Low Carbon Society Roadmap 2050

India

Indian Institute of Management Ahmedabad
National Institute for Environmental Studies
Kyoto University
Mizuho Information and Research Institute

January 2011

Preface

This report is in continuation of an earlier report in November 2009. This report is the outcome of support and collaboration among various academic and research institutions - namely; Indian Institute of Management Ahmedabad, India, National Institute for Environmental Studies (NIES), Kyoto University (KU) and Mizuho Information and Research Institute from Japan.

We are grateful to Mr Subhash Dhar (UNEP) for the number of discussions we had with him for preparing this document. We are also grateful to Dr. Jae Edmond for very insightful discussions on 'Global Technology Strategy' for transition to a low carbon future and providing carbon price data from the global CO_2e stabilization modelling runs. We are thankful to National Institute of Environment Studies (NIES), Japan, for access to the Asia-Pacific Integrated Model (AIM) and the Strategic Databases. Above all, we wish to acknowledge numerous Indian researchers, policy-makers, industry practitioners, sectoral & domain experts, and NGOs for their co-operation to share valuable information and insights into the complex future transition processes underlying the scenario specifications and nuanced modelling.

This LCS scenario roadmap document is intended to communicate to the policy makers - how to effectively integrate climate change actions in the development plans of the country. The actions outlined in the document, we believe, would guide effective transition towards a Low Carbon India. The proposed analysis is in line with national position articulated in India's "National Climate Change Action Plan". The LCS transition analyzed in this report, converges with the 2 ^{0}C global "aspirational" stabilization target, as agreed in various global forums. It is found that US$ 3 Trillion investment in energy infrastructures is needed till 2050, under the BAU scenario, most of which is in the power sector. Delayed actions towards low carbon transitions are likely to result in infrastructure 'lock-in' that acts as barrier to make such a transition. It was also found that the marginal abatement costs under the LCS scenario is significantly lower than the conventional development scenario.

Our research approach and findings, we hope, shall contribute in sustainable transition of India, one of the world's fastest growing economy, to a Low Carbon Society.

- P. R. Shukla

Table of Contents

Executive summary	7
About India	9
Background of Low Carbon Society (LCS)	10
Scenario Driver	11
Scenario Description	12
Energy and Emissions in 2050	14
Analysis of Carbon Tax (CT) Scenario	16
Analysis of Sustainable Scenario (SS)	17
LCS Policy Actions	18
LCS Infrastructure Choices	22
Water-Energy-Climate Change	24
Scenario Comparison: Beyond Carbon	27
New and Renewable Energy	28
Energy and Environment Policy in India	29
Modeling Framework	32
Component Models	33
References	34

Executive summary

Low carbon society scenarios visualize social, economic and technological transitions through which societies respond to climate change. Although India's GHG emissions on per capita basis are very low as compared to other developed countries, but the current assessment considers alignment of India's development pathway with the 2 ^{0}C global "aspirational" stabilization target. This report assesses two paradigms for transiting to a low carbon future in India. First pathway assumes conventional development pattern together with a carbon price that aligns India's emissions to an optimal 450 ppmv CO_2e stabilization global response. The second emissions pathway assumes an underlying sustainable development pattern caricatured by diverse response measures typical of the 'sustainability' paradigm. An integrated modelling framework is used for delineating and assessing the alternate development pathways having equal cumulative CO_2 emissions during the first half of the 21st century.

It can be seen from the figure 1 alongside that under the conventional development pattern (together with a carbon price), the mitigation target of 83.5 billion $tCO_2$for the 450 ppmv CO_2e stabilization scenario is achieved through a major intervention in the infrastructure & the power sector comprising of measures such as extensive use of advance technologies like CCS and greater proliferation of nuclear energy. These measures are predominantly on the supply side. It is also important to mention that the reduction is primarily on account of decoupling energy and carbon, whereas the actual energy consumption increases as compared to the base case.

However, under the sustainability scenario (figure 2), the same mitigation target can be achieved by a combination of initiatives on both supply and demand side, thereby widening the technology use. On the supply side, infrastructure & clean power again plays a crucial role. While on the demand side, measures like dematerialization, sustainable consumption and end use device efficiency play a key role.

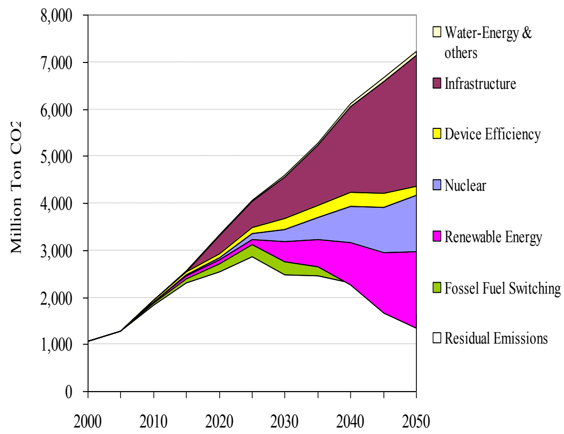


Figure 1: Mitigation Options in Carbon Tax Scenario

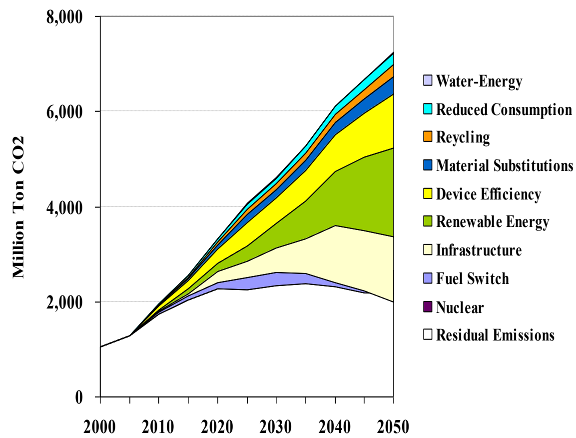


Figure 2:Mitigation Options in Sustainability Scenario

About India

India faces major development challenges - access to the basic amenities like drinking water, electricity, sanitation and clean cooking energy still remain a luxury for both urban and rural dwellers alike. GoI' s Ministry of Environment & Forests released a recent report titled " 4X4 assessment of the impact of climate change on key sectors and regions of India in 2030s ". This detailed study examines implications of climate change for India in 2030s. The study was undertaken for 4 sectors namely; agriculture, water, forestry and health. The study highlighted certain impacts on the above sectors due to climate change, which underscores the fact that appropriate response mechanism/strategy need to be devised so as to mitigate the impacts due to climate change.

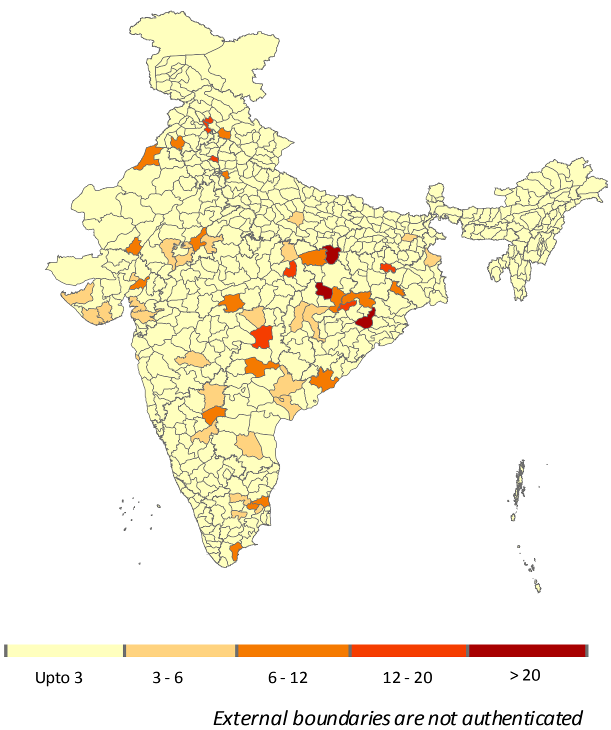
Developing countries, like India, would require building adaptive capacity for facing climate risks with increasing evidence of climate change (IPCC, 2006). Climate change, which happens due to increase in green house gas (GHG) emissions, is in turn related to increased human activities post industrialization (IPCC, 2006) and therefore industrialization of large developing countries, like China and India can add significantly to GHG emissions. Hence, in the coming years, India faces the challenges in economic development which have to be met with the limited resources available, with minimal externalities and in presence of large uncertainties with respect to climate.

The challenges for India are immense, both on meeting the development needs of its people as well as achieving faster and consistent growth of its economy. Aligning the developmental objectives with concerns for climate change has emerged as one of the key challenges for India. growth rate of 7.7% during the plan period.

In the foreword to the 11th plan (2007-8 to 2011-12) document, the Prime Minister (PM) of India highlighted the importance of growth to meet developmental needs of the country's people. To achieve the developmental targets of the nation, the PM reasserted the need of high growth to meet the developmental needs. The plan sets a target for 9% growth in the five year period 2007–08 to 2011–12, with accelerated growth during the period, to reach 10% by the end of the Plan.

From the perspective of the energy sector, the plan document highlights the need of affordable energy as a critical element to achieve the growth targets of the plan period, with an eye on rational energy pricing. Energy security has also emerged as a key theme in the policy document. The Eleventh Plan reaffirms the commitment to work towards policies for the energy sector consistent with the optimal use of various energy resources. The Plan also emphasizes the importance of energy conservation, increasing energy efficiency, and development of renewable sources of energy.

Figure 3: Per Capita CO2 emission (tons/person)



Background of LCS

In the developed world context, the concept of a low-carbon society has the following attributes:

(1) Actions should be compatible with the principles of sustainable development, however not at the cost of the development needs of all groups in the society.

(2) Make an equitable contribution towards global efforts in stabilizing CO_2 concentration in the atmosphere and other GHG gases, through deep emission cuts.

(3) Use low-carbon energy sources and technologies and demonstrate a high level of energy efficiency at all levels of energy usage.

(4) Adopt certain behavioral and consumption styles that are consistent with low levels of greenhouse gas emissions.

However, the concept of a low-carbon society has a different meaning for the developing world. Countries, like India, still have low per capita emissions, are on an increasing economic growth trajectory and have priorities in meeting the development needs, like education, healthcare.

But, the LCS opportunity for developing countries arrives with a window of opportunity, as it gives a chance for such countries to avoid critical lock-ins; particularly in long-lived infrastructure assets. From the perspective of a country, like India, the LCS opportunity is a window to decide about the future flow of energy through infrastructure and other behavioral and lifestyle related choices and therefore the importance of such a study.

In the coming years, India faces the challenges in economic development which have to be met with the limited resources available, with minimal externalities and in presence of large uncertainties with respect to climate. One of the growing and accepted approaches to overcome this development paradox is through adoption of a sustainable development (SD) paradigm (Sathaye et. al., 2006). The relation between climate change and SD was recognised in "Delhi Declaration" during COP-8 in 2002 (Shukla et. al., 2003). In fact, it has been argued that exclusive climate centric vision shall prove very expensive and might create large mitigation and adaptation 'burden' (Shukla, 2006) whereas SD pathway results in lower mitigation costs besides creating opportunities to realize co-benefits without having to sacrifice the original objective of enhancing economic and social development (Shukla, 2006). Modelling results have predicted substantial GDP loss for India to meet the stabilisation targets (Figure 4 below). This GDP

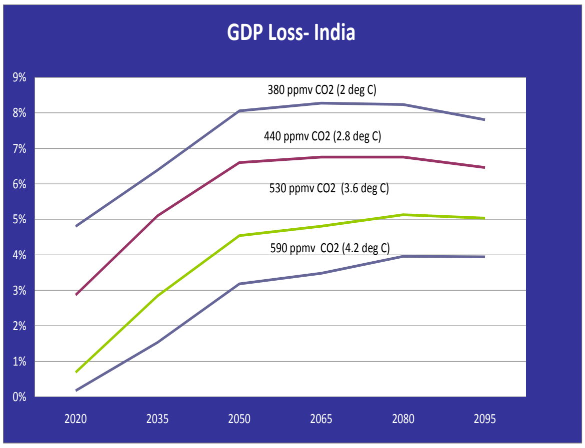


Figure 4: GDP Loss for India

loss needs to be compensated through international financial transfers (either directly in terms of assistance, or technological transfer or through various mechanisms like the CDM).

