INTEGRATED ASSESSMENT OF WATER-ENERGY NEXUS IN THE CONTEXT OF CLIMATE CHANGE

Dr. Subodh K. Sharma
Adviser
Ministry of Environment and Forests, Government of India

Dr. Amir Bashir Bazaz
Expert Consultant
India's Second National Communication

ABSTRACT

Typically the energy-climate nexus has been studied as a mitigation problem, the water-energy nexus as a resource & development issue and the water-climate nexus from the water supply dimension. This paper examines the water-energy nexus, using an integrated assessment framework, in the context of climate change. An integrated modeling framework is developed. Besides secondary data sources from strategic and modeling databases, selected case studies and project specific data was used to augment the database. The long-term assessment (till 2050) is conducted using a scenario-based approach, by integrating and augmenting the existing bottom-up energy systems model at the national level and an energy accounting model at the city level.

The globally agreed long-term climate stabilization target is to limit the temperature rise within 2^oC which is assumed to be the target to assess future water-energy-climate change nexus in this research. The research though examines other scenarios reported in literature. Results from scenario analysis show that there would be a reduction in the electricity demand for water across all sectors, significantly more in the scenario around the 'sustainability' framework. This scenario results show a continuous improvement in the intensity of energy usage for water (improve at the rate of 5.34% CAGR for the period 2005-2050) and that this energy demand being increasingly met from hydro power sources (27% of electricity generated in 2050), facilitated by increased South Asia energy cooperation. Thus policies focusing on facilitating demand transitions, end-use efficiency improvements, improved urban planning, recycling measures & hydro power growth align the water-energy-climate change nexus favorably with sustainable national development.

Energy accounting modeling analysis at the city level, for Ahmedabad city, uses the target of limiting CO_2 emissions to the base year (2005) level or below. The scenarios in this context, however; incorporate water-climate change assessment reported in literature. The model results show that the favorable alignment of the water-energy-climate change nexus is facilitated by focusing on policies aimed at energy intensity improvements. Specific policies, in the context; are aimed at demand reduction, energy efficiency improvement and integrated urban planning. This city level modeling exercise is used to delineate policies that are considered in the assessment of the water-energy-climate change nexus at the national level.

The key methodological contributions of this research include integration of the water-energy-climate change dimensions in an integrated policy modeling framework and construction of national and city level databases for water-energy sector. The key policy contribution of the research is the delineation of a policy road map to address the water-energy-climate change issues in an integrated manner.

1. Introduction and Context

Growing international literature has pointed towards the damage accrued to the environment due to anthropogenic emissions. The various manifestations being increases in global average surface temperature, increases in global average sea level, and decrease in the northern hemisphere snow cover (IPCC, 1990; IPCC, 1995; IPCC, 2001; IPCC, 2007a,b; Stern Review, 2006). The Stern Review (2006) & other publications have also assessed the various costs and risks to society. Recently the Fourth Assessment Report (AR4) of the IPCC[1] (IPCC, 2007a, b) has assessed the changing profile of the environment, and has come out with glaring evidence that points towards the extent of changes taking place in the various physical systems (snow, ice, hydrology, and coastal processes), in the biological systems (terrestrial, marine and freshwater) and also changes in the surface temperature profile of the world's different regions. For eg, there has been shrinkage of 2.7% per decade of ice cover since 1978 (affecting fresh water resources of the world) and also global changes in precipitation.

