Low Carbon Society Roadmap for India and Ahmedabad City

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Abstract

This analysis 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. It can be seen 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. However, under the sustainability scenario, 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.

The study on Ahmedabad, using AIM/End Use model & AIM/ExSS tool, develops a low carbon vision for the city of Ahmedabad. In order to transit to a low carbon society in Ahmedabad, several countermeasures are required. It is interestingly observed from the model output that for such a transition in Ahmedabad, decoupling of economic growth and energy use emerges as the highest mitigation potential as compared to decarbonisation of energy.

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1. Introduction

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, 2001)[3]. Groundwater which has been the key source for meeting the irrigation and consumption needs of urban and rural population is coming under tremendous pressure because of haphazard urban planning and climate change (Burjia, J. S. and Romani, S.,2003 as cited in Mall et al, 2006). Environmental degradation in future will have huge economic impacts[4] on an agrarian and land starved country like India (Reddy, 2003). Developing countries 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.

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). SD is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). 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 cost besides creating opportunities to realize co-benefits without having to sacrifice the original objective of enhancing economic and social development (Shukla, 2006).

GoI’s Ministry of Environment & Forests (MoEF) 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.

2. Energy & Environment Policies in India

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

[3] Of the total 192 million households as per 2001 census only 18 per cent has access to modern cooking energy such as LPG and only 56 per cent of the total households have access to electricity for lighting (CoI, 2001)
[4] Reddy has estimated a GDP loss of 1.4 per cent because of land degradation

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 road-map 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.

The eight National Missions and their related targets are elucidated below in the table below (Table 1). 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.

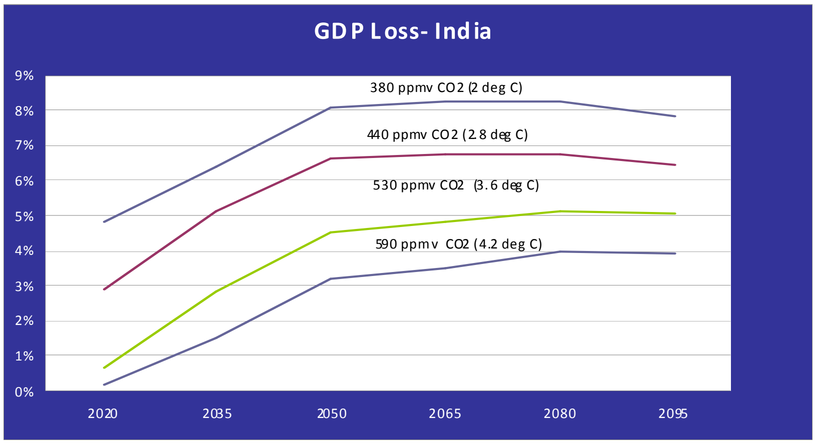
Table 1: National Missions under NAPCC

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

In this paper we examine, using an integrated modeling framework, the realization of a Low Carbon Society through two alternative pathways. The first pathway uses a pure carbon policy instrument in the form of a carbon tax, whereas in the second we follow the sustainability paradigm.

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 1 below). This GDP 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).