The LCS framework should also look at opportunities which create various kinds of co-benefits apart from direct GHG emission reductions. Such co-benefits, like improved air quality, provide an opportunity to minimize social costs of such a transition. The other advantage of such an approach would be in achieving

Scenario Drivers

Macro Economic

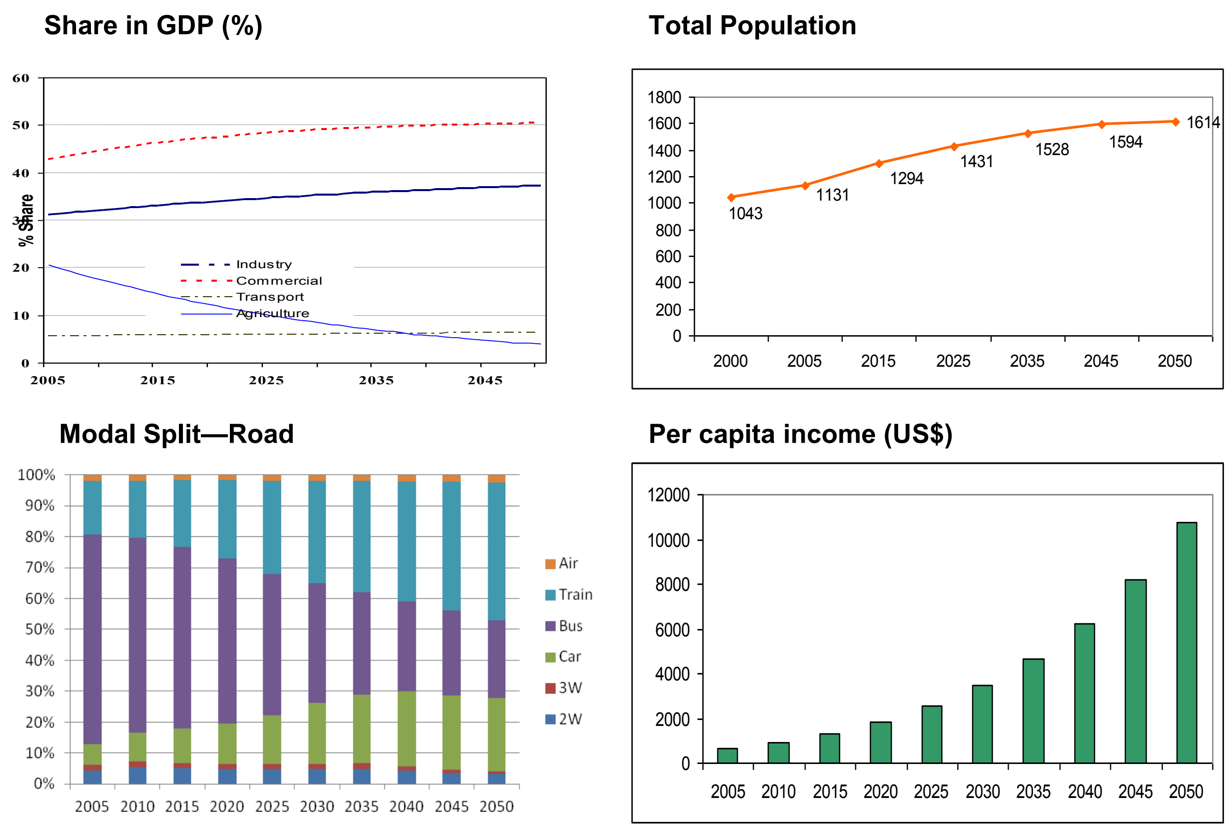
GDP growth for period 2005-2032 is 8% and this is similar to Planning Commission's 8% GDP Scenario (GoI, 2006). Population projections are based on UN Population Medium Scenario, Version 2008 for India (UNPD, 2008). The complete population assumptions are given in Table 1. The GDP assumptions for the initial period till 2030 is in line with the Planning Commissions 8% scenario. Further, during the period beyond 2030; GDP and population assumptions are based as per Table 1 (in this study).

On the other macro-economic factors, the trends and assumptions are given in Figure 6. We can see from the trends, that there is a substantial increase in the % of commercial sector contribution to the GDP; a gradual increase in the per capita income and therefore, an increase in the number of 4W's. Moreover there is a higher penetration of public transportation. Further, the industrial sector would be contributing the next big chunk of the GDP and the remaining being contributed by agriculture (which declines continuously to reach the level of nearly 4-5% by 2050). The modal split assumes an initial higher penetration of public transport, and thereafter towards the later years an increase of private vehicles powered by electricity.

Table 1: Base Case Scenario Drivers

Year	GDP (2005 Prices)	Population
	Bn INR	Mn
2005	32833	1131
2030	229573	1485
2050	774673	1614

Figure 5: Base Case Scenario Drivers



Scenario Description

This analysis considers two scenarios. The scenarios depict two alternative pathways for achieving the Low Carbon Society（LCS）. The scenario stories span the period till 2050. The descriptions of scenarios are as under.

Base Case Scenario

This scenario assumes the future economic development along the conventional path. In case of a developing country, such as India, the scenario assumes the future socio-economic development to mimic the resource intensive development path followed by the present developed countries. The scenario assumes improvements in energy intensity similar to the dynamics-as-usual case and the targeted share of commercial renewable energy. The recently announced National Action Plan on Climate Change（NAPCC）has certain specified sectoral targets. These targets have been incorporated under the Base Case scenario in this analysis.

Low Carbon Scenarios

Conventional Path: Carbon Tax（CT）Scenario

This scenario presumes stringent carbon tax（or permit price）trajectory compared to milder carbon regime assumed under the base case. Besides the difference in carbon tax, the underlying structure of this scenario is identical to the Base Case. The scenario assumes stabilization target of 450 ppmv CO_2e. The carbon price trajectory for 480 ppmv CO_2e concentration stabilization, interpolated from CCSP SAP 2.1a stabilization scenarios is $20 per ton of CO_2 during the Kyoto protocol period and rises to $200 per ton of CO_2 in 2050. The scenario assumes greater improvements in the energy intensity and higher target for the share of commercial renewable energy compared to the Base Case scenario.

Sustainability（SS）Scenario

This scenario represents a very different world view of development as compared to the Base Case. The scenario follows a distinct ‘sustainability’ rationale, like that of the IPCC SRES B1 global scenario. The scenario perspective is long-term, aiming to deliver inter-generational justice by decoupling the economic growth from highly resource intensive and environmentally unsound conventional path. The scenario rationale rests on aligning the economic development policies, measures and actions to gain multiple co-benefits, especially in developing countries where the institutions of governance, rule of law and markets are evolving. The scenario assumes the society to pro-actively introduce significant behavioural, technological, institutional, governance and economic measures which promotes the sustainable development paradigm. In addition, this scenario also assumes a society which is responding to a globally agreed long-term CO_2 concentration stabilization target. The global target assumed for this analysis is also 450 ppmv CO_2e concentration target or temperature target within 2^{o} to 3^{o} Celsius.

In comparison with the mild carbon tax assumed in the sustainability scenario, the carbon price trajectory corresponding to the stabilization target is likely to be higher. Hence, India’s cumulative CO_2 emissions（from 2005 to 2050）in LCS scenario should be lower than the sustainability scenario. Instead of carbon tax trajectory, the SS scenario assumes a cumulative carbon budget for the post-Kyoto period 2013 to 2050.

Energy Prices: A variety of prices are observed in the Indian energy markets especially for coal and gas. The regulatory regime tries to keep prices aligned to the cost of production. Using the regulated prices information available in public domain, supply curves are created; using a step wise linear structure The price assumptions for imported fuels are based on price projections given by IEA.

Carbon Prices : Carbon price trajectory for base case scenario and carbon tax scenario are linked to CO_2e stabilization targets. The price trajectories are obtained from outputs from global Second Generation Model (SGM) results.

Energy demand: the final sectoral energy demand is calculated, and is represented in Figure 7 for the various sectors under BAU and LCS-SUS scenarios.

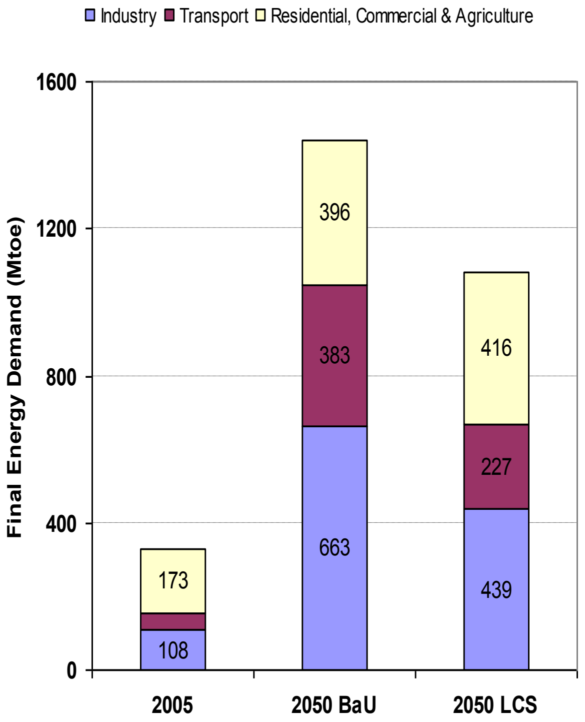
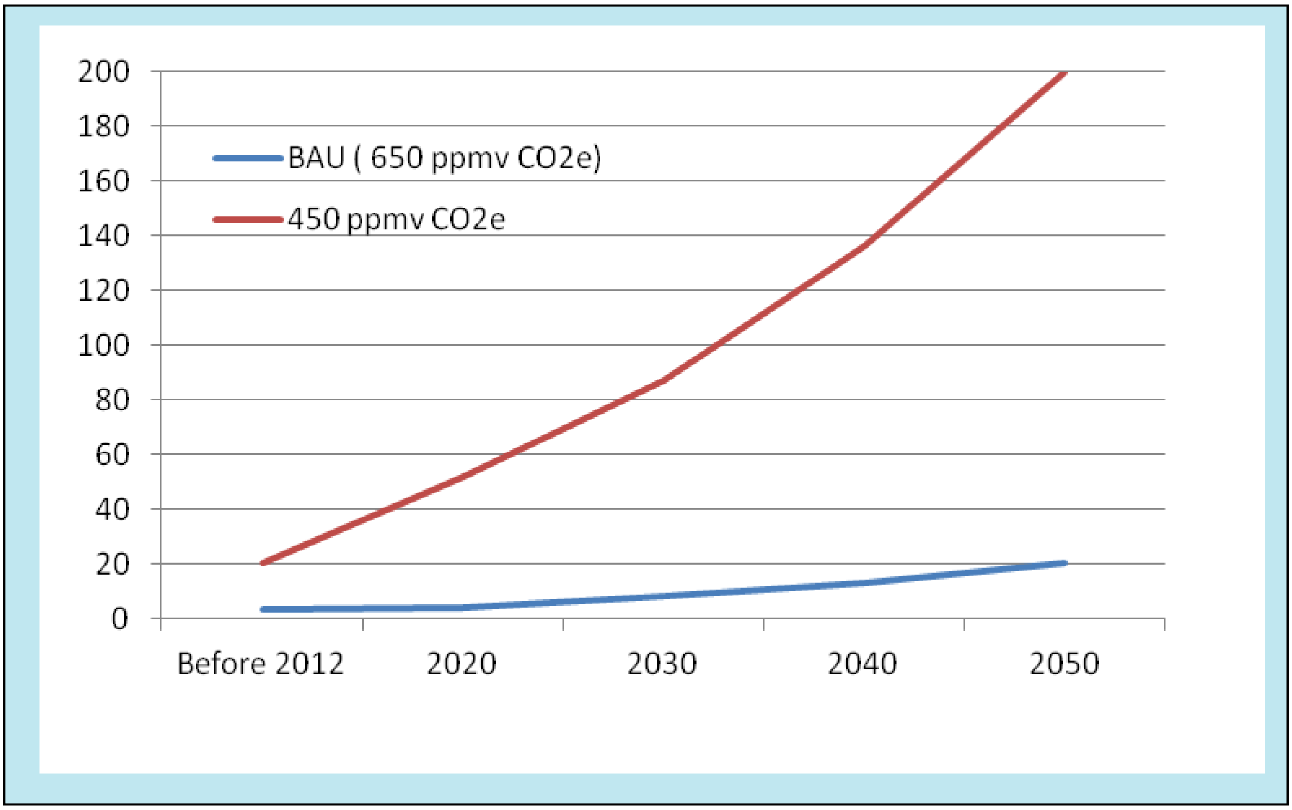


Figure 6: Final Sectoral Energy Demand

Figure 7: Carbon price in US $ per ton of CO2—Base and CT scenario



Energy & Emissions in 2050

The demand for energy increases 5.35 times to 2957 Mtoe in 2050 as compared to 553 Mtoe in 2005, whereas the GDP increases by 23.6 times during the same period. Therefore, decoupling of GDP and Energy takes place as a result of changes in the structure of economy and efficiency improvements. The energy intensity decreases at the rate of 3.2% for the period 2005-2050.