Consequent to the changing climate, AR4 (IPCC, 2007a, b) has identified that it has affected many sectors in the past decades and is bound to affect many sectors & activities significantly in the future. One such sector where the climate change impacts are expected to be the most severe is the water sector and AR4 (IPCC, 2007a, b) has identified that there is significant evidence that climate change would exacerbate water resource stresses. It has identified that water scarcity would be imminent, and would be intensified via population growth and higher standards of living and therefore would be affecting many people. For eg, AR4 (IPCC, 2007a; citing Gupta et al., 2004), reports that gross per capita water availability in India is projected to decline from 1820 m^3/yr in 2001 to 1140 m^3/yr in 2050 (these estimates differ slightly from the GoI[2] estimates). A Central Water Commission (2001) study (as cited in AR4, 2007a) has reported that India would reach a water-stressed status by 2025 (the per capita availability of water less than 1000 m^3, owing to population growth & higher demand). Since water is used as an input for many end-use sectors, AR4 (IPCC, 2007a) has reported that due to increased chances of water scarcity there would be effects on related sectors; crop yield, livestock production, primary energy (hydropower). These climatic-change induced impacts are from the supply side, where changes in the precipitation pattern alters fresh water availability and therefore, impacts human population and dependent sectors alike. On the demand-side also, water-related impacts would be evident. For eg, the increasing temperature profile would increase the rate of evaporation of water from farm fields and therefore impact irrigation water demand; the increase in space conditioning would exert an additional stress on the electricity demand and thereby intensify the cooling water needs for essentially a fossil-based electricity supply system.

2. Response to Climate Change

As a response to climate change, IPCC and other researchers have considered two actions: mitigation of climate change by reducing greenhouse gas emissions & enhancing sinks, and adaptation to the climate induced impacts. Assessment of current commitments have confirmed non-meeting of GHG stabilizations (IPCC, 2007a, b) in the atmosphere and therefore, adaptation has become inevitable. However there are limits and barriers to adaptation as well (Scheffer et al., 2001; Steneck et al., 2002; ToI, 2006; Oppenheimer et al., 2006). Even if the limits are removed, still the adaptation required would not be sufficient enough in the long-run to stem the impact of climate change. Therefore, the contemporary belief among IPCC and other researchers is that it is no longer a question of mitigation or adaptation but 'mitigation and adaptation' together. Some of the issues regarding mitigation and adaptation have been explicitly treated by IPCCs AR4 (IPCC, 2007a, b). The central conclusion of the assessment is that both adaptation and mitigation can help reduce risk to society. Explicitly stating, according to AR4 (IPCC, 2007a), "*climate policy is not about making choices between the two, but where key vulnerabilities are to be addressed adaptation is necessary and where adaptation alone cannot handle the magnitude of climate change and where adaptation requires high social, environmental and economic costs, mitigation is the best strategy*".

On the other hand, adaptation and mitigation can have positive or negative effects on each other's effectiveness. The nature of such an interaction depends on local conditions. Some interactions are direct (involving the same resource base like water) while others are indirect (for eg, financial allocations for the water sector). There is a two-way relationship between mitigation and adaptation: mitigation affects adaptation (if there are regions with hydropower potential, there might be competition for water use if irrigation is considered to be the best coping strategy [provided water use for power generation and irrigation is not mutually exclusive]. On the other hand, a deliberate strategy to reduce hydro power generation could have a negative effect on economic development (shifting towards much costly power generation options). On the contrary, adaptation affects mitigation: the principal interaction or conflict being that due to increased adaptation there is an increase in energy use, which interferes with mitigation efforts (provided the energy source is from a carbon-intensive resource).

Adaptation to the changing hydrological cycle and water availability would also require continuous energy inputs. For eg, in water scarce regions; increasing reuse of wastewater and treatment, deep well pumping and large scale desalination would require significant amount of energy. Adaptation response not only effects energy use but also energy supply. Contribution of hydropower would continuously decrease if competing uses of water

[1] Inter-governmental Panel on Climate Change
[2] Government of India

is given priority. There are choices to be made between flood protection during high water period and water storage during low water period. There are also unavoidable clashes between water supply, hydropower, flood control, and minimum flow requirements (required to maintain ecological balance and water quality). In general, adaptation activities might involve additional inputs: investments (protective and other infrastructure), material (fertilizers, pesticides) or energy (irrigation pumps, air conditioning) and thus may run counter to mitigation efforts. This is particularly true if the energy is drawn from a GHG emitting source.

