Integrated Research and Action for Development (IRADe), New Delhi.

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Modelling Studies on Greenhouse Gas Emissions and Emission Intensity of Indian Economy

Submitted to Ministry of Environment, Forest and Climate Change, New Delhi.

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Integrated Research and Action for Development

IRADe, C-80, Shivalik, Malviya nagar, New Delhi-110017

Report on

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Ministry of Environment, Forests and Climate Change

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Submitted By

Integrated Research and IRADe Action for Development

Integrated Research and Action for Development (IRADe)

C-80, Shivalik, Malviya Nagar, New Delhi – 110 017

Preface

It gives me a great pleasure to present this report on Green House Gases (GHG) emissions and --- for Indian economy. This work is sponsored by the Ministry of Environment, Forests and Climate Change (MOEFCC). It provided insights for climate negotiations at Paris meeting at COP 21 in 2015. It is essential to understand the linkages of the present Indian economy and its future progression over time, with GHG emissions, energy technology changes and options to contain GHG emissions through energy efficiency, Renewable Energy and other Public Policies. The future scenarios are mapped upto 2050 but the interesting points are presented for 2020, 2030, 2040 and 2050 with major emphasis on 2030 and 2050.

During the execution of the project, a number of meetings took place with the senior staff of MOEFCC and some meetings with senior staff of other ministries as well. These exchanges were very helpful in bringing multi-sectoral perspectives and issues of governance. We need to see that the technology progress is a continuous process, on one hand indicated by autonomous energy efficiency brought by external factors such as mobile, internet, etc and on the other hand 11 energy specific technologies comprising of fossil and non fossil technologies.

We are happy that this modeling provided the needed decision support needed to arrive at India's INDC (Intended Nationally Determined Contributions submitted to the UNFCCC prior to Paris COP 21 meeting. It was promised at Paris that India will reduce its GHG intensity by 35% by 2030 and ensure a share of 40% from non fossil energy sources in the energy supply. After Paris COP 21 meeting, IRADe carried out sensitive analysis where we also showed that India can certainly achieve these goals not by one, but by several ways; indicating that the promises are robust. The INDC goals are achievable through focus on renewable energy (including large hydro) nuclear and energy efficiency. We are happy to be able to do this work of national importance.

Acknowledgement

We thank the MOEFCC for giving us this excellent opportunity to utilise our modeling capability. We thank senior members of MOEFCC- Lavassa, Secretary, Mr Susheel Kumar, Additional Secretary, Mr Ravi Prasad, Joint Secretary, Mr J. R. Bhatt, Advisor and Deputy Director Mr Ajay Raghava.

We also thank Niti Aayog and other ministries such as Railways, Power, Renewable Energy and Petroleum & Natural Gas. We thank Ms Arshi Vimal and Mr Sugandh Chowdhary for their able Research support. Dr Kirit Parikh, Chairman, IRADe has tirelessly guided and mentored this effort and we have immensely benefitted from his continuous support.

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Objective

The objective of the scenarios undertaken in this study is to explore options for reducing Green House Gas (GHG) emissions in a long-term perspective and accounts for their macro-economic consequences, feedbacks and rebound effects if any. . Also we explore alternative measures to achieve India's INDCs announced at the Paris COP.

To examine these issues we need to have an analytical framework that permits alternative technologies in various sectors both on demand and supply side, allows specification of alternative policy measures and which covers the whole economy. Also it needs to be dynamic so that year to year changes and actions can be tracked. IRADe's model has these characteristics and has been used for exploring the issues posed.

IRADe's Modelling activities

The IRADe model has evolved over time. Basic IRADe model is capable to carry out policy analysis of many issues in an economy wide context, with endogenous income distribution and demand determination with specific technological alternatives, IRADe models are multi period multi sectoral models that cover the whole economy in activity analysis framework that permits alternatives technologies in different sectors.

The first version supported by MOEF&CC, IRADe AA30 (Activity Analysis) analyzed India's emission profiles under alternative scenarios and was brought out by the Ministry of Environment, Forest and Climate Change(MOEF&CC) prior to the Copenhagen climate conference showing projections of India's emissions upto 2030. IRADe basic model was extended to IRADe-ET50 (Energy Transition), explored energy transition till 2050 in collaboration with International Institute for Applied Systems Analysis (IIASA) and sponsored by Technology, Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology, Government of India. IRADe-ET50had a number of features so that the results from the model for India can be compared to the results that the IIASA model provided at the global level. Keeping 2^{O}C constraint for climate change and resources constraints for coal, crude and natural gas and imports of these commodities were limited to specified global shares.

At the same time, IRADe-AG40 supported by (Centennial Foundation) explored the role of agricultural growth in economic growth and alternative policies needed for double digit growth. This required disaggregation of agricultural sectors and estimation of an elaborate non-linear demand system covering many agricultural and non-agricultural goods and services, with 20 expenditure classes: 10 rural and 10 urban. It also endogenized migration.

MAPS (Mitigation Action Plans and Scenarios) undertaken by SSN (SouthSouthNorth organization) commissioned IRADe to work on a complementary research paper on the broad topic of poverty and low-carbon development strategies from the perspective of Indian researchers. This led to the IRADe – EQ30(Equity) which explored the impact of various mitigation measures on poverty.

In IRADe - HDCB (Human Development with Carbon Budget) funded by WWF and other organisations, number of policies were introduced to ensure level of human development in its various dimensions, consumption, access to water, sanitation , health services, level of education, pucca housing and access to electricity and clean cooking fuels. Also the emission levels till 2050 had to be constrained within carbon budget constraint with global emissions that keep warming within 2^{o}C .

IRADe-LCSIG (Low carbon strategy for Inclusive Growth) supported by Planning Commission, introduced many specific policies for low carbon development. The results were used in the report of the expert group.

The present model IRADe-CCNEG50 (Climate Change Negotiations) supported by MOEF&CC explores emission paths encompassing also the new government policies after 2014 till 2050 that can be attained with determined action and ambition actions and the costs involved . It incorporates many initiatives of the government as a starting point.

IRADe-CC NEG50 – Climate Change Negotiation

The IRADe-CC NEG50 model is a macro-economic model as it works on the activity analysis input output frame-work and uses the Social Accounting Matrix(SAM) based on the input output tables of 2007-08 to make future projection up to 2050 with inter sectoral consistency. It also includes alternative techniques to produce the same good. Thus it is a top-down bottom-up model in the sense that it provides macro-economic consistency and considers specific technological alternatives. The model presented here is based on the previous model of IRADe, but goes beyond and explores specifically the extent and manner in which India can reduce emissions with a time horizon of 2050.IRADe- CC NEG50 presented here constructs scenarios such that along with GHG emissions, it also projects the development indicators for each scenario. These include poverty, growth, life expectancy, infant mortality, and mean years of schooling and higher expenditure on social sectors like education and health. Thus in principle, the model can be used to construct scenario that achieve emission targets as well as social indicator targets.Therefore, the model is able to give a detailed and comprehensive picture of emissions and the sectors that contribute most and can therefore be used to suggest sectors that need interventions and possible policies to help in reduction of emission intensity in keeping with the voluntary pledges of India.Further, details on IRADe- CC NEG50 Model is provided in Annexure 1.

Scenarios

In this study, we have constructed 7 scenarios using the activity analysis model of IRADe: IRADe- CC NEG50 Model, which has been modified to project selected indicators up to 2050.

- Dynamic as Usual (DAU)
- Determined Actions (DETA)
- Ambitious Actions (AMBA)
- India's INDC targets and possible alternatives to achive them
    - Nuclear led scenario to achive India's INDC targets (NUC)
    - Renewable led scenario to achive India's INDC targets (REN)
    - Power sector led scenario to achive India's INDC targets (POW)

In IRADe- CC NEG50 Model, each scenario is successively builds on the earlier scenarios, with higher climate concerns than the preceding ones. For example, whatever is in DAU is also included in DETA, while AMBA has what is already in DETA, but much more and has additional ambitious measures. Although the model maximises welfare, it is necessary to specify some technical constraints, so that the model respects, resource constraints, penetration rates (or market shares of various technologies) and limits up to which scaling up of technologies and resource mobilisation can be done.

General Assumptions

Some of the key assumptions hold valid for all the selected scenarios. Following are the general assumptions that are common for all the scenarios:

a) Inclusive Growth Policies (common to all scenarios)

All scenarios consider inclusive growth policies that are developmental in nature and differ only on nature of low carbon policies. These policies ensure access to electricity, clean cooking fuel, pucca house, education and health services, as well as income transfer to poor. The specification of inclusion policies is described below.

- **Income transfer:** To substantially reduce poverty, income transfer is given beginning with an amount Rs. 1,000 per person per year at 2007-08 prices, increasing to Rs. 2,000 by the end of the Twelfth Five Year Plan and to Rs 3,000 thereafter. The coverage of rural and urban population is gradually increased over the Twelfth Plan period to reach the levels mentioned in National Food Security Act 2013, i.e. bottom 70 percent of the rural, and bottom 50 percent of the urban population.
- **Housing:** The objective is to provide every person with a pucca house by 2030. This is accomplished by stepping up Indira Awas Yojana and Rajiv Awas Yojana and is reflected in the scenario by increased government demand for construction from 2015 to 2025 when an additional 0.7 million houses for the poor are built.
- **Electricity:** Keeping up its promise for sustainable energy access for all (SE4All) , all the households consume atleast 1 kWhr per day of electricity by 2015. The government makes up the deficit from the household's normative consumption and provides it free of cost to the poor households.
- **Cooking gas:** The poor households' expenditure on energy is supplemented by government so that they can have at least 6 cylinders of LPG per year.
- **Education and Health:** Government expenditure on education and health is increased to be 7.3% of GDP in 2015 and stays at that level after that.

The cost of implementing inclusive measures is assumed to be borne by the government and reduces the investment available for other economic activities.

b) Population

All the scenarios use the UN medium variant population for India. The population of rural and urban areas assumed under the scenarios is given in the Table 1.

Table 1 Total, Rural and Urban Population growth

Population* (in millions)

Year	Total	Rural	Urban	Urbanisation (in %)

2007	1158	812	346	30%
2010	1206	833	373	31%
2020	1353	883	471	35%
2030	1476	893	583	39%
2040	1566	864	701	45%
2050	1620	806	814	50%

**** Population UN Medium Variant***

c) Resource Reserves and Growth Assumptions

Reserves of natural resources such as Coal & Lignite, Crude Oil and Natural Gas grow over the years with exploration for new resources. For scenarios, the growth rate assumption for natural resources is provided in Table 2.

Table 2 Resource growth assumptions

Resource	Reserves in 2007	Growth rate in reserves
Coal & Lignite (million tonnes)	153103	1.0%
Crude Petroleum (million tonnes)	725	0.0%
Natural Gas (billion cubic meter)	1055	1.1%

****60% of Proven Coal Reserves is assumed to be available for Mining***

d) GHG assumptions

Increased sequestration due to green India mission is assumed to be same in all the scenarios. Following are the key assumptions common in all the scenarios for GHG.

Table 3 GHG Assumptions for DAU, DETA and AMBA Scenario

Assumptions for GHG	
Agriculture	CH_4 and N_2O emissions from enteric fermentation reduces by 0.7% per year from 2007, CH_4 and N_2O emissions from rice cultivation reduces by 1.1% per year from 2007
Industry Use	Ratio of CH_4 and N_2O emissions from Industry sector to Industry sector output assumed to be constant
Waste	Ratio of CH_4 and N_2O emissions from municipal solid waste and domestic waste water to total urban consumption reduces by 1.0% per year from 2007
LULUCF	Sequestration targets from green India mission assumed
Other	CH_4 and N_2O emissions ratio to total consumption from residential sector reduces by 1.0% per year from 2007

1) Dynamics As Usual Scenario up to 2050 (DAU)

The dynamics as usual scenario serves as a reference case for the other two climate scenarios that capture the challenges to be faced to address climate change.

Under this scenario, the tradition of ever increasing efficiency is kept up and also higher exploitation of renewable energy as India has been following even without the climate policies since the 1980- if not before in a slow manner. However, specific additional climate policies are not envisaged for future in this scenario and dynamics as usual in policy is prescribed. Present policies on energy efficiency are assumed to continue. Current trend of hydro and nuclear expansion are assumed to continue. All new Coal based power generation plants are assumed to be of super critical variety after 2017. Power generation from renewable sources is assumed to grow as per current trends. It incorporates policies of inclusion: cash transfer to the poor, 6 LPG cylinders per household, 1 kWh per household per day of electricity to all by 2030 and pucca house for all by 2030.

Energy efficiency improves by 0.75% per year so that by 2050 energy use goes down by 28%. This Autonomous Energy Efficiency Improvements (AEEI) reflecting annual reduction in energy inputs like coal, oil, natural gas and power is assumed to continue. This captures the trend of long-term technological progress observedon the basis of cost effectiveness. However, AEEI of coal in subcritical plants is assumed at 0.5% and also AEEI of electricity input in power sector is 0.5% to reflect reduction in T&D losses from 20% to 10% and reduction in auxiliary consumption. These have additional costs, and are realised through specific measures for climate change. For details on AEEI refer Annexure 2.

Assumptions of exogenous parameters considered for DAU scenario are provided in Table 4. Assumptions for power sector and technological cost under the DAU scenario are provided in Table 7 and Table 9 respectively. Further, assumptions for transport sector are provided in Table 8.

2) Determined Actions (DETA) - Increasing Efficiency and Reducing Emissions

Various low carbon policies under implementation and consideration are introduced to reduce energy demand in the power sector, transport sector and household sectors.

On the energy supply side, this includes stepping up of hydro, nuclear and renewable; higher share of renewables; fall in costs of low carbon technologies up to 2016; shift of freight movement from road to rail; increased fuel efficiency of motorized vehicles; switch to CNG and electric vehicles at prescribed rate; energy conservation in commercial buildings through higher share of ECBC buildings; reduction in electricity usage by households due to increased use of efficient appliances and also increased sequestration due to Green India mission. Energy efficiency rates are stepped up to 1.5% per year from 2015. Efficiency improvements beyond 0.5% per year require upfront investment, for which the payback period is assumed to be six years at a real discount rate of 4%. Assumptions of exogenous parameters considered for DETA scenario are provided in Table 4.

However, in the case of power sector, a lower rate of AEEI of 1% has been taken to reflect the technological limits for coal, natural gas and petroleum products required as inputs for generation. AEEI for electricity used in the power sector is taken as 0.5%, which reflects reduction in T&D losses from 20% to 10%, and also reduction in auxiliary consumption. *One may note that in the model, the power sector is vertically integrated and includes generation, transmission and distribution activities*. Assumptions for power sector and technological cost under the DETA scenario are provided in Table 7 and Table 10 respectively. Further, assumptions for transport sector are provided in Table 8.

To reflect the use of energy-efficient appliances, the marginal demand for electricity by households is assumed to fall by 2% despite increased rates of appliance and vehicle ownership per 1000 persons per year from 2015, which is a reduction of 50% by the year 2050 over the DAU scenario and to reflect the use of energy efficient vehicles the marginal demand of petroleum products is assumed to reduce by 1.5%.

Higher AEEI rate of 1.5% is assumed for the industrial sector based on various industry studies and the on-going 'Perform, Achieve and Trade (PAT)' scheme introduced by the Bureau of Energy Efficiency (BEE) in India under which large energy consuming firms are required to meet energy efficiency targets[1].

3) Ambitious Action (AMBA) - Increased Rate of Capacity Installation and Cost Reduction

Share of renewables is stepped up to achieve 175 GW (5 GW SHP included in hydro sector) of renewable capacity by 2022, the trend is further extended. Even though this is a current government target, it is highly ambitious even by international standards and has never been attempted or even aimed before. This is why it is neither in DAU nor in DETA scenarios as these will not be attempted. A shift of freight movement from road to rail, increased fuel efficiency of motorized vehicles and switch to CNG and electric vehicles accelerated after 2030. Energy efficiency rates are as in the DETA Scenario. Nuclear power is stepped up and growth of renewable is stepped up after 2022 and higher penetration rates for ECBC buildings is assumed.

In addition to measures taken in DETA we also assume aggressive efforts in technological cost reduction, increasing capacity building efforts and emphasis on making efficient buildings more affordable.

1) 100 GW of solar power by 2022
2) 60 GW of Wind Power by 2022
3) Higher share of renewable compared to DETA to build up on the capacity added by 2022
4) 10 GW of Biomass by 2022
5) Higher nuclear power generation
6) Higher penetration rates for ECBC buildings
7) Fuel mix change from petroleum products to electricity and gas after 2030

It can be seen above that although it is the wind power that has achieved grid parity, the future thrust is on solar power. This could be due to the fact that the solar cycle is more reliable in terms of the hours available (or not available) and synchronised better with the working cycle of say 8 AM to 6 PM. This may be a calculated risk that places faith in continous drop in the solar costs in the future.

Assumptions of exogenous parameters considered for AMBA scenario are provided in Table 4. Assumptions for power sector and technological cost under the AMBA scenario are provided in Table 7 and Table 11 respectively. Further, assumptions for transport sector are provided in Table 8.

[1]Higher AEEI rate of 1.5 percent is assumed as per the assumptions in the "Low Carbon Strategies for Inclusive Growth Report" of Planning Commission, Government of India

Table 4 Assumptions of Exogenous Parameters for DAU, DETA and AMBA

Parameter	Sectors	DAU	DETA	AMBA
TFPG	Agriculture and Power	1%		
	Rest of the Economy	1.5%	1.5%	
AEEI for non-Power sectors	Coal	0.75% per year	1.5% per year	
	Petroleum products	0.75% per year	1.5% per year	
	Natural gas	0.75% per year	1.5% per year	
	Electricity	0.75% per year	1.5% per year	
AEEI for Power sectors	Coal	0.5% per year for coal in sub-critical and 0.75% for super critical coal	0.5% per year for coal in sub-critical 1.0% for super critical coal	
	Petroleum products	0.75% per year	1.0% per year	
	Natural gas	0.75% per year	1.0% per year	
	Electricity	0.5% per year	0.5% per year	
Reduction in energy use by Government and Households	Petroleum Products	0.5% reduction in marginal budget share of expenditure on petroleum products by household due to use of more efficient vehicles	1.5% reduction in marginal budget share of expenditure on petroleum products by household due to use of more efficient vehicles	
	Electricity	1% reduction in marginal budget share of expenditure on Electricity by household due to use of efficient appliances	2 % reduction in marginal budget share of expenditure on Electricity by household due to use of efficient appliances	

* Unless mentioned otherwise, the policies of the earlier scenarios continue and each are successively more climate focused than the previous scenarios

Table 5 AEEI assumption in DETA and AMBA scenarios

AEEI	2008	2013	2019	2023-50
Coal	0	0.001	0.005	0.015
Crude Petroleum	0	0.001	0.005	0.015
Petroleum Products	0	0.001	0.005	0.015
Natural Gas	0	0.001	0.005	0.015
Electricity	0	0.001	0.005	0.015
Fuel for electricity generation	0	0.001	0.005	0.01

Table 6 Energy demand changes due to AEEI as a proportion of the base year demand (2007) for DETA and AMBA Scenario

	2008-2012	2018	2022	2030	2040	2050
Coal	1	0.99	0.97	0.89	0.77	0.66
Crude Petroleum	1	0.99	0.97	0.89	0.77	0.66
Petroleum Products	1	0.99	0.97	0.89	0.77	0.66
Natural Gas	1	0.99	0.97	0.89	0.77	0.66
Electricity	1	0.99	0.97	0.89	0.77	0.66
Fuel in electricity	1	0.99	0.97	0.92	0.79	0.68

Table 7 Power Sector Policies in DAU, DETA and AMBA Scenario

Power Sector Policies	DAU	DETA	AMBA
Costs for Renewable	Normal cost reduction due to efficient use of production factors	Additional cost reduction upto 2015, due to technological advance over and above the cost reduction due to efficient use of production factors#	
Growth of renewable	A minimum share for renewable of 8% by 2030 and 10% by 2050 is prescribed	A minimum share for renewable of 10% by 2030 and 20% by 2050 is prescribed	A minimum share for renewable of 16% by 2030 and 41% by 2050 is prescribed
Minimum share of Solar	A minimum penetration rate for solar power is prescribed to allow for minimum share of 1.4% in 2030 and increases to 1.6% in 2050.	A minimum penetration rate for solar power is prescribed to allow for minimum share of 1.6% in 2030 and increases to 2% in 2050.	A minimum penetration rate for solar power is prescribed to allow for minimum share of 5% in 2030 and increases to 12% in 2050.
Nuclear Power	Nuclear generation capacity is projected to reach up to 8 GW by 2050	Nuclear generation capacity is projected to reach up to 46 GW by 2050	Nuclear generation capacity is projected to reach up to 70 GW by 2050
Thermal Coal	No investment in capacity and no fall in costs due to factor productivity for sub critical coal assumed from 2017		
Hydro Power	constrained to grow by 1.% in keeping with the government plans	constrained to grow by 1.% in keeping with the government plans	
Gas based Power generation	Maximum of 40% of domestic production of Gas is used for Power Generation		
Minimum penetration rate for ECBC buildings	The share of ECBC is specified to increase by0.1 per cent	The share of ECBC is specified to increase by 1 per cent	The share of ECBC is specified to increase by 1 per cent

** The IRADe- CC NEG50 Model logically (without constraints) choses the option for coal, Nuclear, Gas and Biomass (depending on the availability). Further, the model also makes choice between storage and non-storage technologies (depending on the cost and future electricity demands).*

 # In recent years, there has been significant cost reduction on account of technological advances which has been embodied in the additional cost reduction.

Table 8 Transport Sector Policies in DAU, DETA and AMBA Scenario

Transport Sectors Policies	DAU	DETA	AMBA
Share of Railways in total freight movement	No policy assumed	Stipulated to increase by 1.5 per cent per year, from around 20% in the year 2015 to almost 50% by the year 2050.	
Greater use of public and non-motorised transport	No policy assumed	Reducing marginal budget shares for petroleum products by 0.2 per cent per year beginning 2015.	Reducing marginal budget shares for petroleum products by 0.2 per cent per year beginning 2030.
Change in Fuel mix in road transportation sector	No policy assumed	Reducing petroleum products inputs in the transport sector by 1.5 per cent per year, and replacing them by increasing inputs of natural gas and electricity in the ratio 60:40 per cent respectively from 2015.	Rate of reduction of petroleum products inputs stepped up from 1.5% to 1.8% after 2030

Table 9 DAU Scenario: ICOR: Incremental Capital Output Ratios (Rs Crore/Kwh)

DAU Technological cost (ICOR: Incremental Capital Output Ratio*)

	2007	2010	2020	2030	2040	2050
Sub-Critical Coal	3.9	3.9	3.9	3.9	3.9	3.9
Super Critical Coal	4.5	4.4	4.0	3.6	3.2	2.9
Gas	4.1	4.0	3.6	3.3	3.0	2.7
Diesel	4.3	4.2	3.8	3.4	3.1	2.8
Hydro	11.4	11.1	10.0	9.1	8.2	7.4
Nuclear	5.0	4.9	4.4	4.0	3.6	3.3
Solar PV	19.9	17.7	13.3	12.1	10.9	9.9
Solar Thermal	30.3	27.0	20.3	18.4	16.6	15.1
Solar PV with Storage	23.8	21.2	15.9	14.4	13.1	11.8
SolarThermal with Storage	32.7	29.1	21.9	19.8	17.9	16.3
Wind	12.0	10.8	9.5	8.6	7.8	7.0
Wind with Storage	21.2	19.0	16.8	15.2	13.7	12.4
Biomass	7.6	7.6	7.6	7.6	7.6	7.6

- *Rs per one Rs worth of output per year (Thus low load factor of renewable push up the ratio)*

Table 10 DETA Scenario: **Incremental Capital Output Ratios**

DETA Technological cost (ICOR: Incremental Capital Output Ratio)

Capital costs	2007	2010	2020	2030	2040	2050
	2007	2010	2020	2030	2040	2050
Sub-Critical Coal	3.9	3.9	3.9	3.9	3.9	3.9
Super Critical Coal	4.5	4.4	4.0	3.6	3.2	2.9
Gas	4.1	4.0	3.6	3.3	3.0	2.7
Diesel	4.3	4.2	3.8	3.4	3.1	2.8
Hydro	11.4	11.1	10.0	9.1	8.2	7.4
Nuclear	5.0	4.9	4.4	4.0	3.6	3.3
Solar PV	19.9	17.7	12.1	9.8	8.8	8.0
Solar Thermal	30.3	27.0	18.4	14.9	13.5	12.2
Solar PV with Storage	23.8	21.2	14.5	11.7	10.6	9.6
SolarThermal with Storage	32.7	29.1	19.9	16.0	14.5	13.1
Wind	12.0	10.8	9.5	8.6	7.8	7.0
Wind with Storage	21.2	19.0	16.8	15.2	13.7	12.4

Table 11 AMBA Scenario: Incremental Capital Output Ratios

AMBA Technological cost (ICOR: Incremental Capital Output Ratio)

	2007	2010	2020	2030	2040	2050
Sub-Critical Coal	3.9	3.9	3.9	3.9	3.9	3.9
Super Critical Coal	4.5	4.4	4.0	3.6	3.2	2.9
Gas	4.1	4.0	3.6	3.3	3.0	2.7
Diesel	4.3	4.2	3.8	3.4	3.1	2.8
Hydro	11.4	11.1	10.0	9.1	8.2	7.4
Nuclear	5.0	4.9	4.4	4.0	3.6	3.3
Solar PV	19.9	17.7	12.1	9.8	8.8	8.0
Solar Thermal	30.3	27.0	18.4	14.9	13.5	12.2
Solar PV with Storage	23.8	21.2	14.5	11.7	10.6	9.6
SolarThermal with Storage	32.7	29.1	19.9	16.0	14.5	13.1
Wind	12.0	10.8	9.5	8.6	7.8	7.0
Wind with Storage	21.2	19.0	16.8	15.2	13.7	12.4
Biomass	7.6	7.6	7.6	7.6	7.6	7.6

IRADe- CC NEG50 Model:Result Analysis

GHG Emissions

Among all the GHGs, the IRADe- CC NEG50 model minimizes only CO_2 emissions. Methane is largely emitted by the agriculture sector including livestock and the alternative methods of mitigation are not considered here. It may be worth considering later how to reduce it. Basically, the other non- CO_2 GHGs are not a part of optimisation but calculated outside the model and added later. However, we note that it is mainly the CO_2 gas that is strongly correlated with the GDP (i.e.economic activities). The remaining gases are either negatively correlated or weakly correlated with GDP or have a very low GDP elasticity. See Annex 4 for the trends with the GDP per capita, through international comparison.