The energy mix diversifies from being highly dependent on coal, oil and traditional biomass to one which has significant share of natural gas, other renewable, nuclear and commercial biomass. It is also important to mention that the emission reduction under CT scenario is primarily on account of decoupling energy and carbon (share of renewables is 21.8% in 2050), whereas the energy consumption actually increases as compared to the base case. However in the SS scenario the carbon intensities are further moderated, by an increase in the share of renewables (32%), nuclear and gas at the expense of coal and oil. Besides, due to many demand side interventions, there is also a decrease in the energy consumption as compared to the base case.

The CO_2 emissions increase from 1297 Million ton of CO_2 in 2005 to 6128 Million ton of CO_2 in 2050, under the base case (no intervention). Under the low carbon scenarios, CO2 emissions are reduced to 1939 Million ton CO2 in 2050. This results in a cumulative reduction of 83.5 billion ton CO2 over the period 2010-2050.

Figure 8: Primary Energy Demand

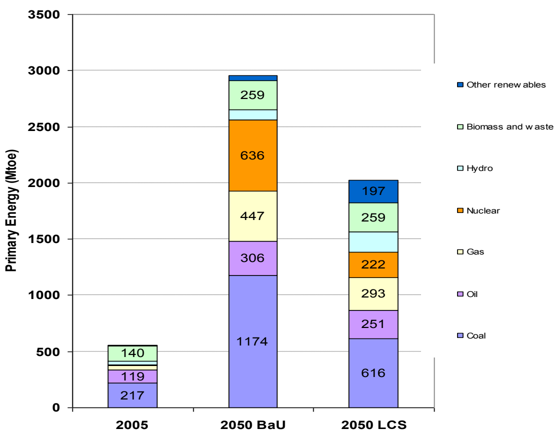


Figure 9: GHG Emissions per capita

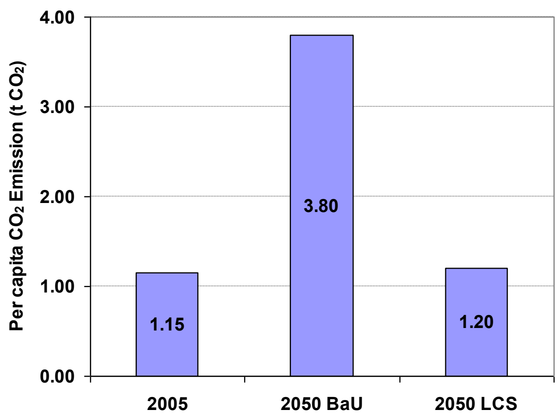


Figure 10: Energy & Carbon Intensities in CT scenario

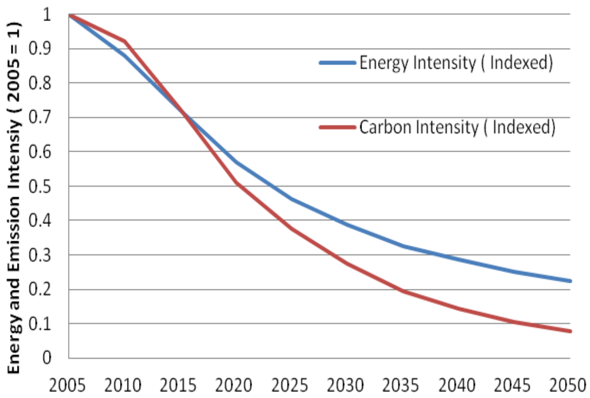
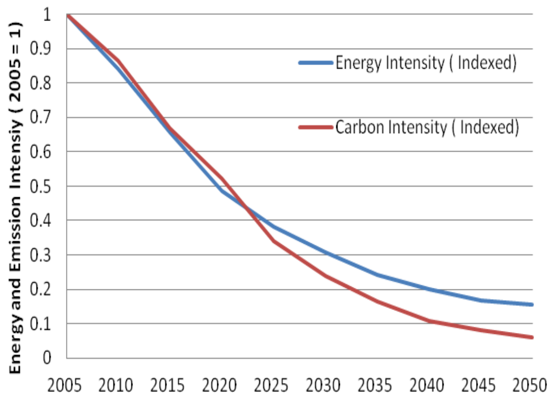


Figure 11: Energy & Carbon Intensities in LCS scenario



Technologies Choices

The CO_2 mitigation choices differ between two LCS scenarios. In SS scenario, mitigation choices are more diverse and include measures that are designed to influence several development indicators simultaneously. SS scenario pays greater attention to public investment decisions, e.g. in infrastructure which lead to modal shifts in the transport sector; and institutional interventions that alter the quality of development. In case of CT scenario, the mitigation measures are more direct and have greater influence on private investments. In developing countries undergoing rapid transitions, aligning the development and carbon mitigation measure have significant advantages (Shukla, 2006). In CT scenario where direct carbon mitigation technologies like CCS find greater penetration, mitigation in sustainable society happens through diverse technology stocks. Implementing diversity of measures in SS would require building higher institutional capacity and influencing behaviours to reduce wasteful consumption as well as recycle and reuse of resources. In brief, in the SS scenario the mitigation are mainstreamed into development pattern causing qualitative shift in the development vis-à-vis Base scenario. In case of CT scenario the mitigation actions take place at the margin of the economic development frontier.

Altering preferences and choices through policies

Policies for promoting sustainable development need to be based on the precautionary principle as this helps in taking care of environmental unknowns. Therefore emphasis is on reducing the anthropogenic influences, which are the root cause of GHG emissions, in all walks of life. However, the reduction of anthropogenic influences does not come at the expense of economic and social development and instead believes in expanding the economic and climate frontier (Shukla, 2005). The policies are shifting frontier by innovations in technology, institutions, international and regional cooperation, targeted technology and investment flows, aligning stakeholder interests, focusing on inputs (and not only outputs) and long-term perspective to avoid lock-ins.

Table 2: Contributions to Cumulative Mitigations over Base Case: 2005-50 (Unit: billion-tonnes of CO2-eq)

Mitigation Choices	Sustainability Scenario	Carbon Tax Scenario
Infrastructure	16.6	43.4
Nuclear	11.0	16.3
Renewable Energy	22.6	10.4
Device Efficiency	16.0	7.4
Material Substitutions	5.2	
Material Recycling	3.9	
Reduced Consumption	3.6	
Fossil Fuel / Switch	4.2	3.4
Others	0.4	2.6
Total Mitigation	**83.5**	**83.5**

Analysis of CT Scenario

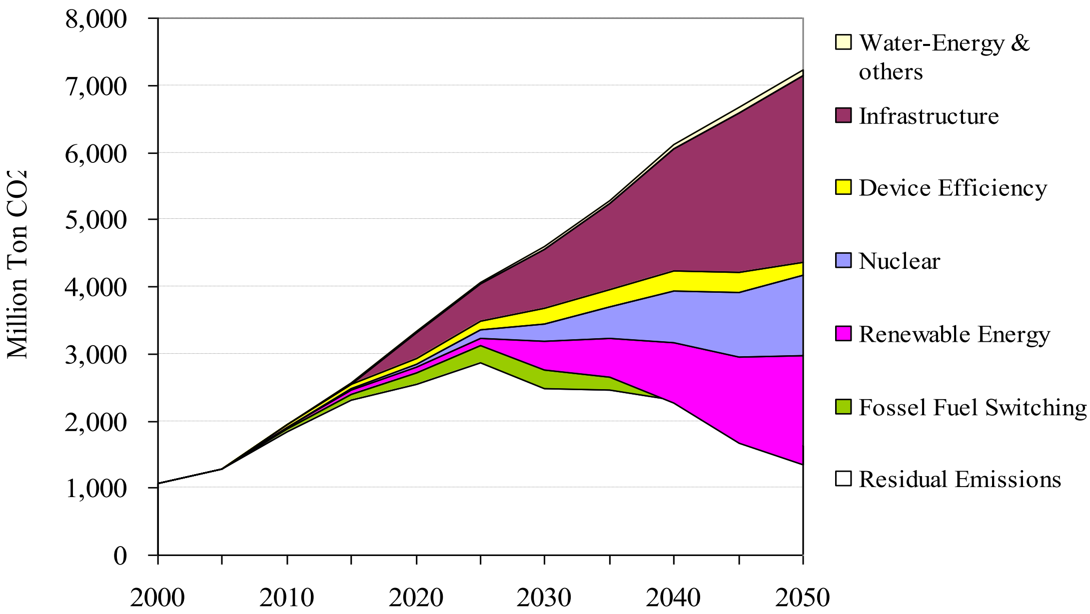
Carbon tax scenario has a steep carbon tax trajectory, which increases to US $ 200 per ton of CO_2. To estimate the inefficiencies and the resultant GDP loss, AIM CGE model has been used. The tax revenues from the carbon tax get invested back in the economy. The GDP loss increases as the carbon tax increases and in 2050 the GDP loss will be around 6.5%.

The GDP loss though not very significant was used to recalculate the end use demands for the carbon tax scenario. The cumulative CO_2 mitigation for the period 2005-2050 came to 83.5 billion ton of CO_2 and the mitigation happened mainly in the infrastructure sector (Figure 13). Post 2030, when the carbon prices exceed US $ 70 per ton of CO_2, CCS along with Coal fired electricity generation, CCS in steel and cement making also turned up as an option (CCS is considered as a part of infrastructure). The remaining mitigation happens due to higher adoption of renewable infrastructure especially biomass, improvements in device efficiencies. The CT scenario is corresponding to 450 ppmv CO_2e stabilization.

In case of India there is a decoupling of CO_2 emissions post -2030. The decoupling however takes 25 years as there is an existing stock of energy infrastructures and a lot of investments in energy infrastructures for future have already been committed. This indicates that introduction of a tax and its impacts will have sufficient lags due to lock-ins.

Figure 12: View of Mumbai Skyline

Figure 13 : Mitigation Options in Carbon Tax Scenario



Analysis of SS Scenario

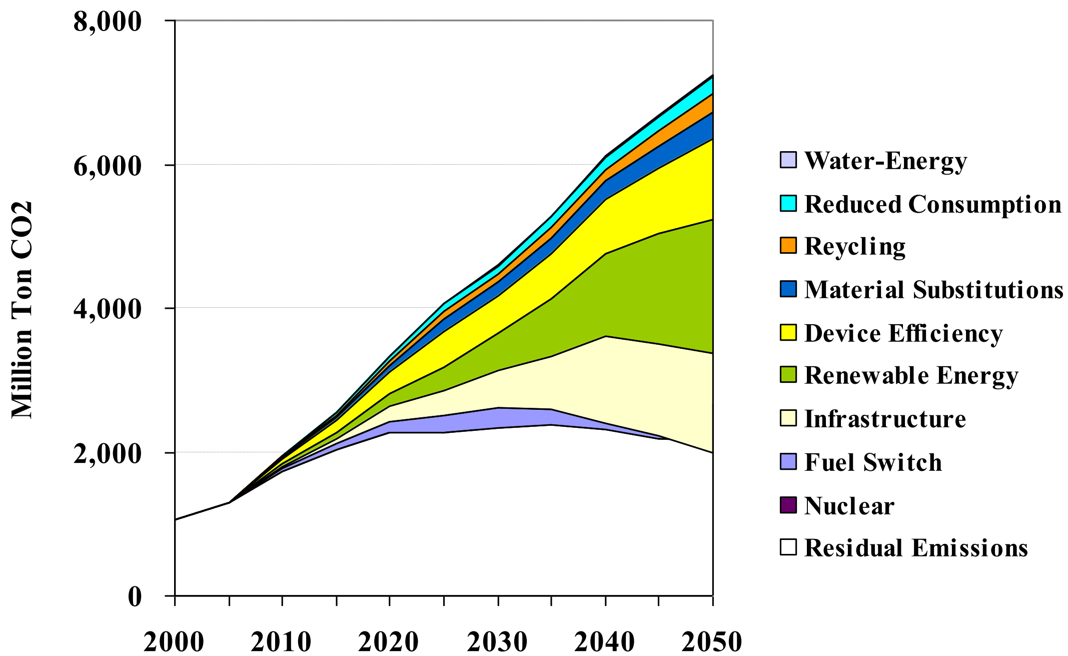
The approach to SS is using a sustainability paradigm; therefore in the first step we keep the tax trajectory similar to the base and introduce sustainability measures. The mitigation that happens by adopting the sustainability paradigm is of 83.5 billion ton of CO_2. The CO_2 mitigation happens due to a diverse portfolio of measures across sectors. All sectors contribute to the mitigation effort, and infrastructure in all sectors plays a dominant role. In the transport sector a large share of mitigation happens due to modal shifts, reduced demand and fuel switching. There is a reduction in demand from industrial sector as demand for steel, cement and other energy intensives commodities goes down due to recycling, reuse, material substitutions, improvement of device efficiencies and fuel substitutions. The demand of energy from agriculture is lower due to reduced consumption on account of improved agricultural practices related to irrigation and cropping patterns. Electricity demand therefore, which is a derived demand, is also lower. Finally there is an increasing reliance on renewable sources like hydro, wind and solar.

