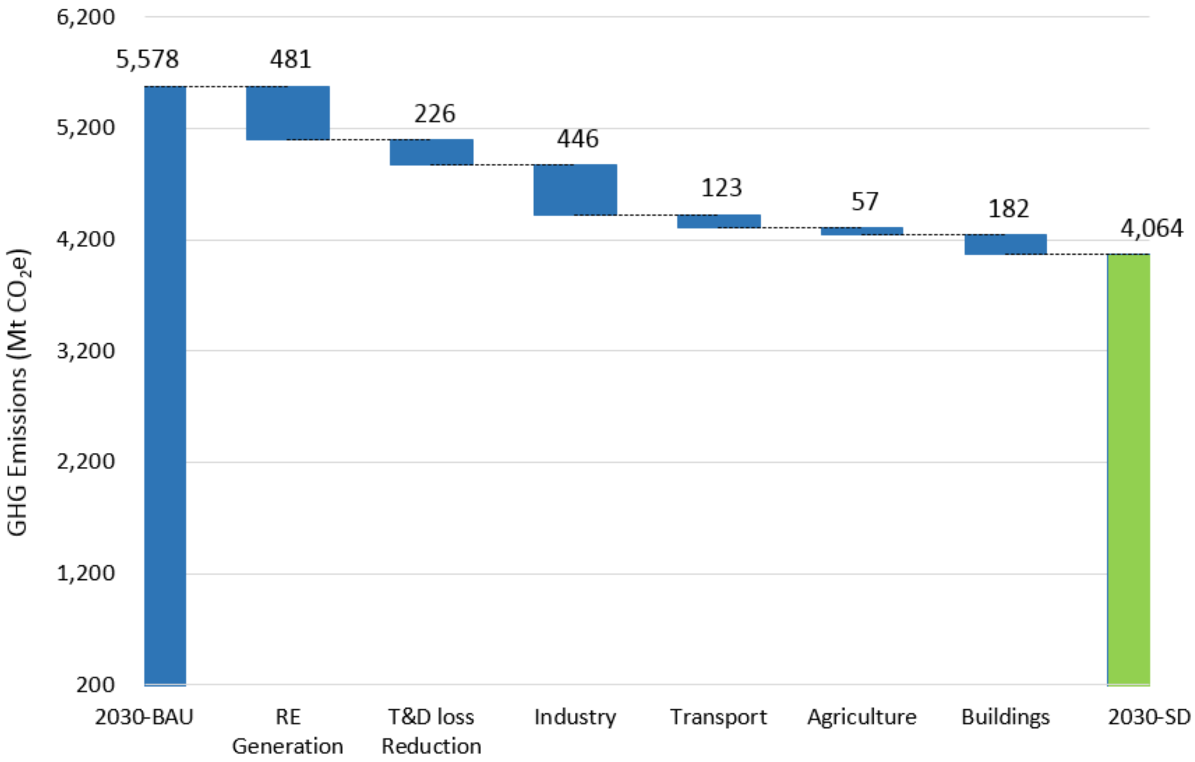


Figure 11: Emissions in BAU and SD Pathways

The scenarios are designed, taking into account a 6.5% projected growth rate of the economy till 2030. Accordingly, energy and emissions intensity are obtained for 2012 and 2030 in both the scenarios. Figure 12 and Figure 13 provide these results.

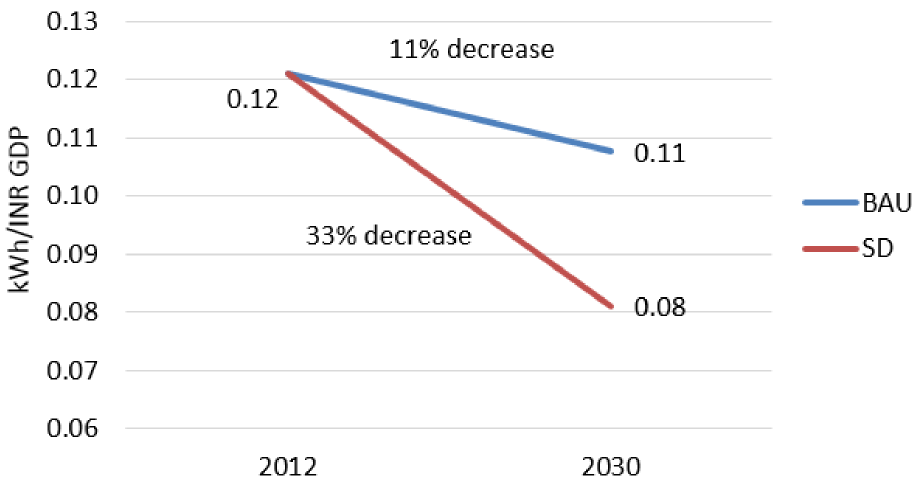


Figure 12: Energy Intensity in BAU and SD Pathways

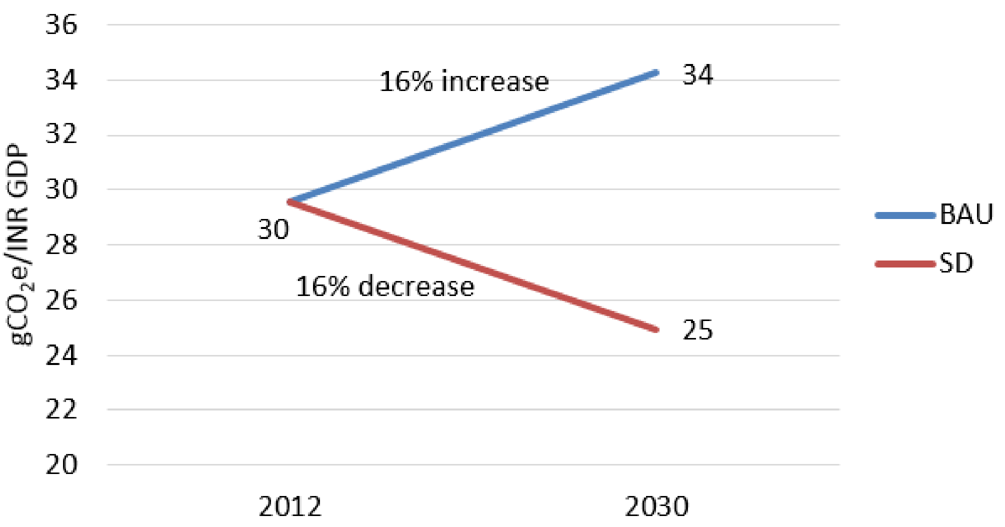


Figure 13: Emissions Intensity in BAU and SD Pathways

In the BAU scenario, the energy intensity improves to 0.11 kWh/ INR in 2030 compared to 0.12 kWh/INR in 2012, while the emissions intensity increases to 34 gCO_2e/ INR from 30 gCO_2e/ INR. On the other hand, the SD scenario offers additional reductions in energy and emissions intensities to 0.08 kWh/ INR and 25 gCO_2e/ INR, representing 33% and 16% decrease compared to 2012 respectively.

F. Conclusions

The SD scenario demonstrates how various factors affecting quality of life - access to electricity services and clean cooking fuels, reduced natural resource extraction and associated impacts, reduced import dependence and waste generation - can be addressed while reducing overall energy production and use in the economy.

This study proposes a 16% emissions intensity reduction[8] compared to 2012 levels based on a 33% reduction in energy intensity and 14% contribution of fossil-free sources in energy supply and 32% in electricity generation by 2030.

We recommend such a 'quality of life' paradigm and associated emission intensity reduction as India's INDC for the upcoming COP.

[8] This study does not consider fugitive emissions, process emissions from industries other than cement, steel and aluminium, and non-energy emissions from agriculture, forestry and other land use sectors.