Fig 1: GDP loss for India under various stabilization scenarios



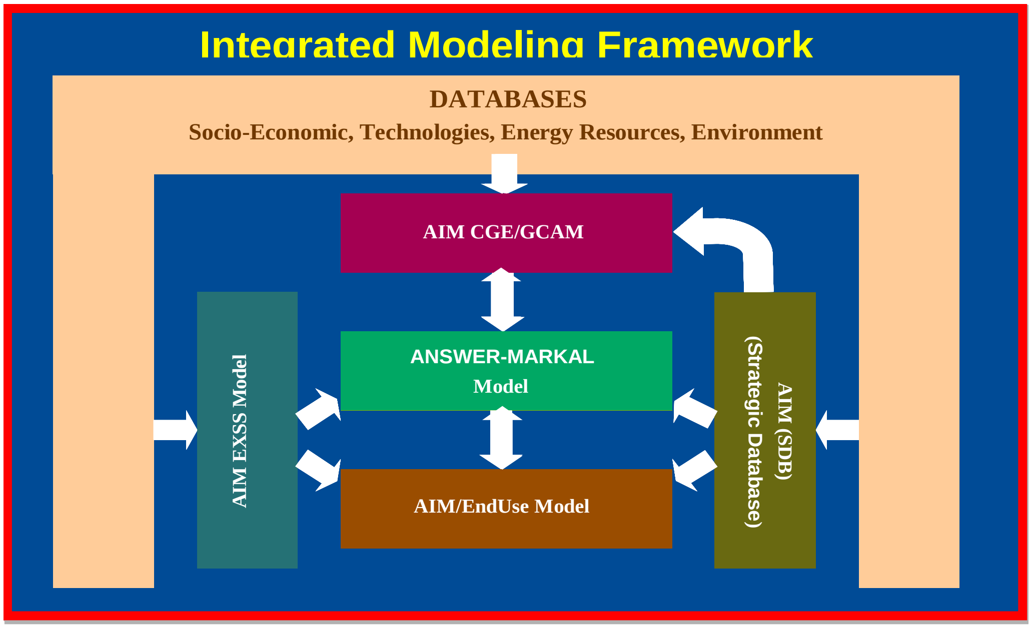
The LCS framework should also look at opportunities which create various kinds of co-benefits apart from direct GHG emission reductions. Such co-benefits, like improved air quality, provide an opportunity to minimize social costs of such a transition. It helps in achieving various developmental goals of the country and therefore, is in line with the concept of sustainable development.

3. Model Framework

The integrated framework proposed in Figure 2 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 will be 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 (Figure 2) 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 (AIM/ExSS & AIM/End Use Model), that help present the results with adequate graphic interfaces.

Figure 2: Integrated Soft-linked Model Framework



3.1 Brief description of component models

3.1.1 AIM-CGE

AIM/CGE is a top down, computable general equilibrium (CGE), model developed jointly by National Institute of Environmental Studies (NIES), Japan and Kyoto University, Japan (AIM Japan Team, 2005). The 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.

3.1.2 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. A detailed discussion of the model concept and theory is provided at the ETSAP website (Loulou, et. al., 2004).
MARKAL has been used extensively for modeling Energy Sector of India (Kanudia, 1996, Garg, 2000, Ghosh, 2000, Nair, 2003, & TERI, 2006). ANSWER is the windows interface for the MARKAL model (ABARE, 1999).

3.1.3 AIM/Enduse

AIM/Enduse is a technology selection framework for analysis of country-level policies related to greenhouse gas emissions mitigation and local air pollution control. It can also assist in energy policy analysis. It simulates flows of energy and materials in an economy, from supply of primary energy and materials, through conversion and supply of secondary energy and materials, to satisfaction of enduse services. AIM/Enduse models these flows of energy and materials through detailed representation of technologies.

3.1.4 AIM/ExSS

The AIM/Exss is a spreadsheet tool designed to calculate the energy balance table and CO_2 emission table with inputs such as service demands, share of energy and energy improvements by classifications of service and energy in the base and target year (NIES, 2006). The tool can be used for i) developing and designing preliminary LCS and SD scenarios ii) doing "what if" analysis iii) checking the consistency among the sectors iv) analyzing the impacts of countermeasures package and v) communicating with stakeholders.

3.1.5 GCAM

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.

3.2 Soft Linking

The framework (Figure 1) contains a top down model (AIM CGE/GCAM) which is soft linked with a technology selection model (AIM/Enduse) and a bottom up energy system model (ANSWER MARKAL). 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 AIM/Enduse model assesses the end use demands and technologies, and the ANSWER MARKAL model provides detailed technology and sector level energy and emission.

3.3 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).

4 Scenario Descriptions

The analysis considers three scenarios. The first scenario is the base case followed by 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.

4.1 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. This scenario assumes the future economic development along the conventional path. In case of 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 annual GDP growth rate of 8% for the 27 years (2005-32) matches with the moderate economic growth projections for India (GoI, 2006). The rate of population growth and urbanization follows the UN median demographic forecast (UNPD, 2006). This scenario assumes stabilization target of 650 ppmv CO_2e. The carbon price trajectory corresponds to Stabilization at 650 ppmv CO_2e concentration target or 550 ppmv CO_2 concentration stabilization target for the CCSP SAP 2.1a[5] equivalent scenario (Clarke et. al., 2007). The carbon price is $[6]3 per ton of CO_2 during the Kyoto protocol period and rises to a modest to $25 per ton of CO_2 in 2050 (Table 2).