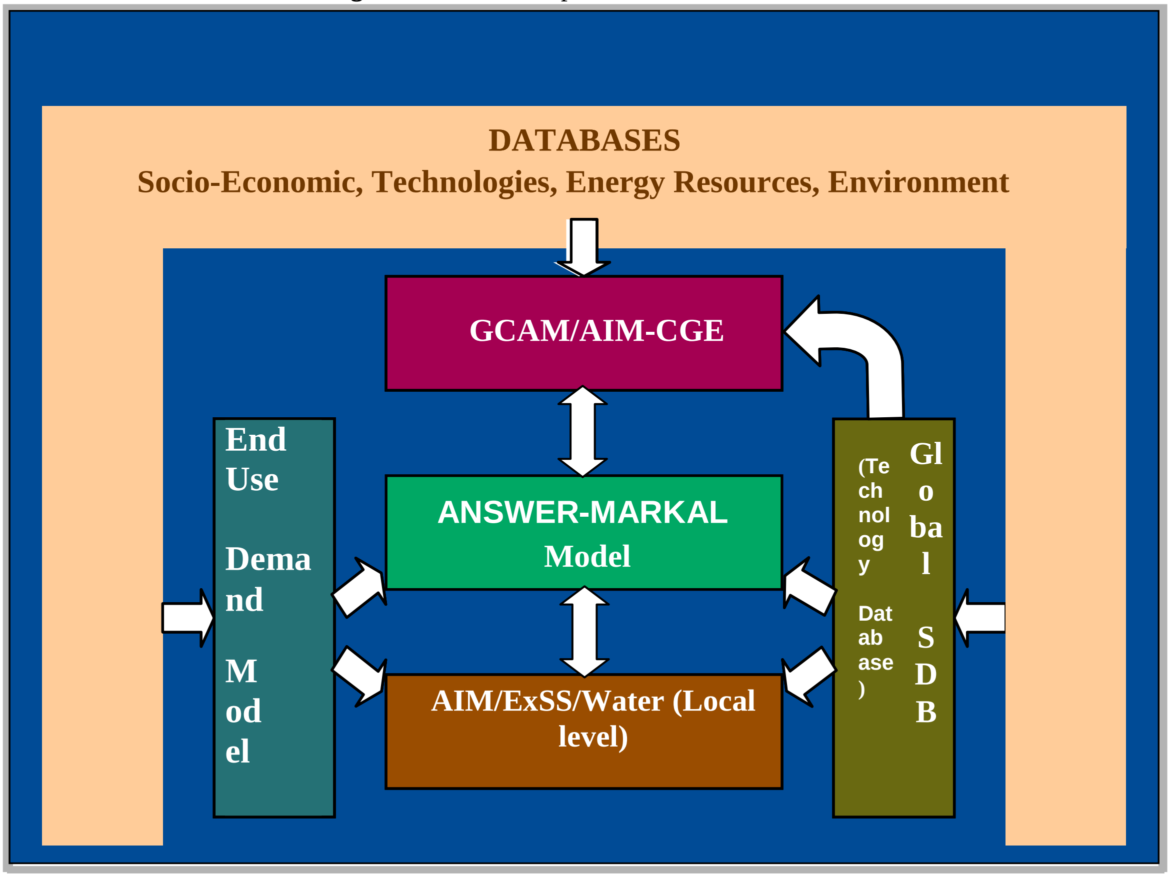
Last but not the least, AR4 (IPCC 2007a,b) makes an interesting admission that enhancing of society's response capacity through the pursuit of sustainable development pathway is one of the most significant ways of promoting both adaptation and mitigation, which in turn also helps in facilitating effective implementation of both the options. The water sector is linked to mitigation (e.g. hydro power) as well as to adverse impacts (e.g. increased rainfall variability and glacier melt). Water-energy-climate change nexus is therefore a central theme in the century scale studies of environmental impacts from human activities. Contemporary research has focused on sustainable development (SD) as a key concept in addressing the issues at the core and interface of this nexus (IPCC, 2007; Halsnaes et al., 2007). This study posits the inquiry of the water-energy-climate change (WECC) nexus within the paradigm of sustainable development. SD has been variously defined and operationalized by researchers and practitioners but in this study it is assumed in terms of energy use and CO_2 emissions.