Appendix 1: Sector-wise Sustainability Interventions

Interventions	BAU	Sustainable scenario
Agriculture		
Increase area under micro-irrigation schemes	Area under micro-irrigation increases from 1.5% of gross cropped area (~3 Mha) in 2012 to 6% (~13 Mha)	13% (~29 Mha) of gross cropped area under micro-irrigation
Water saving techniques for wheat and rice cultivation	Applied on 10% (~9 Mha) of gross cropped area of wheat and rice	Applied on 20% (~17 Mha) of gross cropped area of wheat and rice
Supplementing fertilizers with bio fertilizers	10% (~3 Mt) of chemical fertilizer use supplemented	15% (~5 Mt) of chemical fertilizer use supplemented
Organic farming	Area certified as organic increases from 4% (~5 Mha) of total net cropped area in 2012 to 10% (~15 Mha)	20% of total net cropped area(~30 Mha) certified as organic
Tractor efficiency improvement from 2012	11% improvement in fuel efficiency from 4.5 l/h in 2012 to 4.0 l/h	18% improvement in fuel efficiency to 3.7 l/h
Increase in deployment of solar pumps, reduction in diesel pumps	5% of penetration of solar pumping	15% penetration
Improvement in efficiency of pumps	10-15% improvement in input requirement of electric and diesel pumps	25-30% improvement in input requirement of electric and diesel pumps
Buildings		
Improvement in lighting efficiency	Residential: 30% LED penetration in point and linear lighting Commercial: 30% penetration of LEDs; 50% penetration of high efficiency CFLs	Residential: 80% penetration of LEDs in point and 70% in linear lighting Commercial: 60% penetration of LEDs; 35% penetration of high efficiency CFLs
Improvement in appliance efficiency	Residential: 5-20% penetration of highly efficient	Residential: 50-60% penetration of highly efficiency

	appliances Commercial: 30% penetration of highly efficient appliances	appliances Commercial: 60% penetration of highly efficient appliances
Improvement in building design and equipment controls	Up to 30% penetration over different types urban residential buildings 10-20% penetration over commercial FSA	Up to 60% penetration over different types of urban residential buildings 40% penetration over commercial FSA
Setting AC Thermostat Temperature higher by 2%	Not applied	13% savings in energy consumption of Air Conditioners
Solar Water Heating (SWH)	16 million m^2 of residential and 4 million m^2 of commercial FSA under SWH	48 million m^2 of residential and 12 million m^2 of commercial FSA under SWH
Using Low GWP coolants in refrigerators and air-conditioners	85% penetration of R410-A in ACs 70% penetration of HFC- 134A in Refrigerators	35% penetration of R-32 and 23% penetration of R-290 33% penetration of HFC-600A
Increasing Floor Area Ratio of Buildings	45% penetration of High Rise Residential buildings (FAR- 7)	60% penetration of High Rise Buildings
Affordable Housing	Affordable Housing Gap met by 2030	Affordable Housing Gap met by 2022
Rainwater Harvesting (RWH)	10% of Residential and 15% of commercial rooftop area employed for RWH	25% of Residential and 40% of commercial rooftop area employed for RWH
Residential: Cooking		
Transition to ICS	25% of rural and 5% of urban households use ICS (58 million households)	36% of rural and no urban households use ICS (73 million households)
Improve PNG infrastructure with a focus on domestic supply	23% (33 million) of urban households use PNG	35% (50 million) of urban households use PNG
Biogas plant implementation	4% (8 million) rural households using biogas	8% (16 million) rural households using biogas

Increased use of electric cooking access due to improved electricity access	2% of rural and 2% of urban households use electricity for cooking (7 million households)	6% of rural and 5% of urban households use electricity for cooking (19 million households)
Improve access of LPG to rural areas	25% (51 million) of rural households use LPG as a primary cooking fuel	50% (101 million) of rural households use LPG as a primary cooking fuel
Industries		
Improving Energy Efficiency of Industries	5-8 % reduction in SECs	10-25% reduction in SECs
Process Switching	Steel- Increase in Gas DRI (9% to 12%) and COREX process (10%-12%) Aluminium- Shift to Pre-baked method (70%-75%) Fertilisers- Shift to Natural Gas Feedstock (80%)	Steel- Increase in Gas DRI (9% to 12%) and COREX process (10%-14%) Aluminium- Shift to Scrap (20%-40%) Fertilisers- Shift to Natural Gas Feedstock (100%)
Higher Recycling/ Use of Scrap	15% scrap use in steel 20% scrap use in aluminium 43% recycled fibre use in paper 80% share of blended cement	33% scrap use in steel 40% scrap use in aluminium 65% recycled fibre use in paper 92% share of blended cement
Industrial Waste Water Treatment	Increasing secondary and tertiary treatment by 14% 10% methane recovery	Doubling secondary and tertiary treatment over 2012 30% methane recovery
Transport: Passenger (Urban)		

a) Shift to NMT (walking and cycling) b) Development of compact cities	Reduction in NMT share from 30% in 2012 to 10% in 2030 No compact city intervention, city sprawl trend continues	Maintaining the share of NMT at 30% in 2030 Compact city intervention reduces trip length by 20%
Increase in public transport share	Share reduces from the current 46% (road : 44% ; rail 2%) to about 33% (road : 29% and 4% rail)	Public transport ~ 67% share (road : 61% and 6% rail)
Promoting clean technologies (electric vehicles)	Negligible EV vehicles in 2012 to 2% of cars, 9% of 2W and 3% of buses in 2030	4% of cars, 15% of 2W and 5% of buses in 2030
Transport: Passenger (Non-urban)		
Increase the share of rail based transport	Current shares (Road :83%; rail:16%; air:1%) change in BAU to road: 81%; rail: 18% air: 1%	Increase in 2030 to 75% road share, 22% rail and 2% air
Increased Public Transport	Current bus share of 74% reduces to 62% in passenger kilometers travelled	About 71% share of buses in passenger kilometers travelled
Transport: Freight		
Increasing the share of freight transport by railways	61% road and 39% rail by 2030	50% rail and 50% road by 2030

Electricity Supply		
Reduce air emissions (SOx , NOx, PM2.5)	No restrictions of air pollution	SO_2 & PM 2.5emissions restricted to 40% of BAU
Reduce water use in thermal plants through	No water use standards imposed	Reduce water use in power sector by 40% of BAU
a) closed cooling b) fuel mix change	No restrictions	Specific water consumption in thermal plants in India adhere to global standards; share of renewables in power sector increases
Import dependence	Domestic Coal Mining Capacity at 1,500 Mtpa	Domestic Coal Mining Capacity at 1,500 Mtpa
Increase in access to electricity	75% of household access to electric lighting in rural areas in 2030	100% access to lighting in rural areas

Appendix 2: Key Data and Assumptions

This section contains the data and assumptions used for this study. The data was obtained from various papers and reports of and consultations with government bodies such as Planning Commission, Ministry of Agriculture, Bureau of Energy Efficiency, Central Electricity Authority, Department of Atomic Energy, Ministry of New and Renewable Energy, Ministry of Coal, Ministry of Petroleum and Natural Gas, Ministry of Road Transport and Highways, Ministry of Environment Forest and Climate Change, Department of Industrial Policy and Promotion, Ministry of Steel, Ministry of Mines, Ministry of Urban Development, Ministry of Rural Development, Central Statistics Office, National Sample Survey Organisation, etc., think tanks and private organisations such as Prayas, Council on Energy, Environment and Water, The Energy Resources Institute, Indian Institute for Human Settlements, India Smart Grid Forum, UrbanEmissions.info, Centre for Science and Environment, McKinsey, KPMG, Ernst and Young, etc., and international organisations such as World Bank, Asian Development Bank, International Energy Agency, United Nations Environment Programme, USAID, United States Environmental Protection Agency, World Business Council for Sustainable Development, Inter-governmental Panel for Climate Change, GIZ Lawrence Berkley National Laboratory, etc.