The SS scenario, however has mitigation equal to that in the CT scenario, therefore a cap on cumulative emissions is kept which is equivalent to the mitigation in the CT scenario.

Figure 14 : Delhi Metro Rail

Source: http://new-delhi-tour-india.blogspot.com/2010/10/delhi-metro-rail-corporation-limited.html

Figure 15: Mitigation Options in SS Scenario



LCS Policy Actions

For realizing this vision of a Low Carbon Society for India, a comprehensive list of policy actions are required for implementation of the mitigation measures. The policy package suggested is a menu of recommended actions which are needed to be integrated in the development planning for India.

These set of actions need to be translated into policy actions, focused on specific sectors. These options would have to be considered in

1. Sustainable Transport
- Mass based transit systems
- Promoting electric vehicles
- Use of ICT for better transport management
- Use of pipeline infrastructure
- Increased use of water transport

2. Low Carbon Electricity
- Carbon capture & storage
- Advanced renewable technologies
- Nuclear technologies

3. Fuel Switch
- Coal to gas

4. Building design
- Energy labeling program
- Sustainable, less energy intensive local materials
- Standardization of energy consumption
- Energy audits

5. Material substitution and recycling
- Resource conservation
- Dematerialization
- Recycling

6. Reduced consumption & device efficiency
- Advanced industrial production technologies
- Use of less energy intensive materials & processes
- Device efficiency standardization

7. Urban planning
- Improving built environment
- Increasing green cover
- Improving urban design norms

8. Resource management
- Waste to energy conversion
- Water resource management

9. Governance
- Coordination
- Planning
- Implementation

10. Financing
- Viability gap funding

Details of Actions

1. The action on **Sustainable transport** primarily comprises of a shift from private vehicles to public vehicles (bus and train) and increased penetration of electric vehicles. However there are numerous other actions contributing to this action such as better traffic management, gas/liquid transfer via pipelines and use of waterways for freight transport. But to achieve such a scenario, certain indirect actions would be required.

2. The action on **Low Carbon Electricity** aims at decoupling the carbon intensity of power sector by using more renewable sources of energy for power generation or by using coal with CCS option. However it should be pointed out here that CCS is an end-of-pipe technological solution, which would require substantial technological and financial transfers. On the contrary, the LCS option with sustainability offers the twin benefit of reducing energy consumption as well as increased share of renewables, particularly wind and solar.

3. The action on **Fuel Switch** refers to switching from coal to gas. This switch can happen across sectors. Some examples could be increased use of gas in industries, piped natural gas for domestic usage and gas-based power production technologies. To achieve such a transition, huge amount of financial commitments would be required in not only the technology but also in associated infrastructure, such as gas pipelines.

4. The action on **Building Design** is also important in terms of controlling energy flows in the established assets. Use of appropriate building technologies, energy audits and associated standardization across building types, materials and devices would go a long way in controlling flow of energy across these stocks.

5. The action on **Material Substitution and Recycling** aims at promoting resource conservation, dematerialization, and recycling. This will also provide significant co-benefits in terms of promoting a sustainable lifestyle, better control of energy service flows and resource conservation. These measures would also result in improving livelihood security (generation of employment through local industries) and enhance energy security by the overall reduction in energy demand.

6. The action on **Reduced Consumption & Device Efficiency** is focused on efficiency improvements achieved through device improvements and reducing energy consumption in intensive industrial processes. This efficiency impact is realized across all sectors. These efficiency improvements can be consistently achieved through implementation of uniform building codes (efficiency in residential sector), promotion of local and less carbon intensive material for construction and designing an appropriate institutional mechanism to facilitate such a transition.

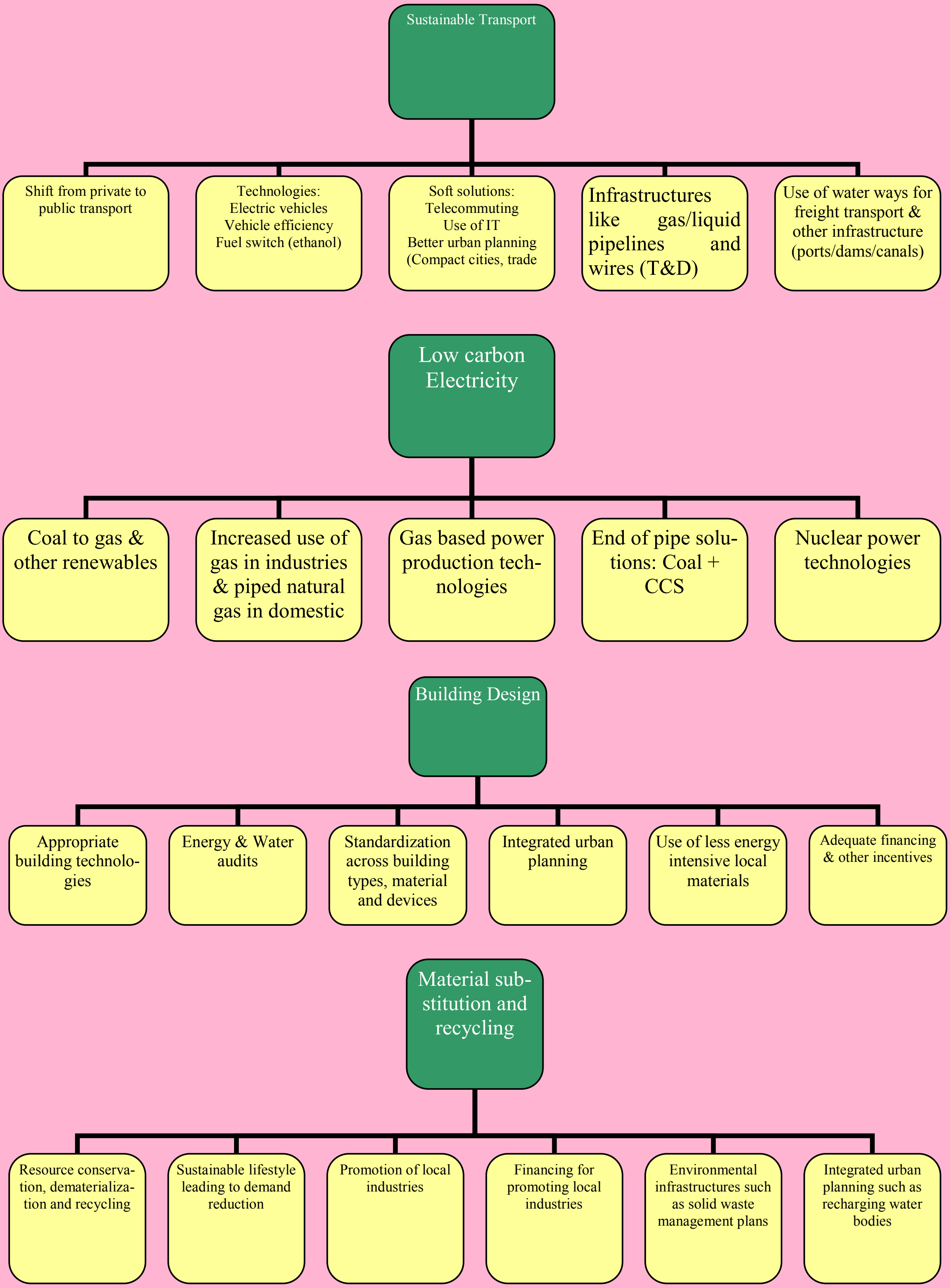
7. The action on **Urban Planning,** targets at increasing the green cover and improving the built environment so as to reduce the urban heat island effect. This will also offer the co-benefits of enhancing the quality of life, controlling energy flows, and better adaptation to extreme weather events. Apart from direct mitigation benefits, these are important in realizing other co-benefits such as promotion of 3R and enhancing the quality of life. Better planning of urban spaces also helps in managing the energy service demand in a sustainable form.

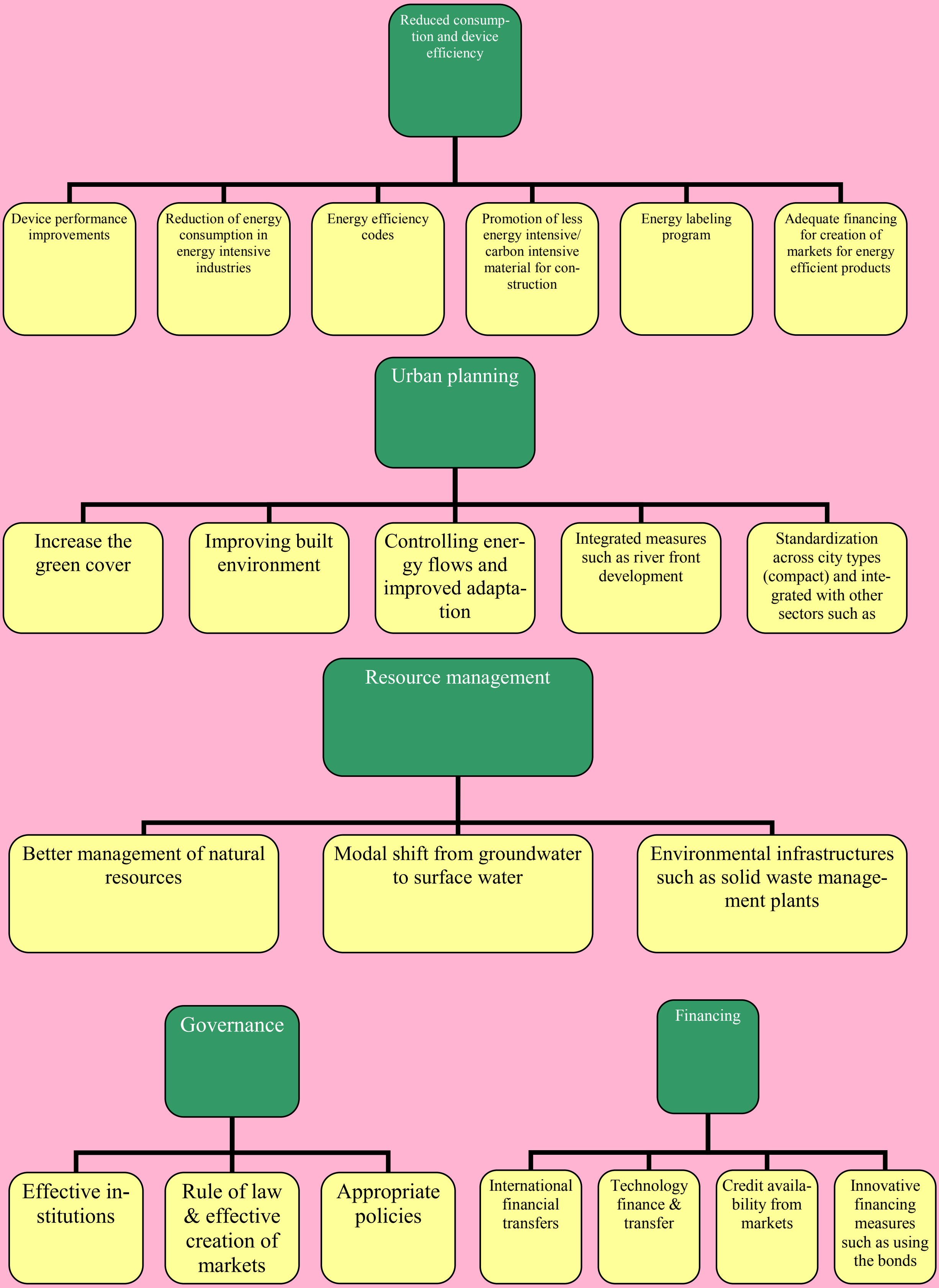
8. The action on **Resource Management** aims at better management of other natural resources for a substantial GHG mitigation. Principal among these are ensuring waste to energy projects materializing in various sectors. Also reduced dependence on groundwater for irrigation and a shift to surface water significantly alters the energy consumption patterns in the agriculture sector. It also comprises of creating various infrastructures such as solid waste management facilities and sewage treatment plants.

9. The larger framework of **Governance** comprises of how to govern. To facilitate a smooth transition to a low carbon society, the government would need an effective governance and institutional mechanism. Governance initiatives will have an overlapping influence in ensuring sustained sectoral emission reductions.