3. Methodology

The complex interaction of energy, economy and environmental parameters such as macro-economic data, demographic characteristics, energy usage, technological penetration and use & carbon emissions is best captured through either top-down models or bottom-up models (Shukla, 1996; 1995). While bottom-up model, as the name suggests, is technology-intensive and disaggregated, the top-down models are instead economic-centric and aggregate models (Bohringer and Rutherford, 2006). In the bottom-up model, the inputs are intensive: technology, resources and demand estimates among others, while in the top-down model the inputs are macro indicators such as economic growth and price feedbacks (for details see Bohringer, 1998). The Indian modeling scenarios has been active in both these two paradigms. However, Market Allocation (MARKAL) – a bottom-up model, has been extensively used for modeling the Indian energy sector (see Kanudia, 1996; Garg, 2000; Nair, 2003; Dhar, 2008).

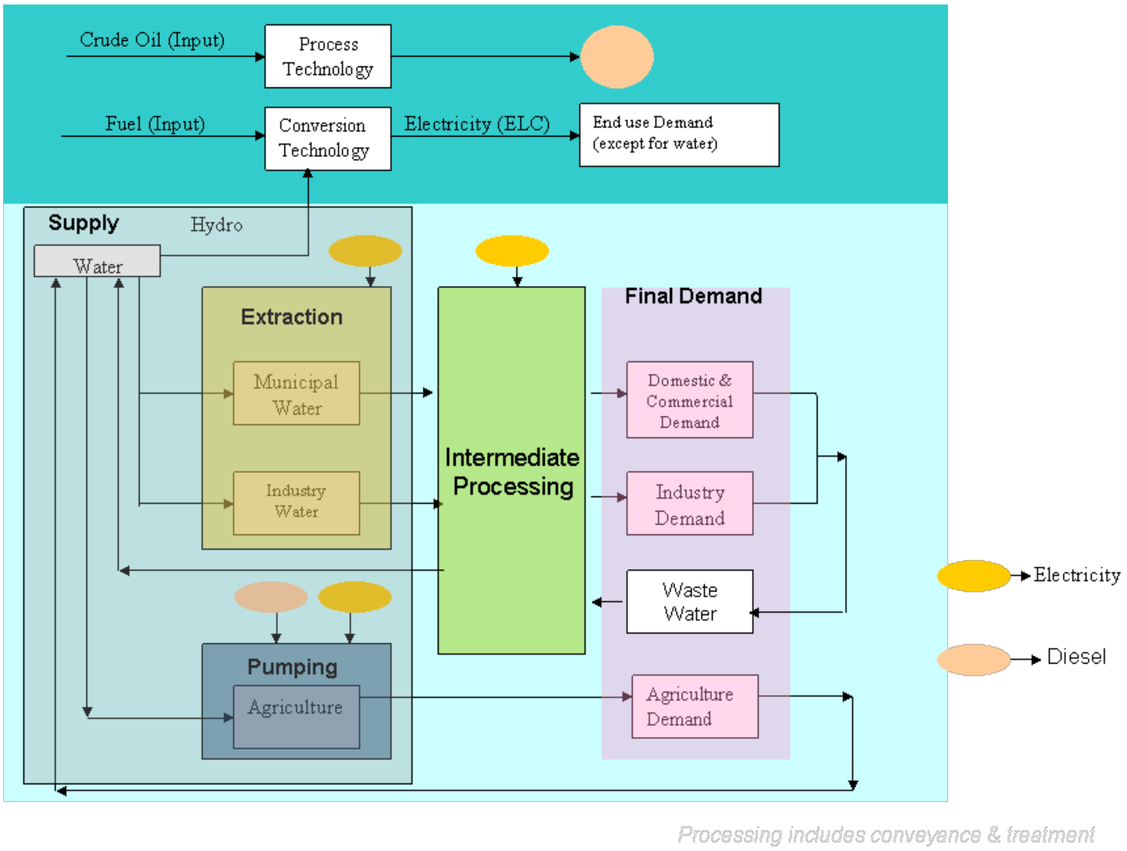
For this research, bottom-up MARKAL model is used. The MARKAL model is a bottom-up driven, energy systems cost optimization model. The user inputs the structure of the energy system to be modeled, including resource supplies, energy conversion technologies, end use demands and the technologies used to satisfy these demands. The user must also provide data to characterize each of the technologies and resources used, including fixed and variable costs, technology availability and other performance parameters. Such a user characterization of various technologies into different grades enables to incorporate differing characteristics such as the risks associated with nuclear power plant. Such risks are manifested in the form of the different cost structures in the graded representation. MARKAL then calculates, using linear programming techniques, the least cost way to satisfy the specified demands, subject to any constraints the user wishes to impose. Outputs of the model include a determination of the technological mix at 5-year time intervals into the future, estimates of total system cost, energy services (by type and quantity) and estimates of greenhouse gas (GHG) emissions among others. The future time-period is usually a longer period (in this case 50 year horizon). Such a long time-period is considered because many of the power plants remain into the energy system for 30-40 years before retiring and therefore, for analyzing its impact such a longer time-period is chosen.