Macroeconomic Assumptions

Variable	2012	2030
Real GDP Growth till 2030	6.5%	
Share of Manufacturing Sector in GDP by 2030	25%	
Population (billion)	1.224	1.476
Urbanisation	32%	40%
Rural Household Size	5.00	4.45
Urban Household Size	4.41	3.54

Sector-wise Data and Assumptions

Cooking

Residential Cooking

Technology Penetration

Technology/ Fuel	Household by Type of Primary Fuel Used for Cooking (%)		
URBAN	Base year (2012)	BAU (2030)	SD (2030)
LPG	65	62	55
Electric	0	0	0
Induction	0	5	10
PNG	0	23	35
Traditional Biomass	23	10	0
Natural Draft Improved Biomass	0	0	0
Forced Draft Improved Biomass	1	0	0
Coal/Coke	3	0	0
Kerosene	8	0	0
Biogas	0	0	0

Technology/ Fuel	Household by Type of Primary Fuel Used for Cooking (%)		
RURAL			
LPG	11	30	50
Electric	0	2	4
Induction	0	2	4
PNG	0	0	0
Traditional Biomass	85	48	8
Natural Draft Improved Biomass	1	6	13
Forced Draft Improved Biomass	1	6	13
Coal/Coke	1	0	0
Kerosene	1	0	0
Biogas	0	6	9

Efficiency Improvements

Technology/Fuel	Efficiency		
	Base year (2012)	BAU (2030)	SD (2030)
LPG	0.58	0.6	0.62
Electric	0.74	0.77	0.8
Induction	0.84	0.85	0.9
PNG	0.58	0.6	0.66
Traditional Biomass	0.1	0.1	0.1
Natural Draft Improved Biomass	0.24	0.3	0.32
Forced Draft Improved Biomass	0.33	0.32	0.35
Coal/Coke	0.17	0.19	0.21
Kerosene	0.46	0.47	0.48
Biogas	0.57	0.6	0.62

Other assumptions:

- **Each household consumes 3,370 MJ of useful energy/year in all scenarios**
- **60% of households using biomass collect their own fuel.**

Annual Emissions and Quality of Life Assumptions

Technology/Fuel	CO_2 (kt/ TWh)	CH4 (ktCO_2eq/ TWh)	N_2O (ktCO_2eq/ TWh)	Black Carbon (kt/ TWh)	Deaths from IAP per household (HH)	Disability Adjusted Life Years per HH	Hours spent on fuel collection/ HH	Capital Costs for user (INR)
LPG	0.059	0	0	0	0	0	0	4800
Electric	BASED ON EMISSIONS FROM GRID CONNECTED ELECTRICITY GENERATION IN ALL SCENARIOS				0	0	0	5345
Induction					0	0	0	2148
PNG	0.038	0	0	0	0	0	0	7400
Traditional Biomass	0	0.084	0.025	$52.6*10^{-5}$	$27.7*10^{-4}$	0.083	$54.8*10^{-5}$	-

Technology/Fuel	CO_2 (kt/ TWh)	CH4 (ktCO_2eq/ TWh)	N_2O (ktCO_2eq/ TWh)	Black Carbon (kt/ TWh)	Deaths from IAP per household (HH)	Disability Adjusted Life Years per HH	Hours spent on fuel collection/ HH	Capital Costs for user (INR)
Natural Draft Improved Biomass	0	0.028	0.014	$9.4*10^{-5}$	$23.6*10^{-4}$	0.0707	$30.3*10^{-5}$	1699
Forced Draft Improved Biomass	0	0.021	0.010	$4.3*10^{-5}$	$23.6*10^{-4}$	0.0707	$30.3*10^{-5}$	3100
Coal/Coke					$27.7*10^{-4}$	0.083	0	-
Kerosene					$27.7*10^{-4}$	0.083	0	-
Biogas	0.069	0.002	0.01	0	0	0	0	19500

Commercial Cooking

Demand

Elasticity wr.t. GDP (2007-2012)	0.94
Service Demand (TWh in 2012)	65

Technology

Technology/Fuel	Share of Fuel Use (%)		
	Base year (2012)	BAU (2030)	SD (2030)
LPG	88	73	66
PNG	12	27	34

Agriculture

Water and Pumping Demand (2012)

Net cropped Area (NCA) (Mha) in Base Year (2012)	140
Growth in NCA (CAGR) (%)	0.34
Cropping intensity (%) in Base Year (2012)	140
Growth in Cropping intensity (CAGR) (%)	0.35
Land under wheat cultivation (%)	15.6
Water use of wheat (m^3/ha)	3500
Land under rice cultivation (%)	22.9

Water use of rice (m^3/ha)	12,000
Average water use by crops (excluding rice and wheat)	12,070
Land irrigated by surface water (Mha)	16.7
Discharge of ground water (m^3/s)	0.0883

The Gross Cropped Area (GCA) is the product of the cropping intensity and net cropped area.

Pumping Demand Projections

	Base year (2012)	BAU (2030)	SD (2030)
Growth of surface irrigation (CAGR) (%)	-	2	4
Pumping savings by water reduction (million hours)	-	3,900	7,900
Pumping demand (million hours)	24, 137	63, 261	59, 261

Pumping Demand met by Technology in 2012 (Hours Used)

Solar	Diesel	Electricity
0%	9%	91%

Characteristics of Pumping Technologies (2012)

	Electric	Diesel	Solar
Rating (HP)	5	5	3
Input (kWh)	6.42	13.32	3.85
Hours of use/year	1,000	500	1,200
Cost (INR)	17,000	20,000	3,47,000
Life (years)	7	5	10
Efficiency Improvement costs (INR/kWh supplied over life)	0.67-0.75	0	-

Fertilizer-use

Base year (2012) of chemical fertiliser use (MT)	27.8
CAGR of chemical fertiliser requirement	1.1%

Industry

Production Projections

Sector	2012	2030	CAGR
Cement	247	856	7.16%
Urea	22	36	2.80%
Ammonia	14	23	2.80%
Aluminium	2	6	7.79%
Steel	74	280	7.65%
Pulp and Paper	11	33	6.39%
Textile	3	5	3.16%
Caustic Soda	3	10	7.86%
Soda Ash	3	12	8.14%

Consumptive Water Requirement *(41; 10)*

WATER REQUIREMENT (m^3/t)	
Iron and Steel	11
Cement	0.5
Aluminium	120
Paper	112.3
Urea	17

Cost of Raw and Alternate Materials *(42; 43; 44; 45)*

Product	Alternate Material	Raw material cost (INR/ ton)	Alternate Material Cost (INR/ton)
Iron and Steel	Steel Scrap (C, A)*	18,000	15,000
Cement	Fly Ash, Blast Furnace Slag	250	223-288
Aluminium	Steel Scrap (A)	3,600*	20,000*
Paper	Recycled Fibre	2,800	2,520

*C &A refer to construction and automotive scrap respectively which differ in the carbon content of scrap (automotive scrap is of a higher purity than construction scrap)

* *The large difference between raw and alternate material prices is partially offset by the fact that 4 tons of bauxite are required to produce 1 ton of aluminium, whereas in the blended case, a ton of automotive scrap leads to 18-23% blending

Mining Footprint Coefficients

Mineral Production	Overburden/Waste(t/t extracted)	Land affected (ha/ Mt extracted)	Water Requirement (m^3/t)
Coal	3.67	25	10
Limestone	1.05	10	0.5
Bauxite	0.61	10	12
Iron Ore	0.93	10	12

Parameters for Industrial Waste Water Generation, COD, TOW and Methane Emissions *(10; 41; 46)*

Sectors	Generation (m^3/ton)	COD[9] (kg/ m^3)
WW generation and COD		
Iron and Steel	7.0	0.40
Cement	0.1	0.01
Aluminium	112.5	0.00
Fertilisers	8.5	0.10
Refinery	0.5	0.60
Textiles	65.0	0.90
PNP	101.0	6.50

TOW and Emissions	2010	2030 BAU	2030 SD
Methane Correction Factor	0.60		
Methane producing potential	0.25		
Emission Factor (EF)	0.15		
Sludge Removal (SR)	35%	40%	70%
Methane Recovery (MR)	5%	10%	30%

Total Organic Waste Water(TOW) kt	*"=SUMPRODUCT(Industrial Production, WW Generation, COD)*(1-SR)"*
Methane Emissions (kt)	*"=TOW*EF*(1-MR)"*
WW Recovery 2030	*"=SUMPRODUCT(Production, WW GENERATION)*(SR 2030 BAU - SR 2030 SD)"*