10. In the context of developing nations, **Financing** plays a key role in any low carbon initiative over and above the business as usual transition. Thus, the deep emission cuts would involve substantial investments in low-carbon infrastructure. Besides, these infrastructure and technology choices would also lead to some economic losses (GDP), which would translate into developmental loss and would have to be compensated through either international investments or technology transfer

Description of Actions—Snapshot




Reduced consumption and device efficiency
Device performance improvements
Reduction of energy consumption in energy intensive industries
Energy efficiency codes
Promotion of less energy intensive/ carbon intensive material for construction
Energy labeling program
Adequate financing for creation of markets for energy efficient products
Urban planning
Increase the green cover
Improving built environment
Controlling energy flows and improved adaptation
Integrated measures such as river front development
Standardization across city types (compact) and integrated with other sectors such as
Resource management
Better management of natural resources
Modal shift from groundwater to surface water
Environmental infrastructures such as solid waste management plants
Governance
Effective institutions
Rule of law & effective creation of markets
Appropriate policies
Financing
International financial transfers
Technology finance & transfer
Credit availability from markets
Innovative financing measures such as using the bonds

LCS Infrastructure choices

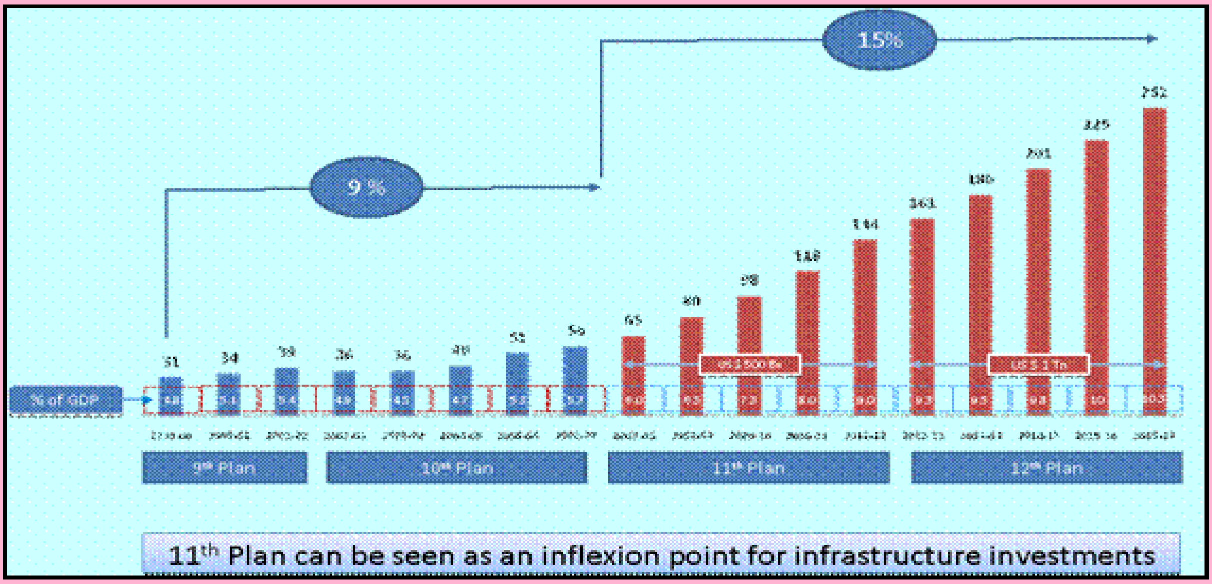
Infrastructure is the backbone of a nation's economic growth, providing a physical framework through which goods and services are provided to public. Since the energy flows transmit via infrastructure networks, the policies governing infrastructure choice are crucial to future energy and carbon intensity path of an economy. Also, being long life assets, infrastructures cause path dependencies by irreversibly locking-in a certain style of development. Co-incidentally, low carbon intensity infrastructures are also low on local pollution and also better in terms of several other sustainability indicators.

In past, the infrastructure choices, such as the transport modes in developed nations, were made when the local air quality as well as climate change had not emerged as environmental concerns. Now, it is crucial for emerging economies countries like India and China, to account for their relative environmental costs and benefits, while making major infrastructure investments.

Already, the high growth trajectory is mounting pressure on constrained infrastructure capacity, thus necessitating a capacity augmentation in almost all infrastructure sectors. Government of India, in the Economic Survey (2008) projects an expected total investment in physical infrastructure (electricity, railways, roads, ports, airports, irrigation, urban and rural infrastructure) to increase from around 5 % of GDP in 2006-07 to 9 % of GDP by the end of 11th Plan period, if the targeted rate of growth of 9 % for the Eleventh Five Year Plan period (2007-12) is to be achieved. The 11th plan is considered to be the point of inflexion (Figure 16). Since sectors like energy and transport are a major contributor to emissions, and at the same time major drivers of economic growth, it is important to appreciate the relationship between energy, infrastructure development and climate change .

Thus, there is an increased need for global cooperation in terms of sharing advanced low carbon technologies, and financial transfer for supporting these transitions in the non annex countries.

Figure 16: Infrastructure spending of the Government of India



Currently, many initiatives are being undertaken for developing low carbon infrastructures, both at the city level and at national level. Bus Rapid Transit System (BRTS) (Fig 17 for key cities in India), Mass Rapid Transit System (Metro) and other such urban infrastructures such as dedicated freight corridors (Fig 18) are being developed in many cities or are under plan or the assessment has been made under the low carbon scenario, to alter the transport profile. There is also an increased impetus to alter the energy profile (Fig 19), as an input to many such infrastructure. City gas distribution network is being developed in many states, so as to shift the use of petroleum oil in transport. An assessment shows the need for augmenting gas infrastructure of the country (Fig 20). Similarly, many state and national level policy initiatives support the development of renewable energy infrastructure. It would require an investment of around US $ 3 trillion till 2050.

Figure 17: Estimated BRT and metro routes for India

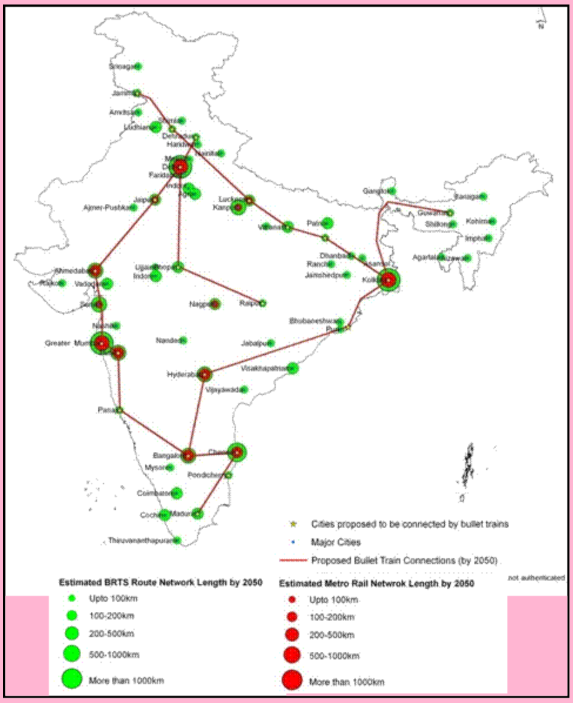


Figure 18: Estimated freight routes & corridors

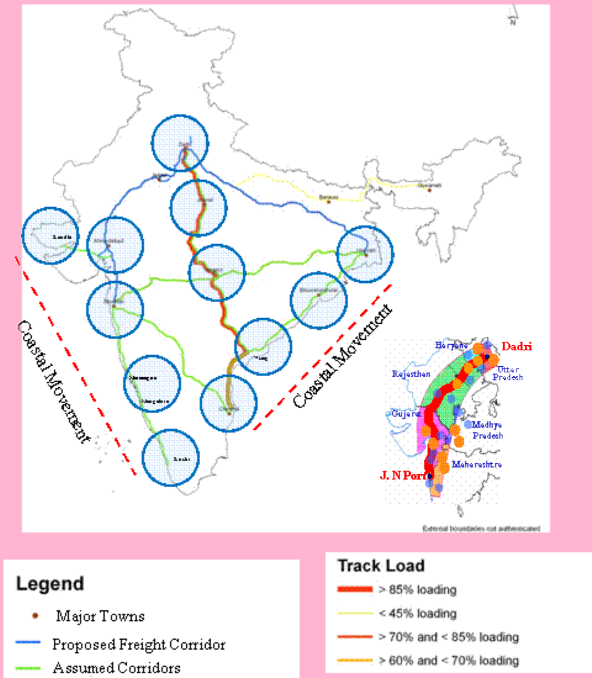


Figure 19: Power sector infrastrucuture in LCS

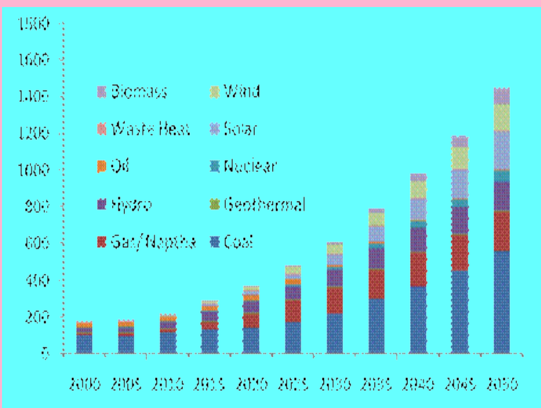
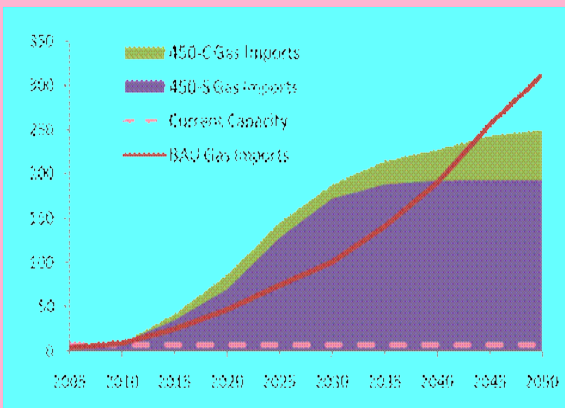


Figure 20: Gas infrastructure in LCS



Water-Energy-Climate Change

The water – energy – climate change linkage has evoked significant interest among researchers worldwide at present. The highly visible impacts on water resources and the associated changes in the energy mix have become important areas of research, particularly on a century scale. IPCC has also recognized the climate related impacts on water resources, and has released findings in its 4th assessment report, showing that climate change would significantly alter the water resources profile of nations. This would lead to serious negative implications for the energy sector as well.

Thus from the LCS perspective, it becomes imperative to study the water-energy-climate change nexus in an integrated framework, embedded within the principles of sustainable development. This would require a serious study on the necessary policies, institution and governance to manage the inter-relationships.

The focal point of the inter-relationship is the role of river bodies in India. The rivers in India are either rain-fed or glacier-fed, both being affected by climate change. Research studies in India have found an increase in run-off in the glacier-fed rivers till 2050 with subsequent decline. Even the rain-fed rivers are going to be impacted due to increased spatio-temporal variability in the monsoon rainfall (more so without adequate storage facilities). Such changes in water availability would have serious ramifications for various sectors, particularly agriculture, and would indirectly affect the energy consumption profile in India. It would also affect the amount of hydro-power generation in the country (a carbon neutral energy source).

However from the perspective of this LCS study, such transformations in the water sector would result in serious affects on "quality of life" and sustainability of life. From the perspective of providing adequate clean drinking water to its citizens, decrease in the availability of surface water would seriously hamper the lives of millions of vulnerable Indians. Notwithstanding the impact due to floods, without adequate protection systems.

Thus the water sector is an important sector to be looked at from the mitigation (hydro power) and adaptation (floods, droughts) perspective.

Figure 21: Hydro power dam

Source: http://www.einfopedia.com/biggest-dam-in-india.php

Some of the government programmes are already addressing, particularly the adaptation side related issues of the water-energy-climate change connection. Such as the programmes like National Rural Employment Guarantee Scheme, watershed management programme, growth of bioenergy crops.

There has been a consistent growth in the number of electric pumpsets in India, owing to a phenomenal rise in groundwater irrigation in the country. Surface irrigation growth has been sluggish (Fig 23) and consequently the water nexus in agriculture has intensified over the years. In the urban areas, due to rise in urban population and the increasing rate of urbanisation in the country, demand for water has increased considerably and therefore the energy intensity of water has also increased.

Hydro power growth has been slow (Fig 22), but due to the recent initiative of the PM, it is expected to touch 50 GW. LCS scenario model runs reveal a nearly 50% reduction across all sectors in the energy intensity of water use. Similarly, the same model runs suggest that there is a possibility of aligning hydro power generation to a capacity of 200 GW through regional cooperation.

Low carbon scenarios following a sustainable pathway could mitigate nearly 4.5 btCO2 during 2010-2050 period in the water sector (Fig 24 & 25). However such a pathway provides a significant co-benefit of water savings which is under stress and is likely to intensify further.