Fig 1: General description of the MARKAL model



Since MARKAL is an energy systems model, certain adaptation of India MARKAL is necessitated for this research (Fig 2). In this research we are trying to model energy usage in the water sector. Therefore we need to modify the Reference Energy System (RES) to include water in the model to finally arrive at a Reference Water Energy System (REWS). This modification involves activities at two levels. Firstly, the water (both surface and ground water) is considered to be an energy source and secondly, the energy interface of water is modeled through a feature of 'process' given in the model. In order to understand the interface, the following simplified diagram would help in that direction. This is the principal modification carried out in the India MARKAL system. The end use energy and corresponding water demand is estimated based on certain accepted water demand projections, calculations done by author, norms set for water consumption at domestic level (urban) and the corresponding energy usage. It must be noted here that due to less intensive energy use interface in rural water systems, only urban water supply systems is modeled in this research.

Fig 2: Setting up the Reference Energy Water System in India MARKAL



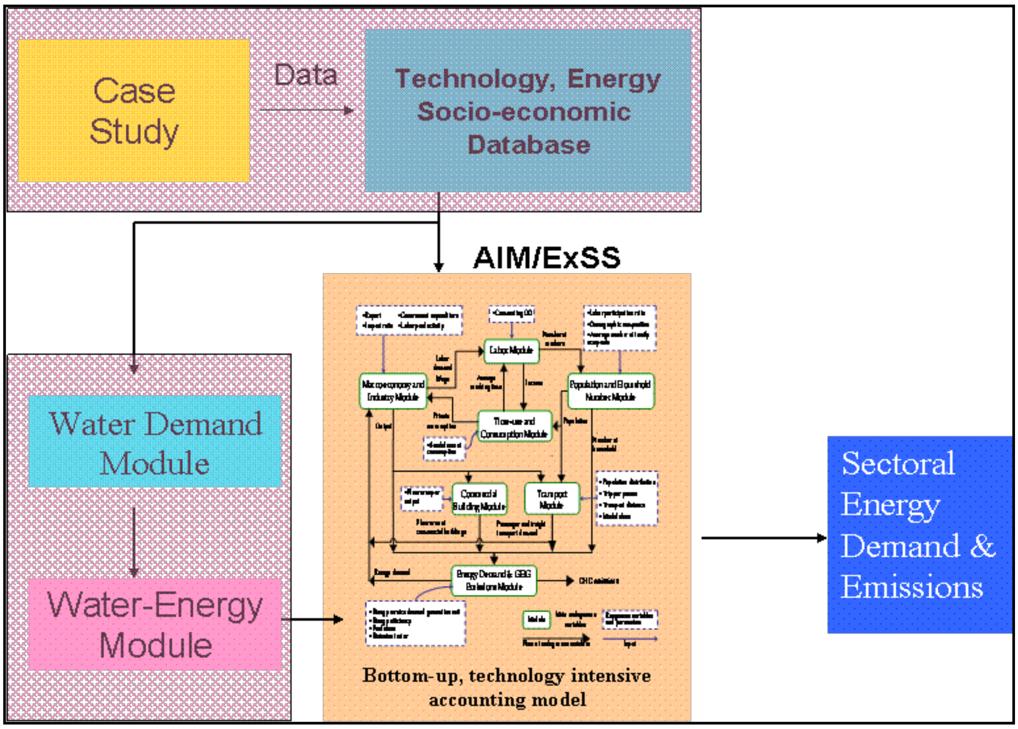
3. Scenario development

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (IPCC, 1994). Recent work on scenario development, especially the IPCC Special Report on Emission Scenarios (SRES) (Nakicenovic et al., 2000) provides the theoretical underpinnings of the comprehensiveness of this assessment method for the estimation of future. Scenario analysis has been a widely accepted approach to model complex and uncertain future though provisioning of a robust framework (see for egShukla, 2006).