The GHG emissions trajectories for the different scenarios are reported in Table 12 to 15 and Figure 1. (Note that in figure 1 the vertical scales for different years are different). Per capita emissions are shown in Figure 2. GHG and CO_2emission intensities of GDP are provided in Figure 3 and Figure 4 respectively.

Figure 1 GHG Emissions Trajectories for different Scenarios

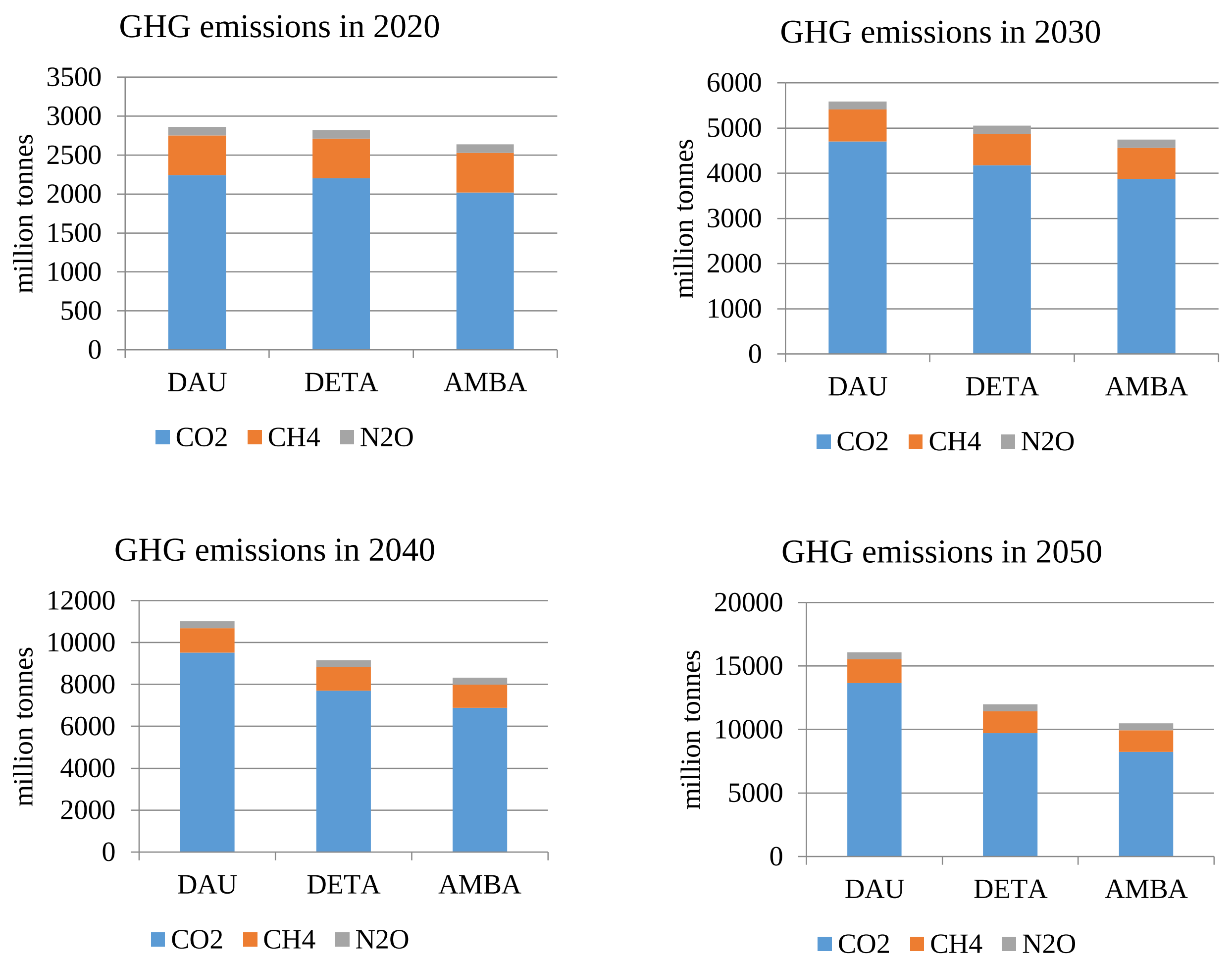


Table 12 GHG emissions (million tonnes of CO_2 equivalent)

Year	DAU	DETA	AMBA
2020	2864	2823	2638
2030	5588	5052	4742
2040	11015	9154	8315
2050	16082	11991	10483

Table 13 CO_2 emissions (million tonnes)

Year	DAU	DETA	AMBA
2020	2243	2204	2021
2030	4704	4179	3874
2040	9518	7702	6878
2050	13660	9711	8234

Table 14 CH_4 emissions (million tonnes CO_2 equivalent)

Year	DAU	DETA	AMBA
2020	511	508	507
2030	705	690	687
2040	1169	1118	1107
2050	1868	1724	1699

Table 15 N_2O emissions (million tonnes of CO_2 equivalent)

Year	DAU	DETA	AMBA
2020	110	111	110
2030	180	183	182
2040	328	335	331
2050	554	556	550

Figure 2 Per Capita GHG Emissions (CO_2 Equivalent)

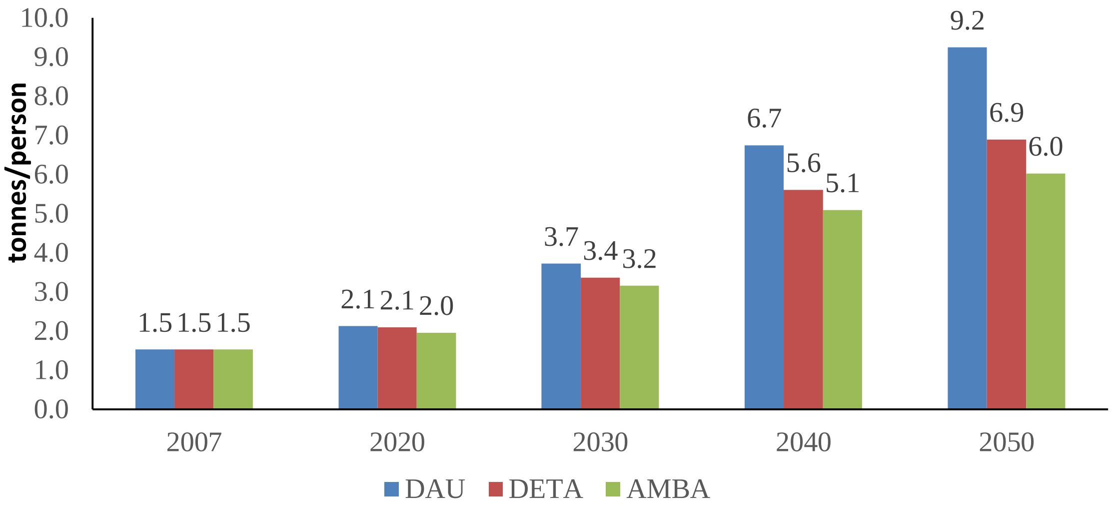


Table 16 Per capita CO_2 emissions (in tonnes per person)

Year	DAU	DETA	AMBA
2020	1.7	1.60	1.50
2030	3.2	2.80	2.60
2040	5.8	4.70	4.20
2050	7.90	5.60	4.70

Figure 3 GHG Emissions Intensity of GDP (In Kg/$GDP (PPP 2007))

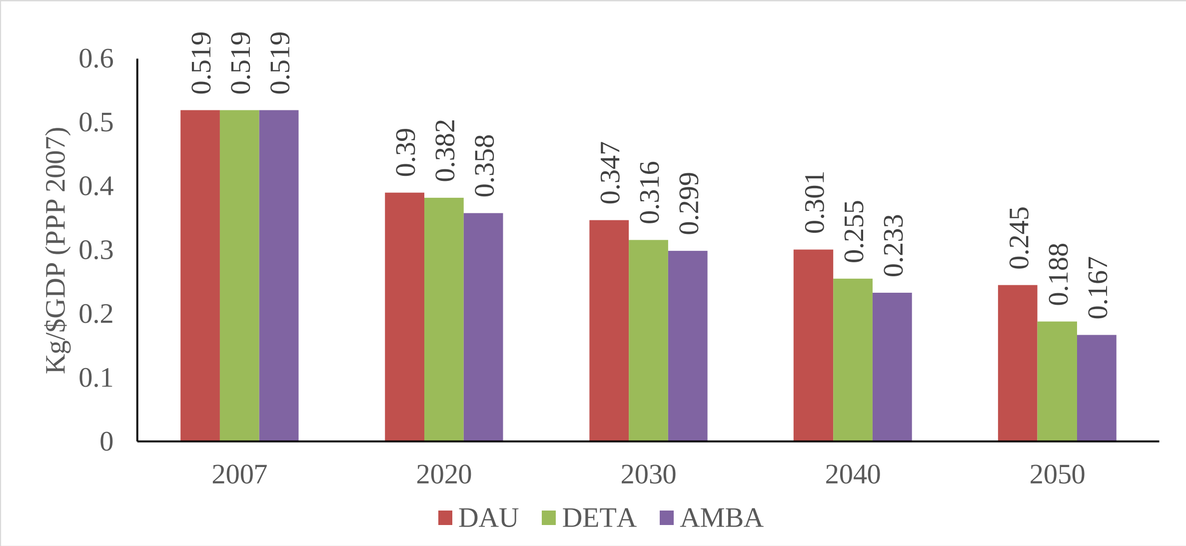
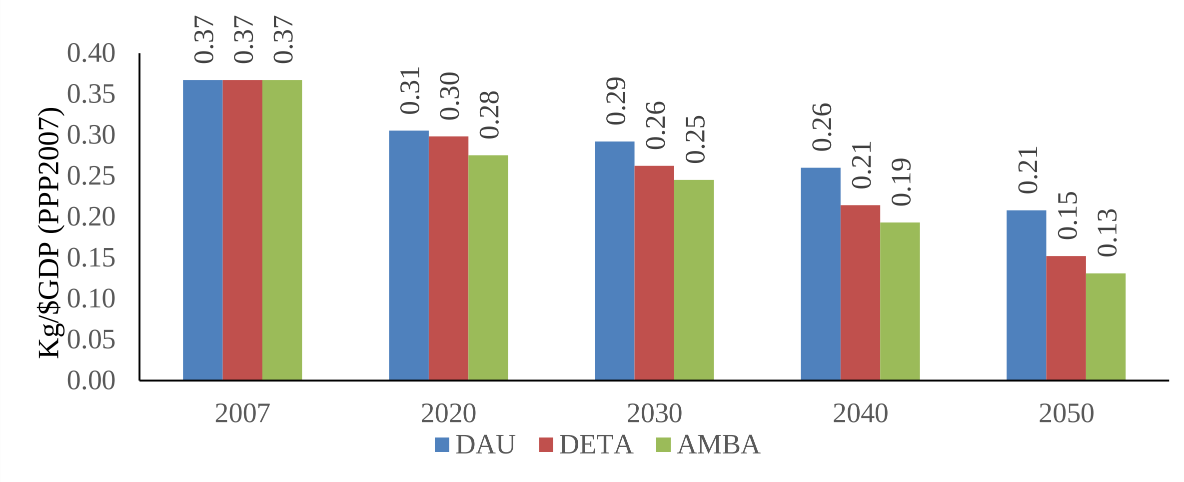


Figure 4 CO_2 Intensity of GDP (In Kg/$GDP (PPP 2007))



Emissions Implications of the scenarios

a) GHG emissions in 2050 reach 16.10 GT in the DAU scenario of which CO_2 contributes 13.66 GT. GHG reduces to 11.99 GT in 2050 in the DETA scenario of which contributions of CO_2 is 9.71 GT, and in AMBA scenario GHG reaches to 10.48 GT of which CO_2 is 8.23 GT.

b) Per capita GHG emissions in DAU increase from 1.5 tonnes/person in 2007 to 3.7 t in 2030 and to 9.2 t in 2050. They come down to 3.4t and 3.2t in DETA and AMBA respectively in 2030 and to 6.9t and 6.0t in the year 2050 for DETA and AMBA scenarios.

c) The Per capita CO_2 emissions increase from 1.1 tonnes/person in 2007 to 3.2t in 2030 and to 7.9t in 2050 in DAU. They come down to 2.8t and 2.6t in 2030 for DETA and AMBA scenarios and to 5.60t and 4.7t in 2050 for DETA and AMBA respectively.

d) GHG intensity decreases from 0.52 Kg/$GDP (PPP 2007) in 2007 to 0.35 0.32 and 0.30 Kg/$(GDP 2007) in 2030 for DAU, DETA and AMBA respectively. This further decreases to 0.25, 0.19 and 0.17 in 2050 for DAU, DETA and AMBA respectively.

e) CO_2 intensity decreases from 0.37 Kg/$GDP (PPP 2007) to 0.31, 0.30 and 0.28 for DAU, DETA and AMBA in 2020 respectively implying a 16%, 19% and 24% decline in CO_2 intensity of the Indian Economy in 2020 (reference to 2007).

f) The CO_2 intensity of the economy declines further to 0.29, 0.26 and 0.25 in 2030 for DAU, DETA and AMBA scenario respectively. This implies22%, 30% and 32%decline in CO_2 intensity of the Indian Economy in 2030 (with reference to 2007) under the DAU, DETA and AMBA scenario respectively.

g) In 2050, the CO_2 intensity of the economy further declines to 0.21, 0.15 and 0.13 in 2050 for DAU, DETA and AMBA scenario respectively. This implies 43%, 59% and 65% decline in CO_2 intensity of the Indian Economy in 2050 (with reference to 2007) under the DAU, DETA and AMBA scenario respectively.

These reductions are obtained at some cost. The investments required in relatively expensive technologies affect GDP and consumption levels. However, on account of our assumptions of falling costs the investment requirement in the three scenarios are quite comparable.

Cumulated CO_2 Emissions

The cumulated CO_2 emissions over 2007 to 2050 reach a level of 248 Giga Tonnes in the DAU Scenario and this decrease to 204 Gt and 184 Gt in the DETA and AMBA scenarios respectively.

Table 17 Cumulative CO_2 emissions (in Giga Tonnes)

Cumulated CO_2 emissions (Giga Tonnes)			
Year	**DAU**	**DETA**	**AMBA**
2020	22.1	21.9	21.2
2030	56.3	53.8	50.2
2040	127.5	113.7	104.8
2050	248.1	204.7	184.1

As per the estimates by German Advisory Council on Global Change (WBGU), which was also used as a reference in IRADE's "Low-Carbon Development Pathways for a Sustainable India", the global carbon budget of CO_2 emissions is arrived from the probability of the increase in global mean temperature by 2ºC. By the middle of the 21st century, a maximum of about 750 (750000 MT) Gt CO_2 (billion metric tonnes) may be released into the earth's atmosphere if the 2ºC limit is to be adhered to with a probability of 67%. If the probability is raised to 75%, the cumulative emissions within this period would have to remain below even 600 Gt CO_2. India had a share of 18% in the world population in 2010, giving the country an allocation of 156 Gt or 133 Gt (133000 MT) of CO_2 emissions from 2010 to 2050 under the two probabilities respectively.. This when compared to the DETA and AMBA levels of 204 and 184 Gt respectively shows that India's Low carbon efforts are not too far from what is needed to be done for achieving the 2-degree target.

Significant reduction in CO_2 emissions is expected from the power and transport sector. Under DETA and AMBA scenario, CO_2 emissions from power sector is expected to reduce by 14% and 26% by 2030 respectively as compared to DAU scenario (refer Table 18). This reduction is expected to continue and by 2050 the CO_2 emissions from power sector is expected to reduce by 37% and 60% by 2050 under the DETA and AMBA scenario respectively as compared to DAU.

Table 18 CO_2 emissions from power sector in MT

CO_2 emissions from the Power Sector (MT)					
	CO_2 emissions from the Power Sector			**% reductions from DAU**	
Year	**DAU**	**DETA**	**AMBA**	**DETA**	**AMBA**
2020	1193	1176	1104	2%	16%
2030	2293	1972	1688	14%	26%
2040	4319	3278	2503	24%	42%

2050	6188	3906	2506	37%	60%

Reduction in CO_2 emissions from Transport sector is also expected. Under, DETA and AMBA scenario the CO_2 emission are expected to reduce by 34% as compared to DAU scenario (refer Table 19)

Table 19 CO_2 emissions from transport sector in MT

CO_2 emissions from the Transport sector (MT)

	CO_2 emissions from the Transport sector			**% reductions from DAU**	
Year	**DAU**	**DETA**	**AMBA**	**DETA**	**AMBA**
2020	148	139	138	6%	7%
2030	310	266	263	14%	15%
2040	703	551	542	22%	23%
2050	1461	1091	1068	25%	27%

Energy Mix

India is the fourth largest primary energy consumer of the world after China, U.S. and Russian Federation[2]. Primary energy resources include coal, crude oil, and natural gas, nuclear, hydro, wind, solar and wood. India's primary energy consumption is expected to increase from 398 MTOE in 2007 to 3,434 MTOE by 2050 under the DAU scenario (growing at a CAGR of 5.1%). However in 2050, the primary energy consumption is expected to decrease to 2,769 MTOE and 2,877 MTOE respectively under the DETA and AMBA scenario due to focus on low carbon technologies. The reduction in primary energy consumption under the DETA and AMBA scenario is about 19% and 16% respectively as compared to DAU scenario by 2050. Table 20 highlights the primary energy consumption under the three scenarios. In addition, Figure 5 illustrates the consumption shift in share of each fuel under the three scenarios considered. *It is to be noted that the increase in primary energy consumption under AMBA scenario in 2050 is primarily due to increase in share of solar, hydro and nuclear energy wherein the major contributor is electricity generation from solar that increases almost by 4.5 times in the AMBA scenario as compared to DETA.*

Table 20 Primary Energy Consumption (in MTOE*)

	2020			2030		
	DAU	DETA	AMBA	DAU	DETA	AMBA
Coal & Lignite	379	377	364	760	693	670
Crude oil	188	178	176	402	354	350
Natural gas	81	86	85	129	133	133
Nuclear	10	22	23	11	62	15
Hydro	13	13	13	15	15	20
Wind	6	7	9	15	21	78
Solar	2	2	12	4	4	20
Wood	2	2	2	3	3	3
Total	**680**	**688**	**684**	**1338**	**1285**	**1290**
Fossil Share (in %)	95%	93%	91%	96%	92%	89%
Non-Fossil Share (in %)	5%	7%	9%	4%	8%	11%

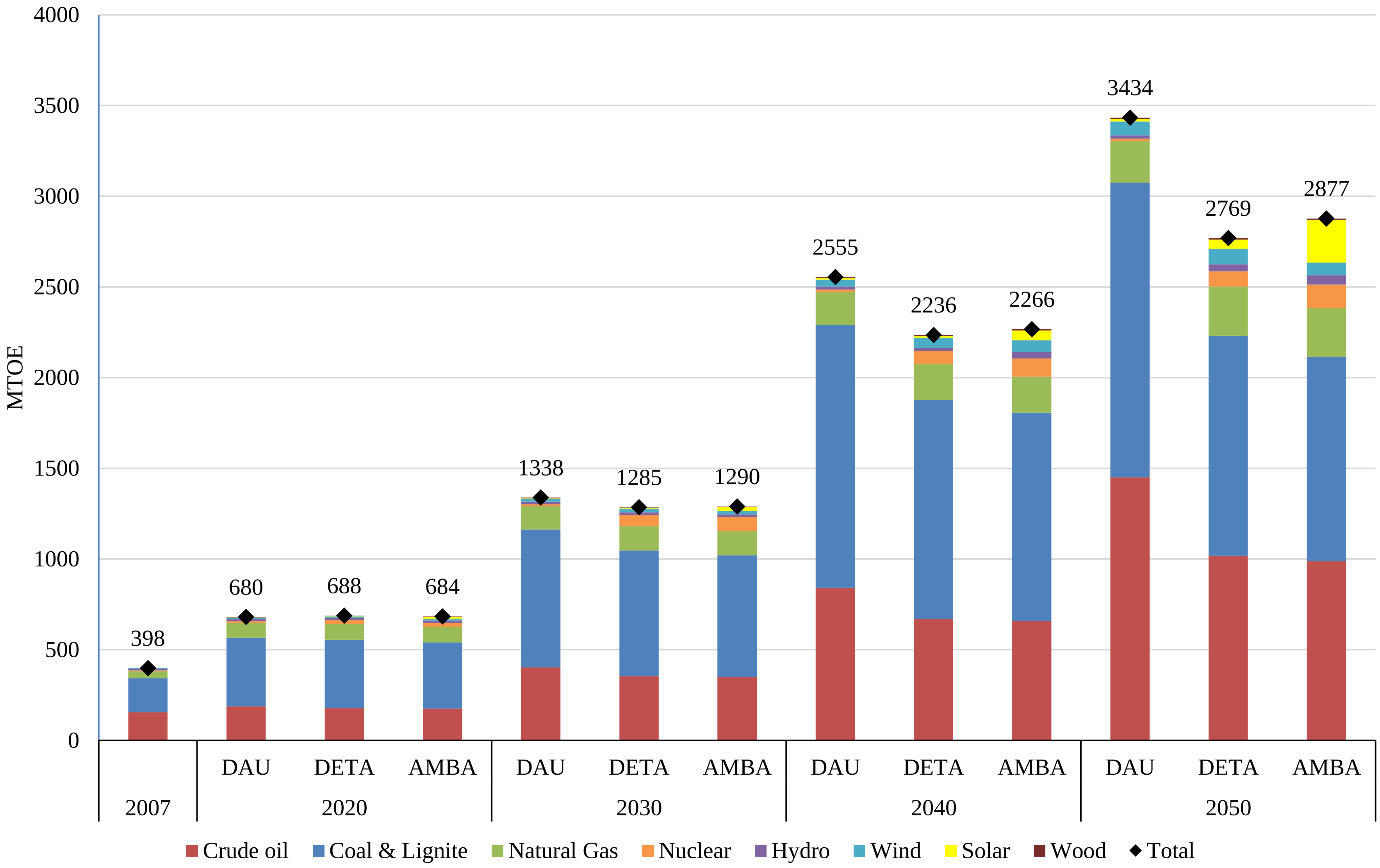
	2040			2050		
	DAU	DETA	AMBA	DAU	DETA	AMBA
Coal & Lignite	1449	1205	1149	1624	1213	1127
Crude oil	842	671	658	1451	1018	988
Natural gas	183	199	199	229	272	270
Nuclear	13	73	100	14	84	128
Hydro	17	16	36	18	38	52
Wind	38	56	65	76	86	70
Solar	9	11	54	15	51	236
Wood	6	6	6	7	7	7
Total	**2555**	**2236**	**2266**	**3434**	**2769**	**2877**

[2] BP Statistical Review of World Energy, 2014

Fossil Share (in %)	97%	93%	88%	96%	90%	83%
Non-Fossil Share (in %)	3%	7%	12%	4%	10%	17%

Conversion factor used as per Integrated Energy Policy, which uses MToE conversion factors as per International Energy Agency (IEA) Practice

Figure 5 Fuel-wise Share in Primary Energy Consumption (in percentage)



Coal and Lignite

India presently holds 7% of total global coal reserves and it has fifth largest proven coal reserves globally[3]. Coal is the most abundantly available domestic energy resource in India having a reserve to production ration of about 94 years[4]. Coal is a crucial fuel for power, steel and cements industry, which are critical sectors for the growth of Indian economy. Out of all the primary energy resources, for India coal is the key primary resource of energy due to its endowment, availability and price competiveness compared to other primary energy resources such as oil and natural gas.