Processes- Steel

Technology	Investment Cost (INR billion/ Mt)	Production (% of total)	SEC (GJ/t)	Coal	Gas	Electricity
BF-BOF	14.40	42%	26.75	87%	0%	13%
Coal DRI-EAF	12.84	25%	26.46	84%	0%	16%
Gas DRI-EAF	12.84	9%	24.56	14%	70%	16%
COREX-BOF	34.98	10%	26.00	85%	0%	15%
Scrap-based EAF/IF	10.38	14%	12.85	75%	0%	25%

[9] Biological Oxidation Demand (BOD) and Chemical Oxidation Demand (COD) represent the amount of degradable organic material in wastewater. BOD concentration indicates the amount of aerobically degradable carbon, while COD is a measure of the total material availability (both bio-degradable and non-biodegradable) for chemical oxidation. BOD is more frequently reported for Domestic Waste Water (DWW) and COD for Industrial Waste Water (IWW) (IPCC, 2007). MoEF uses the same principle for reporting emissions from DWW and IWW

Processes- Aluminium

Technology	Investment Cost (INR billion/Mt)	Production (% of total)	SEC (GJ/t)	Coal	Electricity	Oil
Pre-baked	180.00	70%	82.02	27%	68%	5%
Soderberg	174.00	10%	91.91	27%	68%	5%
Blended	145.51	20%	67.99	18%	77%	5%

Processes- Paper

	Production (% of total)	SEC (GJ/t)	Thermal	Coal	Biomass	Electricity
Integrated Kraft (Wood/bamboo/agro waste)	57%	41.17	91%	58%	33%	9%
RCF based (includes market pulp)	43%	19.76	85%	51%	34%	15%

Processes- Cement

	Investment Cost (INR Billion/Mt)	Production (% of total)	SEC (GJ/t)	Coal	Waste	Electricity
Ordinary Portland Cement	3.96	25%	3.15	85%	1%	15%
Portland Pozzolana Cement	4.20	67%	2.90	79%	4%	18%
Portland Slag Cement	4.20	8%	2.72	79%	4%	17%

Processes- Fertiliser

Type	Technology	Investment Cost (INR Billion/Mt)	Production (% of total)	SEC (GJ/t)	Natural Gas	Naptha	Fuel Oil	Electricity
Urea	Natural Gas based	72.00	80%	19.25	77%	14%	0%	10%
	Naptha based	72.00	10%	22.84	0%	77%	14%	10%
	Fuel Oil based	72.00	10%	28.83	0%	14%	77%	10%
Ammonia	Natural Gas based	114.35	80%	25.79	77%	14%	0%	10%
	Naptha based	114.35	10%	35.00	0%	77%	14%	10%
	Fuel Oil based	114.35	10%	44.11	0%	14%	77%	10%

Process- Textiles

	Investment Cost (INR Billion/Mt)	Production (% of total)	SEC (GJ/t)	Coal	Electricity
Integrated Textile Mills	336.00	100%	12.60	9.50%	90.50%

Processes- Chlor- Alkali

		Investment Cost (INR Billion/Mt)	Production (% of total)	SEC (GJ/t)	Coal	Oil	Electricity
Soda Ash	Solvay	23.76	40%	16.95	89%	5%	6%
	Modified Solvay	23.76	20%	15.41	89%	5%	6%
	Akzo dry lime	23.76	40%	11.50	76%	5%	19%
Caustic Soda	Mercury cell	49.20	5%	11.88	0%	0%	100%
	Membrane cell	49.20	95%	10.25	0%	0%	100%
	Oxygen Depolarised Cathode	54.12	0%	8.51	0%	0%	100%

Energy Efficiency Interventions

Sector	Technology	Coal Savings (GJ/t)	Electricity Savings (GJ/t)	Oil Savings (GJ/t)	Gas Savings (GJ/t)	Naptha Savings (GJ/t)	Investment Costs (INR Billion/Mt)
Steel	ISPs_IISBOF	0.20	0.03				0.18
	Steel Making-EAF_IISCDRI	0.10	0.02				0.15
	ISPs Additonal_IISCRX	0.49	0.07				0.48
	EAF Gas_IISGDRI	0.01	0.02		0.09		0.14
	Steel Making-EAF_IISSCRAP	0.10	0.02				0.15
Aluminium	Improved Bayer_ALUSOD	1.06	0.26				13.14
	Improved Prebaked_ALUPB	0.49	9.11				61.34
	Improved Prebaked_ALUSCRAP	0.49	9.11				61.34
Cement	4 to 5 stage_CEMOPC	0.21	0.04				6.80
	5 to 6 stage_CEMPPC	0.35	0.07				7.30
	5 to 6 stage_CEMPSC	0.35	0.07				7.30
Fertiliser	NG based_NGAMM		0.02		0.14	0.01	2.11
	NG based_NGUR		0.02		0.14	0.01	2.11
	Naptha		0.02	0.01		0.14	0.95

Sector	Technology	Coal Savings (GJ/t)	Electricity Savings (GJ/t)	Oil Savings (GJ/t)	Gas Savings (GJ/t)	Naptha Savings (GJ/t)	Investment Costs (INR Billion/Mt)
	based_NAPAMM						
	Naptha based_NAPUR		0.02	0.01		0.14	0.95
	FO based_FOAMM		0.04	0.29		0.03	0.56
	FO based_FOUR		0.04	0.29		0.03	0.56
Paper	WoodEff_PNPWB	2.93	0.35				0.84
	RCFEff_PNPRCF	2.93	0.35				0.84

Buildings

Floor-space Area (million sq. meters)

	2012	2030	CAGR
Residential	13, 470	28, 544	4%
Commercial	1, 139	4,826	8%

Share of Residential Floor-space area under different building types

URBAN	2012	2015	2022 SD	2030 BAU	2030 SD
High rise	40%	42%	50%	45%	60%
Horizontal	59%	53%	41%	41%	26%
Affordable	1%	5%	9%	14%	14%
RURAL	2012	2015	2022 SD	2030 BAU	2030 SD
Kaccha	30%	27%	0%	0%	0%
Semi-Pucca	18%	16%	0%	0%	0%
Pucca	52%	57%	100%	100%	0%

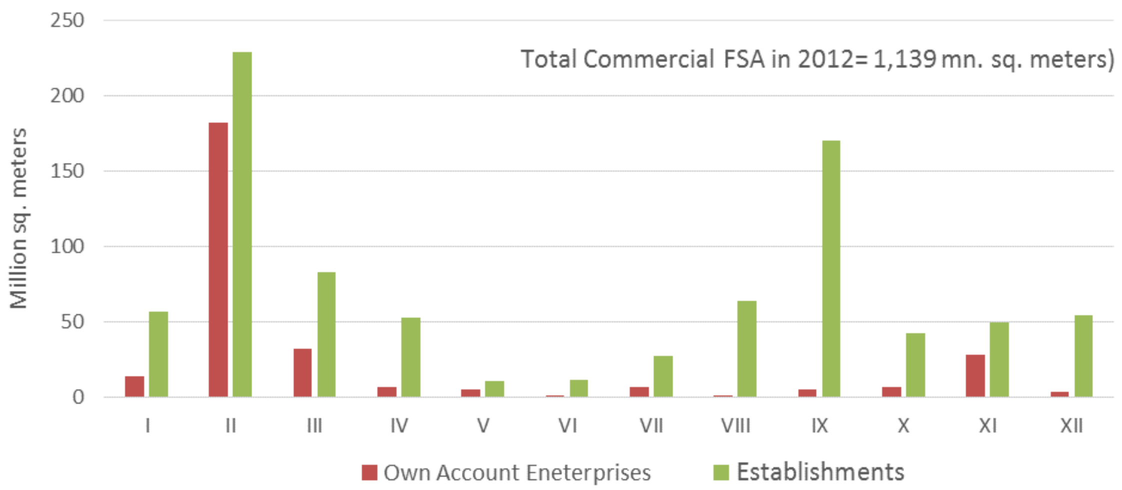
Floor-space Index (FSI) of Buildings

	FSI 2012	FSI 2030 BAU	FSI 2030 SD
High Rise	5	5	7
Horizontal	1.25	1.25	8
Affordable	3.5	3.5	3.5
Pucca	1.25	1.25	1.25
Semi-Pucca	1	1	1
Kachcha	1	1	1
Commercial	4	6	7