4. City level Assessment Methodology

For the city level assessment, a bottom-up style energy-environment model is used. This model was developed by Kei Gomi at University of Kyoto (Yoshimoto et al., 2009). The model is generally an accounting model, but incorporates certain assumptions to give us the flexibility regarding modeling alternate scenarios. Refer Fig 3 for a detailed description.

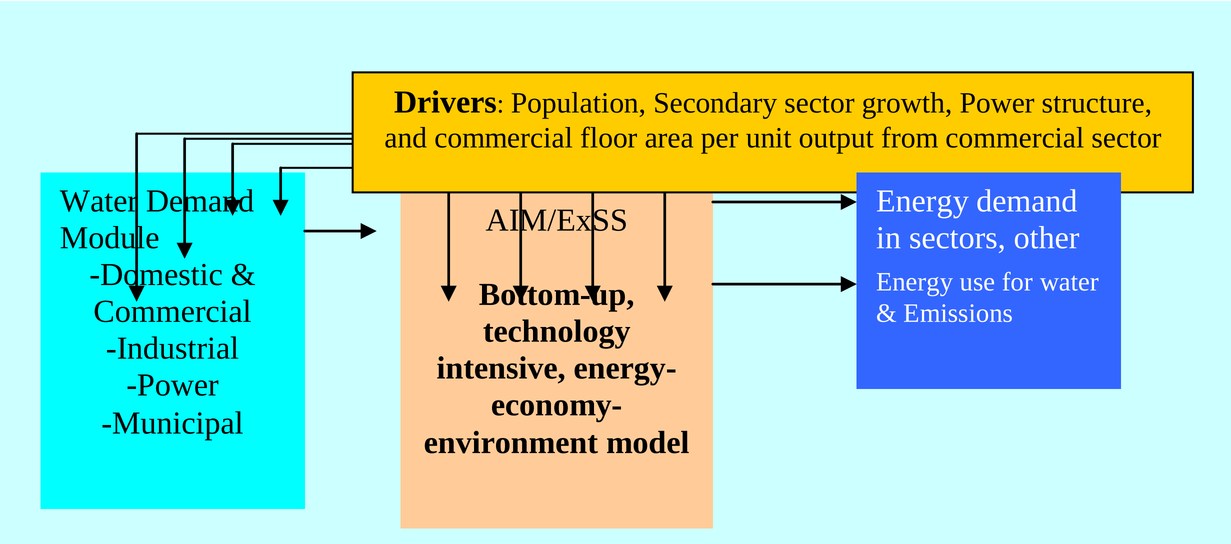
Fig 3: Detailed description of the AIM/ExSS Model



The model has various modules like the transportation module, the building sector module, the commercial sector modules and the energy sector module. This model has seven blocks with input parameters, exogenous variables and variables between modules. AIM/ExSS is essentially a system of simultaneous equations. Given a set of exogenous variables and parameters, solution is uniquely defined. In this simulation model, only CO_2 emission from energy consumption is calculated, even though, ExSS can be used to estimate other GHG and environmental loads such as air quality. This model enables us to consider viewpoints of regional economic development to estimate energy demand and CO2 emissions.