Coal (including lignite) demand for India will increase to 4,668 MT in 2050 under the DAU scenario (increasing at a CAGR of 5.1%). Further, the overall coal (including lignite) demand is expected to decrease by 1,183 MT and 1,430 MT by 2050 under DETA and AMBA respectively compared to DAU scenario. Table 21 provides the coal (including lignite) demand under various scenarios.

Table 21Coal & Lignite Demand (in MT)

Coal and Lignite Demand (in MT)

Year	DAU	DETA	AMBA
2020	1088	1084	1047
2030	2184	1991	1926
2040	4163	3462	3301
2050	4668	3485	3238
CAGR (2007-50)	5.1%	4.4%	4.2%

Share of Coal & Lignite in MTOE is highlighted in Table 20 and Figure 5 respectively. From these, it is observed that coal is expected to remain a dominant fuel in India's energy mix over the year under the DAU scenario with a share of around 47% in 2050. Whereas, the contribution of Coal & Lignite is expected to reduce over the years under DETA and AMBA scenarios, however the share is not significantly lower (between 44% to 39% in 2050) which makes coal as an important fuel under these scenarios also *(Coal resource and resource growth assumption is provided in the section for detailed scenario assumptions).*

Coal (including Lignite) production is expected to reach 4,393 MT in 2050 under the DAU scenario increasing at a CAGR of 5.2 percent. However, push to low carbon technologies and increase in harnessing renewable energy resources will reduce the coal (including lignite) requirement. Therefore, coal & lignite production will reduce under the DETA and AMBA scenario as highlighted in Table 22.

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[3] BP Statistical Review of World Energy, 2015

[4] BP Statistical Review of World Energy, 2015

Table 22 Coal & Lignite Production (in MT)

	Coal & Lignite Production (in MT)		
	DAU	**DETA**	**AMBA**
2020	1024	1020	985
2030	2056	1874	1813
2040	3918	3258	3107
2050	4393	3280	3048
CAGR (2007-50)	5.2%	4.5%	4.3%

Crude Oil

Crude oil is the second largest energy commodity used in India after Coal (including lignite) for primary energy consumption. The IRADe- CC NEG50 Model results highlights that crude oil demand for India will increase to 402 MT in 2030 and to 1,451 MT in 2050 under the DAU scenario. However, the oil demand is expected to decrease by 171 and 184 MT in 2030 and to 433 MT and 463 MT by 2050 under DETA and AMBA respectively compared to DAU scenario. Table 23 highlights the crude oil demand under various scenarios.

Table 23 Oil Demand (in MT)

Crude Oil Demand (in MT)			
	DAU	**DETA**	**AMBA**
2020	188	178	176
2030	402	354	350
2040	842	671	658
2050	1451	1018	988
CAGR (2007-50)	5.5%	5.3%	4.5%

From the Figure 5 it is evident that the oil still continues to have a high share in primary energy mix. Since India is having limited resources of oil it will continue to import crude oil in future for meeting its domestic requirement. Under DAU scenario, the economy meets 93% of its requirement through oil imports in 2050 whereas in DETA and AMBA India will import around 90% of its crude oil requirements. In absolute terms, though the imports of crude oil fall in the DETA and the AMBA scenario as highlighted in the Table 24.

Table 24 Oil Production and imports (in MT)

Crude Oil Production (in MT)

	DAU	DETA	AMBA
2020	54	51	50
2030	95	95	95
2040	95	95	95
2050	95	95	95
CAGR (2007-50)	2.4%	2.4%	2.4%

Crude Oil Imports (in MT)

	DAU	DETA	AMBA
2020	134	127	126
2030	307	259	255
2040	747	576	563
2050	1356	923	893
CAGR (2007-50)	5.8%	4.8%	4.8%

Petroleum Products

Petroleum products demand for India will increase to 443 MT in 2030 and 1,727 MT in 2050 under the DAU scenario. The demand is expected to decrease by 59 MT and 66 MT in 2030 and to 555 MT and 594 MT by 2050 under DETA and AMBA respectively compared to DAU scenario. Table 25 highlights the petroleum products demand under various scenarios.

Table 25 Petroleum Products Demand (in MT)

Petroleum Products Demand (in MT)

Year	DAU	DETA	AMBA
2020	204	192	190
2030	443	384	377
2040	978	758	742
2050	1727	1172	1133
CAGR (2007-2050)	6.2%	5.2%	5.2%

Table 26 Petroleum Products Production, Imports and Exports (in MT)

Petroleum Products Production (in MT)

Year	DAU	DETA	AMBA
2020	172	162	161
2030	375	324	319
2040	827	641	627
2050	1460	990	957
CAGR (2007-50)	5.5%	4.6%	4.5%

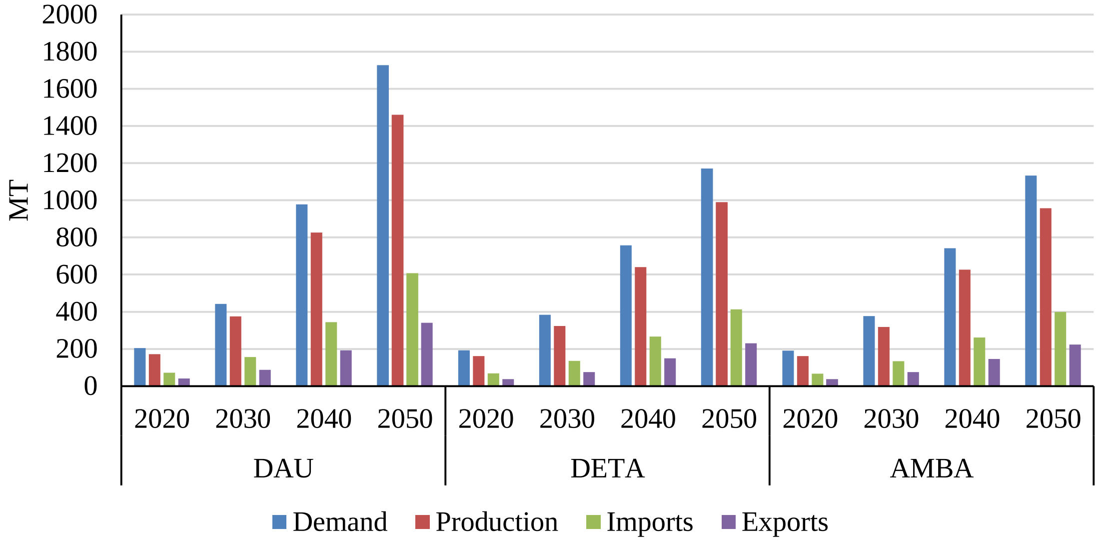
Petroleum Products net imports (in MT)

Year	DAU	DETA	AMBA
2020	72	68	67
2030	156	135	133
2040	344	267	261
2050	608	413	399

Petroleum Products Exports (in MT)

Year	DAU	DETA	AMBA
2020	40	38	38
2030	88	75	75
2040	193	150	146
2050	341	231	223

Figure 6 Demand, Production, Import and Export of Petroleum Products (in MT)



Natural Gas

Natural Gas demand for India will increase to 143 BCM in 2030 and to 254 BCM in 2050 under the DAU scenario. Further, the gas demand is expected to increase to 148 BCM and 148 BCM in 2030 and to 302 BCM and 300 BCM by 2050 under DETA and AMBA scenarios respectively. Table 27 highlights the Natural Gas demand under various scenarios.

Table 27 Natural Gas Demand

Natural Gas Demand (in BCM)

Year	DAU	DETA	AMBA
2020	90	96	94
2030	143	148	148
2040	203	221	221
2050	254	302	300
CAGR (2007-50)	4.3%	4.7%	4.7%

Total Demand of Natural gas is sum of in-house production and imports. Imports of natural Gas are crucial and the dependence on natural gas continues.The total natural gas production and imports is shown in Table 9 and Table 10.

Table 28 Natural Gas Production and Imports (in BCM)

Natural Gas Production (BCM)

Year	DAU	DETA	AMBA
2020	85	90	88
2030	123	123	123
2040	138	138	138
2050	154	154	154

Natural Gas Imports (BCM)

Year	DAU	DETA	AMBA
2020	5	6	6
2030	20	25	25
2040	65	83	83
2050	100	148	146

CAGR (07-50)	3.7%	3.7%	3.7%

CAGR (07-50)	5.5%	6.5%	6.4%

From the Figure 5, it is evident that the Natural Gas will have the third largest share in primary energy mix. However, since India has limited resources of Natural Gas, it will keep on importing natural gas for meeting its domestic energy requirements. In DAU scenario, India imports around 39% of gas whereas in DETA and AMBAscenario, it will import around 49% of the required Natural Gas in 2050.

Power Sector

Electricity is one of the key inputs for economic development of any country. All economic activities utilize electricity directly or indirectly. In case of developing countries like India, electricity plays a prominent role in supporting development activities both economic and social.

The power sector requirement is expected to rise from 813 BU in 2007 to 3,175 BU in 2030 and to 10,608 BU in 2050 under the DAU scenario, which implies a CAGR of 6.2% (between 2007-50). Table 29 highlights the expected increase in electricity requirement over the years. Reduction in overall electricity requirement in the DETA and AMBA scenario is observed due to improved energy efficiency measures for buildings through ECBC, use of energy efficient electrical appliances and implementation of energy efficient measures in industrial processes under Bureau of Energy Efficiency 'PAT Scheme'. Further, with reduction in T&D losses and auxiliary consumption by power plants the availability of electricity will increase that will also help in reducing overall requirement.

Table 29 Electricity Requirement (in BU)

	Electricity Requirement (in BU)		
	DAU	**DETA**	**AMBA**
2020	1555	1591	1545
2030	3175	3083	3012
2040	6573	5938	5728
2050	10608	8833	8421
CAGR (2007-50)	6.2%	5.7%	5.6%

With increase in urbanization and improved energy access (through Government of India's target for Power to All and increased village electrification) will increase the per capita electricity requirement over the years (refer Table 30). However, India's per capita electricity requirement will still be lower than many of the developed economies. For details on top global countries per capita electricity requirement refer to Annexure 3.

Table 30 Per-Capita Electricity requirement (in kWh per Capita)

	Per Capita Electricity Demand (in kWh per Capita)		
	DAU	**DETA**	**AMBA**
2020	1154	1181	1147
2030	2115	2054	2007
2040	4028	3638	3510
2050	6100	5079	4842

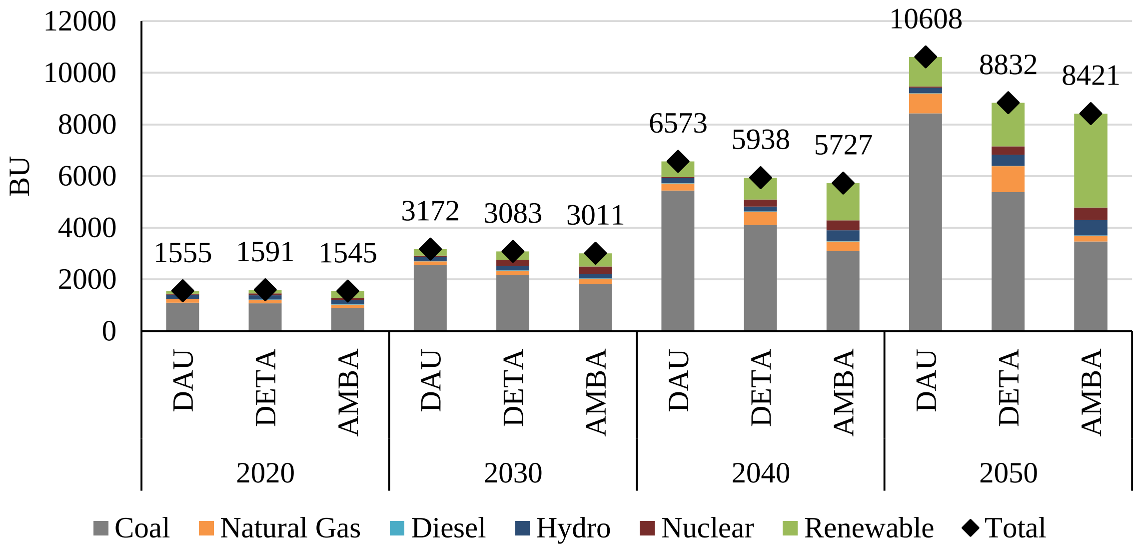
The increased electricity demand will be met through electricity generation from various technologies. Table 31 highlights the electricity generation from various technologies and fuels under the three scenarios.

Table 31 Electricity Generation by Fuel Type (in Billion Units)

	2020			2030			2040			2050		
	DAU	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**
Sub-critical Coal	797	816	734	792	811	731	788	806	726	783	801	722
Super-critical Coal	304	255	166	1757	1351	1091	4649	3310	2372	7651	4575	2745
Sub Total Coal	1101	1071	900	2549	2162	1822	5437	4116	3098	8434	5376	3467
Natural Gas	142	142	129	149	177	204	277	505	367	766	1007	220
Diesel	10	10	10	10	10	10	10	10	10	10	10	10
Sub Total Fossil	1253	1223	1039	2708	2349	2036	5724	4631	3475	9210	6393	3697
Hydro	155	156	154	170	170	171	194	189	422	208	438	600
Nuclear	37	84	89	43	239	299	48	278	383	53	322	490
Wind w/o Storage	64	80	101	172	240	233	440	651	753	884	999	814
Wind Storage	2	2	2	1	1	1	1	1	1	1	1	1
Solar PV w/o Storage	15	16	119	42	43	156	97	109	103	169	527	68
Solar PV Storage	2	2	11	1	3	76	1	11	520	1	68	2668
Solar Thermal w/o Storage	2	2	2	1	2	2	1	1	1	1	1	1
Solar Thermal Storage	2	2	2	1	2	2	1	1	1	1	1	1
Biomass	23	24	26	33	34	35	66	66	68	80	82	81
Sub Total Renewable	110	128	263	251	325	505	607	840	1447	1137	1679	3634
Sub Total Non-Fossil	302	368	506	464	734	975	849	1307	2252	1398	2439	4724
Total	1555	1591	1545	3172	3083	3011	6573	5938	5727	10608	8832	8421

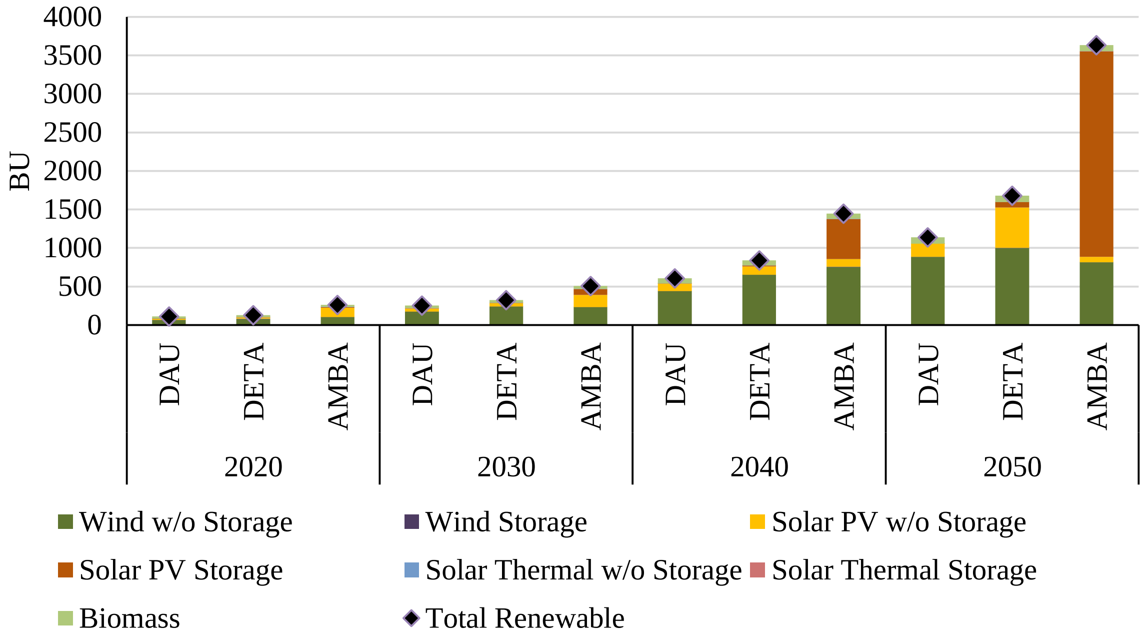
In the **DAU scenario**, coal based super critical technologies will have the highest share in electricity generation by 2050 as Government of India is also stressing that the new coal based capacities should use super-critical technology and sub-critical technology based power plants will not be built in future. This important initiative viz; the mandatory use of super-critical technology in all the coal based UMPP's in India and is shown in DAU scenario. Hence, major reduction due to this measure will not be seen in any scenario, as they are the part of DAU itself. Share of Natural gas based electricity generation over the years is expected to reduce due to resource availability.

Figure 7 Electricity Generation by Fuel-Type (in Billion Units)



Under the **DETA and AMBA scenario**, renewable based electricity generation will increase significantly specifically from solar and wind as the Government of India is giving high focus on the utilization of these resources. Further, cost of renewable technologies also reduces in future.

Figure 8 Renewable Electricity Generation-Technology wise (in Billion Units)



Under the DAU scenario, coal will be a dominant fuel for power generation and its share increases from 73% in 2030 to 84% in 2050. Whereas, share of renewable increases significantly under the DETA and AMBA scenario as highlighted in Table 32 and Figure 9. In DETA scenario, the model prefers renewable electricity generation from wind without storage and solar PV without storage whereas in AMBA scenario model prefers soalr thermal storage due to cost reductions.

Table 32 Electricity Generation by Fuel Type (in %)

	2030			2050		
	DAU	**DET**	**AMB**	**DAU**	**DET**	**AMB**
Coal	80%	70%	61%	80%	61%	41%
Natural Gas	5%	6%	7%	7%	11%	3%
Diesel	0.32%	0.32%	0.33%	0.09%	0.11%	0.12%
Sub Total Fossil	**85%**	**76%**	**68%**	**87%**	**72%**	**44%**
Hydro	5%	6%	6%	2%	5%	7%
Nuclear	1%	8%	10%	0.5%	4%	6%
Renewable	8%	11%	17%	11%	19%	43%
Sub Total Non-Fossil	**15%**	**24%**	**32%**	**13%**	**28%**	**56%**

Share of Fossil and Non-Fossil Fuel based Electricity Generation:

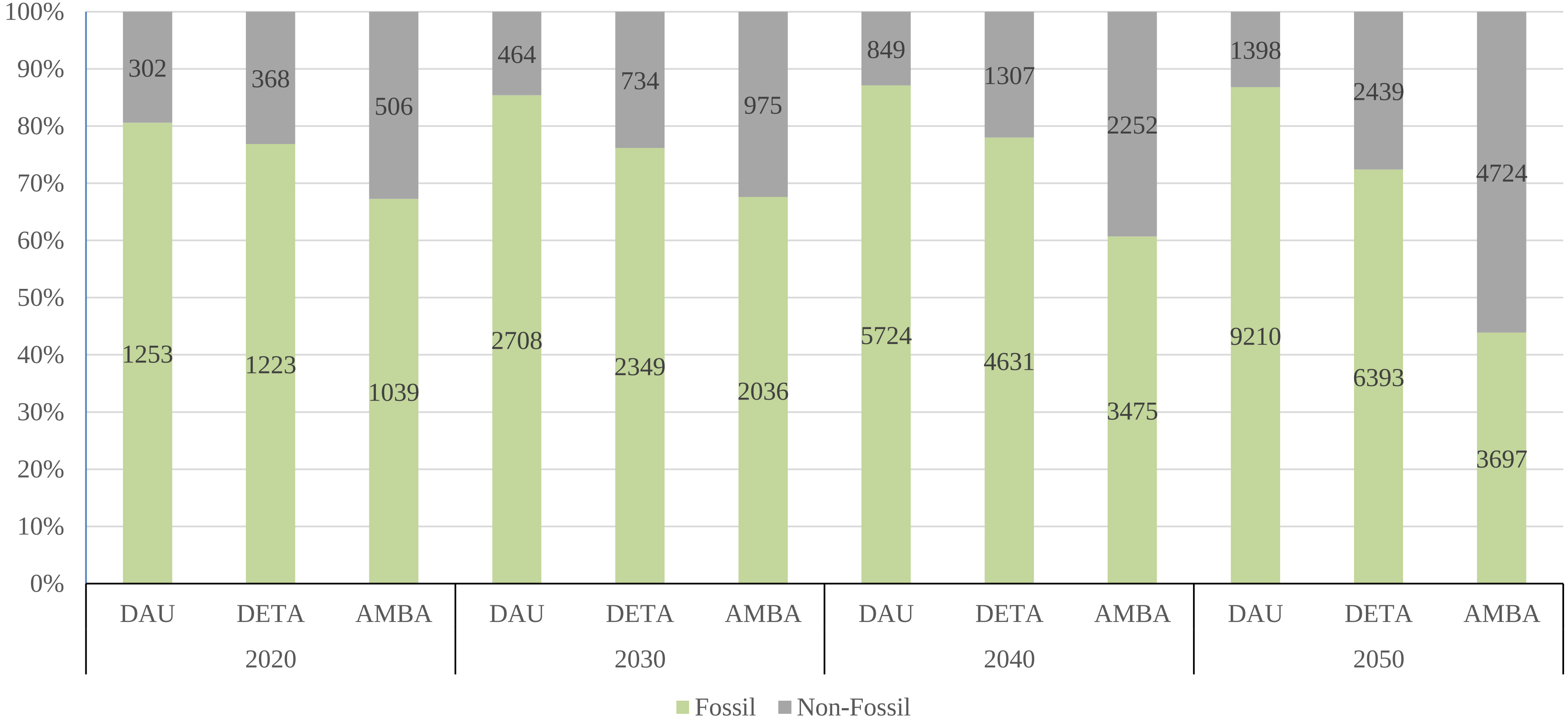
Fossil fuel based electricity generation includes electricity generated from coal, natural gas and diesel whereas the non-fossil fuel based electricity generation includes electricity generated from hydro, solar, wind and biomass.

DAU: Under the DAU scenario, fossil fuel based electricity generation dominates the overall electricity mix with share increasing from 85% in 2030 to 87% in 2050 (refer Table 32). Increase in electricity generation from super-critical coal based technology has major share in the electricity mix by 2050.

DETA: Under the DETA scenario, fossil fuel based electricity generation decreases from 76% in 2030 to 72% in 2050. Decrease in fossil fuel is due to the reduction in the share of electricity from super-critical coal based power plants, whereas electricity generation from non-fossil fuels increases such as electricity generation from Hydro, Nuclear, Wind and Solar PV.

AMBA: Under AMBA scenario, fossil fuel based electricity generation decreases from 68% in 2030 to 44% in 2050. Increase in non-fossil fuel electricity generation share is majorly from solar based generation that accounts for almost 33% in electricity generation by 2050.

Figure 9 Electricity Generation by Fuel Type (in %)



The equivalent capacity requirements for meeting the above electricity generation targets from various fuel sources are given in Table 33. Trend in growth of power generation capacity requirement is shown in Figure 10 and Renewable generation capacity growth trend is highlighted in Figure 11. Under the AMBA scenario, solar PV storage share increases to 39% respectively by 2050.