Housing Deficit in 2012

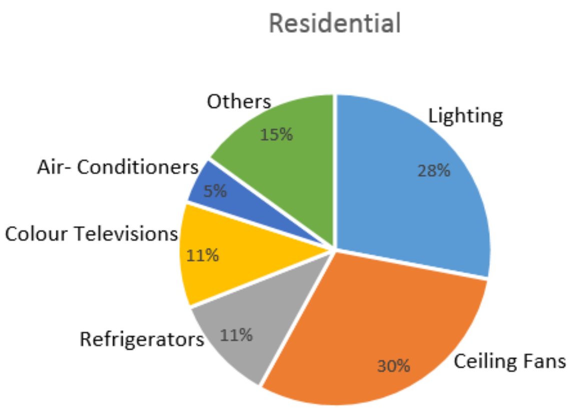
Rural- 44 million
Urban- 19 million
Pucca Housing Deficit- 48%

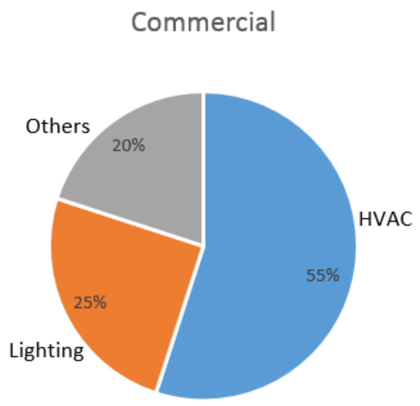
Commercial FSA by building Type (2012)



I- Wholesale Trade. II- Retail Trade. III- Restaurants and Hotels. IV- Transport & Haulage. V- Post & Telecom. VI- Financial Intermediation. VII- Real Estate, Renting & Business Services. VIII- Public adm. & defense; compulsory social security. IX- Education. X- Health & Social Work. XI-Other Community, social & personal

Shares of Energy Consumption by Different Services





Material Requirement for Different Building Types (adapted from (47))

Materials	Horizontal	Affordable	High Rise (RCC frame)
Bricks (1000 nos)	2.26*FSA + 66.8	2.15*FSA + 63	-26.2 + 2.56*FSA - 0.0096*FSA 2
Cement (ton)	0.153*FSA + 0.57	0.145*FSA + 0.54	0.182*FSA - 0.35 + 0.0204*FSA-0.014
Steel (kg)	21.3*FSA - 314	21.97*FSA - 305	(-1491) + 92*FSA- 0.36*FSA2 + -171 + 10.46*FSA- 0.041*FSA 2
Coarse aggregate (m^3)	0.176*FSA -0.21 + 0.145*FSA + 1.5	0.178*FSA -0.21 + 0.075*FSA + 0.78	0.295*FSA - 0.75 + 0.45 + 0.0027*FSA + .0001*FSA 2 +0.071*FSA-0.01
Brick aggregate (m^3)	0.113*FSA - 0.83	0.056*FSA -0.42	0.021*FSA + 0.01
Timber (m^3)	0.019*FSA + 0.23	0.019*FSA + 0.23	0.02*FSA + 0.1 I
Lime (100 kg)	0.145*FSA - 0.35	0.073*FSA - 0.17	0.063*FSA - 0.08
Surkhi (m^3)	0.052*FSA - 0.37	0.026*FSA -0.18	0.01*FSA
Bitumen (kg)	1.836*FSA- 9	0.918*FSA - 4	0.90*FSA - 2.41
Glass (m^2)	0.064*FSA - 0.73	0.064*FSA - 0.73	0.056*FSA - 0.06
Primer (l)	0.068*FSA	0.068 *FSA	0.061*FSA + 0.56
Paint (I)	0.108*FSA + 0.27	0.108*FSA + 0.27	0.085*FSA + 1.93

Stock of Residential Appliances

Stock (million)		
Appliance	2012	2030
Point Lighting	687	1312
Tubular Lighting	258	500
Refrigerators	47	244
RAC	4	116
CTV	123	396
Fans	305	776

Hours of Use of Residential Appliances

Hours of Use		
Appliance	2012	2030
Lighting	1360	1500
Ceiling fans	3000	3600
Televisions*	1	1
Refrigerators*	1	1
Room Air Conditioners	1200	1500

*Considered to be in mixed use (Operational and Standby for 3600 hours per year)
**Considered to be in mixed use (operational and standby, during the year)

Service Technologies in Residential Sector

Appliance	Type	Consumption(Watt)		Life (Years)	Price (INR)		Stock Vintage (years in use by 2012)
Bulb	Low	60		0.6	12		0.3
CFL	Medium	11		5	110		2.5
LED	High	6		20	350		2
Ceiling Fans	Low	60		12	1880		8
	Medium	50		12	2040		6
	High	30		15	2500		
Televisions		Cathode Ray Tube	Light Emitting Diode		Cathode Ray Tube	Light Emitting Diode	
	Low	188	145	12	7464	13020	7
	Medium	140	108	12	8100	14390	3.5
	High		70	15			
Refrigerators		Direct Cool	Frost Free		Direct Cool	Frost Free	
	Low	400	555	15	9030	15800	10
	Medium	260	364	15	11700	19300	6
	High			15			
Room Air-conditioners		Window	Split		Window	Split	
	Low	1884	1870	10	25320	28209	5
	Medium	1550	1570	10	32640	38100	3
	High			12			
TFL	Low	40		3	47		2
	Med	30		3	75		1
	High	14		10	800		

Service Technologies in Commercial Sector

Lighting					
Efficiency	Wattage	Hours	Cost	Lifetime	cost/kwh lifetime
High	6	2400	350	20	1.22
Med	10	2400	120	5	1.00
Low	15	2400	110	5	0.61

HVAC					
Efficiency	Wattage	Hours	Cost	Lifetime	cost/kwh lifetime
High	1115	2400	66553	15	1.66
Med	1570	2400	38100	10	1.01
Low	1870	2400	28209	10	0.63

Others					
Efficiency	Wattage	Hours	Cost/watt	Lifetime	cost/kwh lifetime
High	80	2000	59.01	20	1.47
Med	109	2000	18.13	10	0.91
Low	139	2000	11.20	10	0.56

ECBC Interventions

ECBC Interventions	Applicable on	Description	Incremental Costs (INR/m^2)	% Savings
Envelope Insulation	HVAC	Wall assembly U- factor – 0.44	565	4.18%
Envelope Insulation	HVAC	Wall assembly U- factor – 0.405	580	4.36%
Envelope Insulation	HVAC	Wall assembly U- factor – 0.35	698	4.73%
Roofing	HVAC	Roof assembly U-factor – 0.409	189	9.09%
Roofing	HVAC	Roof assembly U-factor- 0.354	230	9.27%
Roofing	HVAC	White roof assembly U-factor- 0.30	326	14.24%
Window Glazing	HVAC	(U-3.3; SHGC- 0.25; VT- 0.27)	2251	10.93%
Window Glazing	HVAC	(U- 3.3; SHGC-0.25- VT-0.20)	2261	11.09%
Window Glazing	HVAC	(U- 3.3; SHGC-0.20- VT-0.16)	2433	14.19%
Window Glazing	HVAC	(U- 3.3; SHGC-0.20- VT-0.13)	2461	14.35%
Window Design	HVAC	Window-to-wall area ratio at 40%	112	13.17%
	HVAC	Projection Factor - 0.25	112	4.45%
	HVAC	Projection Factor - 0.50	270	7.48%
Daylight Control	Lighting	Dual level switching at daylit areas w/separate control	56	5.09%
Lighting Control	Lighting	Central EMS sweep after hours	105	4.19%