This model is adapted and modified for assessment of the water-energy nexus at city level. The modification is done via soft linking the drivers of energy for water in the various sectors. The adapted and modified AIM/ExSS model, termed as AIM/ExSS/Water Model, is described in Fig 4. Such an adaptation helps us in estimating the magnitude of energy usage for water and also helps in assessing the impact of this magnitude in alternate climate-centric scenarios. In order to use the exogenously and endogenously built parameters, we have chosen population growth as the driver for water demand in domestic sector, commercial floor space area per unit output of commercial sector as driver for commercial sector water demand (included in the domestic sector) and secondary sector growth rate as the driver for industrial water demand. Power sector water demand is assessed through following the NCIWRD norms (NCIWRD, 1999a; 1999b), and based on the existing and future power structure of the city.

Fig 4: Modified AIM/ExSS Model – the AIM/ExSS/Water Model



The methodology of AIM/ExSS/Water starts with collecting information about the current socio-economic state of the city. This set of information comprises of many elements, such as population across age classes, total population, type and number of households, and the most fundamental of all, is the base year energy balance table. Base year in this study is considered as 2005. Image of the future is important to ascertain the future state of society and economy. Future is defined in terms of the target year under study. Having chosen the target year, future image of the society (qualitative and quantitative scenario) is assumed. The assumption about the state and nature of future society is an outcome of reviewing literature and expert consultations.

Having decided about the future time period, a qualitative storyline about the future of the society in that time is to be visualized. All the quantitative indicators for the same will mimic the future societal image. For eg; one might argue that in future, incomes would increase to such a level that there will be a greater ownership of home appliances. Another example is that the future population growth would be to such a level, that it would warrant expansion of the city limits, and therefore greater per capita distance travelled by an average inhabitant of the city. Not only the image of future society is considered but also the inclusion of all relevant and foreseen policies is essential to quantify societal indicators. For eg, the government must have announced certain policies, and therefore these policies should be included in the image of the future society, even if it takes some time to fully operationalise.

Having made the qualitative assumptions about the future society, translation of these qualitative indicators into quantitative indicators is essential. Since the model is an economy wide model, certain basic steps have to be followed to make quantitative assumptions about the future society.

4. RESULTS

The result is analyzed two different levels: national level assessment as well as city level assessment. Bottom-up type energy-environment model is used to ascertain the evolution of the water-energy nexus in the future. Two models: India MARKAL model and modified AIM/ExSS model (AIM/ExSS/Water) is used for the assessment of the water-energy nexus. It is found that the Water-Energy nexus (WE nexus) increases in intensity (as a ratio of total energy used per unit of water use). Secondly, it is found that the power supply structure in the country would be fossil-dominated in the future as well and therefore, a major portion of country's power needs would not be satisfied by harnessing the water available in the country.
The emergence of the global externality of carbon has put an extra strain on the resources of countries. The increase in emissions profile worldwide has resulted in a universal proclamation towards migrating to a sustainable growth trajectory, which is less-carbon intensive at the same time. India is also aligned with the global carbon regime and is doing its bit in terms of mitigating carbon as well as adapting to the impacts due to the changing carbon stock in the atmosphere (promotion of nuclear technology is one manifestation of its carbon centric strategy). India is following a sustainable development pathway to respond to the global carbon externality and also, not compromise on its growth targets. This question is answered by following a scenario-

based approach. Two scenarios (for national level assessment): climate-centric and sustainability centric are chosen to distinguish between two key approaches i.e. a pure carbon reduction centric approach and a sustainable development approach. India MARKAL is used for answering this question at the national level. At the city level also, using AIM/ExSS/Water model, two alternate scenarios across different time scales are constructed to analyze the alignment of the global carbon regime with city level priorities. The following table (Table 1) summarizes the key results of scenario analysis for national level assessment.

Table 1: Evolution of the water energy nexus at national level – alternate scenarios

S.No.	Indicator	Base year (2005)	2050 BAU	2050 Climate centric scenario	2050 Sustainability scenario
1	Total power generation (PJ)	3156.3	24410.3	23342.7	16635.0
2	Hydro power generation (% of total)	13.0	4.9	8.0	27.3
3	Renewables power generation (% of total)	1.6	2.9	26.6	20.6