Figure 10 Equivalent Power Generation Capacities Requirement (in GW)

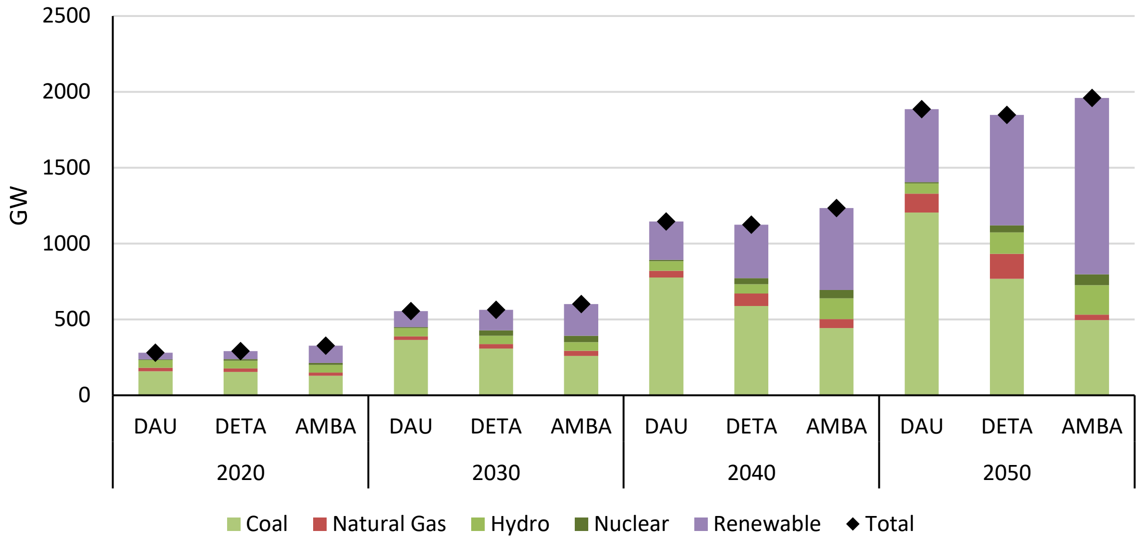


Figure 11 Equivalent Renewable Generation Capacities Requirement (in GW)

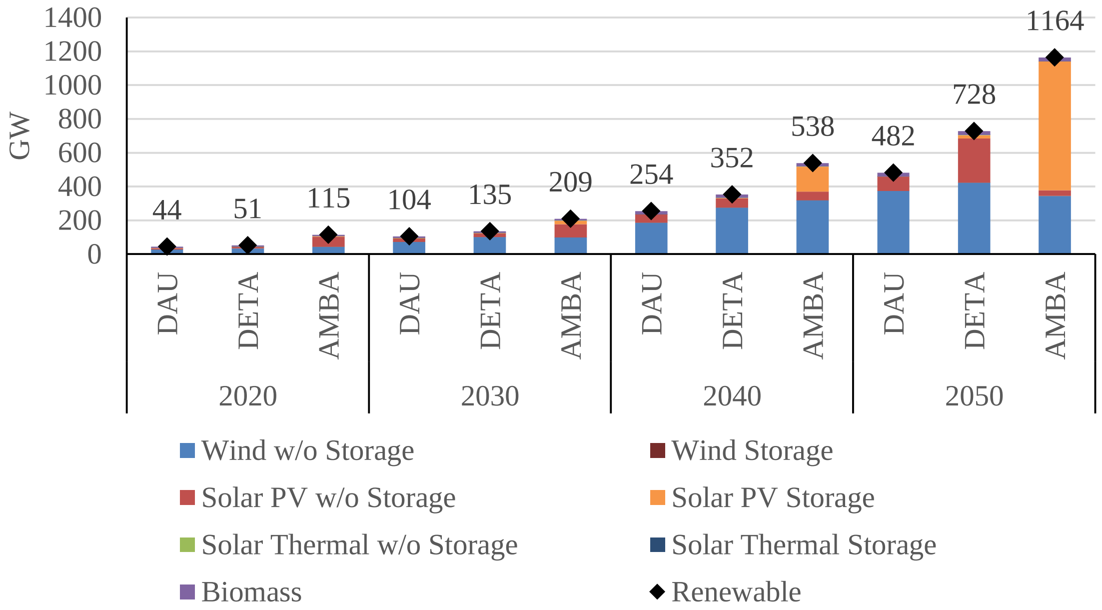
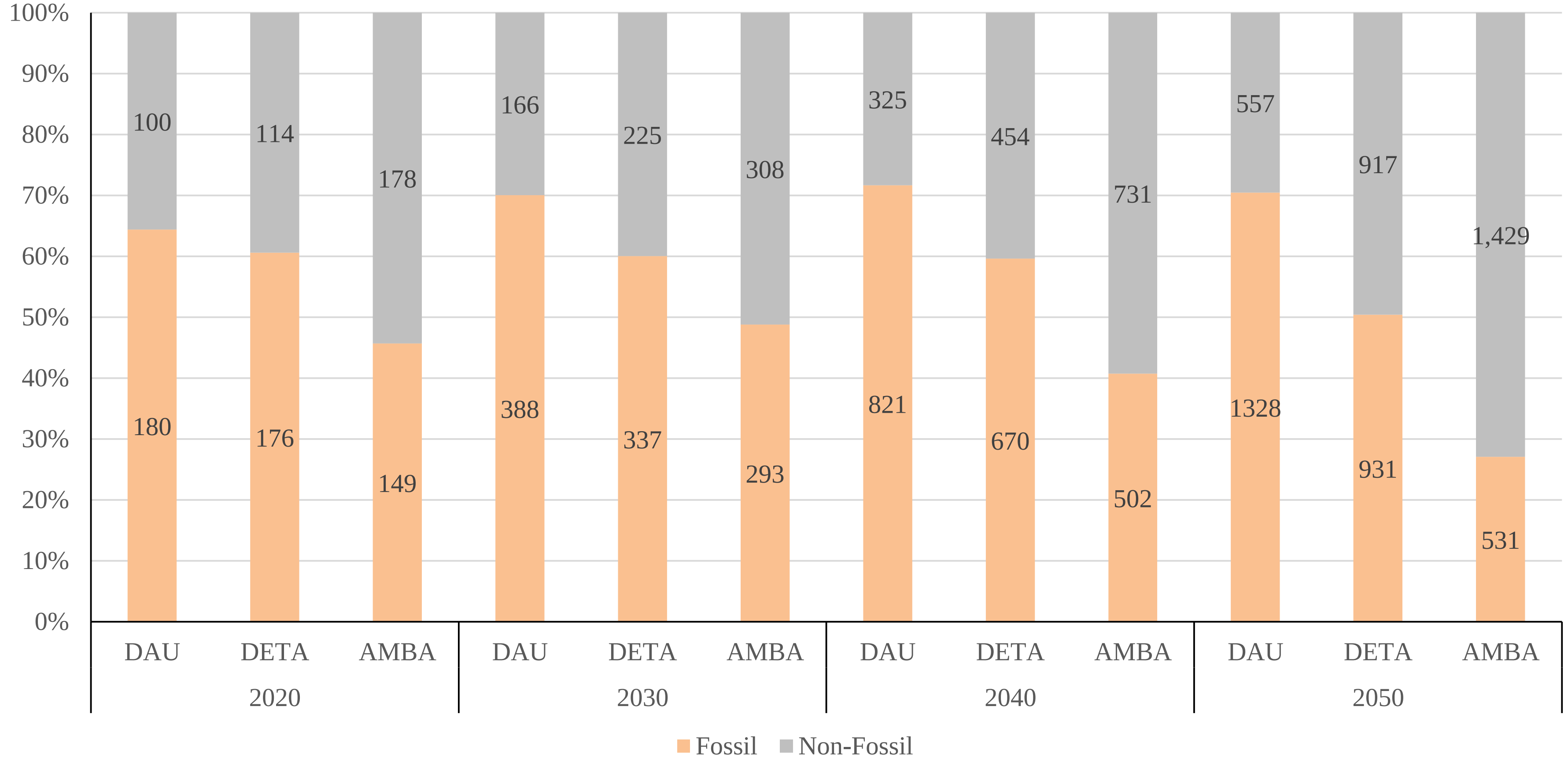


Table 33 Equivalent Power Generation Capacities Requirement (in GW)

	2020			2030			2040			2050		
	DAU	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**
Sub-critical Coal	114	116	105	113	116	104	112	115	104	112	114	103
Super-critical Coal	43	36	24	251	193	156	663	472	338	1092	653	392
Sub Total Coal	157	153	128	364	309	260	776	587	442	1203	767	495
Natural Gas	23	23	21	24	29	33	45	82	60	125	164	36
Sub Total Fossil	**180**	**176**	**149**	**388**	**337**	**293**	**821**	**670**	**502**	**1328**	**931**	**531**
Hydro	51	51	50	55	55	56	63	62	138	68	143	196
Nuclear	5	12	13	6	34	43	7	40	55	8	46	70
Wind w/o Storage	27	34	43	73	101	99	186	275	318	374	422	344
Wind Storage	1	1	1	0	0	0	0	0	0	0	0	0
Solar PV w/o Storage	7	8	59	21	21	77	48	54	51	84	262	34
Solar PV Storage	1	1	3	0	1	22	0	3	148	0	19	761
Solar Thermal w/o Storage	1	1	1	0	1	1	0	0	0	0	0	0
Solar Thermal Storage	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	7	7	7	9	10	10	19	19	19	23	23	23
Sub Total Renewable	44	51	115	104	135	209	254	352	538	482	728	1164
Sub Total Non-Fossil	**100**	**114**	**178**	**166**	**225**	**308**	**325**	**454**	**731**	**557**	**917**	**1429**
Total	**280**	**290**	**327**	**554**	**562**	**601**	**1146**	**1123**	**1233**	**1886**	**1848**	**1960**

Figure 12 Equivalent Power Generation Capacities Requirement by Fuel Type (in %)



Reduction in CO_2 Emissions per unit of Electricity

With focus on advance coal technologies such as super-critical coal technology under DAU and renewable technologies such as wind and solar in DETA and AMBA scenario will reduce the overall CO_2 emissions per unit of electricity generated. The CO_2 emissions are expected to reduce from 0.72 Kg/kWh in 2030 to 0.58 Kg/kWh by 2050 under the DAU scenario. Further, the CO_2 emissions are expected to reduce to 0.44 Kg/kWh and 0.30 Kg/kWh by 2050 under the DETA and AMBA scenarios respectively. Table 34 shows the reduction in CO_2 emissions per unit of electricity under the three scenarios.

Table 34 CO_2 Emissions per Unit of Electricity (in Kg/kWh)

CO_2 Emissions per Unit (in Kg/ kWh)			
	DAU	**DETA**	**AMBA**
2020	0.77	0.74	0.65
2030	0.72	0.64	0.56
2040	0.66	0.55	0.44
2050	0.58	0.44	0.30

Transport Sector

Transport is a critical infrastructure for development. Adequate transport provision in terms of quality, quantity and resource-efficiency is essential. The sector accounts for a substantial share of consumption of petroleum products in India therefore managing the transport sector to meet the requirements at the same time minimizing externalities such as GHG emissions is a challenge.

Table 35 Contribution of different modes of transport to total freight kilometres

	Freight in BTK		Freight share (in %)	
	Road Transport	**Railways transport**	**Road transport share**	**Rail transport share**
1950-51	6	38	14	86
1960-61	14	72	16	84
1970-71	48	111	30	70
1980-81	91	148	38	62
1990-91	145	236	38	62
1999-2000	467	305	60	40
2010-11	113	626	64	36

Figures in billions tones kilometers, Source-Road transport year book 2011-12

Table 36 Growth in the transport demand (GDP)

	Railways			Road &Other Transport*		
CAGR (in %)	**DAU**	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**
2010-20	6.15	12.23	11.29	4.01	3.44	2.49
2020-30	10.06	11.76	11.62	8.73	8.85	8.43
2030-40	11.00	11.31	11.35	9.62	9.77	9.67
2040-50	9.51	8.17	8.92	8.63	9.28	9.63

****Other transport includes air, water and inland water***

Table 37 Share of Road and other modes of transports, and Railways in GDP

	Share of railways in GDP			Share of Road &other in GDP		
	DAU	DETA	AMBA	DAU	DETA	AMBA
2020	0.75%	1.31%	1.30%	3.83%	3.61%	3.59%
2030	0.90%	1.84%	1.83%	4.04%	3.89%	3.88%
2040	1.12%	2.39%	2.37%	4.45%	4.39%	4.39%
2050	1.55%	2.95%	2.96%	5.67%	6.01%	6.00%

The decadal shares of both railways and other transport is increasing in DAU scenario The other scenarios show lower share compared to DAU owing to low carbon measures that reduce the overall demand for transport.

Table 38 Petroleum products flow across sectors

2020	Road &Other Transport*	Rail Transport	Consumption**	2030	Other Transport	Rail Transport	Consumption
DAU	58.50	0.72	64.64	DAU	122.38	1.72	172.47
DETA	49.21	1.25	65.57	DETA	80.01	3.28	169.92
AMBA	48.83	1.24	64.57	AMBA	79.13	3.24	167.23
2040	Other Transport	Rail Transport	Consumption	2050	Other Transport	Rail Transport	Consumption
DAU	276.45	4.49	389.44	DAU	572.21	10.24	629.17
DETA	141.13	8.07	366.52	DETA	242.34	14.99	544.71
AMBA	134.91	7.96	360.49	AMBA	223.27	14.82	535.61

Other transport includes air, water and inland water

*****Consumption includes private and government***

CO_2 emissions(in MT) from Transport use and by households and government for transportation needs are given below.The figures below reflects the increasing trend of emissions numbers over period for transport sector.

Table 39 CO_2 emissions from transport use

2020	Road &Other Transport*	Rail Transport	Consumption**	2030	Road &Other Transport	Rail Transport	Consumption
DAU	176.10	4.70	183.00	DAU	380.90	11.80	463.00
DETA	159.60	8.70	185.00	DETA	304.20	22.40	457.00
AMBA	179.60	10.50	219.00	AMBA	345.50	26.50	532.00
2040	Road &Other Transport	Rail Transport	Consumption	2050	Road &Other Transport	Rail Transport	Consumption
DAU	856.40	30.50	1024.00	DAU	1506.20	57.10	1660.00
DETA	630.70	52.10	970.00	DETA	1096.40	82.10	1456.00
AMBA	717.90	58.70	1078.00	AMBA	1026.20	82.00	1501.00

Other transport includes air, water and inland water

*****consumption includes private and government***

Railways GDP showed high growth in the initial two decades in the DETA and AMBA scenarios. The railways GDP growth was projected to increase from 6.15% in DAU to 12.23% in DETA and 11.29% in AMBA in 2010-2020. In 2020-2030 the railways GDP growth rate increased from 11% in DAU to 11.31% in DETA and 11.35% in AMBA scenarios. In the subsequent years the Growth rates are similar across scenarios. The other transport growth rates are comparable across scenarios.

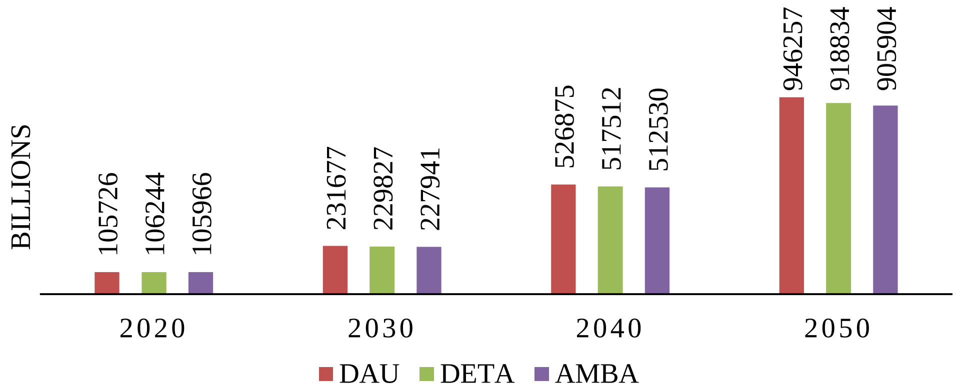
The decadal share of railways in GDP increases in DETA and AMBA scenario compared to DAU and the share of other transport decreases only marginally.

In 2030, the petroleum products flowing in the railways increases from 1.72 MT in DAU to 3.28 MT in DETA and 3.24 in AMBA. In 2050 the petroleum products usage increases from 10.24 MT in DAU to 14.99 MT in DETA and 14.82 MT in AMBA. Petroleum consumption in the other transport sector decreases from 380 MT to 304 MT in DETA and 345 MT in AMBA in 2030. In 2050 the consumption of petroleum products decreases from 1660 MT in DAU to 1456 MT in DETA to 1501 MT in AMBA scenario.

Macro-economic Impacts

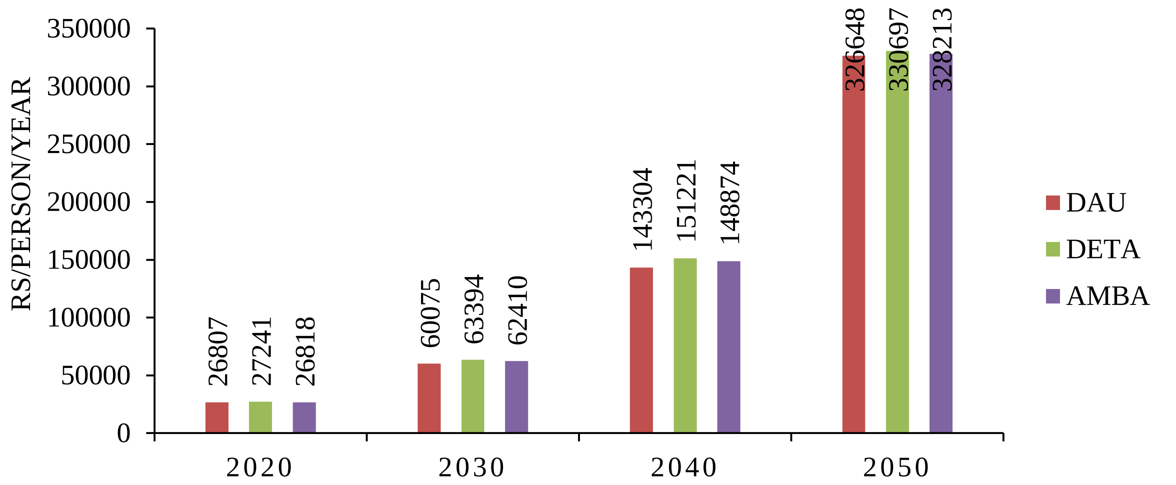
The IRADe-CC NEG50 model result highlights the key macro-economic indicators of the economy for 2020, 2030, 2040 and 2050. Key indicators highlighted by the model includes GDP (in Rs trillions), Per capita consumption (Rs/person/year), Poverty (to reflect inclusive growth policies) and the structural change in the economy (sectoral share of agriculture, industry and services in all the scenarios).

Figure 13 Gross Domestic Product (Rs billion)



Per Capita Consumption

Figure 14 Per Capita Consumption (Rs/person/year)



1) The compound annual growth rate (CAGR) from 2007 to 2030 is 7.10%, 7.06% and 7.03% for DAU, DETA and AMBA scenarios. GDP growth is lower in the low carbon scenario. The growth rate from 2007 to 2050 is 7.19%, 7.12% and 7.08% respectively.
2) The reductions GDP growth rates appear to be small and the losses appear to be small in percentage terms however they are quite large when seen in absolute terms. When cumulated GDP differences are compared as in Table 40, we see that over 2007 to 2050, compared with DAU the cumulated GDP is lower by Rs 483 trillion at constant 2007-08 prices in DETA and in AMBA the is a loss of Rs 623 trillion at constant 2007-08 prices.

3) GDP includes the effect of both investment and consumption in 2050. It should be noted that additional policy measures are introduced in the power and transport sectors in the DETA and AMBA scenarios. We have assumed reduction in consumption of petroleum products implying greater use of non-motorised travel.
4) There is a gain in consumption in the low carbon scenarios as there are reduction in the expenditures on petroleum products and mobility. This leads to an efficiency gain and higher consumption. See Figure 2. The cumulated consumption gain over 2007 to 2050 in DETA and AMBA increases by Rs.23 trillion and by Rs.13 trillion 2007-08 prices compared with BAU scenario which is no constraint (no low carbon also) scenario.

Table 40 Cumulated GDP and Cumulated Consumption (in Rs Billion)

	Cumulated GDP			Cumulated total Consumption		
Year	**DAU**	**DETA**	**AMBA**	**DAU**	**DETA**	**AMBA**
2020	992969	995113	993280	420127	420711	420142
2030	2636217	2631078	2620419	1029665	1063923	1053371
2040	6389201	6329805	6286969	2610644	2732240	2695798
2050	14199053	13950619	13810642	6672795	6970822	6877677

5) Poverty is not much impacted in the low carbon scenarios and is virtually wiped out by 2040 in rural and by 2030 in urban areas. It may be noted that in DAU many measures of inclusion are added and that 7% plus growth rate has a strong impact on reduction in poverty. Of course, this is based on present poverty line which is not raised with economic prosperity. One should expect it to be revised upward as society's norms for what is minimum tolerable level of living changes with prosperity.

Figure 15 Persons below poverty line in rural areas (In Million)

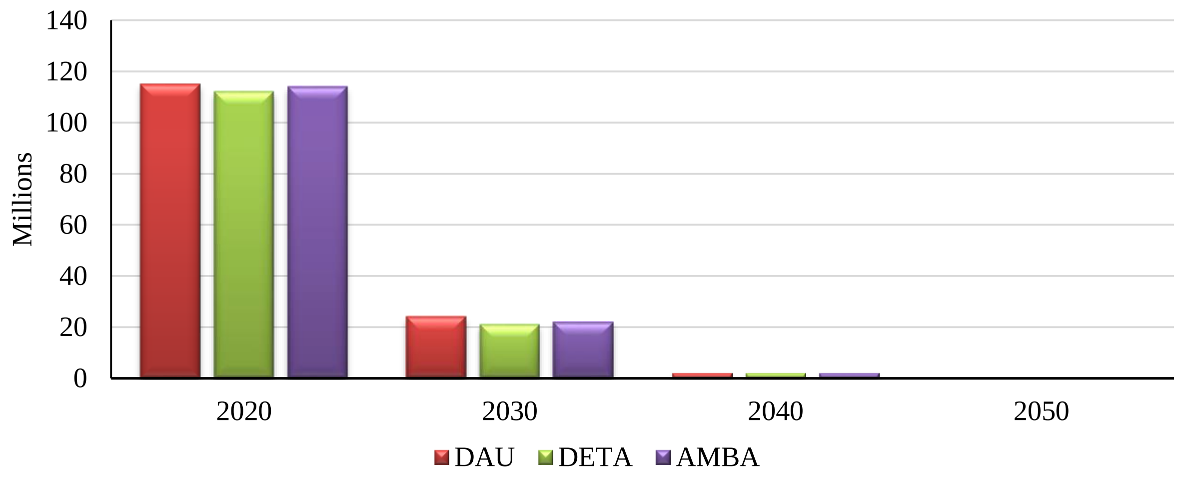


Figure 16 Persons below poverty line in urban areas (In Million)

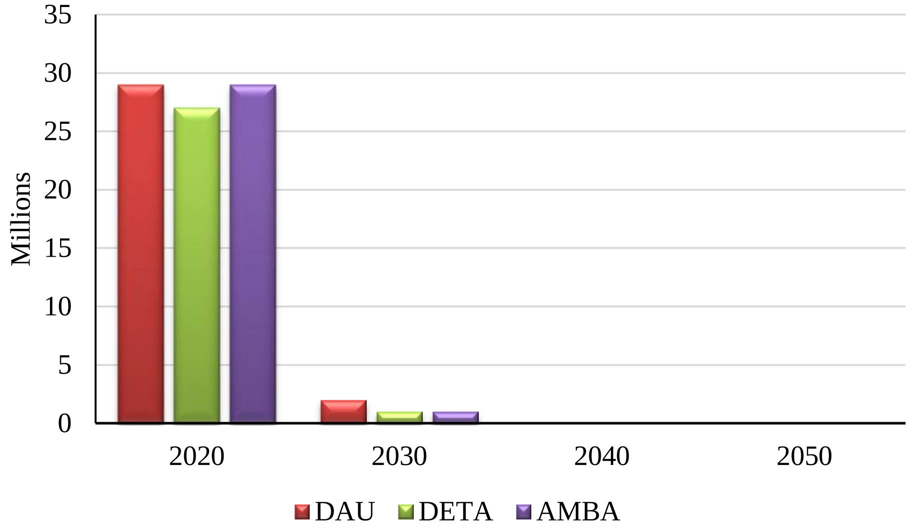


Table 41 Rural Poverty (in Millions)

Year	DAU	DETA	AMBA
2020	115	112	114
2030	24	21	22
2040	2	2	2
2050	0	0	0

Table 42 Urban Poverty (in Millions)

Year	DAU	DETA	AMBA
2020	29	27	29
2030	2	1	1
2040	0	0	0
2050	0	0	0

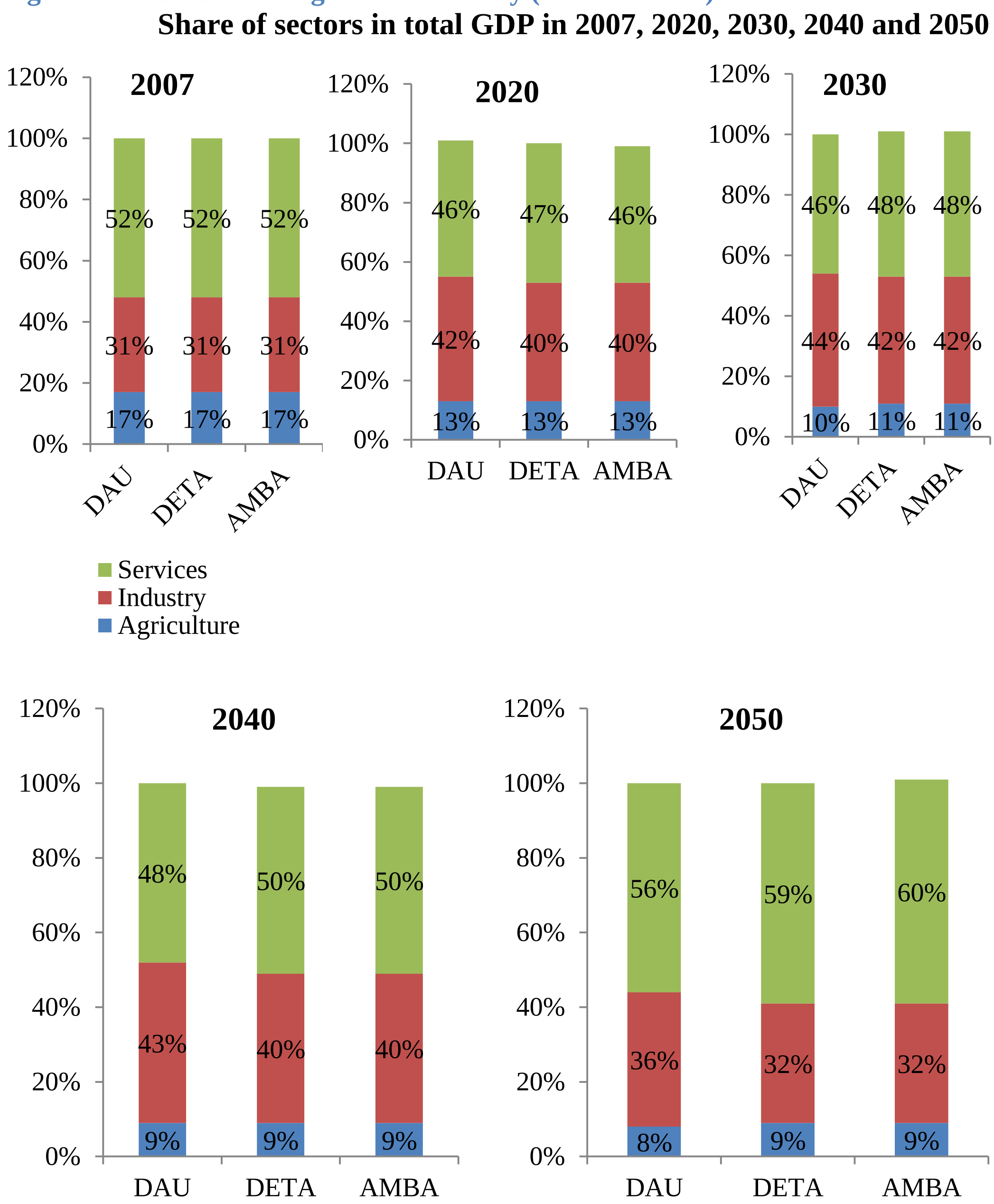
Structural Change

The share of agriculture decreases from 17% in 2007 to 10 -11% in 2030 and 8-9% in 2050 in general across scenarios. The share of industry icreases from 31% in 2007 to 43% in 2030 and reduces to 34% in 2050. The share of services increases from 52% in 2007 to 46-48% in 2030 and further to 57-60% in 2050. The share of services in 2050 is the highest in the DAU scenario at 56%. International comparison of how these shares change with increase in per capita income is shown in Annex 5.