Figure 22: Hydro power growth in BAU scenario

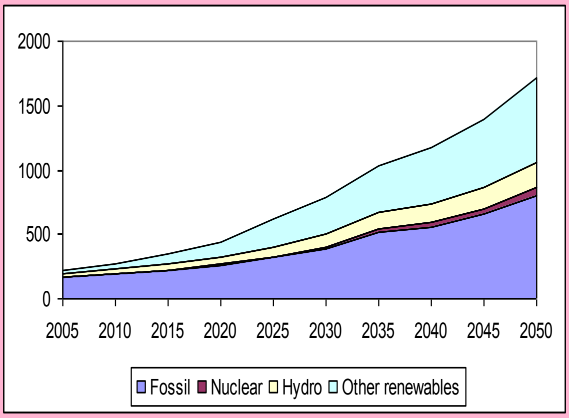


Figure 23: % irrigated area across sources

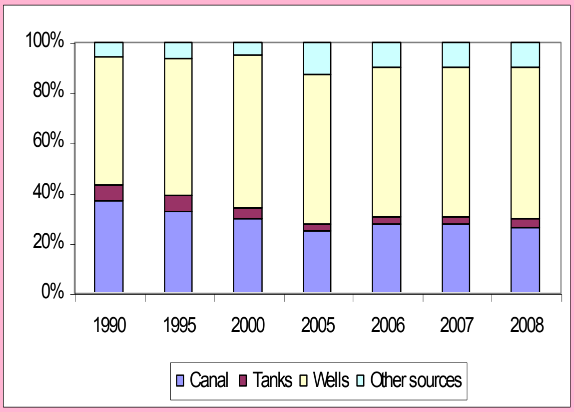


Figure 24: Mitigation under conventional scenario

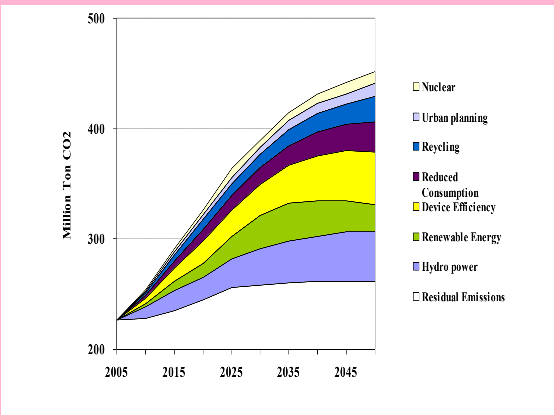
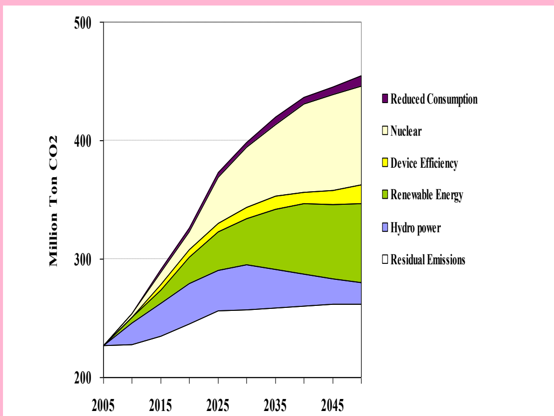


Figure 25: Mitigation under sustainable scenario



Scenario Comparison: Beyond Carbon

Energy Security

A major concern in transition to Low Carbon Society is its implications for 'Energy Security', i.e. the "aggregate risk" related to energy vulnerabilities, especially the energy supply and its diversity. In the Carbon Tax scenario, the aggregate energy demand trajectory is almost identical to that in the base case whereas the energy demand is lower by a third in the SS scenario. The fossil fuel use declines in both LCS scenarios compared to the Base scenario, although the CT scenario has significantly higher use of nuclear energy compared to the base scenario and a relatively higher use of fossil fuels together with a greater penetration of CCS technologies compared to the SS scenario. In the SS scenario, the dependence on oil, gas and nuclear energy reduces substantially. Since India has limited resource availability of these fuels, the SS scenario will improve energy security in a conventional sense of dependence on energy imports.

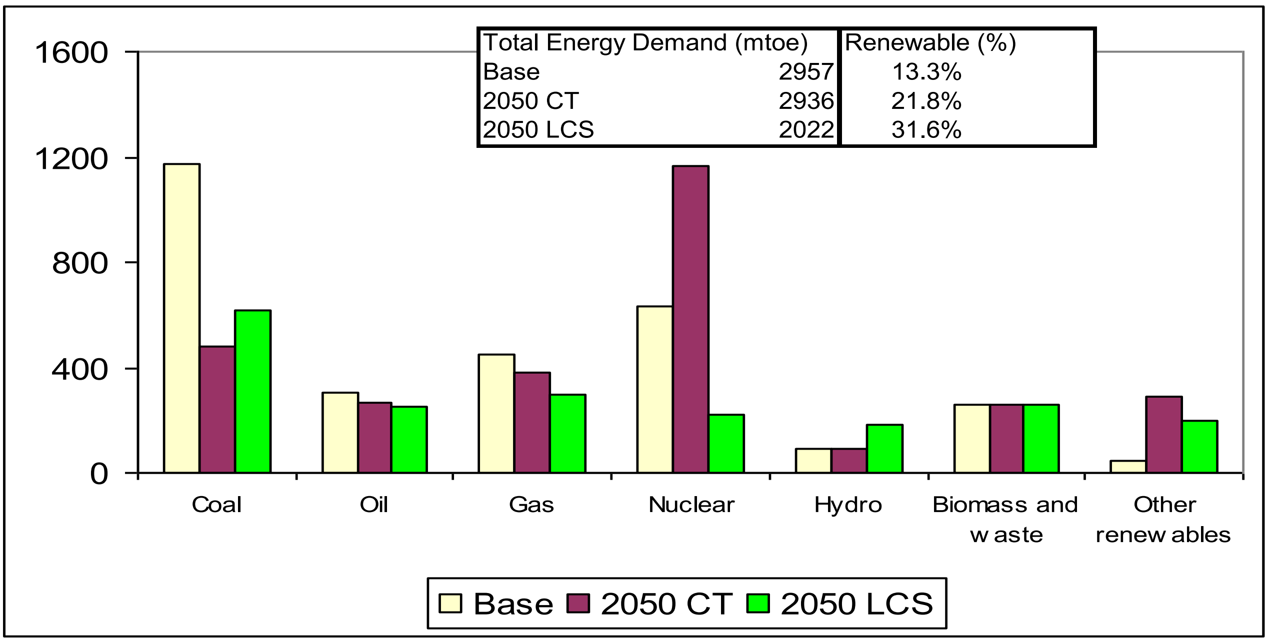
In case of nuclear energy, the base case scenario has a nuclear capacity lesser than that of CT scenario in 2050. A fraction of this capacity corresponds to the conventional fuel cycle with dependence on imported uranium fuel. Rest is the capacity under the three stage nuclear program which would use indigenously available thorium as fuel.

The CT scenario has a higher share of nuclear, and which would require higher import of uranium affecting adversely the energy security issues for India.

Figure 26: Solar panel with sun

Source: http://www.dancewithshadows.com/business/moser-baer-india-to-develop-1-megawatt-solar-power-project-in-maharashtra/

Figure 27: Fuel mix across CT, SS and Base scenarios (Year 2050)



Co-benefits of Conjoint Mitigation

Energy emissions contribute significantly to the local air quality in urban and industrial areas. The control of local air pollutants, e.g. SO_2, has been a major aim of environmental programs in the developed world. But at the time when SO_2 controls were initiated in the developed world, climate change was not yet a major concern. In India where SO_2 control policies are being instituted more recently, there are opportunities to develop conjoint measures to control SO2 and CO_2. Whereas base case scenario includes dynamics as usual SO_2 control measures which by themselves would decouple economic growth and the SO_2 emissions, the LCS scenarios would lead to higher and cheaper reduction in SO_2 emissions (Figure 29) since the conjoint measures would share the cost of their simultaneous mitigation. Thus, during the low carbon transition, the conjoint policies can deliver benefits of improved air quality or alternatively through the reduced cost of achieving air quality targets. Evidently, the 'Sustainability' scenario would deliver greater air quality co-benefits compared to the 'Carbon Tax' scenario

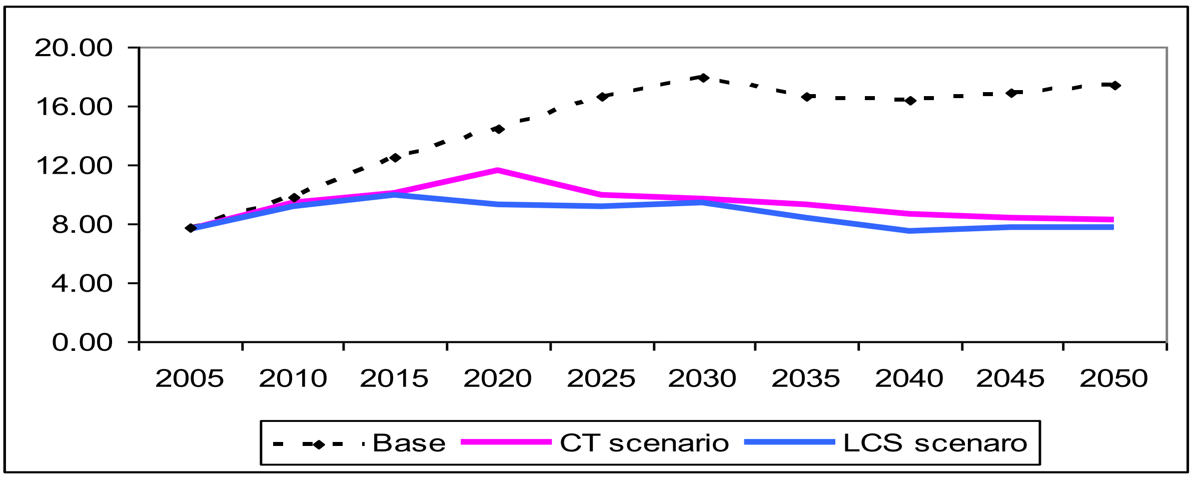
Adaptive Capacity

Sustainable development is characterized by higher investment in human and social capital compared to that under the conventional development. In developing countries this translates into higher capabilities, especially among lower income groups, to adapt to risks. Thus, a low carbon society following 'sustainability paradigm, would also deliver additional co-benefits

Figure 28: BRTS system in Ahmedabad

Source: http://www.vandeindia.com/ahmedabad-brts-nominated-for-international-award.html

Figure 29 : SO2 Emissions in CT, SS and Base Scenario (mt-SO2)



New and Renewable energy

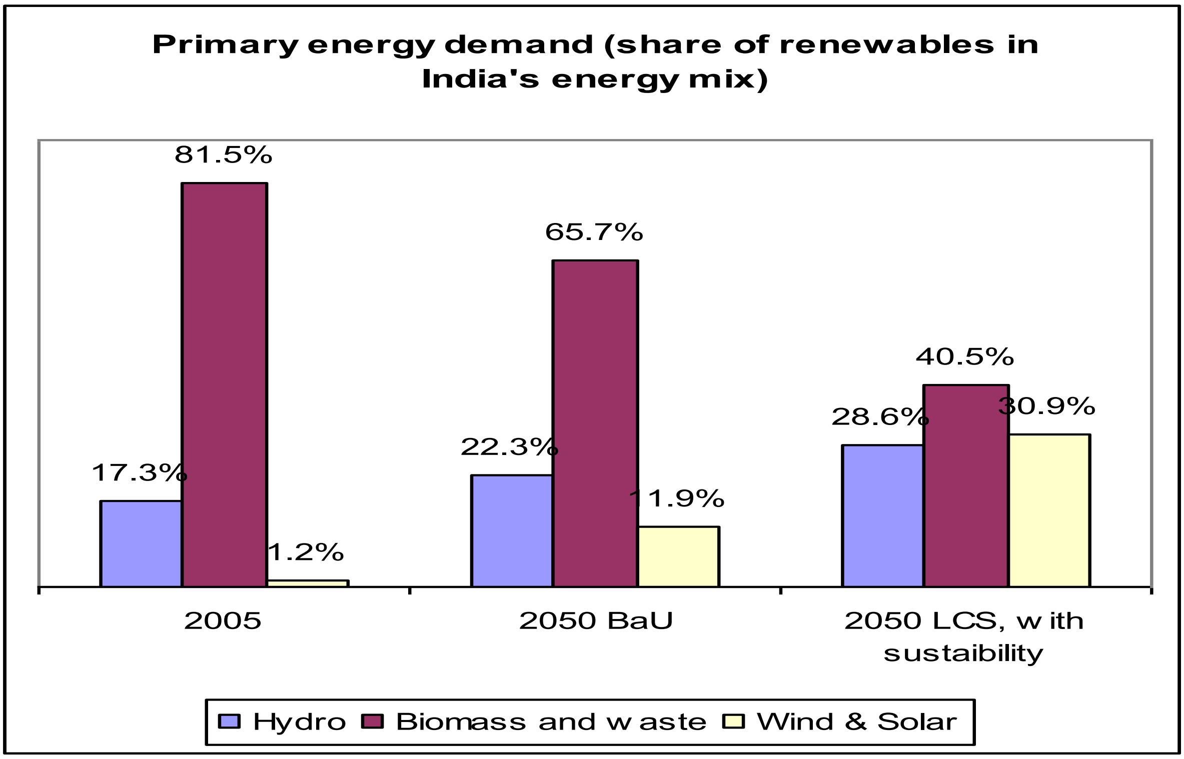
New and Renewable energy is set to play a key role in India 's future. There are numerous programs and policies underway in India, with special focus on developing renewables. The Government of India recognised the need, and extended this responsibility to a full fledged ministry which will look into its development.