4.2 Low Carbon Scenarios

4.2.1 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,

[5] US Climate Change Science Program Synthesis and Assessment Product 2.1a (CCSP SAP 2.1a) used three models - Integrated Global Systems Model (IGSM), Model for Evaluating the Regional and Global Effects (MERGE) and MiniCAM. Four GHG stabilization scenarios corresponding to CO_2 concentration levels of 450 ppm, 550 ppm, 650 ppm and 750 ppm were evaluated using the models (Clarke et. al., 2007).

[6] $ corresponds to 2005 US $

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.

4.2.2 Sustainability (SS) Scenario

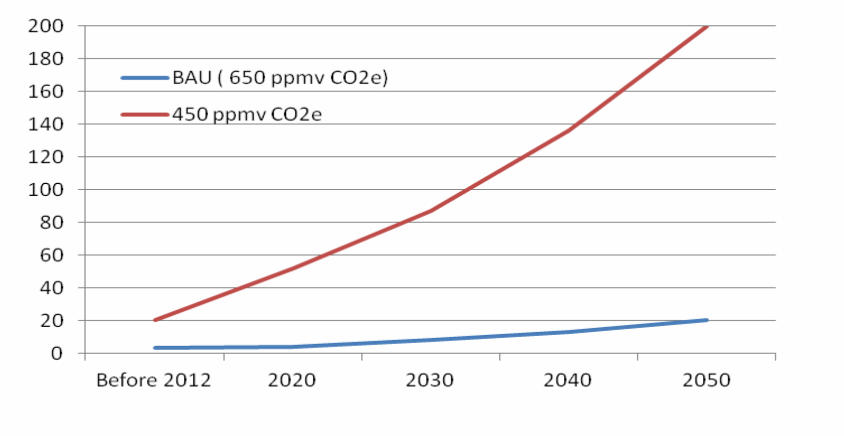
This scenario represents a very different world view of development as compared to the Base Case. The scenario follows a distinct 'sustainability' rationale, like that of the IPCC SRES B1 global scenario. The scenario perspective is long-term, aiming to deliver intergenerational justice by decoupling 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.

4.3 Scenario Drivers

4.3.1 Carbon Prices

Carbon price trajectory for base case scenario and carbon tax scenario are linked to CO_2e stabilization targets of 650 ppmv CO_2e concentration target and 550 ppmv CO_2e respectively (Fig 3). The price trajectories are obtained from outputs from global Second Generation Model (SGM) results (Edmonds, 2007). For the SS scenario the price trajectory is similar to the base case. However, India's cumulative carbon budget remains same as the cumulative emissions in Carbon Tax scenario.

Fig 3: Carbon price trajectory (US $ per ton CO2)



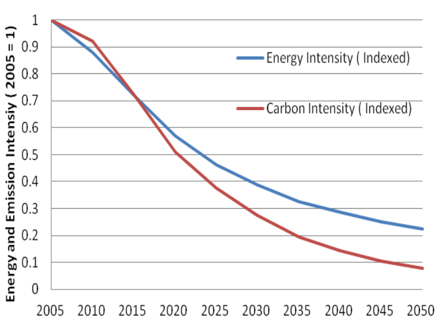
5 Results

5.1 Base Case - Energy & Emissions

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 (Fig 4).

However in the LCS scenario the carbon intensities are further moderated (Fig 5), 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.



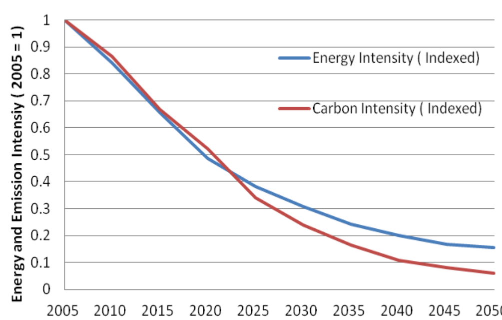


Fig 4: Energy/Carbon Intensity under conventional Fig 5: Energy/Carbon Intensity under sustainability

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 (Fig 6 & 7).

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.