Table 43 Structural change in the economy (Share in GDP)

		2020			2030		
	2007	DAU	DETA	AMBA	DAU	DETA	AMBA
Agriculture	17%	13%	13%	13%	10%	11%	11%
Industry	31%	42%	40%	40%	44%	42%	42%
Services	52%	46%	47%	46%	46%	48%	48%
		2040			2050		
		DAU	DETA	AMBA	DAU	DETA	AMBA
Agriculture		9%	9%	9%	8%	9%	9%
Industry		43%	40%	40%	36%	32%	32%
Services		48%	50%	50%	56%	59%	60%

Figure 17 Structural change in the economy (Share in GDP)



Cost to the Economy

The loss in GDP is computed with respect to a reference scenario (BAU) where unlike DAU no low carbon policies are considered (similar to BIG scenario of LCIG see Planning Commission 2014).

While DETA and AMBA show signinficant loss when compared to it, they show little loss in GDP or additional investment required for energy sector in 2030 compared to DAU. This may seem very different from the LCSIG scenarios of the expert group on low carbon strategy for inclusive growth. The reasons are two folds- The current reference scenario DAU incorporates many low carbon policies where as in the LCSIG report the reference scenario BIG did not include any low carbon policy. Secondly, we incorporated faster reductions in costs of renewable in DETA and AMBA.

Since DAU itself considers some low carbon measures, comparison of costs of DAU to DETA and AMBA underestimates the true cost of shifting to a low carbon pathway and hence the costs of DETA and AMBA have been computed with respect to this fossil fuel based reference scenario. The GDP and consumption loss, and the increase in overall and energy sector investment for implementing low carbon pathways is provided in the table below.

Cummulated Energy Investment

The cumulated energy investment under the DETA scenario will decrease by 1.7 Billions INR in 2050 as compared to DAU scenario, whereas the cumulated energy investments are expected to increase under the AMBA scenario by 3.4 Billion INR in 2050. Figure 18 hghlights the cumulated energy investements in Energy up to 2050.

Figure 18 Cumulated Energy Investment (in Billion INR)

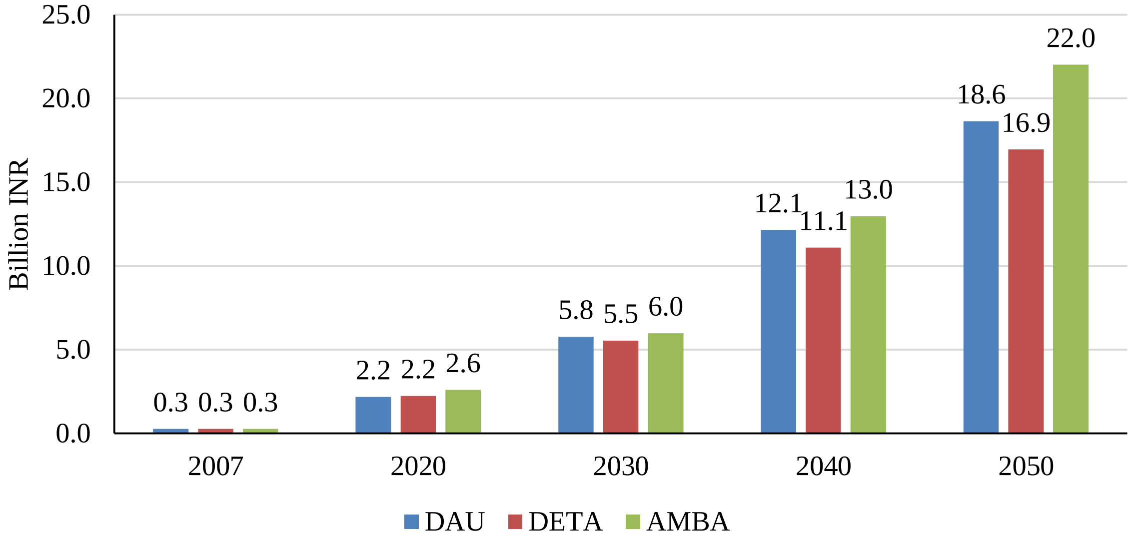


Table 44 Cost to the Economy Compared to a Reference Scenario with No Specific Measures for Low Carbon Growth

Cumulated GDP loss from 2007 (billion US$ 2007 PPP)			**Cumulated Energy Investment increase from 2007 (billion US$ 2007 PPP)**		
Year	DETA	AMBA	Year	DETA	AMBA
2030	1886	2627	**2030**	477	782
2050	33589	43316	**2050**	2091	5605

INDC and Policy options to achieve them

Here we analyse India's announced INDCs and we examine the possibilities of india achieving its INDC targets

Since 40% Non-fossil fuel capacity by 2030 is an announced INDC target, power sector has a important role to play in achieving the INDC targets. We consider three possible type of Non-Fossil fuel intervention in power sector. Hydro being constrained by various environmental and safety concerns has limited scope of rapid expansion. Therefore the two technologies that can be used to meet the INDC targets is Nuclear and Renewables (wind, solar and biomass). We conside alternatives to the DETA scenario, which also satisfy INDC targets

The scenarios considered for this analysis are

- Determined actions scenario (DETA)
- Nuclear led scenario to achive India's INDC targets (NUC)
- Renewable led scenario to achive India's INDC targets (REN)
- Power sector led scenario to achive India's INDC targets (POW)

DETA combines supply side interventions with the demand side measures, while POW only relies on supply side measures in power sector. The NUC and REN is even more specific in their technological choice in the sense that NUC scenario tries to achive the INDC targets relying mostly on the Nuclear program of the Government of India while the REN scenario tries to realise India's INDC commitment relying on the success of the Renewable energy program.

Table 45 Electricity Requirement (in BU)

Electricity Requirement (in BU)

	DETA	POW	NUC	REN
2020	1591	1551	1555	1544
2030	3083	3155	3174	3117
2040	5938	6465	6534	6324
2050	8833	10342	10533	9977
CAGR (2007-50)	5.7%	6.1%	6.1%	6%

Table 46 Electricity Generation by Fuel Type (in Billion Units)

	2030				2050			
	DETA	**POW**	**NUC**	**REN**	**DETA**	**POW**	**NUC**	**REN**
Sub-critical Coal	811	767	768	782	801	757	759	773
Super-critical Coal	1351	1405	1403	1449	4575	5705	6549	4273
Sub Total Coal	2162	2172	2171	2231	5376	6462	7308	5046
Natural Gas	177	188	153	231	1007	943	942	943
Diesel	10	10	10	10	10	10	10	10
Sub Total Fossil	2349	2370	2334	2472	6393	7415	8260	5999
Hydro	170	170	170	170	438	579	262	594
Nuclear	239	284	392	43	322	382	643	53
Wind w/o Storage	240	246	194	284	999	999	998	999
Wind Storage	1	1	1	1	1	1	1	1
Solar PV w/o Storage	43	40	45	70	527	604	285	618
Solar PV Storage	3	7	1	39	68	276	1	1630
Solar Thermal w/o Storage	2	2	1	2	1	1	1	1
Solar Thermal Storage	2	2	1	2	1	1	1	1
Biomass	34	34	33	33	82	82	80	81
Sub Total Renewable	325	332	276	431	1679	1964	1367	3331
Sub Total Non-Fossil	734	786	838	644	2439	2925	2272	3978
Total	3083	3156	3172	3116	8832	10340	10532	9977

Table 47 Generation Capacity requirement by Fuel Type (in GW)

	2030				2050			
	DETA	**POW**	**NUC**	**REN**	**DETA**	**POW**	**NUC**	**REN**
Sub-critical Coal	116	109	110	112	114	108	108	110
Super-critical Coal	193	200	200	207	653	814	935	610
Sub Total Coal	**309**	**310**	**310**	**318**	**767**	**922**	**1043**	**720**
Natural Gas	29	31	25	38	164	154	154	154
Sub Total Fossil	**337**	**341**	**335**	**356**	**931**	**1076**	**1196**	**874**
Hydro	55	55	55	55	143	189	85	194
Nuclear	34	41	56	6	46	55	92	8
Wind w/o Storage	101	104	82	120	422	422	422	422
Wind Storage	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Solar PV w/o Storage	21	20	22	35	262	300	141	307
Solar PV Storage	1	2	0.3	11	19	79	0.3	465
Solar Thermal w/o Storage	1	1	0.5	1	0.5	0.5	0.5	0.5
Solar Thermal Storage	0.4	0.4	0.2	0.4	0.2	0.2	0.2	0.2
Biomass	10	10	9	9	23	23	23	23
Sub Total Renewable	**135**	**137**	**115**	**177**	**728**	**825**	**588**	**1219**
Sub Total Non-Fossil	**225**	**233**	**227**	**239**	**917**	**1069**	**765**	**1420**
Total	**562**	**574**	**561**	**595**	**1848**	**2145**	**1961**	**2294**

Figure 19 Electricity Generation by Fuel-Type (in Billion Units)

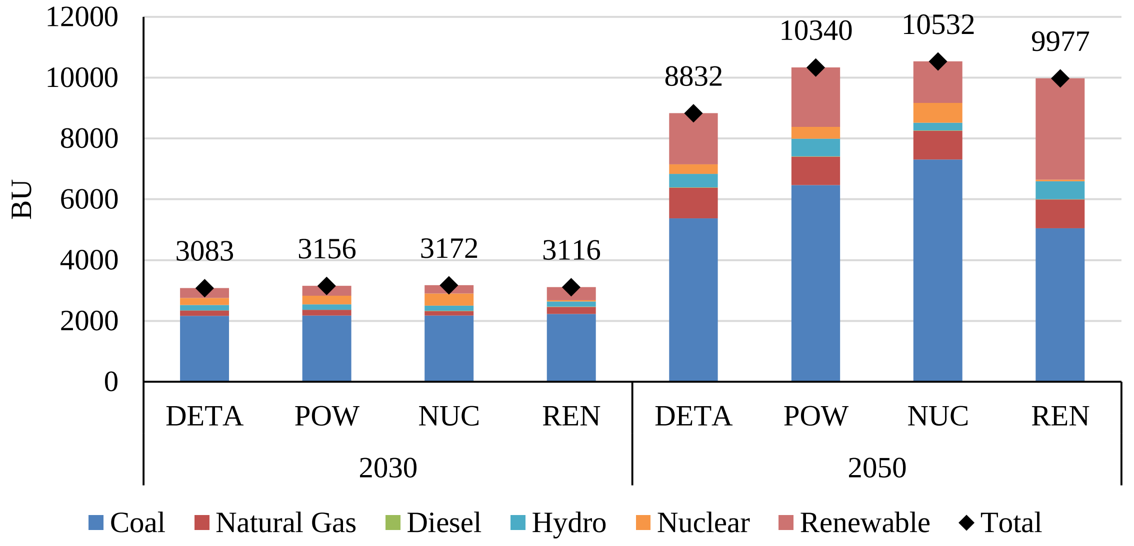


Figure 20 Generation Capacity requirement by Fuel Type (in GW)

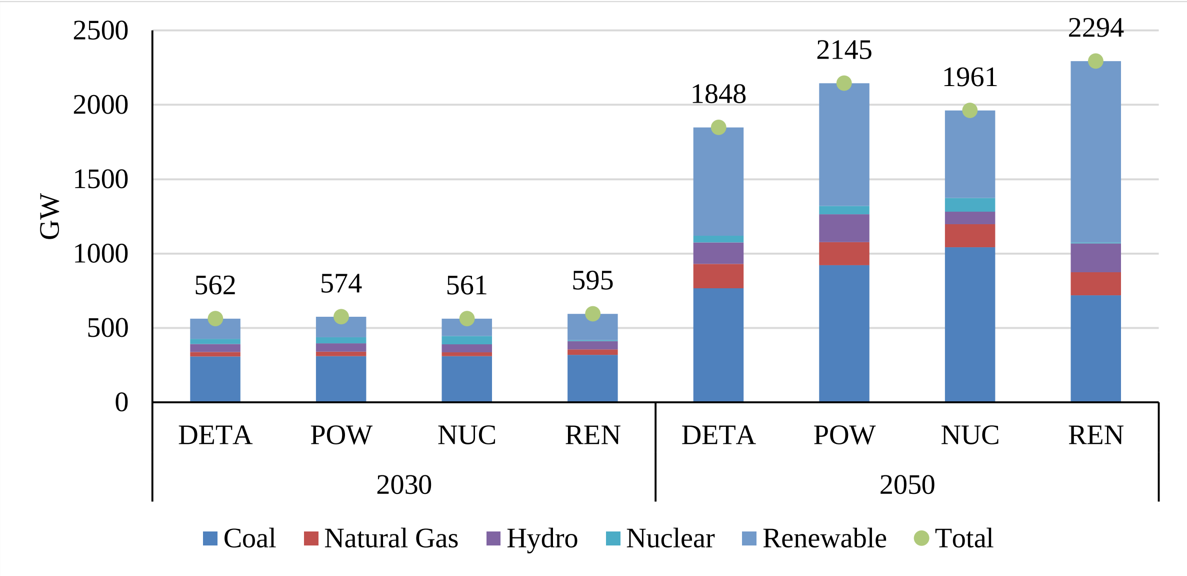


Figure 21 Renewable Electricity Generation-Technology wise (in Billion Units)

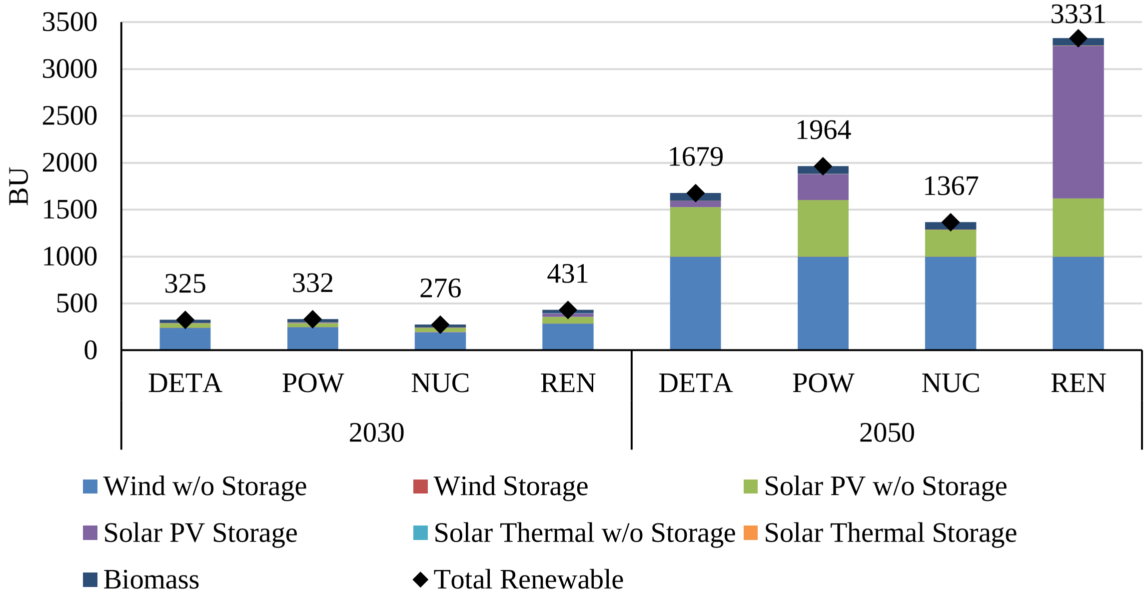


Figure 22 Renewable Generation Capacity requirement -Technology wise (in GW)

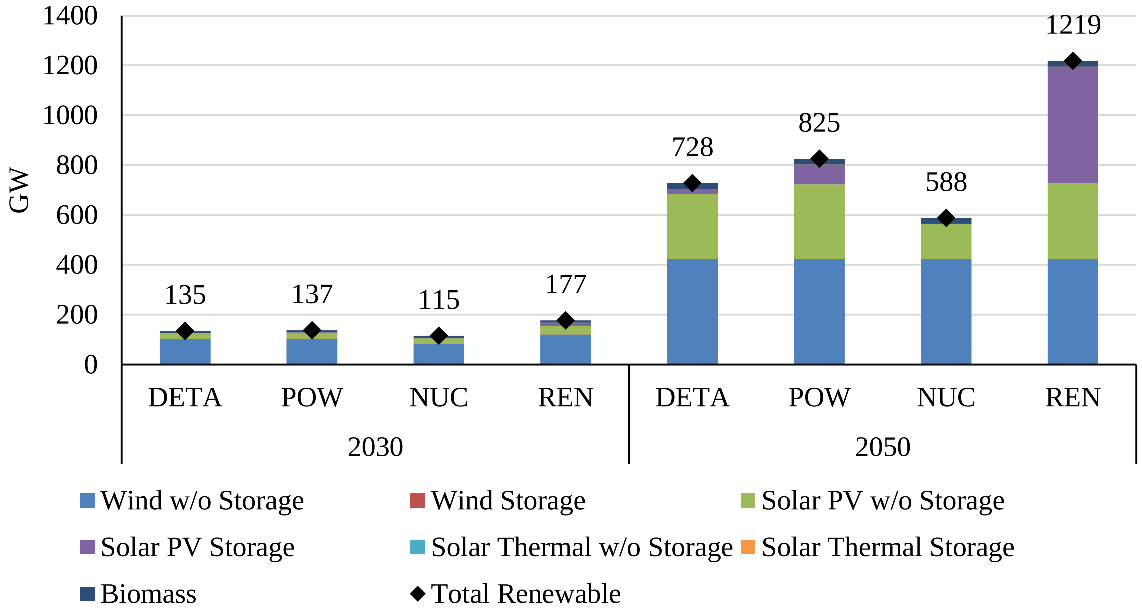


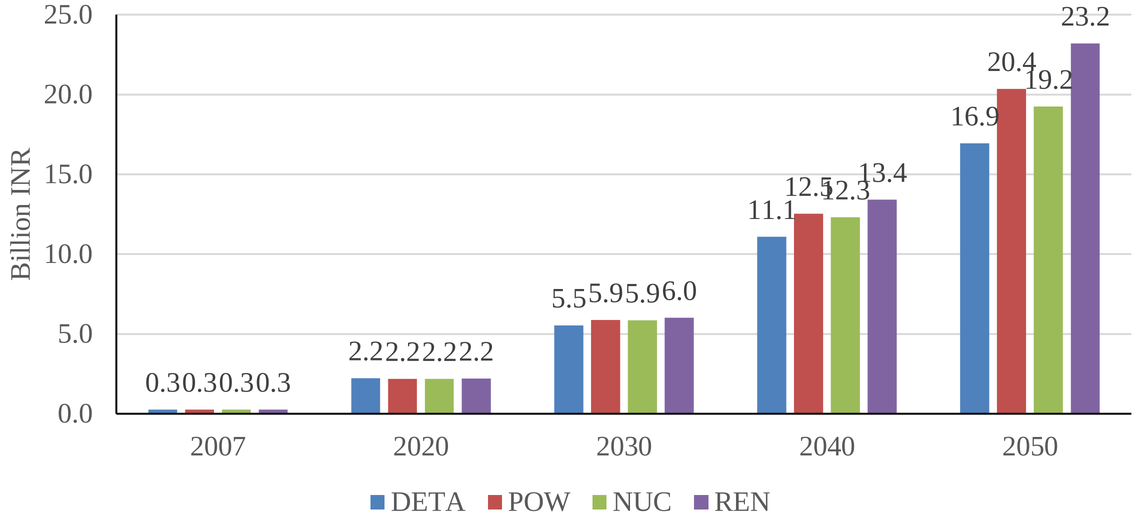
Table 48 Electricity Generation by Fuel Type (in %)

	2030				2050			
	DETA	**POW**	**NUC**	**REN**	**DETA**	**POW**	**NUC**	**REN**
Coal	70%	69%	68%	72%	61%	62%	69%	51%
Natural Gas	6%	6%	5%	7%	11%	9%	9%	9%
Diesel	0.3%	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%	0.1%
Sub Total Fossil	76%	75%	74%	79%	72%	72%	78%	60%
Hydro	6%	5%	5%	5%	5%	6%	2%	6%
Nuclear	8%	9%	12%	1%	4%	4%	6%	1%
Renewable	11%	11%	9%	14%	19%	19%	13%	33%
Sub Total Non-Fossil	24%	25%	26%	21%	28%	28%	22%	40%

Table 49 Generation Capacity Requirement by Fuel Type (in %)

	2030				2050			
	DETA	**POW**	**NUC**	**REN**	**DETA**	**POW**	**NUC**	**REN**
Coal	55%	54%	55%	54%	42%	43%	53%	31%
Natural Gas	5%	5%	4%	6%	9%	7%	8%	7%
Sub Total Fossil	60%	59%	60%	60%	50%	50%	61%	38%
Hydro	10%	10%	10%	9%	8%	9%	4%	8%
Nuclear	6%	7%	10%	1%	2%	3%	5%	0%
Renewable	24%	24%	21%	30%	39%	38%	30%	53%
Sub Total Non-Fossil	40%	41%	40%	40%	50%	50%	39%	62%

Figure 23 Cumulated Energy Investment (in Billion INR)



The results show that while there are many options to achive India's stated INDC, It is much less costlier to achive if combined with other measures. Hence DETA is the least costly followed by POW where power sector technologies are combined compared to NUC or REN that rely solely on specific technology programs.