It must be noted here that in the base scenario, the share of renewable in the total energy mix of India is dominated by biomass (25.3%). However due to the Indo-US nuclear deal, it is estimated that the BAU scenario would have a significant penetration of nuclear energy (10.9%. In the conventional scenario, nuclear energy and CCS would be dominating on the new energy front. The SS Scenario in 2050 has a substantially higher share of renewables, as compared to the base case and CT scenario (see figure 31 below). Sustainable biomass and waste to energy would also contribute significantly to the energy mix (the National Urban Renewal Program for cities in India has a special focus on waste to energy projects). The share of hydro power would also increase, with particular emphasis on small hydro energy and ensuring its faster deployment on a commercial scale.

Figure 30: Wind farm in India

Source: http://forum.xcitefun.net/dhule-largest-wind-farm-india-t35556.html

Figure 31 : Share of renewable energy in the various scenarios



Energy & Environment Policies

There have been numerous policy initiatives, legislations and acts enacted and introduced in the environment and energy domain in India. These policies, legislations and acts have focused either individually on an environmental sector like water, air or they have targeted broadly the entire value chain of the energy sector. For example, the latest policy document adopted by the Government of India - the Integrated Energy Policy Roadmap, 2006. This policy roadmap has been accepted by the Government of India (GoI) in 2009, and which broadly links energy sector to the goals of Sustainable Development by developing policies that promote 'efficiency' and reflect externalities associated with energy consumption.

Further in June, 2008; the Prime Minister of India released India's first National Action Plan on Climate Change (NAPCC) outlining existing and future policies and programs addressing climate mitigation and adaptation. The plan identifies eight core "national missions" running through 2017 and directed ministries to submit detailed implementation plans to the Prime Minister's Council on Climate Change by December 2008.

Emphasizing the importance of high economic growth rates, the plan "identifies measures that promote our development objectives while also yielding co-benefits for addressing climate change effectively." It says "these national measures would be more successful with assistance from developed countries", and pledges that India's per capita greenhouse gas emissions "will at no point exceed that of developed countries even as we pursue our development objectives."

The eight National Missions and their related targets are elucidated below in the table below. These targets are in line with the mitigation of GHG emissions across many sectors, and therefore are important from the perspective of an LCS study.

Moreover, there are other specific programs identified for implementation, within the National Action Plan from the mitigation perspective.

No.	National Mission	Targets
1	National Solar Mission	Specific targets for increasing use of solar thermal technologies in urban areas, industry, and commercial establishments
2	National Mission for Enhanced Energy Efficiency	Building on the Energy Conservation Act 2001
3	National Mission on Sustainable Habitat	Extending the existing Energy Conservation Building Code; Emphasis on urban waste management and recycling, including power production from waste (3R)
4	National Water Mission	20% improvement in water use efficiency through pricing and other measures
5	National Mission for Sustaining the Himalayan Ecosystem	Conservation of biodiversity, forest cover, and other ecological values in the Himalayan region, where glaciers are projected to recede
6	National Mission for a "Green India"	Expanding forest cover from 23% to 33%
7	National Mission for Sustainable Agriculture	Promotion of sustainable agricultural practices
8	National Mission on Strategic Knowledge for Climate Change:	The plan envisions a new Climate Science Research Fund that supports activities like climate modeling, and increased international collaboration; It also encourage private sector initiatives to develop adaptation and mitigation technologies

National Missions & Actions

Table 3: Actions in line with National Missions

S.No.	National Mission	Actions
2	National Mission on Sustainable Habitat	Increasing EE in Buildings: building bye laws and standards, energy performance monitoring, national standards for construction & recycling of construction waste Urban transport: norms integrating congestion charges, parking etc, norms for pedestrian & cycling, integrating transport planning with spatial planning Water supply: mandatory rainwater harvesting, water & energy audits
3	National Mission on Green India	2 m ha of moderately dense forests 4 m ha of degraded forests regenerated/afforested 0.10 m ha of mangroves restored, 0.1 m ha wetlands conservation 0.20 m ha urban/peri-urban forests, 1.50 m ha degraded land under agro-forestry
4	National Mission: Sustaining Himalayan Ecosystem	Continuous Monitoring of Himalayan Ecosystems Identification of desirable Adaptation and Development Policies (Sustainable urbanization, Water security: rejuvenation of springs, Infrastructure development: Green roads)
5	National Mission on Enhanced Energy Efficiency	Specific Energy Consumption (SEC) reduction targets for energy-intensive units Incentivising action through Energy Savings Certificates (ESCerts) - Traded & Used for compliance National Energy Efficiency CDM Roadmap National Energy Efficiency Financing Platform Creating markets for energy efficient products and services
6	National Water Mission	Improving efficiency of urban water supply system; Promotion of water efficient technologies; Incentives for recycling of water, including waste water; Water Regulation for equitable water distribution Incentives for water conservation and efficient use of water ; Incentives for efficient irrigation practices
7	National Mission on Sustainable Agriculture	Use of Genetic Engineering to produce carbon responsive crops; Low input sustainable agriculture: enhanced water & nitrogen use efficiency, Micro-irrigation for efficient use of water (40 Mha); Water conservation in 35 Mha of rain-fed areas (2009 – 2017); Utilizing large fallow lands (development of land lease markets)
8	National Mission on Strategic Knowledge on CC	Climate change research & fellowship program

Table 4: Post – Copenhagen domestic action

S.No.	Actions
1	Carbon tax on coal to fund clean energy (US $1/ton on domestic & imported coal; fund to be used for Clean Energy)
2	Enhanced Energy Efficiency measures (Mandate to reduce specific energy consumption; Energy savings certificates & trading; Energy efficiency ratings mandatory for 4 key appliances from Jan 2010)
3	Bachat Lamp Yojana – mass distribution of CFLs (Help reduction in peak load; Potential reduction of 6 GW of electricity demand)
4	Mission on sustainable habitat (Energy efficiency in residential, commercial and urban transportation; Better management of water, wastewater and solid waste with recycling, reuse and energy creation)
5	Green and EE Buildings (Better program implementation and financial incentives; Comprehensive approach to manage water, wastewater and solid waste; Potential used for recycling, reuse and energy creation) Refurbishing Urban transportation to achieve energy efficiency (Vehicle Fuel efficiency standards; Enhance Supply of Cleaner Fuels (e.g. Gas))

Jawaharlal Nehru National Solar Mission (JNNSM)

One of the main thrust area of the National Action Plan on Climate Change (NAPCC) has been on energy security, and utilizing the immense potential of solar energy available over the Indian sub-continent. The mission JNNSM, is a major initiative of the GoI (GoI, 2010) and the various state governments in order to promote "ecologically sustainable growth" while at the same time addressing India's energy security challenge. The objective of the mission is to make India the global leader in solar energy, by creating enabling policy framework for its quick dissemination & adoption across the length and breadth of the country. The mission will adopt a 3-phase approach: Phase- I (remaining period of the 11th five year plan and the first year of the 12th plan i.e. 2012-2013), Phase II (2013-2017) and Phase III (2017-2022). At specified intervals, targets and the achievements would be reviewed. At the immediate level, it is considered that the main aim is to evolve an enabling policy environment for quick penetration of solar technology (both at the centralized as well as the decentralized level). Key objectives of Phase-I are: capturing all options in solar thermal, promoting off-grid solutions, and modest capacity additions in on-grid systems. The second and subsequent phases would involve aggressive capacity additions in all aspects of solar technology. The mission targets are:

(1) To create an enabling environment to deliver 20 GW of solar power by 2022

(2) Grid connected solar power capacity of 1 GW by 2013, additional 3 GW by 2017 through mandatory purchases backed with preferential tariff. This capacity could be more than doubled (reached 10 GW installed power by 2017, based on enhanced international financial and technology transfer)

(3) To create favorable conditions for solar manufacturing capabilities

(4) Promote programs of off-grid applications, reaching 1 GW by 2017 and 2 GW by 2022

(5) To achieve 15 million sq.m. solar thermal collector area by 2017 and 20 million sq. m by 2022

(6) To deploy 20 million solar lighting systems for rural areas by 2022

India has already embarked on an ambitious path in terms of aligning its development agenda with the global carbon architecture. Apart from the National Solar Mission, other missions have also gained pace and developed their own targets, in line with the national commitments and climate goals (Table 3 & 4 for details). Salient features across other missions have been highlighted in the table before. However some targets have been more explicit and are mentioned here and they come as a package under post-Copenhagen domestic action:

(1) Reduction of emissions intensity of GDP by 20-25% between 2005 and 2020

(2) Carbon tax on coal to fund clean energy (US$ 1/ton on imported & domestic coal)

(3) Perform, Achieve and Trade Mechanism as a part of National Mission on Enhanced Energy Efficiency

(4) Bachat Lamp Yojana , mass distribution of CFLs—to help in reducing peak load demand and reduce electricity demand by 6 GW

(5) Green India Mission—doubling the area to be afforested/ecorestored to 20 Million hectares

(6) National Water Mission—reduce water use by 20%

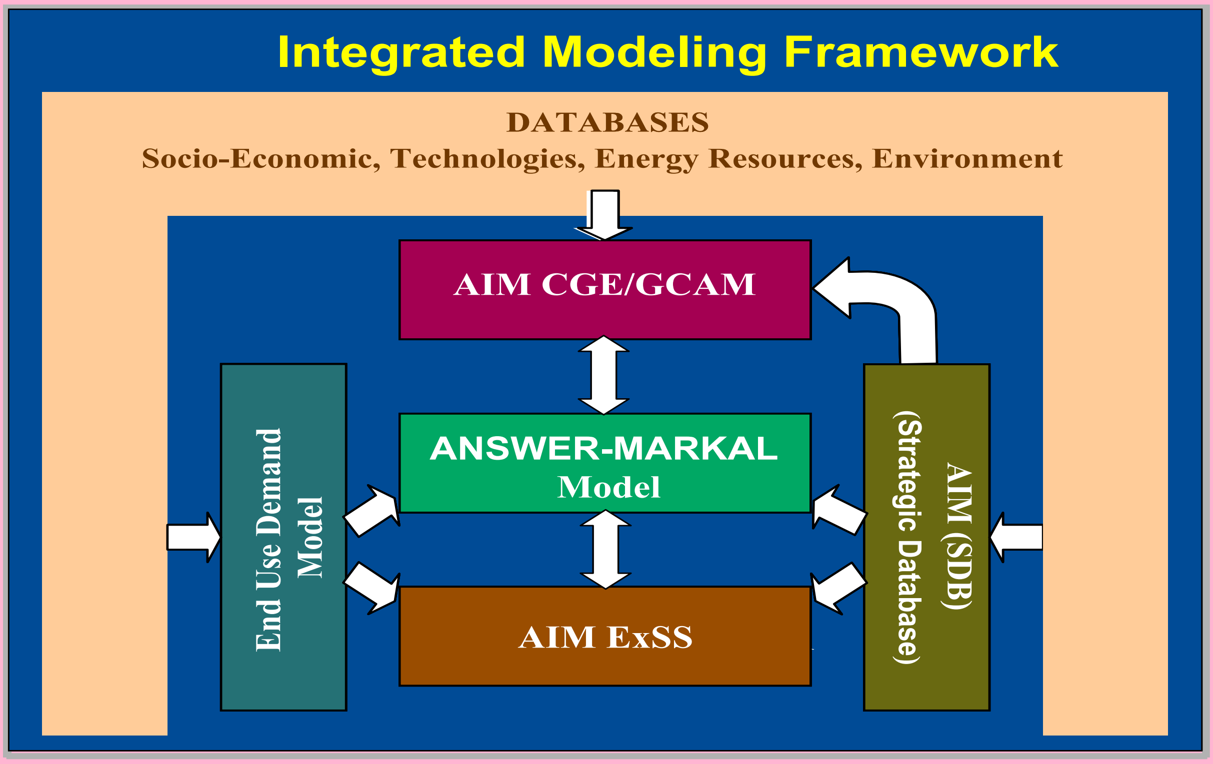
Modeling Framework

The integrated framework proposed in Figure below falls under the earlier AIM family of models (Kainuma et. al., 2003; Shukla et. al., 2004). In order to improve the policy interface one new model AIM SNAPSHOT, having a simple graphic interface, has been included. The bottom up analysis was done by the MARKAL model (Fishbone & Abilock, 1981).