Fig 6: Mitigation under conventional

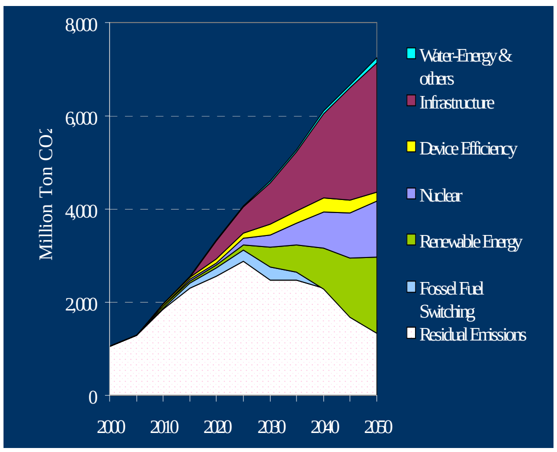
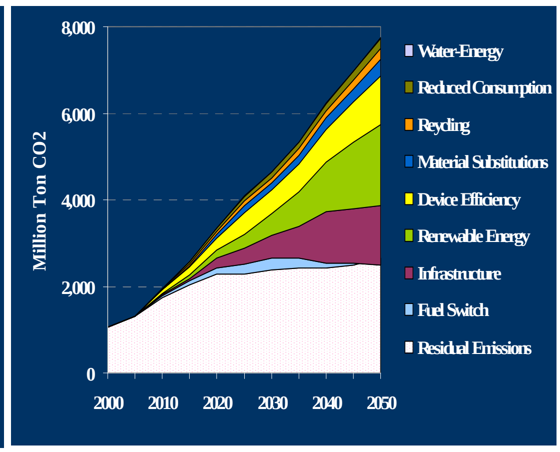


Fig 7: Mitigation under sustainable path



5.2 Low Carbon infrastructure & Water-Energy-CC nexus

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 economy 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. 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.

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), Mass Rapid Transit System (Metro) and other such urban infrastructures such as dedicated freight corridors 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, as an input to many such infrastructures. 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. 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.

Under the BAU scenario (Fig 8 & 9), it was found that coal based power generation is the main stay of the power generation pie. It was also found that the trajectory under BAU was heavily energy and emission intensive, with potential technological-lockins. local air quality.

Fig 8: Power structure under BAU

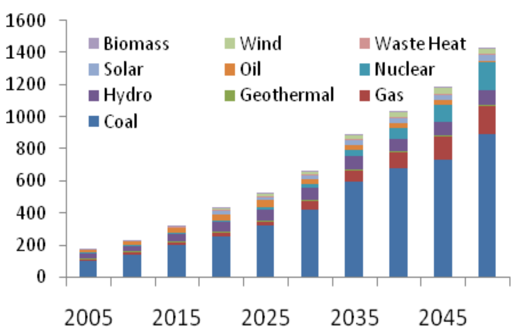
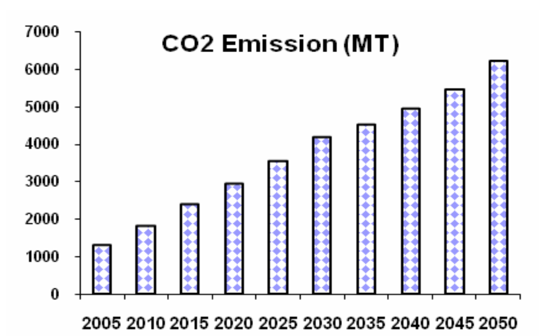
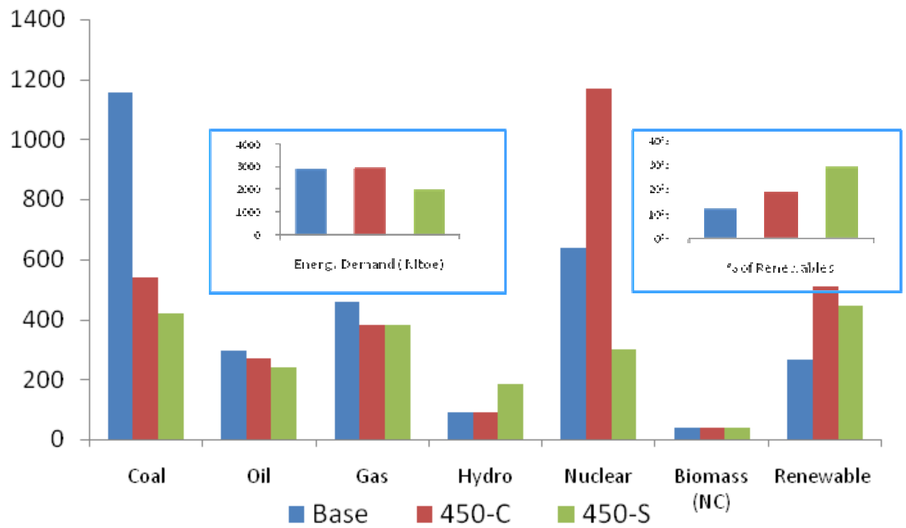