Table 50 India's INDC Achievements under various Scenarios

INDC in 2030	CO2 Emissions Intensity reduction	Non-Fossil Fuel Capacity
DAU	0.324	30
DETA	0.393	40
AMBA	0.433	51
POW	0.366	41
NUC	0.368	40
REN	0.359	40

Table 51 Possible INDC Targets for India in 2050

INDC	CO2 Emissions Intensity reduction	Non-Fossil Fuel Capacity
DAU	0.518	30
DETA	0.648	50
AMBA	0.697	73
POW	0.565	50
NUC	0.544	39
REN	0.599	62

As can be seen India falls slightly short of its INDC commitment in the DAU scenario. However by taking determined actions (DETA) and even in with the ambitious action s (AMBA), India over exceeds its INDC commitments. Even if all proposed action s are not put in place India can still achieve its INDC using its Nuclear program or renewable program or a combination of both.

Main Observations

Emissions

- India is able to achieve its INDC targets and more by increased efforts on the supply side to step up the share of renewables, hydro and nuclear in power sector. On the demand side, a shift in freight movement from road to railways, fuel mix change by shifting to gas based transportation and electricity based transportation from conventional petroleum products based transportation, higher use of public transport and increased vehicular fuel efficiency and finally increased share of ECBC buildings help in reducing the energy demand.
- With Determined actions (DETA scenario), India can bring down its GHG emissions to 4.2 GT level by 2030 and to 9.7 GT by 2050 compared to 4.7 GT in 2030 and 14 GT in 2050 in DAU Scenario.
- With Ambitious actions (AMBA scenario), India can further bring down its GHG emissions to 3.9 GT level by 2030 and to 8.2 GT by 2050 compared to 4.7 GT in 2030 and 14.1 GT in 2050 in DAU Scenario.
- Low carbon policies are likely to bring the per capita GHG emissions further down in 2050 as compared to DAU to around 6.9 and 6 tonnes per capita in the DETA and AMBA scenario respectively from 9.2 tonnes per capita in (DAU).
- Low carbon policies are likely to bring the per capita GHG emissions further down in 2050 as compared to DAU to around 6.9 and 6 tonnes per capita in the DETA and AMBA scenario respectively.
- GHG intensity decreases from 0.52 Kg/$ GDP (PPP 2007) in 2007 to 0.35, 0.32 and 0.3 Kg/$ (GDP 2007) in 2030 for DAU, DETA and AMBA respectively. This further decreases to 0.25, 0.19 and 0.17 in 2050 for DAU, DETA and AMBA respectively.
- Current Government Policies and stated future Plans have the potential of reducing CO_2 emissions in 2050 from 14 GT to 10 GT.
- Present policies (DAU) would imply a per capita CO_2 emissions of 8 tonnes/person by 2050 which is still far below where many developed countries are today.
- The INDC commitments of 33-35% reduction in CO2 intensity reduction is met in the DETA (determined effort) and AMBA (ambitious effort for efficiency, substitution and technology development).
- CO_2 emissions from power sector are reduced by 37% and 60% in 2050 in the DETA and AMBA scenario. In the transport sector, CO_2 emissions reduce 28% an 30% in 2050 in DETA and AMBA scenarios.
- Low carbon policies are likely to bring the per capita CO_2 emissions further down as compared to DAU scenario in 2050 to around 5.6 to 4.7 tonnes per capita in the DETA and AMBA scenarios respectively.

Primary Fuels Consumption

- India’s primary energy consumption is expected to increase from 398 MTOE in 2007 to 1338 MTOE in 2030 and 3434 MTOE by 2050 under the DAU scenario (growing at a CAGR of 5.1%). In 2030, the energy consumption decreases to 1,285 MTOE in DETA and 1,290 MTOE in AMBA. Further in 2050, considering the DETA and AMBA scenario the primary energy consumption is expected to decrease to 2,769 MTOE and 2,877 MTOE respectively
- Coal would continue to be a major fuel source for meeting the future energy demand. Coal demand in 2007 was 541 MT (216 MTOE) which increases to 2184 MT (874 MTOE) under the DAU scenario in 2030. However, under the DETA and AMBA scenario coal demand reduces to 1991 MT (796 MTOE) and 1926 MT (770 MTOE) respectively in 2030. Further, under the DAU scenario coal demand increases to 4668 MT (1867 MTOE) by 2050, but in DETA and AMBA scenario it is 3485 MT (1394 MTOE)and 3238 MT (1291 MTOE) respectively.
- Imports of Natural Gas increases from 10 BCM in 2007 to 20 BCM in 2030 under DAU scenario. In 2050, the imports of natural gas increases to 100 BCM, 148 BCM and 146 BCM under DAU, DETA and AMBA scenario.

Electricity Requirement and Renewable Generation

- Electricity requirement increases from 813 BU in 2007 to 3175 BU by 2030 and 10,608 BU by 2050 under the DAU scenario. In DETA, electricity requirement reduces to 3083 BU by 2030 and 8833 BU in 2050. Further, in AMBA scenario electricity requirement is 3012 BU in 2030 and 8421 BU in 2050.
- In terms of electricity generation mix for future, coal based electricity generation will be dominant under the DAU scenario (with a share of 80% in total electricity generation by 2030 and 2050). However, Coal share is expected to decrease under the DETA scenario to 70% by 2030 and 61% by 2050 as significant increase in Renewable based electricity generation is expected (share of renewables16% by 2030 and 24% by 2050 under DETA). Further, the coal share decreases to 61% by 2030 and 41% by 2050 under the AMBA scenario as share of renewable increases to 22% by 2030 and 50% by 2050.
- Under the DAU scenario, the total solar and wind installed capacities by 2050 are expected to be 85 GW and 374 GW respectively. Further increase is expected under the DETA scenario as total solar and wind installed capacity requirement is expected to be 282 GW and 422 GW respectively. Under AMBA scenario, the solar and wind capacities are expected to be significant with installed capacity of 795 GW and 344 GW respectively.
- In DAU, share of non-fossil fuels based electricity generation mix is 15% and 13% in 2030 and 2050 respectively. Whereas, share of non-fossil fuels in DETA and AMBA by 2030 is to be 24% and 33% respectively. In 2050, share of non-fossil fuel is 28% and 56% in DETA and AMBA scenarios respectively.
- In power generation while, super critical coal, nuclear and gas based power generation have major role, solar PV with storage plays an important role. The installed capacity of solar PV with storage increases to 1 GW in 2030 to 19 GW in 2050 in the determined

actions (DETA) scenario. In the ambitious actions (AMBA) scenario the installed capacity increases to 22 GW in 2030 and 761 GW in 2050.

Transport Sector

- Railways GDP showed high growth in the initial two decades in the DETA and AMBA scenarios. The railways GDP growth was projected to increase from 6.15% in DAU to 12.23% in DETA and 11.29% in AMBA in 2010-2020. Over2020-2030 the railways GDP growth rate increased from 10% in DAU to 11.76% in DETA and 11.62% in AMBA scenarios. In the subsequent years, the growth rates are similar across scenarios. The road & other transport growth rates are comparable across scenarios.
- The decadal share of railways in GDP increases in DETA and AMBA scenario compared to DAU and the share of other transport decreases only marginally.
- The petroleum products flowing in the railways increases form 2 MT in DAU to 3.2 MT and 3.4 MT in DETA and AMBA in 2030. In 2050 the petroleum products usage increases from 10.24 MT in DAU to 15 MT in DETA and AMBA. Petroleum consumption in the other transport sector decreases from 122 MT to 80 MT in DETA and 79.13 MT in AMBA in 2030. In 2050 the consumption of petroleum products decreases from 572 MT in DAU to 242.34 MT in DETA to 223.27 MT in AMBA scenario.

Macro-Economic Impacts

- The compound annual growth rate (CAGR) from 2007 to 2030 is 7.1%, 7.06% and 7.03% for DAU, DETA and AMBA scenarios. GDP growth is lower in the low carbon scenarios.
- These measures in determined actions (DETA) involve additional investment of 515 billion US$ (PPP US$ 2007) over 2010 to 2030 and 2091 billion US$ over 2010 to 2050 at 2007 constant prices.
- The additional investment required with ambitious actions (AMBA) is 855 billion US$ over 2010 to 2030 and 5605 billion US$ over 2010 to 2050 at 2007 constant prices and in PPP US$ 2007.

The cumulated but un- discounted loss in GDP would be 1886 billion US$ over 2010 to 2030 and 33589 billion US$ over 2007 to 2050 with determined actions scenario.

- The loss in cumulated but un- discounted GDP would be 2627 billion US$ over 2010 to 2030 and 43316 billion US$ over 2007 to 2050 with ambitious actions scenario.
- These losses occurs even though we have made optimistic assumptions in the rates of technical progress leading to substantial reduction in the cost of solar power plants, whose incremental capital output ratio(capital required in rupees to increase capacity to produce one rupee worth of electricity per year) falls from 17.7 in 2010 to 9.9 in 2050.

Conclusions

- India can bring down its per capita GHG emissions to 6.9 and 6 tonnes by 2050 where non fossil electricity generation would be 28% and 56 % in the two scenarios.
- This will require support from international community on two fronts: Financial support for meeting the additional investment needed and access to technology or international co operation in technology development.
- Financial support as well as low interest long term loans with interest payment moratorium for 20 years can help overcome GDP loss.
- Also important is technology access at low and reasonable costs to advances in solar, wind and other power sector technologies as the installed capacity for solar and wind becomes 705 GW and 1140 GW in DETA and AMBA in 2050. Of these solar with storage is 19 GW and 761 GW in 2050.
- Thus, access to technology becomes critical including that for storage technologies, smart grid, ICT technologies for promoting energy efficiency and energy efficient transport technologies etc.
- INDC commitments are over achived if the proposed plans of Government are put in place.
- However even if plans in all sectors are not achieved INDC can still be achieved by pursuing accelerated Nuclear program or Renewable program or a combination of both.
- Niether of the scenarios shows India's GHG emissions peaking even by 2050.

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Annexure 1 IRADe- CC NEG50 Model Description

The original SAM that covers the whole economy is aggregated into 25 consumption commodities and 34 production sectors. The Production side in the model has been 7 agricultural sectors which can be disaggregated into 15 sectors comprising of major crops, horticulture, animal husbandry and livestock, forestry, fishing, fruits and vegetables. The Industry has 26 sectors of which 13 sectors are power generation sectors and 4 sectors are fossil fuel based energy sectors of Coal, Crude Oil, petroleum production and Natural Gas. The remaining industrial sectors consist of sectors like agro processing, textiles, cement, fertilizers, non-metallic minerals, manufacturing, water supply & gas. The remaining sectors are services sectors like Railways, other transport and the other services sector, which contains commercial activities like real estate, financial services, legal services, medical services, educational services, trade, hotels and restaurants, public administration. The consumption side of the economy (final demand) is represented in the SAM as the sum of private consumption demand, Government consumption demand, investment demand, intermediate consumption demand from the production sectors and export demand. The IRADe-CC NEG50 model considers each of these and projects them into the future in a consistent manner. The Private household demand is modelled by using a Linear expenditure based demand system separately for Rural and urban areas. The Governments consumption expenditure is exogenously projected to grow at 7% per annum for each commodity. The Investment demand and sectoral investment is endogenously determined by the model based on its optimising strategy. The intermediate demand is computed using the Input-output coefficients from the SAM of 2007-08. The exports and imports are computed endogenously such that they satisfy the economic relations of balance of payment and investment-savings relationships.

Overall, the models projections for commodity demand and production is sectorally consistent and it satisfies all macroeconomic relationships. This feature helps the model to assess the energy economy linkages in a more accurate manner and hence provides a more accurate assessment of the environmental GHG emissions due to activities in the economy. Therefore, the IRADe- CC NEG50 Modelis able to give a detailed and comprehensive picture of emissions and the sectors that contribute most and can therefore be used to suggest sectors that need interventions and possible policies to help in reduction of emission intensity in keeping with the voluntary pledges of India.The model along with emissions also projects the development indicators for each scenario. These include poverty, growth, life expectancy, infant mortality, and mean years of schooling and higher expenditure on social sectors like education and health. Thus in principle, the model can be used to construct scenario that achieve emission targets as well as social indicator targets.

The following equations are introduced in the IRADe- CC NEG50 Model as constraints.

Constraint equation

$$C_{iht} = c_{iho} + \beta_{ih}(E_{ht} - \sum_i c_{iho}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

C_{iht} = per capita consumption of the ith commodity by the hth household group in tth time period,

c_{ih0} =minimum per capita consumption of the ith commodity by the hth household,

β_{ih} = share of ith commodity in total per capita consumption of the hth household and

E_{ht} = Total per capita consumption expenditure of the hth household.

As incomes rise, per capita consumption increases, which results in people moving from lower expenditure classes to higher classes. Such changes would impact the demand structure of the economy. The model has an endogenous income distribution, separately for rural and urban areas, to incorporate the change in the number of people in different classes over the period of time (2005-2050). The linear expenditure system (LES) and endogenous income distribution together provide a dynamically changing commodity-wise non-linear demand structure of the economy. The original input–output table consisting of 115 sectors was aggregated to 25 commodities, being produced by 38 production activities. The model considers one commodity being produced by each production activity, except electricity. For example, to produce power, the model employs renewable (wind, solar thermal, solar photovoltaic, wood gasification) and nuclear-based technologies. Assumptions on nuclear are based on plants that are already present or are in the process of construction. No further policies on nuclear are assumed, apart from the traditional technologies of thermal, hydro and gas, similar to those assumed in the IEP (2006) model. Coal, crude, natural gas and electricity are energy inputs into the model. The model ensures equilibrium between demand and supply in the optimal path for each commodity.

Demand and supply equilibrium equation

$$C_{it} + G_{it} + I_{it} + IO_{it} + E_{it} \leq Y_{it} + M_{it} \ldots (2)$$

Private consumption demand + government consumption demand+ investment demand + intermediate input demand+ export demand = domestic production + imports

Government consumption ($G_{i,t}$) is exogenous and specified to grow at a growth rate of 7 per cent. (The government’s tax collections and revenue are not modelled explicitly but accounted for implicitly.)

Intermediate demand ($IO_{i,t}$) is determined endogenously by the input–output coefficients. Total private consumption ($C_{i,t}$) is obtained from the LES demand function and endogenous income distribution. Exports ($E_{i,t}$) and imports ($M_{i,t}$) are determined endogenously from trade-side equations of balance of payments and other constraints.

Domestic availability of commodities is assumed to come from domestic output ($Y_{i,t}$) and imports ($M_{i,t}$). Domestic production is constrained by capacity constraint, i.e., the maximum output that can be produced at the given capital stock.

Capacity constraint

$$(X_{j,t} - X_{j,t-1}) \le (K_{j,t} - K_{j,t-1}) / ICOR_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

(Incremental output is related to incremental capital.)

Where,

$X_{j,t}$ = domestic output of the jth sector at time t,

$K_{j,t}$ = capital of the jth sector at time t and

$ICOR_j$=incremental capital output ratio of the jth sector, which is exogenously specified in the model.

Capital stock in sector j depends upon the rate of depreciation, and investment and is modelled using the following relation.

Capital stock equation

$$K_{j,t} = DEL(J) * K_{j,t-1} + I_{j,t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where $DEL(J)$ is the rate of depreciation in sector j, which is exogenous, and $I_{j,t}$ is the investment in sector j.

Aggregate investment demand is assumed to depend on aggregate domestic investible resources (domestic savings determined by the marginal savings rate) and foreign investments available. Investment goods, which reflect the structure of capital goods in the sectors, are identified separately and are allocated to different sectors as fixed proportions ($P_{i,j}$) of the total investment ($I_{i,j}$) in each sector.

Investment equations

$$\sum_i Z_{it} \leq Z_o + S*(VA_t - VA_0) + (FT_t - FT_0) \quad \text{…………..} \ (5)$$

$$\sum (P_{i,j} * I_{j,t}) \leq Z_{i,t} \quad \text{………………………………........} \ (6)$$

$$FT_t = (a - b*t)*VA_t \quad \text{………………………………….} \ (7)$$

Where,

$Z_{i,t}$ = investment demand of commodity i at time t,

VA_t = value added at time t,

FT_t = foreign investment at time t,

S = exogenously specified maximum marginal savings ratio,

Z_0= investment in the base year (2004-05) and

$P_{i,j}$ and a and b are pre-specified constants.

Trade is endogenous to the model. Foreign capital inflow (*FT*) is a changing proportion of value added. Though exports and imports are endogenous to the model, upper and lower limits are exogenously specified on the growth rate of exports and imports. The model has a balance of payment constraint for exports and imports so that they grow in a realistic manner.

Balance of payment equations

$$\sum_i (M_{i,t} * MTT_i) = \sum_i E_{i,t} + FT_t \quad \text{……………} \quad (8)$$

$$M_{i,t} \geq (1 + MGRU_i) * M_{i,t-1} \quad \text{…………………………} \quad (9)$$

$$M_{i,t} \leq (1 + MGRL_i) * M_{i,t-1} \quad \text{…………………………} \quad (10)$$

$$E_{i,t} \leq (1 + EXGRU_i) * E_{i,t-1} \quad \text{…………………… ……} \quad (11)$$

Where,

MTT_i= trade and transport margins for commodity i,

$MGRU_i$ and $MGRL_i$=upper and lower bounds for imports growth rates of commodity i and

$EXGRU_i$=upper bound for exports growth rate of commodity i.

Equations (7) to (11) form the complete specifications of the trade-side of the model.

Equations (1) to (11) form a set of constraints, based on economic criteria, for the model solution to be meaningful.

Annexure 2 Autonomous energy efficiencyimprovements for India

The changes in energy/GDP ratio that are not related to the deviations in the relativeprice of energy are referred to as the trends in autonomous energy efficiencyimprovement (AEEI). It is an empirical representation of non-price driven changes intechnology, which are increasingly energy-saving changes. The IRADe study showsthe value of AEEI for India over the period between 1991 and 2011.

The data used in this study is obtained from two sources. Data for energy is fromthe website of the US Energy Information Agency; the variables– total energyconsumption (measured in quadrillion btu) and gross domestic product (measuredin INR crores at constant prices) –are obtained from the database of the Ministry ofStatistics and Programme Implementation (MoSPI).

The process of calculating the AEEI is conducted over several stages. The annual data spans from 1991 to 2011. The ratio of energy/GDP is used in logs and isregressed over a period of time using the method of least squares. This is done inthree parts: initially, from 1991 to 2011, then, from 1991 to 2000 and finally, from 2001to 2011. The coefficient of time, when multiplied by 100, gives the AEEI value for India.The values for this are tabulated in Table below.

Time	Coefficient	AEEI (%)
1991- 2000	-0.008	0.8
2001-2011	-0.020	2.0
1991-2011	-0.017	1.7

It should be noted that the value of the autonomous energy efficiency index has shown an increasing incline over the years, with the value growing from 0.8 per cent in 1991-2000 to 2 per cent in 2001-2011. The study shows that the AEEI ratio increases in 2011 contrary to the trend shown for the rest of the decade. This is due to a fall in the GDP. The AEEI number, resulting from this study, correlates to the values derived from several other studies as well. Thus, it can be concluded that the autonomous energy efficiency improvement for India is at 1.7 per cent from 1991 to 2011.

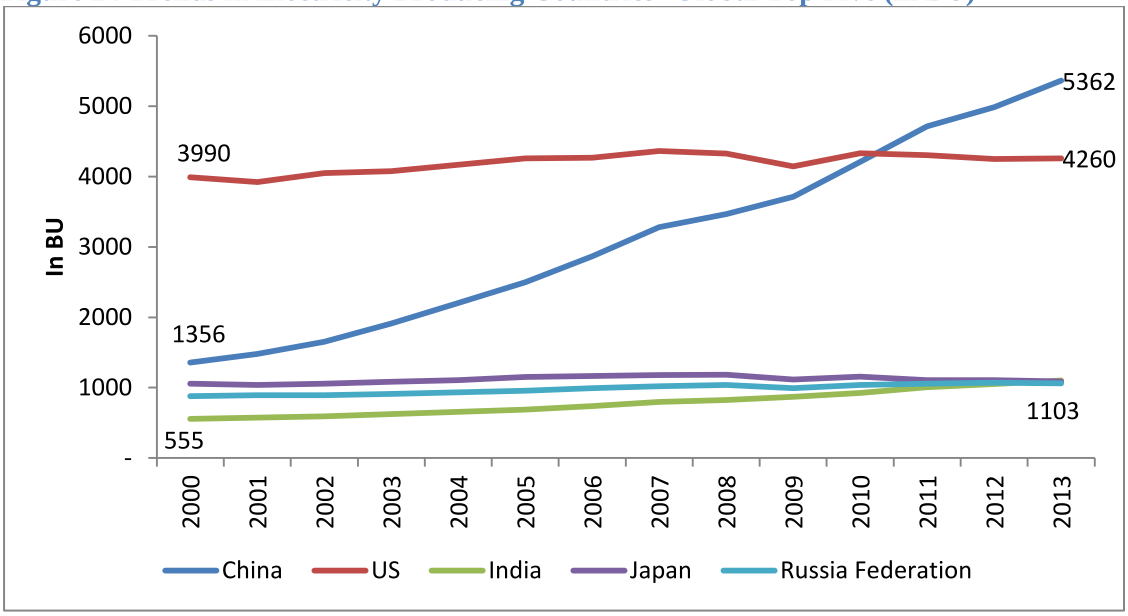
For this study, we have assumed conservative AEEI value of 1.5% for India.

Annexure 3 India's Power Sector- Present Scene

Global Scene

Globally, India was the third largest electricity producer in the world with production of 1,103 BU[5] in 2013. Whereas, China is the largest electricity producer with production of 5,362 BU followed by United States with production of 4,260 BU[6]. During the past 10 years (between 2004 to 2013) electricity production in India increased at a CAGR of 5.9%, however in the global top five countries China's electricity generation has increased highest with the a CAGR of 10.4% during the same period[7]. Figure below illustrates the past trends of electricity generation for the top five countries.

Figure 24 Trends in Electricity Producing Countries- Global Top Five (in BU)



(Source: B.P. Statistical Review of World Energy 2014)

Although, India ranked third globally in electricity generation but its per capita electricity consumption is much lower than the world average per capita electricity consumption. In year 2011, India's per capita electricity consumption was only 684 kWh per capita, which was much lower than the world average per capita electricity consumption of 3,045 kWh per capita[8]. An interesting fact to be noted is that although China is the largest electricity producer but its per capita electricity consumption is only 3,298 kWh per capita, which is much lower than the global top 10 countries per capita consumption[9]. Table below highlights the per capita electricity consumption of global top 10 countries for year 2011.

[5] B.P. Statistical Review of World Energy 2014
[6] B.P. Statistical Review of World Energy 2014
[7] B.P. Statistical Review of World Energy 2014
[8] World Bank
[9] World Bank

Table 52 Per Capita Electricity Consumption for 2011- Global Top 10 Countries

Electricity Consumption (in kWh per Capita)	
Iceland	52,374
Norway	23,174
Canada	16,473
Kuwait	16,122
Qatar	15,755
Finland	15,738
Luxembourg	15,530
Sweden	14,030
United States	13,246
Australia	10,712

(Source: World Bank)

Present India's Power Sector

Electricity Generation

In FY 14, the gross electricity generation in India was 1,179 BU[10] including generation by utilities and non-utilities[11], which increased from 906 BU in FY10 at a CAGR of 6.8% during FY10 to FY14. However, the highest growth of 9.3% was observed in the non-utilities segment whereas the utilities segment increased at a CAGR of 6.5% during the same period (FY10 to FY14). The utilities segment is the largest electricity generation segment with the gross electricity generation of 1,023 BU in FY14. Trends in gross electricity generation of utilities and non-utilities are given in Table below.