The need for a revised framework arose as the climate change discussion with the increasing scientific evidence (IPCC, 2006) has become quite central and an intensely debated topic with politicians and policy makers. Stern Review and more recently the Energy Technology Strategies, 2006 (IEA, 2006a; Stern, 2006) were a direct result of political mandates. In view of this, robust frameworks are required which convey to the policy makers in simple terms the impacts of alternative policies. The framework uses the modelling resources developed over the last few years by the AIM team with a widely used energy system model ANSWER-MARKAL and finally combine it with a model (SNAPSHOT Model), that help present the results with adequate graphic interfaces.

The framework contains a top down model (AIM CGE) which is soft linked with a bottom up model (ANSWER MARKAL) which in turn is soft linked to AIM SNAPSHOT model. Soft linking of models has been used earlier in literature (Nair et. al., 2003; Bhattacharya et. al., 2003). The inputs and outputs of each of the individual models are suitable to address specific but diverse economic, technological, social, environmental and energy sector issues, assuming consistent and similar assumptions and a shared database.

The top down model, AIM CGE is used for estimating the GDP for different scenarios and these are used as an exogenous input to the bottom up ANSWER MARKAL model. The ANSWER MARKAL model provides detailed technology and sector level energy and emission projections which are in turn inputted to the AIM SNAPSHOT model for doing factor analysis.



Component Models

GCAM Model

GCAM is an integrated assessment model, which are tools for exploring the complex relationship between economic activity, energy systems, land use systems, ecosystems, emissions and resulting impact on climate change. It focuses on technology analysis and implications of various technology pathways for emissions abatement. It is a partial equilibrium model that examines long term and large scale changes in the energy and emission pathways. The model includes 14 region and runs from 1990 to 2095 in time steps of 15 years. The end-use energy service demands associated with time path of economic activity have been aggregated as three energy services- industrial energy services, building energy services, and transportation energy services. A range of energy sources compete to provide energy to meet the service demands in the three final aggregate sectors. These energy sources include fossil fuels, bio-energy, electricity, hydrogen and synthetic fuels. A detailed land use module is included for analyzing land use patterns and emissions.

AIM-CGE

AIM/CGE is a top down, computable general equilibrium (CGE), model is used to study the relationship between the economy and environment (Masui, 2005). The top down framework can do cost analysis of both CO_2 mitigation and other GHG mitigation (Shukla et. al., 2004). The model includes 18 regions and 13 sectors. The model can be used to assess the environmental and economic effects of new markets, new investment, technology transfer and international trade.

ANSWER-MARKAL Model

MARKAL is a mathematical model for evaluating the energy system of one or several regions. MARKAL provides technology, fuel mix and investment decisions at detailed end-use level while maintaining consistency with system constraints such as energy supply, demand, investment, emissions etc.. ANSWER is the windows interface for the MARKAL model.

End-use Demand Model

The approach used in the past is to model the demands using a logistic regression (Edmonds and Reilly, 1983). First the long term GDP projections are made using the past data available from the Ministry of Finance, GoI. Logistic regression using past data is then used to estimate the sector specific shares from industry, transport, commercial and agriculture. These sectoral shares on multiplication with GDP projections give us gross valued added (GVA) for each sector. The last step involves estimation of elasticity of each sub-sector (e.g., industry is divided into eleven sub sectors like steel, cement, etc.) with the sector specific GVA. The elasticity is then used for estimating the future demand from each sector. The methodology described helps in capturing past trends and ensuring consistency with macroeconomic growth (Shukla et. al., 2004).

AIM Strategic Database (SDB)

Models require diverse databases such as economic growth, global and regional energy resource availability, input-output tables, sectoral and temporal end use production processes and technologies, emission types and much more. The data requirements are different for top down and bottom up models. The outputs from different models also serve as data for other models. There is essentially a complex flow of data between models and database wherein the models interact through the database in a soft link framework. AIM database plays a critical role in ensuring data consistency across the models (Hibino et. al., 2003; Shukla et. al., 2004, Chapter 7).

References

AIM Japan Team (2005), "AIM/CGE [Country] : Data and Program Manual." Tsukuba: National Institute for Environmental Studies.

Bhattacharya, Sumana, N. H. Ravindranath, P. R. Shukla, N Kalra, A K Gosain, and K K Kumar (2003), "Tools for Vulnerability Assessment and Adaptation," in Climate Change and India: Vulnerability Assessment and Adaptation, P. R. Shukla and S. K. Sharma and N. H. Ravindranath and Amit Garg and Sumana Bhattacharya, Eds. Hyderabad: Universities Press.

Clarke, L E, J A Edmonds, H D Jacoby, H M Pitcher, J M Reilly, and R G Richels (2007), "Scenario of Greenhouse Gas Emissions and Atmospheric Concentrations," in Synthesis and Assessment Product 2.1a: United States Climate Change Science Program and Subcommittee on Global Change Research.

Edmonds, J. and J. Reilly (1983), "A long-term energy-economic model of carbon dioxide release from fossil fuel use," Energy Economics, April, 74-88.

Edmonds, J A, M A Wise, J J Dooley, S H Kim, S J Smith, P J Runci, L E Clarke, E L Malone, and G M Stokes (2007), "Global Energy Technology Strategy: Addressing Climate Change," in Phase 2 Findings from an international public-private sponsored research program: Joint Global Change Research Institute; Pacific Northwest National Laboratory & Battelle.

Edmonds, J A (2007), "Personal communication on global carbon price trajectories for various stabilization scenarios," P R Shukla (Ed.).

Fisher, B. S., Nakicenovic, N., Alfsen, K., Morlot, J. C., Chesnaye, F. d. l., Hourcade, J.-C., Jiang, K., Kainuma, M., E. La Rovere, Matysek, A., Rana, A., Riahi, K., Richels, R., Rose, S., Vuuren, D. v., & Warren, R. (2007). Issues related to mitigation in the long term context. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental. Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer (Eds.)]., Cambridge University Press, Cambridge, United Kingdom

Fishbone, L G and H Abilock (1981), "MARKAL, A Linear Programming Model for Energy System Analysis: Technical Description of the BNL Version," International Journal of Energy Research, 5, 353-75.

GoI, Government of India (2006), "Integrated Energy Policy: Report of the Expert Committee." New Delhi: Planning Commission.

Hibino, Go, Yuzuru Matsuoka, and Mikiko Kainuma (2003), "AIM/Common Database: A Tool for AIM family Linkage," in Climate Policy Assesment: Asia- Pacific Integrated Modeling, Mikiko Kainuma and Yuzuru Matsuoka and T Morita, Eds. Tokyo: Springer

IEA (2006a) Energy Technology Perspectives 2006: Scenarios & Strategies to 2050. Paris: OECD/IEA.

IEA (2006b), World Energy Outlook 2006. Paris: OECD/IEA.

IPCC (2000), Emission Scenarios. Cambridge: Cambridge Universities Press.

Kainuma, Mikiko, Yuzuru Matsuoka, and Tsunehuki Morita (2003), "AIM Modeling: Overview and Major Findings," in Climate Policy Assesment: Asia Pacific Integrated Modeling, Mikiko Kainuma and Yuzuru Matsuoka and Tsunehuki Morita, Eds. Tokyo: Springer.

Kainuma, Mikiko, Toshihiko Masui, Junichi Fujino, Shuichi Ashina, Yuzuru Matsuoka, Reina Kwase, Osamu Akashi, Go Hibino, Maho Miyashita, Tomoki Ehara, Rahul Pandey, Manmohan Kapshe, and Pedro Piris-Cabezas (2006), "Development of Japan Low Carbon Scenarios," Ministry of the Environment, Japan.

Kumar, K Rupa, K Krishna Kumar, V Prasanna, K Kamala, N R Deshpande, S K Patwardhan, and G B Pant (2003), "Future Climate Scenarios," in Climate Change and India: Vulnerability Assessment and Adaptation, P. R. Shukla and S. K. Sharma and N. H. Ravindranath and Amit Garg and Sumana Bhattacharya, Eds. N Delhi: Universities Press.

Larsen, Hans and Leif Sønderberg Petersen (2007), "Future options for energy technologies," in Risø Energy Report 6. Rosklide: Risø Energy Centre.

Loulou, Richard, Gary Goldstein, and Ken Noble (2004), "Documentation for the MARKAL Family of Models, October 2004," Vol. 2007: Data downloaded on 26th June 2007 from http://www.etsap.org/documentation.asp

Nair, Rajesh, P. R. Shukla, Manmohan Kapshe, Amit Garg, and Ashish Rana (2003), "Analysis of Long-Term Energy and Carbon Emission Scenarios for India," Mitigation and Adaptation Strategies for Global Change, 8, 53-69.

Nair, Rajesh (2003), "Energy Security In South Asia: Integrating The Primary Energy And Electricity Markets," Unpublished doctoral dissertation, Indian Institute of Management, Ahmedabad.

NIES (2006), "Energy Snapshot tool (ESS): Manual." Tsukuba: National Institute of Environmental Studies.

Rana, Ashish and Tsuneyuki Morita (2000), "Scenarios for Greenhouse Gas Emissions Mitigation: A Review of Modeling of Strategies and Policies in Integrated Assessment Models," Environment Economics and Policy Studies, 3 (2).

Rana, Ashish and P. R. Shukla (2001), "Macroeconomic Models for Long-term Energy and Emissions in India," OPSEARCH, 38 (1).

Sathaye, Jayant, P. R. Shukla, and N. H. Ravindranath (2006), "Climate change, sustainable development and India: Global and national concerns," Current Science, 90 (3), 314-325.

Shukla, P R (2006) India's GHG emission scenarios: Aligning development and stabilization paths, Current Science, 90 (3), 384-395.

Shukla, P R (2005), "Aligning Justice and Efficiency in the Global Climate Regime: A Developing Country Perspective," in Advances in the Economics of Environmental Resources, Volume 5: Perspectives on Climate Change: Science, Economics, Politics, Ethics, Walter Sinnott0Armstrong and Richard B. Howarth, Eds. Oxford, UK: Elsevier.

Shukla, P. R., Ashish Rana, Amit Garg, Manmohan Kapshe, and Rajesh Nair (2004), Climate Policy Assessment for India: Applications of Asia Pacific Integrated Model (AIM). New Delhi: Universities Press.

Shukla, P. R., Subodh K. Sharma, Amit Garg, Sumana Bhattacharya and N. H. Ravindranath (2003) Climate Change Vulnerability Assessment and Adaptation: The Context. In P. R. Shukla, Subodh K. Sharma, N. H. Ravindranath, Amit Garg and Sumana Bhattacharya (eds.), Climate Change and India: Vulnerability Assessment and Adaptation. Hyderabad: Universities Press.

UNPD (2008), "The World Population Prospects: The 2008 Revision Population Database," United Nations Population Division, 23rd July 2009 <http://esa.un.org/unpp/>

GoI (2007). Report of the Steering Committee on Water Resources for Eleventh Five Year Plan (2007-12). Planning Commission, Government of India

GoI (2008a). Preliminary consolidated report on effect of climate change on water resources. Government of India, New Delhi

GoI (2008b). National Hydro Power Policy. Ministry of Power, Government of India. Retrieved from http://www.powermin.nic.in/whats_new/pdf/new_hydro_policy.pdf on 17th March, 2009

GoI (2008c). Eleventh Five Year Plan 2007-2012. Vol I. Planning Commission, Government of India. Oxford University Press, New Delhi

GoI (2008d). Eleventh Five Year Plan 2007-2012. Vol II. Planning Commission, Government of India. Oxford University Press, New Delhi

GoI (2008e). Eleventh Five Year Plan 2007-2012. Vol III. Planning Commission, Government of India. Oxford University Press, New Delhi

GoI (2008f). National Hydro Power Policy. Ministry of Power, Government of India

GoI. (2010). Mid-term Appraisal of the 11th five-year Plan: Water Resources. Planning Commission, Government of India

MNRE. (2010). Annual Report 2009-10. Ministry of New & Renewable Energy, Government of India

MoEF. (2010). Presentations made at the National Consultation Workshop on State Action Plans on Climate Change, Government of India

MoEf. (2010). Climate Change and India: A 4X4 Assessment—A Sectoral & Regional Analysis for 2030s. Retrieved from http://moef.nic.in/downloads/public-information/fin-rpt-incca.pdf

LCS Roadmap 2050

India Low Carbon Society Roadmap 2050
January 2011

Indian Institute of Management Ahmedabad
P. R . Shukla
Amir Bashir Bazaz
Prasoon Agarwal
Minal Pathak
Somesh Sharma

External boundaries are not authenticated