ECBC Interventions	Applicable on	Description	Incremental Costs (INR/m²)	% Savings
Lighting Control	Lighting	Central EMS control by floor	131	7.60%
Lighting Control	Lighting	Private office occupancy sensor control	124	5.84%
Lighting Control	Lighting	Conference occupancy sensor control	41	2.96%
Lighting Control	Lighting	Storage/miscellaneous occupancy sensor control	21	1.67%

Cooling Technologies used in Air Conditioners				
Technologies	GWP 100 year (t CO_2/t)	ODP (tR 11/t)	Life	Coolant Requirement g/kW
R-22	1810	0.055	11.9	150
R-410A	2088	0		140
R-32	677	0	5.2	97
R-290	3.3	0	0.041	74.5

Stock Share Assumptions			
Technologies	2012	2030 BAU	2030 SD
R-22	90.0%	5.0%	2.5%
R-410 A	8.5%	85.0%	40.0%
R-32	1.0%	5.0%	35.0%
R-290	0.5%	5.0%	22.5%

Cooling Technologies used in Refrigerators				
Technologies	GWP 100 year (t CO2/t)	ODP (tR 11/t)	Life	Coolant Requirement g/kW
CFC 12	10900	1	100	150
HFC-134a	1,430	0		150
HC-600a	3	0		150
Other (HFC-152 A)	124	0		150

Stock Share Assumptions			
Technologies	2012	2030 BAU	2030 SD
R-22	95.00%	20.00%	2.50%
R-410 A	4.50%	70.00%	50.00%
R-32	0.25%	5.00%	33.00%

Run-off coefficients for Rainwater Harvesting

Type of Catchment		Run off coefficient	
Roof	Catchments	Min	Max
Ground Surface Coverings	Tiles	0.8	0.9
	Corrugated metal sheets	0.7	0.9
	Surface		
	Concrete	0.6	0.8
	Brick pavement	0.5	0.6
Untreated Ground Catchments	Soil on slopes <10%	0	0.3
	Rocky natural catchments	0.2	0.5
	Green area	0.05	0.1

Cost (INR/ m^3) of rainwater harvesting systems- 13.59

Climate-zone specific assumptions

Climate Zone	(% area India)	Rainfall	Value Used	Summer High	Summer Low	Winter High	Winter Low	Diurnal Change
Hot Dry	25%	<500	300	43	25	15	5	15 to 20
Warm Humid	15%	>1200	1300	35	27.5	27.5	22.5	5 to 8
Composite	45%	500-1300	800	38	29	18	6	35 to 22'
Temperate	2%	>1200	1200	32	21.5	30	17	8 to 13
Cold	13%	200-1000	400	23	11	5	0	10 to 15
Average			706	37	25	17	8	

Rooftop Solar Water Heating Assumptions

Electricity used by storage water heater/year	2012	2030
Specifications		
Storage tank capacity (lit)	25	25
Power Rating (kW)	2	2
Assumptions		
Usage per person per day(lit)	15	15
No. of people per Household	4.42	3.54
Room Temp. of Water (Celsius)	27	27
Final Heating Temp. (Celsius)	45	45
Number of Usage days per annum	200	250
Constants		
Specific heat of water (kWh/(l*C))	0.001163	0.001163

Electricity used by storage water heater/year	2012	2030
Calculation		
Energy used to heat 25 l (kWh)	0.523	0.523
Usage per family per day (lit)	66	53
Energy required (kWh)	278	278
Efficiency	0.67	0.7
Energy used (kWh)	414	397

Electricity Demand offset by solar water heaters (SWH)

SWH system characteristics (2 sq. m)		
Capacity	100	LPD
Cost	20,000	INR
Life	20	years
Techno economic potential	80	MSM

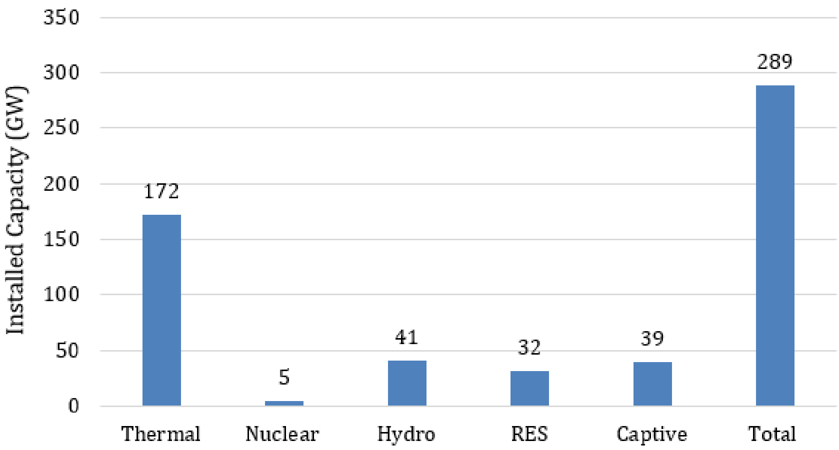
Electric Storage Water Heater (ESWH) Replaced		
Input	2	kW
Capacity	25	Litres
Productivity	0.7	kWt/sq. m
Efficiency of Geyser replaced versus SWH	0.70	
Market price of geyser replaced	8000	INR

Installation (million m^2)	2012	2030 BAU	2030 SD
Residential	4.5	16.0	48.0
Commercial	1.1	4.0	12.0
Total	5.6	20.0	60.0
Urban Households (#)	87	169	169
Saturation	3%	5%	14%

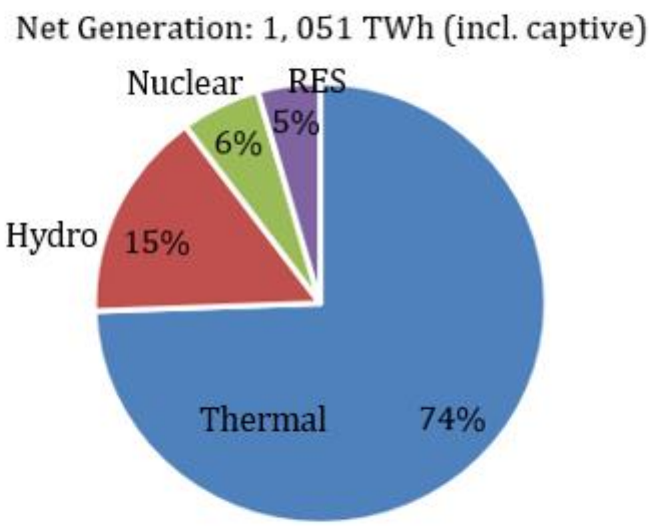
Power

- Plant wise information for operating generating stations was used along with geospatial locations and operating parameters
- Current and future non-fossil plants with expected capacity additions were provided
- Current and future thermal power plants were fed into the model along with their proposed capacities and status- announced, commissioned, under construction, permitted, and those under pre-permit development.