Table 53 Trend in Gross Electricity Generation in India (in BU)

Year	Utilities (in BU)				Non-Utilities (in BU)	Grand Total (in BU)
	Thermal*	Hydro	Nuclear	Total	Total**	
FY08	585	120	17	723	90	813
FY09	618	113	15	746	96	843
FY10	671	107	19	796	110	906
FY11	704	114	26	845	114	959
FY12	708	131	32	922	128	1,051
FY13	817	114	33	964	148	1,112
FY14 (P)	854	135	34	1023	157	1179

**** Thermal includes Renewable Energy Resources.***

***** Capacity in respect of Self Generating Industries includes units of capacity 1 MW and above.***

(Source: Energy Statistics 2015 and Central Electricity Authority)

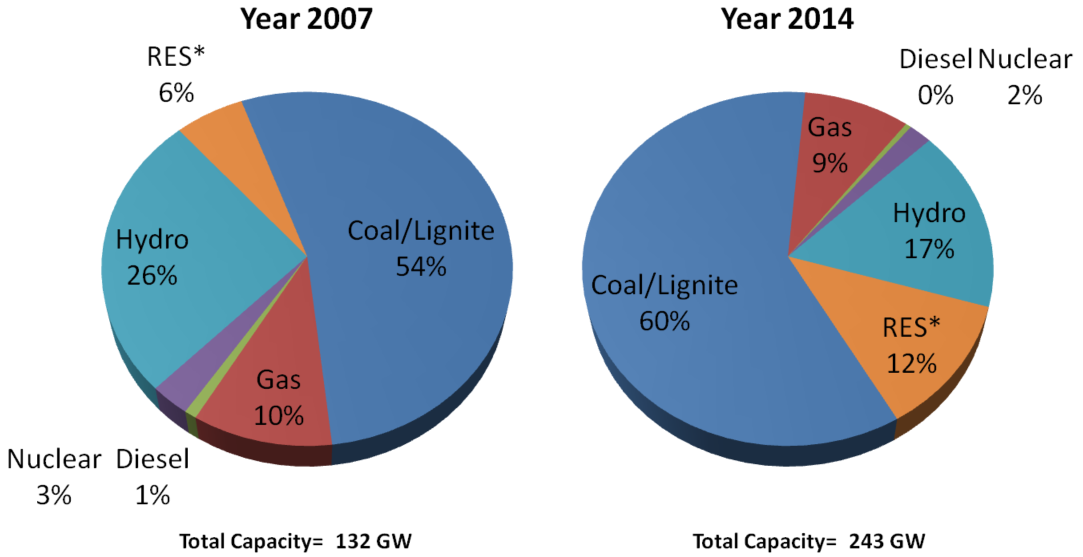
[10] Provisional figures from Energy Statistics 2015 andCentral Electricity Authority

[11] Non-Utility: An Independent Power Producer which is not a public utility, but which owns facilities to generate electric power for sale to utilities and end users. They may be privately held facilities, corporations, cooperatives such as rural solar or wind energy producers, and non-energy industrial concerns capable of feeding excess energy into the system. (Source: Energy Statistics 2015)

Installed Power Capacities

Indian power sector has significantly grown in the past. The installed power generation capacities has reached 243 GW[12] (utilities) as on 31 March 2014 from merely 1.3 GW at the time of independence. In the present installed generation capacities, Coal based generation (including lignite) accounts for 60% (145 GW) followed by Hydro at 17% (40.5 GW), Renewable at 12% (29 GW), Gas at 9 percent (22 GW) and rest by others[13]. Over the years, share of coal based power generation technologies has increased over the years as highlighted in Figure below. It is to be observed from the figure that share of hydro based generation capacities has decreased significantly and slight decrease in the share of Gas based generation. However, Renewable based capacity has increased significantly over the years. Table below shows the trend in fuel wise capacity addition over the years.

Figure 25 Change in Share of Installed Power Generation Capacities (Fuel Type for utilities) between 2007 and 2014



Renewable Energy Sources (RES) includes Wind, Small Hydro Project, Biomass Gasifier, Biomass Power, Urban & Industrial Waste Power & solar power

(Source: Central Electricity Authority)

[12] Energy Statistics 2015, Ministry of Statistics and Programme Implementation

[13] Central Electricity Authority

Table 54 Fuel-wise Power Generation Capacity Addition over the Years (in MW)

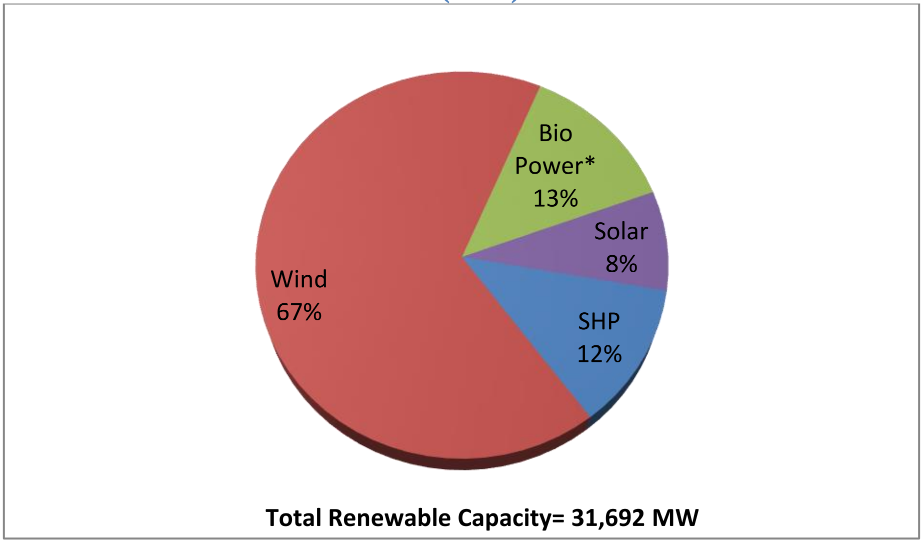
Years	Capacity addition over the past 5 years					
	Coal/ Lignite	**Gas**	**Diesel**	**Nuclear**	**Hydro**	**RES***
Between 1997 to 2002	7977	4601	841	495	4611	728
Between 2002 to 2007	8990	2529	67	1180	8385	6132
Between 2007 to 2012	40901	4689	-2	880	4336	16744

Renewable Energy Sources (RES) includes Wind, Small Hydro Project, Biomass Gasifier, Biomass Power, Urban & Industrial Waste Power & solar power

(Source: Central Electricity Authority)

Wind based power generation capacities accounts for about 66 percent (21 GW) in India's installed Renewable (grid connected) based capacities of 31.7 GW[14]. Other renewable based power generation installed capacities include Bio Power (4.1 GW), Small Hydro Power (3.8 GW) and Solar (2.6 GW)[15]. However, the growth in installation of solar capacities in the past five years has been tremendous as solar capacities increased from 10 MW in FY10 to 2,632 MW in FY14[16]. Figure 20shows the share of various Renewable (grid connected) based power generation capacities in FY14.

Figure 26 Share of type-wise Renewable (Grid Connected) Power Generation Capacities in FY 14 (in %)



Bio Power includes Biomass and Waste to Energy

(Source: Energy Statistics 2015 and MNRE)

The Government of India has also initiated various regulatory and fiscal policies for promoting renewable energy installation in India such as

[14] MNRE and Central Electricity Authority
[15] MNRE and Central Electricity Authority
[16] MNRE and Central Electricity Authority

- **Regulatory and Policy Support**- through Renewable Purchase Obligation's (RPO) under National Tariff Policy, state specific solar Policies and RPO targets, and Renewable Energy Certificate (REC) mechanism, etc.
- **Fiscal Policy Support-** through Generation based incentive scheme, Accelerated depreciation mechanism, capital/interest subsidy, concessional excise and custom duties and 100% FDI in renewable energies etc.

Annexure 4 Role of Non- CO_2 Gases During Economic Transformation

Greenhouse Gases

Greenhouse Gases are essential to keep the life going on earth, but excess amount of these gases is equally harmful, since they trap the heat coming from sun. Human activities are the drivers of anthropogenic GHG emissions which is the cause of Climate Change. Burning of fossil fuels, agricultural activities and waste handling & processing are the main sources of anthropogenic GHG emissions. Burning of fossil fuels majorly emit CO_2, CH_4 is emitted because of agricultural activities and waste. Agricultural activities are also the source of N_2O. These three greenhouse gases hold the major share of total GHGs. Other three GHGs (HFCs, PFCs and SF_6) are available in fraction of percentage out of total GHGs. very low amount out of total GHGs e.g. for India share of all the three F gases in total GHGs is only 1.6%.

CO_2 holds the major share in total GHG emissions hence the main culprit of climate change. Other two major non CO_2 GHGs (methane and nitrous oxide) are present in less quantity compare to CO_2 but since their Global Warming Potential is high, the same amount of those gases as compared to CO_2 is far more harmful. The GWP of methane is 21, which provides a relative measure of how much heat a greenhouse gas traps in the atmosphere. If same amount of CO_2 and CH_4 is released into the atmosphere, CH_4 will trap 21 times more heat than CO_2, whereas GWP of N_2O is 310 and it will trap 310 times more heat than CO_2. Impacts of anthropogenic GHG emissions on climate change are unequivocal.

Aerosols

Apart from Greenhouse Gasses, aerosols are also present in the atmosphere. They are also natural and anthropogenic both. Aerosols are small particles or droplets suspended in the atmosphere. In most of the cases they create temporary cooling effect in the atmosphere, as they reflect the radiations coming from Sun, without aerosols, earth's temperature would be much high than it is now. Aerosols create a guarding layer in the stratosphere which settle down with time and not washed away with rain, and these tiny particles (radius around 0.01 μm) by that time work against the global heating process created by GHGs, e.g. In 1991, the eruption of Mount Pinatubo in the Philippines ejected more than 20 million tons of sulfur dioxide—a gas that reacts with other substances to produce sulfate aerosol—as high as 60 kilometers (37 miles) above the surface, creating particles in the stratosphere. Those bright particles remained above the clouds and didn't get washed from the sky by rain; they settled only after several years. Climatologists predicted global temperatures would drop as a result of that global sulfate infusion. They were right: Following the eruption, global temperatures abruptly dipped by about a half-degree (0.6°C) for around two years. Pinatubo isn't a unique event. Large, temperature-altering eruptions occur about once per decade. (Earth Observatory NASA http://earthobservatory.nasa.gov/Features/Aerosols/page3.php).

Aerosols, though create temporary climate cooling effect, but also becomes the cause of other harmful climatic events like acid rain. So is not reliable to fall upon.

Some of the sources of aerosols are fossil fuel burning, sea salt, mineral dust volcanic eruption and biomass burning. As per NASA's observations, India is the second largest emitter of sulfur dioxide and emissions of SO_2 from Indian power plants have increased by more than 60 percent between 2005 and 2012 (http://climate.nasa.gov/news/1022/).

Inventory for all major GHGs are prepared as a part of project for the year 2007. IPCC default as well as country specific emission factors are used to prepare the inventory. Global warming potentials of the greenhouse gasses are used on 100-year time horizon.

Table 55 Global Warming Potential of different gases

Gas	Chemical Representation	GWP
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbon	HFC-134a	1300
	HFC-23	11,700
Tetrafluoromethane	CF_4	6500
Hexafluoroethane	C_2F_6	9200
Sulphur hexafluoride	SF_6	23,900

Source: Second AR, WG I

Methane Inventory

Methane is the second most prominent GHG present in atmosphere and agriculture is the largest source of it. In the year 2011, India's CH_4 emissions were far below than that of China and USA. India had emitted 23500 Gg of CH_4, whereas China and USA emitted 32700 and 44000 Gg of CH_4 respectively during the same time (WRI). In spite of India being dependent on agriculture, we are far behind China and USA in CH_4 emissions.

CO_2 emissions from the agriculture sector were 28347 Gg in 2000, which reached to 33277 Gg in 2007. At the same time methane emissions from the sector was around 14088 Gg (295848 Gg CO_2e) in the year 2000, whereas it came down to 13768 Gg (289128 Gg CO_2e) in 2007 (2nd National communication and INCCA Report published by MoEF, GoI), which is still very high in amount and harmful for the environment.

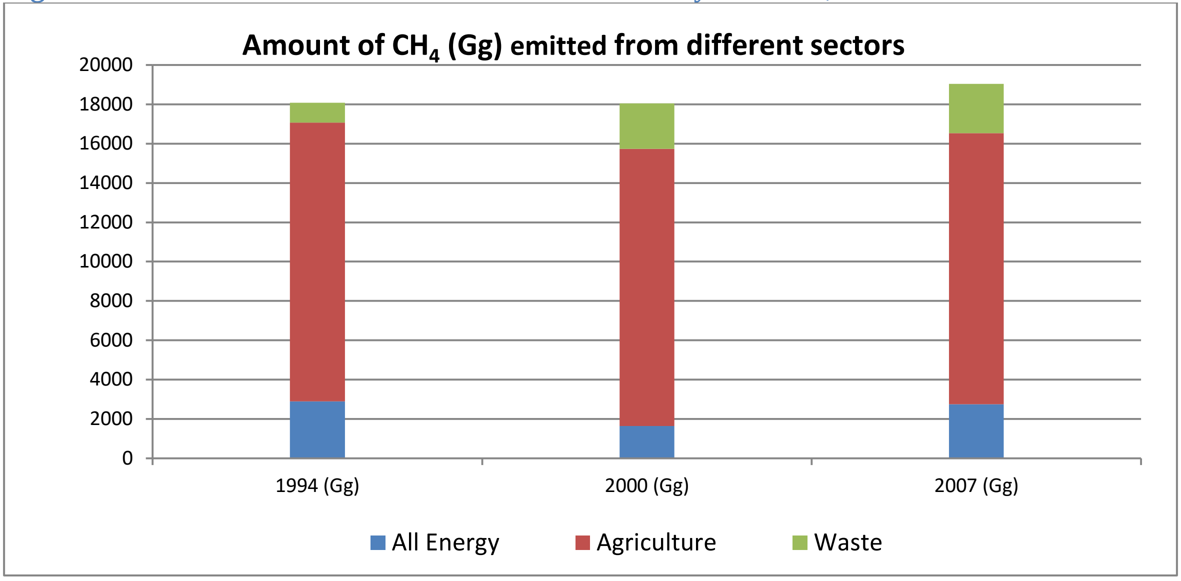
Indian society is widely based on agriculture; the share of agriculture in the gross domestic product (GDP) has been continuously declining and has reached to 13.7% in 2012-13. Agriculture sector is a large emitter of methane, which is a Greenhouse Gas.

Different subsectors like enteric fermentation, manure management, rice cultivation, agriculture soils, and field burning of agricultural residue, under agriculture are responsible for their share of CH_4 and other GHG emissions.

To prepare this methane inventory a combination of IPCC default and country specific emission factors are used. Other input values are taken from government sources. Emissions from Agriculture sector are presented in table 1.

Methane holds the largest share in non CO_2 GHGs. Agriculture, waste and energy are the three main sectors responsible for anthropogenic methane emissions. Emissions of methane by different sectors are shown in figure 1. Emissions of methane by agriculture sector is more than 70% of the total, the rest coming mainly from energy and waste sectors. Industrial processes, LULUCF and other sectors all together comprise not more than 3 percent of the total.

Figure 27 Methane Emissions from different sectors in years 1994, 2000 and 2007



Source: Indian NATCOM 1, 2 and INCCA Greenhouse Gas Emissions 2007

Agriculture and Livestock

The share of agriculture in the gross domestic product (GDP) has been continuously declining and has reached to 13.7% in 2012-13. Agriculture sector is largest emitter of methane, which is a Greenhouse Gas.

Different activities like enteric fermentation, manure management, rice cultivation, agriculture soils, and field burning of agricultural residue, under agriculture are responsible for the emissions of CH_4 and N_2O in agriculture sector.

Enteric Fermentation

Enteric fermentation is a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal. This process produces methane. Share of methane is largest from enteric fermentation in agriculture sector. It shows a very little positive growth, if emissions from the years 1994, 2000 and 2007 are compared. This is shown in the figure 2 below.

Mitigation measures like strategic supplementation provides critical nutrients such as nitrogen and important minerals t animals on low quality feeds. The use of molasses/urea multi nutrient blocks (MNBs) are found to be cost effective diet supplementation strategy with a potential to reduce CH_4 emissions by 25-27% (http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.203.5840&rep=rep1&type=pdf) and increase milk prouction at the same time. Supplementation with concentrates, adding oils or oilseeds to the diet, optimizing protein intake to reduce nitrogen excretion (impact on N_2O emissions), specific agents and dietary additives etc. can reduce methane emissions from enteric fermentation.

Rice Cultivation

India is one of the largest rice producing country and it is the staple diet in many parts of the country. Anaerobic decomposition of organic matter in flooded rice fields produces methane. Depending upon the availability of water, rice is cultivated under various water management options in India viz. upland, rain fed (flood prone and drought prone), continuously flooded, intermittently flooded (single aeration and multiple aeration), and deep water. Share of methane emitted from rice cultivation is second largest in Agriculture sector. It however shows a negative growth of methane emissions. Different options to mitigate CH_4 emissions from the sector are presented in the table below:

Method	Explanation
Rice production management	A policy option of producing rice at a rate, which is sufficient for meeting the consumption requirement of increasing population. It will reduce production of extra amount of rice and therefore reduce methane emissions.
Rice production management	Use of low methane emitting varieties of rice could significantly reduce the amount of methane emissions.
Cultivars variation	Low methane emitting variety of rice and the variety of rice which needs less water for harvesting
Water management	Changing water management is the most promising mitigation option and is particularly suited to reduce emissions in irrigated rice production. Midseason drainage and intermittent irrigation reduce methane emissions by over 40 percent. Shallow flooding provides additional benefits, including water conservation and increased yields. Midseason drainage may create nearly saturated soil conditions, which may promote N_2O productions. According to an empirical model proposed by Yan et al. (2005), midseason drainage generally tends to be an effective mitigation option, although 15 to 20 percent of the benefit gained by decreasing methane emission may offset by the increase in N_2O emission. (http://www.ifpri.org/sites/default/files/publications/focus16_03.pdf)
Fertilizer amendment	The nitrogenous fertilizer is seen to have a positive effect on the methane emissions. The applied fertilizers may help to increase methanogenesis by supplying methanogens with nitrogen for their metabolism. The fertilizers also have a positive effect on the quantity of biomass associated with paddy plants. This may increase rhizo deposition of carbon compounds, which may enhance methanogenesis. Further, as the rice plants serve as a conduit for methane transport from the soil to the atmosphere, increased volume of the biomass provides more of gaseous transport. Hence altering the type of fertilizers can reduce significant amount of methane.

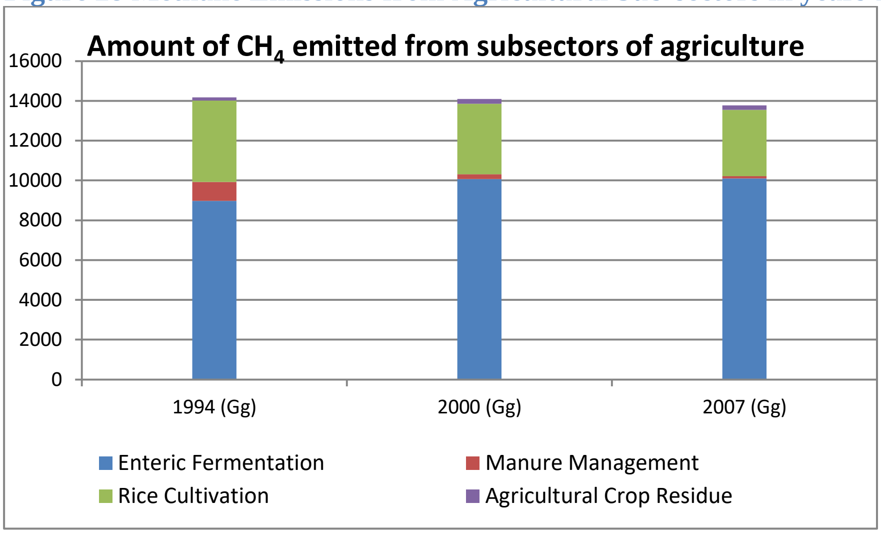
Manure Management

Manure management was not a common practice in India. It was mainly converted into dung cakes to use as a non commercial source of energy in rural areas. But recently biogas plants, organic fertilizers (manure management practices) etc has become common which has reduced the amount of methane emitted from the manure. It also shows a negative growth for the years 1994, 2000 and 2007 (946, 241.19 and 115 Gg respectively).

Burning of Agricultural Crop Residue

Burning of crop residues is a common practice in many Indian states. The left over parts of the crops are burnt in the fields which emit methane. Emission of CO_2 is not considered in this process because that is reabsorbed during next growing season. Farmers burn the residue to clear the remaining straw and stubble after the harvest and to prepare the field for the next cropping cycle. Methane emissions from burning of agricultural crop residue are almost same in the years 1997, 2000 and 2007, which shows, that this emissions is also getting reduced in India. Very small amount of N_2O is also being emitted from the burning of crop residues, which is also almost stagnant. Crop residues can alternatively be used for compost making, energy source, bio-fuel and bio-oil production, gasification and bio-char production which will also mitigate CH_4 emissions from the sector.

Figure 28 Methane Emissions from Agricultural Sub-sectors in years 1994, 2000 and 2007



Source: Indian NATCOM 1, 2 and INCCA Greenhouse Gas Emissions 2007

 # Since soil emits only N_2O because of the use of nitrogenous fertilizers, so it is not visible in the graph.

Agricultural Soils

Agricultural soils are a source of N_2O, mainly due to application of nitrogenous fertilizers in the soils and the subsequent microbial denitrification of the soil. Microbial denitrification is a natural process in soil, but denitrification is higher when soil has been fertilized with chemical fertilizers.

Table 56 Summary of GHG emissions from agriculture sector in the year 2007:

Summary Report For National Greenhouse Gas Inventories (Gg)

Greenhouse Gas Source and Sink Categories	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO
1 Agriculture			**14,320**	**578**	**78**	**2,107**
a) A Enteric Fermentation			10,075			
b) B Manure Management			549	46		
c) C Rice Cultivation			3,596			
d) D Agricultural Soils				530		
e) E Prescribed Burning of Savannas			0	0	0	0
f) F Field Burning of Agricultural Residues			100	2	78	2,107
g) G Others			0	0		

Source: IRADe's preparation

If the time series pattern of CH_4 is taken into account, we find a continuous growth in its emissions but if CH_4 emissions per capita is considered, it is almost stagnant at 0.02 tons of CH_4 per capita. If these parameters are compared with USA, China and World average, we are far below.

Table 57 Methane Emissions in India, USA and China

Parameters	Years	USA	China	India
Total CH4 Emissions (Mt)	1990	31.93	34.63	18.91
	2010	32.51	43.84	23.23
Cumulated CH4 Emissions from 1990 onwards (Mt)	1990	31.93	34.63	18.91
	2010	652.20	817.62	439.35
Annual CH4 Emissions above that of 1990 (Mt)	1990	31.93	34.63	18.91
	2010	620.27	783.00	420.45
CH4 Emissions/Capita (tons/person)	1990	0.13	0.03	0.02
	2010	0.11	0.03	0.02

Carbon Dioxide Inventory

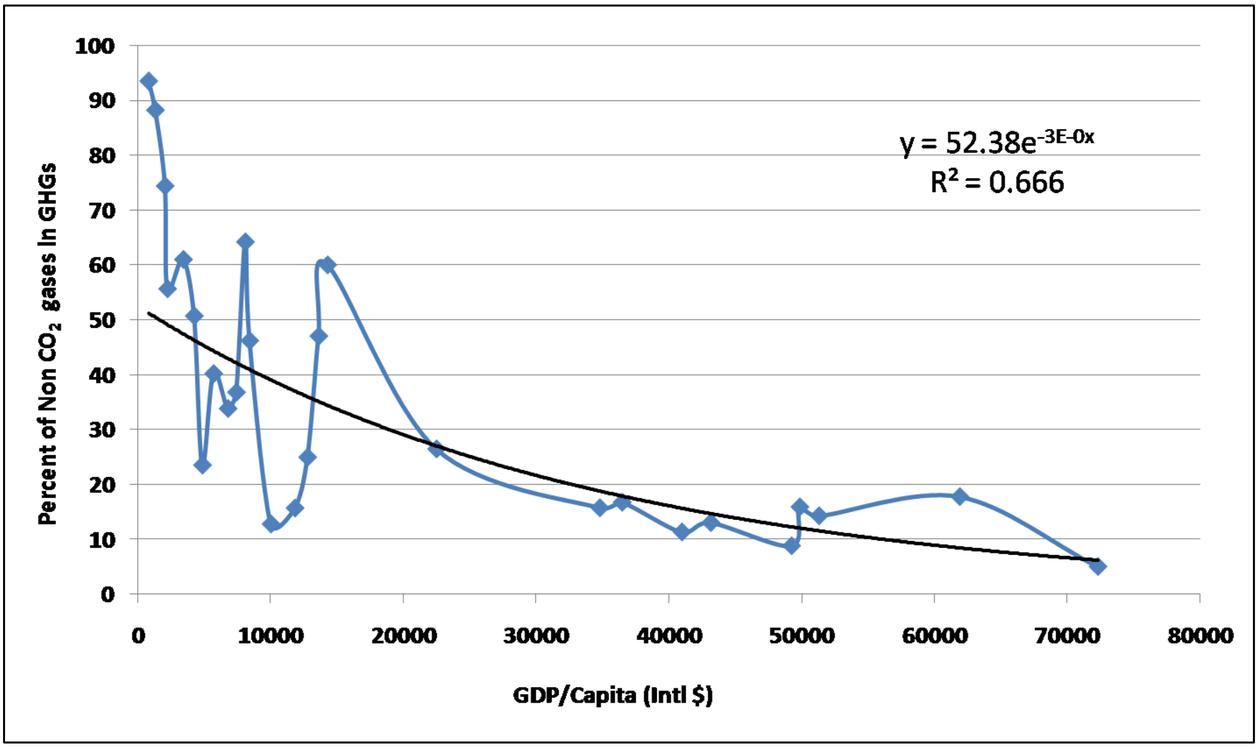
Carbon Dioxide holds the major share in total Greenhouse Gas emissions. India is the fourth largest emitter of CO2 in the world, where as its per capita CO_2 emissions are one of the lowest. India's per capita CO_2 emissions are just 1.5 tons which is around one fourth of the world average of around 4.6 tons of CO_2 per capita and far less than the per capita CO_2 emissions of USA and China, which are around 17.6 and 6.1 tons respectively.