Fig 9: Emissions under BAU



However under the conventional development path (with carbon tax), significant investments were required on the supply side (in advance technologies like CCS, smart grid, electric vehicles, renewable energy). At the same time, we observed significant carbon decoupling but energy intensity was found to be similar to the BAU case. In the LCS scenario, investments were found to be necessary for demand side transitions (such as BRTS, metro) but there was significant carbon and energy decoupling observed. Thus the LCS scenario offered a significant co-benefit in terms of avoiding critical infrastructure lock-ins, enhancing energy security position and improving local air quality (Fig 10).

Fig 10: Energy structure under base, conventional and sustainable scenarios



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.

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 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. However , following a sustainable development trajectory we found significant decoupling of energy and CO_2 from water (Fig 11 & 12).

Fig 11: Energy-water decoupling (PJ/BCM)

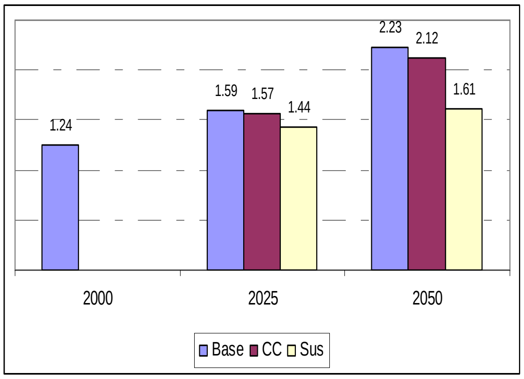
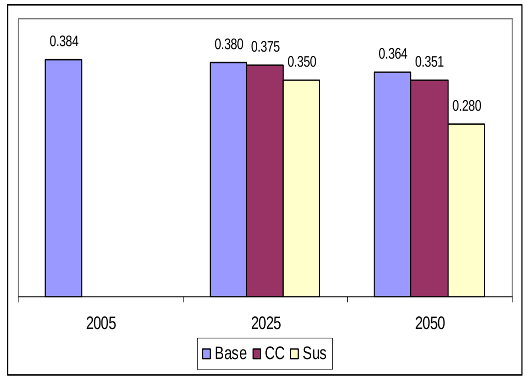


Fig 12: CO2-water decoupling (mt-CO2/BCM)



Low carbon scenarios following a sustainable pathway could mitigate nearly 4.5 bt-CO2 during 2010-2050 period in the water sector (Fig 13 & 14). However such a pathway provides a significant co-benefit of water savings which is under stress and is likely to intensify further.

Fig 13: Mitigation for water-energy under conv

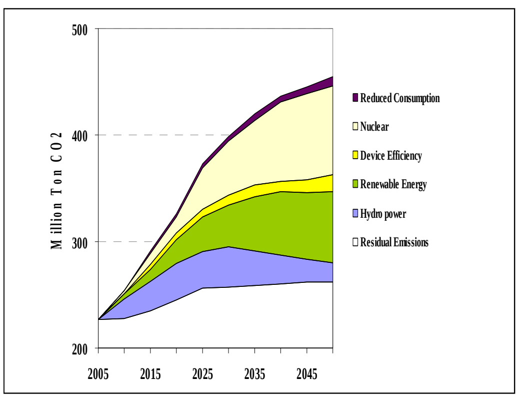
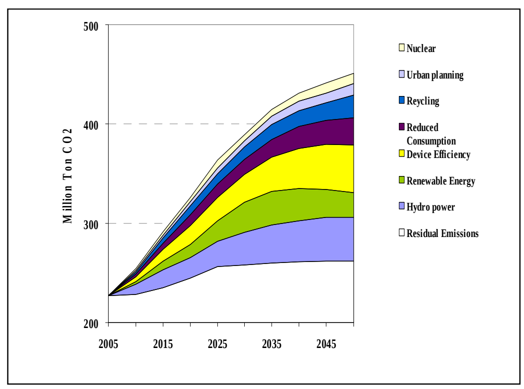


Fig 14: Mitigation for water-energy under sus



6 Low Carbon roadmap for Ahmedabad (a case study)

Ahmedabad is the seventh largest urban agglomeration (UA) in India, and the largest city in the state of Gujarat. The city plays a significant role in the economy of the state of Gujarat, accounting for almost 19 percent of main urban workers in the state.