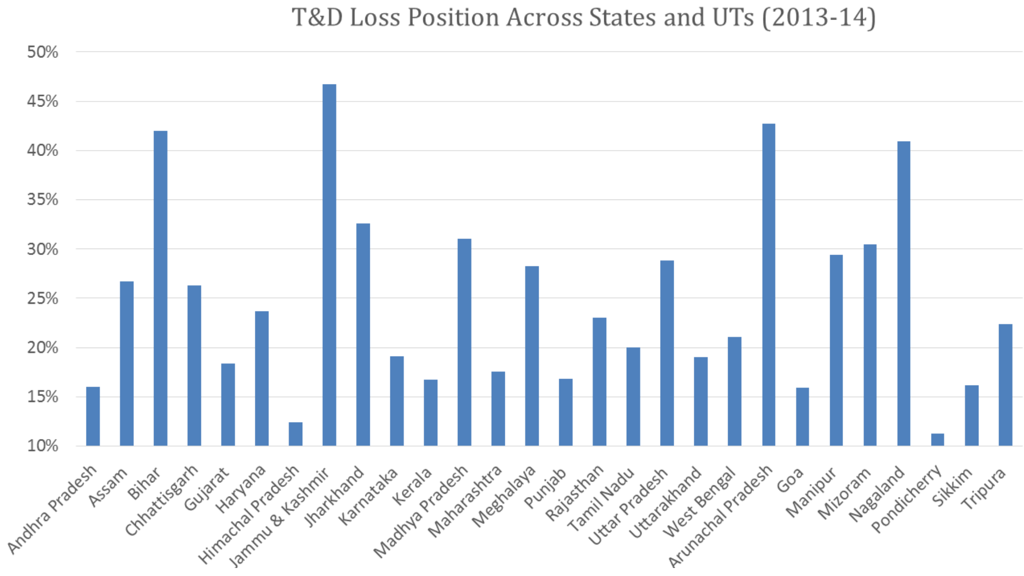
Installed Capacity 2013-14



Electricity Generation Mix 2013-14



Transmission and Distribution Losses across States and UTs (2013-14)



Emission Factors for Different Fuels (kt/TWh)

	Biomass	Domestic Bituminous Coal	Imported Coal	Lignite	Washed Coal	Diesel	Domestic Gas	Imported Gas	Naphtha	Fuel Oil
SO_2		1.98	0.55	0.55	1.9764	0.47				0.84
Total Suspended Particulate (TSP)		4.14	2.07	4.14	4.14					
Fly Ash		0.08	0.02		0.06					
CO_2		344.92	345.96	382.14	344.92	266.64	201.96	201.96	264.00	278.52
CH_4	47.63	0.08	0.08	0.08			0.08	0.08		0.23
N_20	4.46	1.56	1.56	1.56			0.11	0.11		0.67
NO_x	0.36	1.08	1.08	1.08			0.54	0.54		0.72
CO	3.60	0.07	0.07	0.07			0.07	0.07		0.05
Volatile Organic Compounds (VOC)	0.18	0.02	0.02	0.02			0.02	0.02		0.02

Input parameters for New Generation Technologies

Technology Description	Investment Cost (INR Billion/ GW)	Availability Factor	Fixed O&M (INR Billion/TWh)	Variable O&M (INR Billion/TWh)	LIFE
Small Hydro	55	0.45	1.4	0	50
RunofRiver - New	150	0.48	0.9	0	50
Pumped - New	80	0.93	0.8	0	50
Nuclear-HWR-220	100	0.93	2.5	1	40
Nuclear-FBR-160	100	0.93	2.5	1	40
Nuclear-LWR	200	0.93	5	1	40
Coal - SubCrit-500	47.1	0.92	1.04	0.12	40
Coal - SubCrit-250	47.1	0.92	1.3	0.12	40
Coal - LowSuperC-660	50.1	0.92	0.9	0.13	40
Coal - HighSuperC-800	47.9	0.92	0.87	0.14	40
Coal - UltraC-1000	78.2	0.92	0.74	0.15	40
Coal - SubCrit-500 Imported	78.2	0.92	1.3	0.12	40
Coal - SubCrit-250 Imported	78.2	0.92	1.04	0.12	40
Coal - LowSuperC-660 Imported	45.53	0.92	0.9	0.13	40
Coal - HighSuperC-800 Imported	42.53	0.92	0.87	0.14	40
Coal - UltraC-1000 Imported	101.2	0.92	0.74	0.15	40
Coal - UltraC+CCS-1000 Imported	165.6	0.92	1.55	0.15	40
Gas-500	30	0.92	0.42	0.06	30
Gas-250	30	0.92	0.42	0.06	30
Oil-250	30	0.92	0.42	0.06	30
Biomass - New	50	0.86	4	0.04	25
Wind turbines 80m - wind class 01	59	0.2	1.063		25
Wind turbines 80m - wind class 02	61.952	0.24	1.063		25
Wind turbines 80m - wind class 03	59	0.26	1.063		25
Wind turbines 80m - wind class 04	59	0.27	1.063		25
Wind turbines 100m - wind class 01	64.8	0.24	1.063		25
Wind turbines 100m - wind class 02	64.8	0.28	1.063		25
Wind turbines 100m - wind class 03	64.8	0.3	1.063		25
Wind turbines 100m - wind class 04	64.8	0.31	1.063		25
CSP power tower no storage - Lev 7	180	0.25	2.35		25
CSP power tower 3h storage - Lev 7	230	0.35	3.43		25
CSP power tower 6h	280	0.4	3.87		25

Technology Description	Investment Cost (INR Billion/ GW)	Availability Factor	Fixed O&M (INR Billion/TWh)	Variable O&M (INR Billion/TWh)	LIFE
storage - Lev 7					
CSP LFR no storage - Lev 7	170	0.2	2.1		25
CSP LFR 3h storage - Lev 7	220	0.35	3.57		25
CSP LFR 6h storage - Lev 7	270	0.4	3.96		25
CSP Parabolic Trough no storage - Lev 7	158.02	0.25	2.93		25
CSP Parabolic Trough 3h storage - Lev 7	213.94	0.38	4.02		25
CSP Parabolic Trough 6h storage - Lev 7	262.22	0.47	4.97		25
PV C-Si - Lev 7*	66	0.19	0.66		25
PV Thin Film - Lev 7	65	0.19	0.66		25
Offshore Wind _Cl4_Shal	150	0.36	1.5		25
Coal - SubCrit-500-PS	47.1	0.92	1.04	0.12	40
Coal - SubCrit-250-PS	47.1	0.92	1.3	0.12	40
Coal - LowSuperC-660-PS	50.1	0.92	0.9	0.13	40
Coal - HighSuperC-800-PS	47.9	0.92	0.87	0.14	40
Coal - UltraC-1000-PS	78.2	0.92	0.74	0.15	40
Coal - SubCrit-500 Imported-PS	78.2	0.92	1.3	0.12	40
Coal - SubCrit-250 Imported-PS	78.2	0.92	1.04	0.12	40
Coal - LowSuperC-660 Imported-PS	45.53	0.92	0.9	0.13	40
Coal - HighSuperC-800 Imported-PS	42.53	0.92	0.87	0.14	40
Coal - UltraC-1000 Imported-PS	101.2	0.92	0.74	0.15	40
Coal - UltraC+CCS-1000 Imported-PS	165.6	0.92	1.55	0.15	40
Coal - SubCrit-500-NS	47.1	0.92	1.04	0.12	40
Coal - SubCrit-250-NS	47.1	0.92	1.3	0.12	40
Coal - LowSuperC-660-NS	50.1	0.92	0.9	0.13	40
Coal - HighSuperC-800-NS	47.9	0.92	0.87	0.14	40
Coal - UltraC-1000-NS	78.2	0.92	0.74	0.15	40
Coal - SubCrit-500 Imported-NS	78.2	0.92	1.3	0.12	40
Coal - SubCrit-250 Imported-NS	78.2	0.92	1.04	0.12	40
Coal - LowSuperC-660 Imported-NS	45.53	0.92	0.9	0.13	40
Coal - HighSuperC-800 Imported-NS	42.53	0.92	0.87	0.14	40
Coal - UltraC-1000 Imported-NS	101.2	0.92	0.74	0.15	40