Major sectors which contribute towards the emissions of CO_2 are energy, transport, residential, commercial/institutional, agriculture/fisheries, minerals production, chemicals production, Metals production, and other industries like pulp and paper, textile and mining etc. grassland under LULUCF also a source of CO_2 emissions.

Share of CO_2 and Non CO_2 gases in total GHGs

If share of CO2 and non CO2 gases in total GHG emissions are compared, in the different countries, we find more the GDP/capita of the country less the share of non CO2 gases in total GHG emissions. Majorly developed and industrialized countries are emitting more CO2 than non CO2 gases in GHGs.

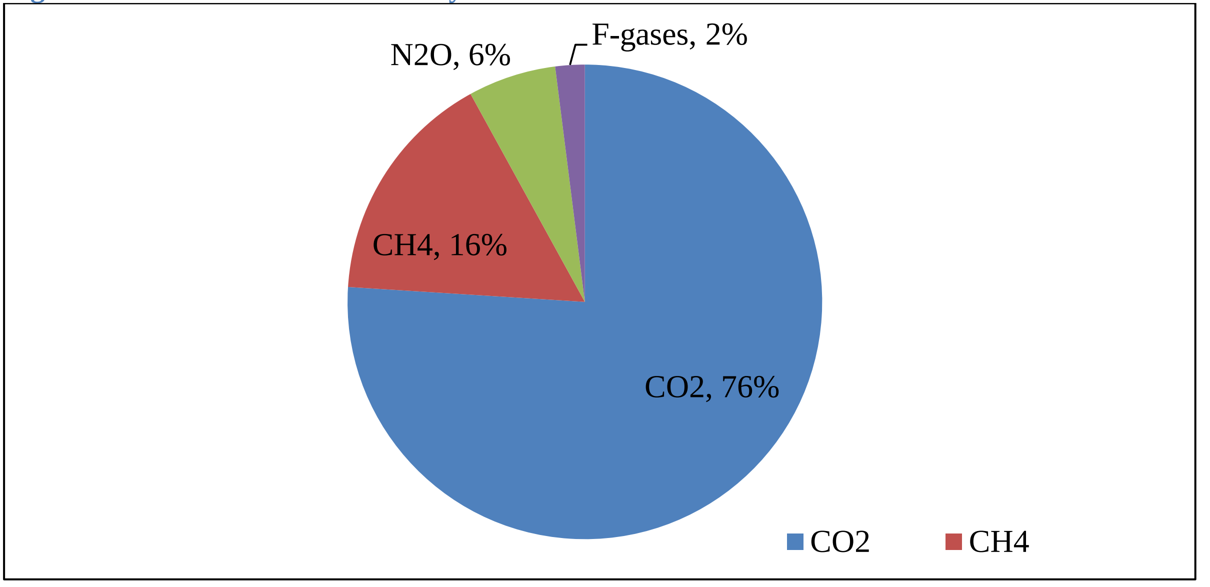
Figure 29 Decreasing share of non CO2 gases with increase in GDP/capita



Source: IRADe Research

Global share of non CO_2 gases in total GHG emissions apart from CH_4 and N_2O is very less. As per a report published by International Energy Agency in 2010 (http://edgar.jrc.ec.europa.eu/docs/IEA_PARTIII.pdf) it is evident that the share of F gases in total global GHG emissions is only 2%.

Figure 30 Global GHG Emissions by Gases in 2010



Source: IEA, CO2 Emissions from Fuel Combustion (Part III) (http://edgar.jrc.ec.europa.eu/docs/IEA_PARTIII.pdf)

Energy

Energy is one of the important aspects of the modern economy which makes the energy policy inseparable from the entire national development strategy. India's per capita energy consumption is around one fourth of world's average per capita energy consumption. Carbon dioxide is the major Greenhouse Gas emitted from the energy sector (fuel combustion as well as fugitive fuel emissions), but methane also hold its share in total GHG emissions by energy sector. Out of total methane emissions energy sector holds a share of around 15% in 2007 which is second highest in all sectors. Subsectors from where CH_4 is emitted in energy sector are transport, residential and fugitive fuel emissions (oil and natural gas systems coal mining) and other small sectors.

Transport

Methane is often found alongside petroleum, the production, refinement, transportation, and storage of crude oil is also a source of CH_4 emissions. These emissions are largely associated with leakage from the production of natural gas and the filling of compressed natural gas vehicles also CH_4 is emitted from gasoline, diesel, methanol, ethanol, LPG, and natural gas internal-combustion-engine vehicles. These emissions occur due to incomplete fuel combustion, which produces CH_4 along with other unburned hydrocarbons (http://rael.berkeley.edu/sites/default/files/very-old-site/Climatic_Change.pdf).

Biomass burnt for energy

Biomass is used as the conventional cooking fuel in the country. Cow dung, wood, residues from dead trees, rice husk, saw dust, crop residues etc are mainly used as biomass. Cow dung is mainly responsible for emission of methane from this sub-sector. Storage of these organic biomass leads to the emission of CH_4 which can be reduced, utilizing them for bio-methanation to generate/collect usable methane to use as a source of energy.

Waste

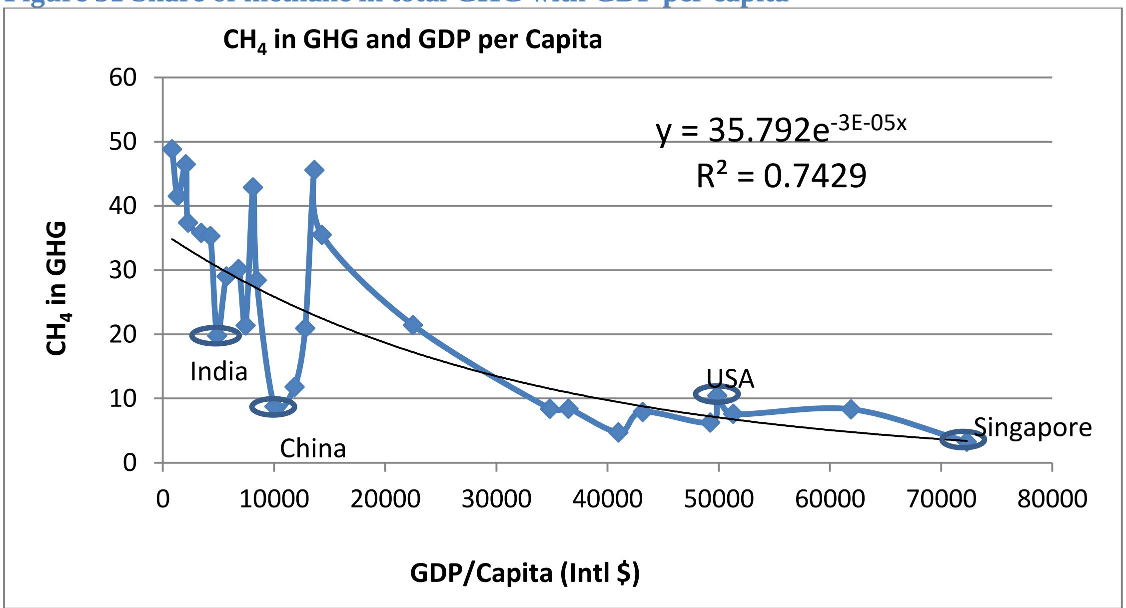
Waste is the third largest sector in terms of methane emissions in India. In 2007 its share in total methane emissions was 13.20% after 14.47% share of methane emissions from energy sector. Three main subsectors from where CH_4 is being emitted in India are municipal solid waste disposal, domestic waste water and industrial waste water. There are number of ways to mitigate CH_4 emissions from the sector. Waste prevention/minimization, composting, recycling, landfill gas collection and utilization, anaerobic digestion and waste to energy etc.

Since there is very little collection and treatment of waste water (from lagoons, septic systems, and latrines) therefore methane emissions are higher. If treated properly reduction of methane as well as associated air pollutants is possible. It can serve as local source of energy to support energy independence. Also like same way of organic biomass, organic waste can be utilized for bio-methanation to generate/collect usable methane, which can further be used as the source of energy.

Share of Methane in other countries

Since main source of methane is agriculture and live stock, therefore more the industrialized/developed country, less its methane emissions level. Methane emissions levels are coming down with increase in GDP/capita. Figure 3 explains the same. Share of agricultural in GDP is very less for Singapore and the country is 100% urbanized (World Bank database), its GDP per capita is also very high, and so share of methane in its total GHG emissions is very low. At the same time, for India, share of agriculture is high, it is only 32% urbanized by 2013 (World Bank database) and its GDP per capita is also very low, and hence its methane emissions share in total GHG emissions are higher. Since China's total GHG emissions including LULUCF are higher than USA, (China: 10260 $MtCO_2$ e and USA: 6135 $MtCO_2$ e) so its share of methane in total GHG is less.

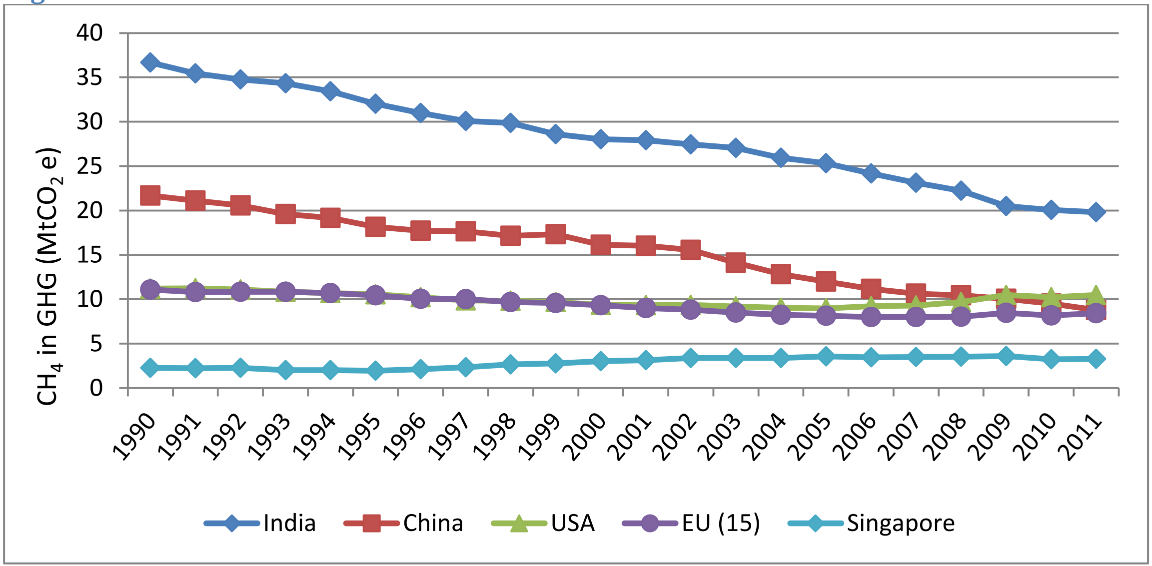
Figure 31 Share of methane in total GHG with GDP per capita



Source: WRI

If time series of share of CH_4 in total GHGs for different countries are taken into account, a downward trend is visible in the graph, which again shows, more the urbanization less the share of methane in total GHGs. Figure 4 shows the methane emissions trend over the time for India, USA, China, EU 15 and Singapore.

Figure 32 Methane emissions

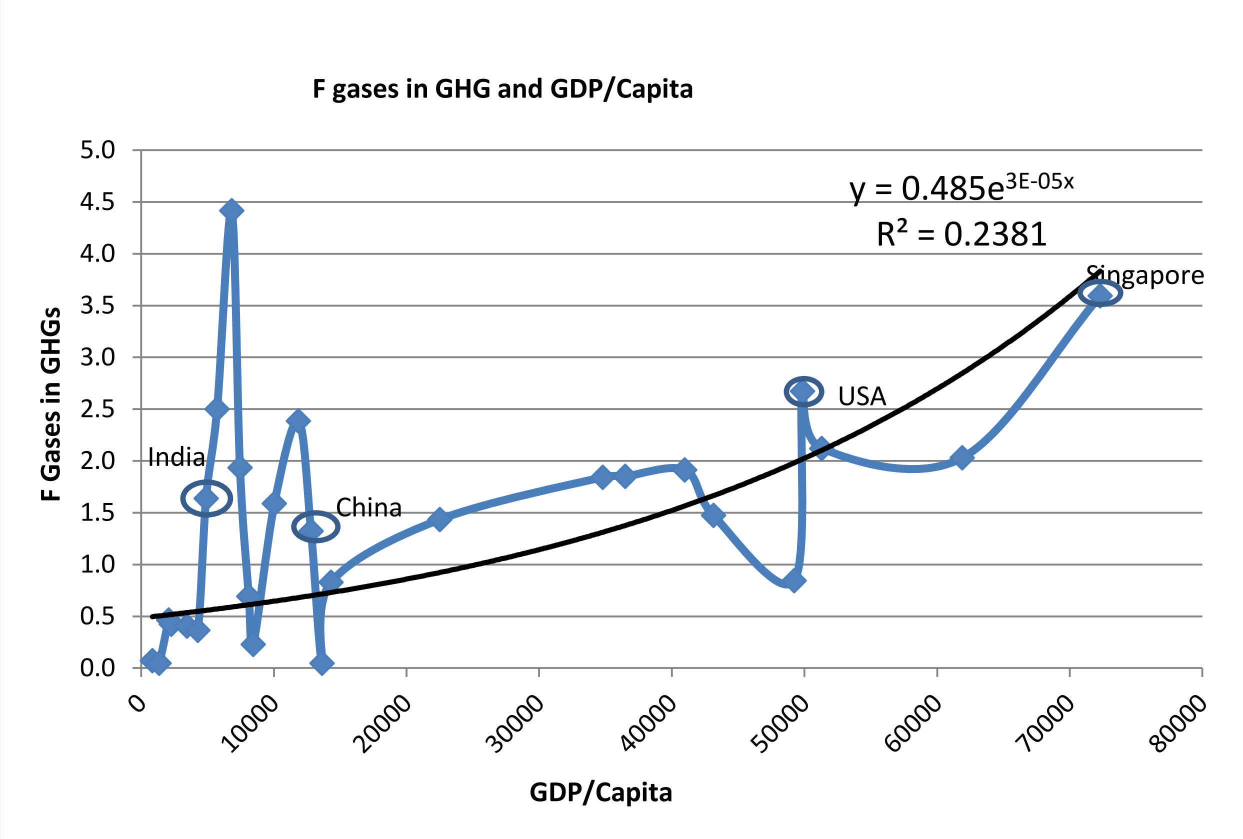


Source: WRI

F Gases in GHG

Hydro Fluoro Carbon (HFCs), Per Fluoro Carbon (PFCs) and Sulphur Hexa fluoride (SF_6) are the F gases included in GHGs. Unlike other GHGs, F gases does not have natural sources. They only come from man-made sources. These F gases have very high GWP values. On 100 year time scale GWP of HFCs are 140-11,700, PFCs are 6,500-9,200 and SF_6 are 23,900. Even the small quantities of these gases are very harmful. Since these gases come only from anthropogenic sources, there share in total GHG increases with increase in GDP/capita, it is shown in figure 5.

Figure 33 Methane Emissions from Agricultural Sub-sectors in years 1994, 2000 and 2007



Source: WRI

To avoid F gases EU has passed two legislations, F gas Regulation and Mobile Air Conditioning Directive (MAC). India comes at fourth place with total F gas emissions of around 41 $MtCO_2$ e after USA, China and Japan (175.12, 167.87 and 51.80 $MtCO_2$ e respectively). India has not passed any legislation to combat emissions of F gases. Developed world is still on the way to find out the substitutes of highly potent F gases.

Sources of HFCs

HFCs are man-made GHGs, developed to substitute CFCs, which were banned by Montreal Protocol in 1992 to save atmospheric ozone layer from depletion. Though HFCs are not responsible for O_3 depletion, but they are highly potent GHG. Major applications which use F gases are, air conditioning, refrigeration, foam blowing agent, aerosols and fire protection etc. Air conditioning and refrigeration are two applications responsible for the emission of around 90% HFCs. (An article from Greenpeace- HFCs and other F-gases: The Worst Greenhouse Gases You've Never Heard Of).

Sources of PFCs

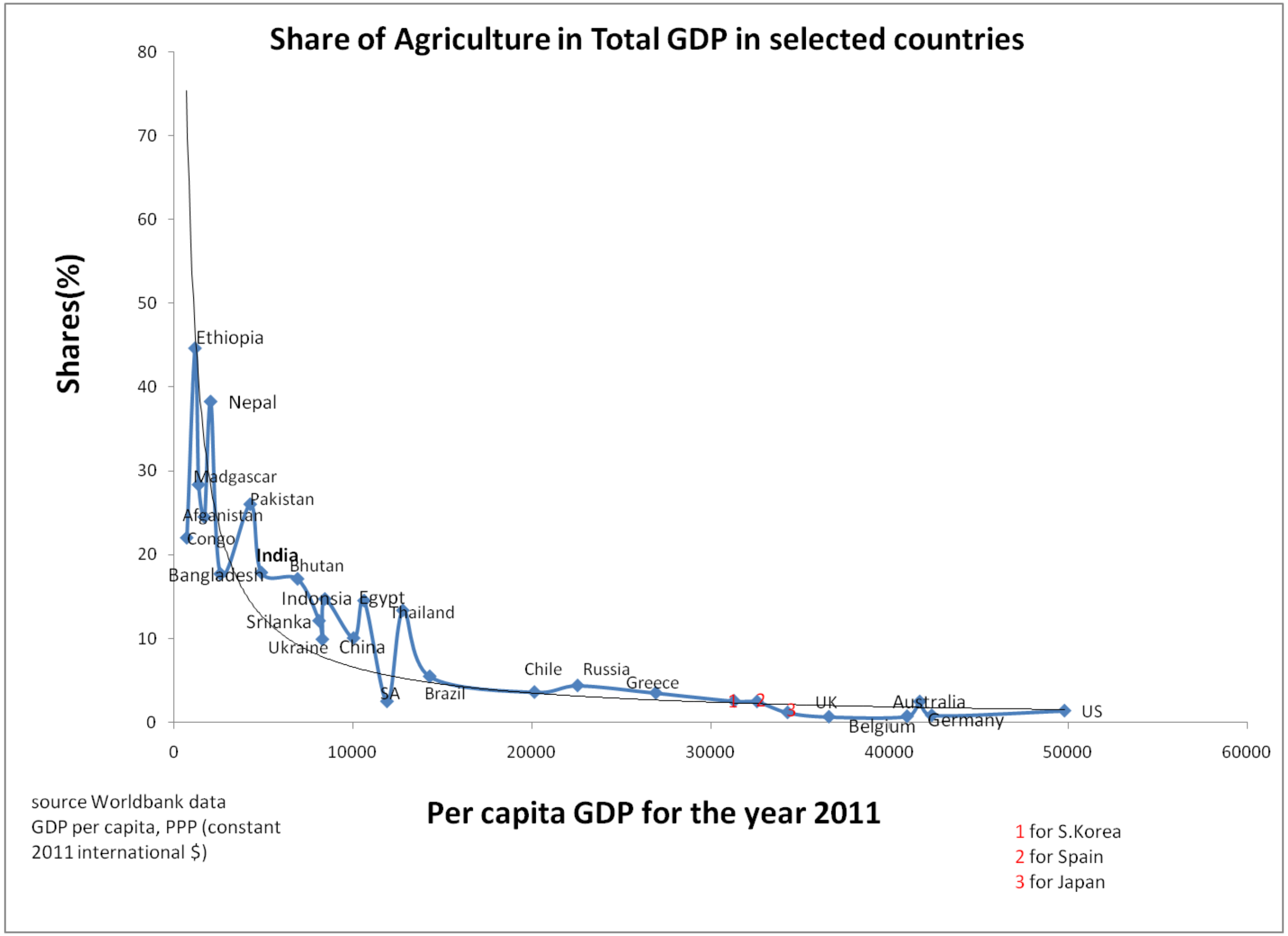
Perfluorocarbons are compounds produced as a by-product of various industrial processes associated with aluminum production and the manufacturing of semiconductors.

Sources of SF_6

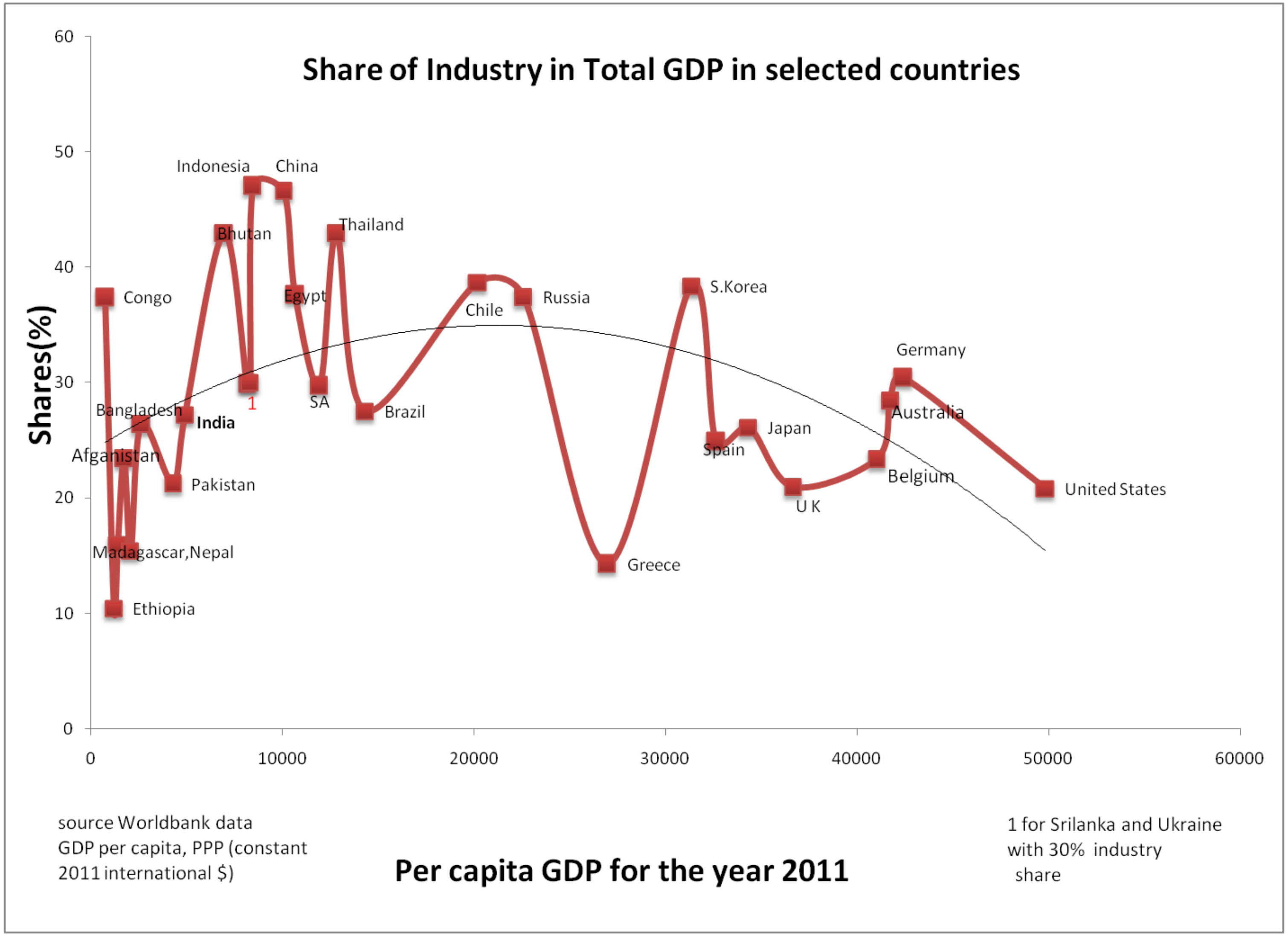
SF_6 is used in magnesium processing and semiconductor manufacturing, as well as a tracer gas for leak detection. It is also used in electrical transmission equipment, including circuit breakers. SF_6 is the most potent GHG as the GWP of the gas is highest amongst all GHGs.

Annexure 5 Selected Country GDP Share and Per Capita GDP

Share of Agriculture in Total GDP in Selected Countries



Share of Industry in Total GDP in selected countries



Share of Service in Total GDP in selected countries