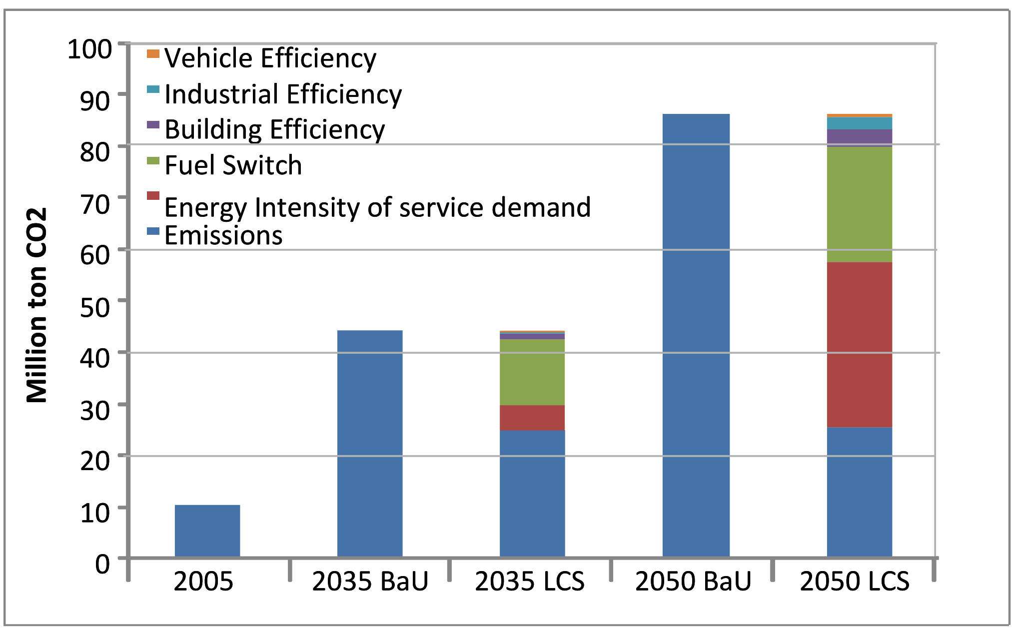
The city was founded in the year 1411 AD and is located on the banks of River Sabarmati. Ahmedabad gets its name from Sultan Ahmed Shah, who founded the city. Over the last 600 years, the city of Ahmedabad has come a long way, from what was developed as a cluster enclosed by a wall in 1456 AD. In the late 19th century, development started spilling over towards the northeast and southeast of the walled city.

Today some of the industrial activities that have flourished in the city over the last few decades include chemicals, pharmaceuticals, electronics, dyes and paints. Ahmedabad's status as an important centre of trade and commerce remains unchanged. The city also has a large market for consumer goods in the retailing sector. Several key high-growth industries such as textiles, pharmaceuticals and natural gas are already firmly anchored in Ahmedabad. The industrial centers around Ahmedabad are continuously experiencing expansion on account of economic growth. The economic base of the city is now shifting towards tertiary (service) sectors, which now account for more than 50% of total employment. Ahmedabad is also a major financial centre contributing about 14% of the total investments in stock exchanges in India.

This section articulates a low carbon vision for the city of Ahmedabad. The methodology involves deducing current socio economic, energy and emission parameters for the city using the base year (2005) data . This data has been methodically prepared using various approaches as enunciated in literature for various sectors. These parameters are used in conjunction with the future energy service demands, energy technology assumptions, and socio economic assumptions for Ahmedabad (population, etc) from the City Development Plan (CDP) and expert opinion, to obtain the target years (2035, 2050) socio economic and other assumptions.