Technology Description	Investment Cost (INR Billion/ GW)	Availability Factor	Fixed O&M (INR Billion/TWh)	Variable O&M (INR Billion/TWh)	LIFE
Coal - UltraC+CCS-1000 Imported-NS	165.6	0.92	1.55	0.15	40
Coal - SubCrit-500-PN	47.1	0.92	1.04	0.12	40
Coal - SubCrit-250-PN	47.1	0.92	1.3	0.12	40
Coal - LowSuperC-660-PN	50.1	0.92	0.9	0.13	40
Coal - HighSuperC-800-PN	47.9	0.92	0.87	0.14	40
Coal - UltraC-1000-PN	78.2	0.92	0.74	0.15	40
Coal - SubCrit-500 Imported-PN	78.2	0.92	1.3	0.12	40
Coal - SubCrit-250 Imported-PN	78.2	0.92	1.04	0.12	40
Coal - LowSuperC-660 Imported-PN	45.53	0.92	0.9	0.13	40
Coal - HighSuperC-800 Imported-PN	42.53	0.92	0.87	0.14	40
Coal - UltraC-1000 Imported-PN	101.2	0.92	0.74	0.15	40
Coal - UltraC+CCS-1000 Imported-PN	165.6	0.92	1.55	0.15	40
Coal - SubCrit-500-PNS	47.1	0.92	1.04	0.12	40
Coal - SubCrit-250-PNS	47.1	0.92	1.3	0.12	40
Coal - LowSuperC-660-PNS	50.1	0.92	0.9	0.13	40
Coal - HighSuperC-800-PNS	47.9	0.92	0.87	0.14	40
Coal - UltraC-1000-PNS	78.2	0.92	0.74	0.15	40
Coal - SubCrit-500 Imported-PNS	78.2	0.92	1.3	0.12	40
Coal - SubCrit-250 Imported-PNS	78.2	0.92	1.04	0.12	40
Coal - LowSuperC-660 Imported-PNS	45.53	0.92	0.9	0.13	40
Coal - HighSuperC-800 Imported-PNS	42.53	0.92	0.87	0.14	40
Coal - UltraC-1000 Imported-PNS	101.2	0.92	0.74	0.15	40
Coal - UltraC+CCS-1000 Imported-PNS	165.6	0.92	1.55	0.15	40
Gas-500-N	30	0.92	0.42	0.06	30
***Solar PV costs are expected to decline by 21.50% between 2014 and 2030**					

Water Requirement by Thermal Power Plants:

Cooling Water Requirement by TPPs (m^3/MWh generation)		2012	Increase in Capital Costs
Existing Plants	Wet CT	3.39	-
	Once Through	1	-
	Dry CT	0.1	15% increase
New Plants	Wet CT	2.56	-
	Once Through	1	-
	Dry CT	0.1	15%

Ash Handling (m^3/ ton ash generated)

Types of Ash handling (m3/ton ash generated)	2012	Increase in Capital costs
W/o recycling	10	-
With recycling (Zero Liquid Discharge Systems)	3	5-7%
High Concentration Slurry Disposal	1.00	3-4%

Pollution Control Technologies

Pollutant	Technology	Removal Efficiency	Aux. Power Consumption	Increase in Capital Cost
PM	ESP	>96.5% (< 1 micrometer size particles); >99.5% (> 10 micrometer size particles)	0.1-1.8 %	<included in current costs>
	Bag filters	>99.6% (< 1 micrometer size particles); >99.95% (> 10 micrometer size particles)	0.2-3.0	1.5 times cost of ESP technologies
PM & SO_x	Wet scrubbers (FGD)	98%	1.0-3%	11-14%
	Semi-Dry FGD	94%	0.5-1.0%	9-12%
	Seawater FGD	90%	0.8-1.6%	7-10%
NO_x	Low nox burners (air and fuel staging)**	50-60% & 25-35%	--	--
	Selective Catalytic Reduction***	80-95%	0.50%	4-9%
	Selective Non Catalytic Reduction***	30-50%	0.1-0.3%	1-2%

*ESP and Bag filters may be preferred in Indian context; Indian coal has higher sulpher content that US coal where wet scrubbers have been used effectively
** These are currently deployed in plants but adversely impact boiler efficiency and yield other emissions
***These are end of pipe technologies currently not applied in India but which may convert NOx emissions to liquid ammonia which needs safeguards for handling

Fuel Costs (INR/ kWh primary energy)

Fuel	2012	2030
Naptha	1.30	1.30
Hydro	0.00	0.00
Diesel	3.40	3.40
Fuel Oil	4.00	2.91
Uranium	0.05	0.05
Thorium	0.05	0.05
Plutonium	0.39	0.39
Light Enriched Uranium	0.11	0.11
Lignite	0.25	0.25
Imported Coal	0.96	0.69
Biomass	0.32	0.32
Wind	0.00	0.00
Solar	0.00	0.00
Domestic Coal (bituminous)	0.47	0.66
Gas (Domestic)	1.00	1.26
Gas (imported)	1.84	2.23

Job- Factors

Technology	Construction Time	Construction Job Years/MW	Manufacturing Job Years/ MW	O&M Job Years/MW	Fuel Processing Jobs/GWh
Coal	5	19.5	8.9	0.3	0.2
Hydro	2	17.3	4.3	0.8	0.0
Nuclear	5	14.2	1.3	3.0	0.0
Small Hydro	2	43.2	15.8	6.9	0.0
Solar	1	17.5	11.0	0.5	0.0
Wind	2	6.2	14.7	0.5	0.0
Gas/Diesel	2	4.5	2.6	0.2	0.3
Biomass	1	13.6	0.0	2.5	0.1
Job factors are adjusted for the Indian region and expected productivity improvements till 2030 are factored in					

Transport

Passenger Transport

Demand

Service Demand (BPKMs)	2012	2030-BAU	2030-SD
Passenger transport demand	7,110	15,067	14,263
Urban	671	2,315	1,511
Non-Urban	6,439	12,572	12,752
Mode share - Urban			
Road	98%	96%	94%
Rail	2%	4%	6%
Air	0%	0%	0%
Mode share - Non Urban			
Road	83%	82%	76%
Rail	16%	16%	22%
Air	1%	2%	2%
Sub-mode share - Urban Road			
BUS	43%	28%	60%
ONMI-BUS	1%	1%	1%
CAR	13%	17%	11%
2W	28%	35%	11%
3W	11%	14%	12%
TAXI	4%	5%	5%
Sub-mode share - Non Urban Road			
BUS	71%	60%	69%
ONMI-BUS	2%	2%	1%
CAR	9%	15%	12%
2W	15%	16%	11%
3W	3%	4%	4%
TAXI	2%	3%	2%
Electric vehicle share – Urban			
CAR	0%	2%	4%
2W	0%	9%	15%
BUS	0%	3%	5%

Technologies

Mode	Sub-mode	Technology	Efficiency (ml fuel/ passenger km)	Investment Cost ('000 INR)	Operation and Maintenance Cost ('000 INR/year)
ROAD	BUS	DIESEL	4.19	2,490	124
(in petrol equiv.)		CNG	6.31	3,675	184
		ElectricR	2.88	4,698	235
	ONMI-BUS	DIESEL	14.20	1,004	50
		CNG	14.20	1,004	50
	CAR	PETROL	23.01	497	25
		DIESEL	27.61	637	32
		CNG	23.01	320	16
		LPG	23.01	320	16
		ElectricR	2.88	653	33
	Scotter	PETROL	15.53	27	1
	Motor cycle	PETROL	11.30	31	2
	Moped	PETROL	12.43	20	1
	Electric motor cycle	ElectricR	0.92	25	1
	AUTO	CNG	16.14	201	10
		LPG	18.83	201	10
		PETROL	16.14	201	10
		DIESEL	20.17	201	10
	TAXI	CNG	31.86	320	16
		LPG	31.86	320	16
		DIESEL	38.23	637	32
RAIL		DIESEL	2.87	5,10,442	25522
(petrol eq.)		ELECTRIC	14.76	5,40,562	27028
AIR		AIR	34.99	48,01,707	301807

Freight Transport

Demand

Service Demand (BTKMs)	2012	2030-BAU	2030-SD
Total freight demand	1,415	6,470	6,470
Modal share			
ROAD	58%	60%	49%
RAIL	41%	38%	49%
AIR	1%	1%	1%
WATER	0%	1%	1%

Technologies

Mode/ Technology	Efficiency (Wh/ Vehicle km)	Investment Cost ('000 INR)	Operation and Maintenance Cost ('000 INR/year)
ROAD (HCV - Diesel)	300	2,192	110
ROAD (HCV-Diesel)	462	920	46
RAIL(Diesel)	52	2,86,145	14,307
Rail (Electric)	15	3,13,253	15,663
AIR	2473	48,01,707	2,40,085

Technology-specific emission factors for local and global pollutants were obtained from urbanemissions.info

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