In order to transit to a low carbon society in Ahmedabad, several countermeasures are required (Fig 15). It is interestingly observed from the model output that for such a transition in Ahmedabad, decoupling of economic growth and energy use emerges as the highest mitigation potential as compared to decarbonisation of energy. Besides, there is a substantial mitigation potential from fuel switch and energy efficiency. Specifically, this would mean improvements in energy intensity of economic activities, like reduction in energy service demand for industrial, transport and commercial sector, cleaner and greener power (renewable like hydro, solar and biomass), and promoting end-use device efficiency in the transport sector, industrial and residential sector.

Fig 15: Mitigation measures for Low carbon Ahmedabad city



The current selection of target years: 2035 and 2050 is done by keeping in mind the three time periods: Period up to 2020 (the terminal year of Post-Kyoto global carbon architecture period), by which many developing nations (including India) have promised voluntary emission reductions. Intermediate year of 2035, which gives an opportunity to check the progress made towards the long-term global commitments of GHG emission reduction by 2050. Period terminating in 2050, the year by which most of emission cuts are pledged by the developed as well as the developing world alike.

The idea of LCS is not committing to the 2 deg C target, but an aspirational attempt being made by India. However this target is subject to adequate financial and technological commitment as agreed upon under the Framework Convention on Climate Change and also by the declaration of world leaders of the major economies. A city like Ahmedabad is also participatory to these global efforts but would need financial, technical and other (carbon finance) instruments, as agreed upon under the framework convention on climate change, to achieve these aspirational targets. These efforts do not under any circumstance undermine the importance of various bilateral efforts in achieving the LCS targets.

7. Conclusions: Achieving LCS with Sustainability

Many of India's development choices today and in the near future will determine its carbon emissions pathways for the long term. The paper analyzed two pathways for India's transition to 'Low Carbon Society'. The pathways correspond to two different paradigms. The first, which follows conventional development paradigm, treats the carbon mitigation as an issue to be treated at the margin of development decisions through carbon centric market efficient instruments like carbon tax or permits to decouple the carbon emissions from the economy. This pathway has little direct implications for major development choices, including aggregate energy demand. The alternate paradigm considers low carbon transition as an issue embedded within the larger development issue of transition to a 'sustainable society'. The strategy in this case is to mainstream carbon emissions mitigation by embedding low carbon choices within the numerous development decisions. Thus, the low carbon society transition through 'sustainability' route decouples economic growth not only from carbon but several key resources, including energy. In this scenario, weaker carbon price signals would be an adequate driver for low carbon transition. The mitigation signals would manifest through a diverse portfolio of technologies, with relatively little dependence on pure carbon mitigation technologies like CCS which could have negative development dividends.

Renewable energy sources emerge as a preferred choice for carbon mitigation in both 'Carbon Tax' scenario as well as 'Sustainable Society' scenario, though their drivers are different. In the CT scenario, the relative price difference between renewable and fossil fuels is reduced by a carbon tax which enables faster penetration of renewable. In a sustainable society, the co-benefits of renewable energy as well as higher deployable potential and lower transaction costs due to cooperation among the stakeholders propel the penetration of renewable resources. Such low carbon transition would hence be accompanied by improved local environment and energy security, which are the key issues a rapidly developing large economy like India would need to address regardless of carbon mitigation..

Even in a low carbon world, there will be significant climate change to which society must adapt. In a large developing country like India which would see transition to higher incomes in the twenty first century, the conventional path would exert enormous crunch on natural resources and ecosystems that could be large enough to impede the global economic growth. In contrast, prudent use of natural resources in the global 'sustainability' vision would reduce resource competition and conflicts, reduce prices of resources and permit sustained higher economic growth. This, together with a greater emphasis on social and human capital, under sustainability vision, would increase adaptive capacity to counter the adverse impacts of climate change.

Finally, in a globalizing world, a single country cannot decide a development pathway that is significantly different than the global trend. The advancement of knowledge stocks on which the future technology transitions occur depends on the global efforts. Besides, the global cost-effectiveness of carbon mitigation requires equalization of carbon price across nations. In our analysis of SS scenario for India, a significantly lower carbon mitigation shadow price is needed to achieve the same cumulative mitigation compared to the carbon tax needed if the global as well as India's economic development followed a conventional path. A globally efficient low carbon transition would require harmonization of development visions across nations. The sustainable global development, led by the industrialized nations, thus would be pre-condition for sustainable development in developing countries and so also for aligning the low carbon society transition in developing countries with their sustainable development goals.

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