Fig 5: Share of nuclear power (%) – All scenarios

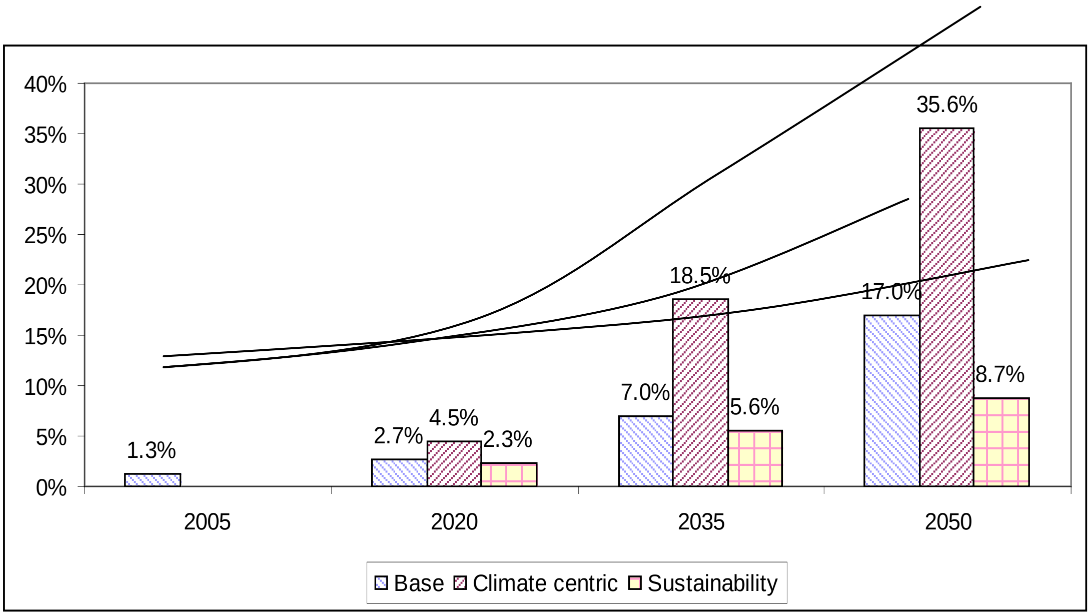
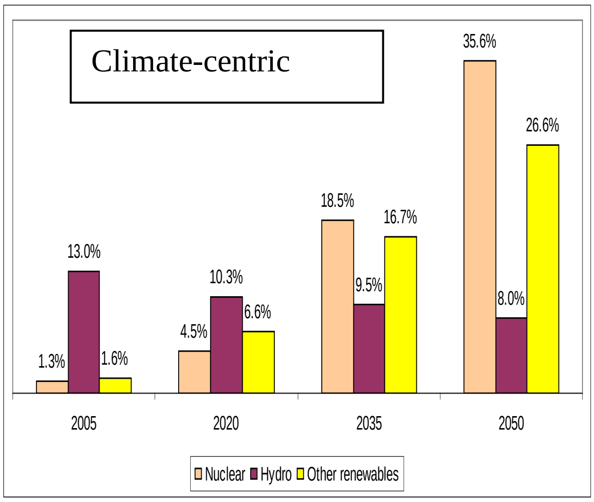


Fig 6: Share of nuclear, hydro and other renewables – alternate scenarios



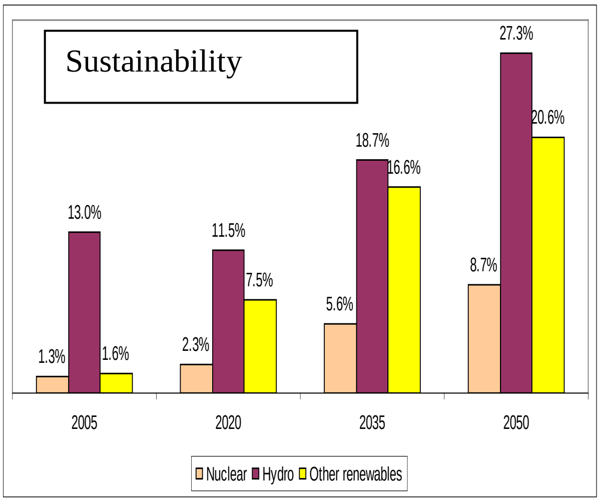
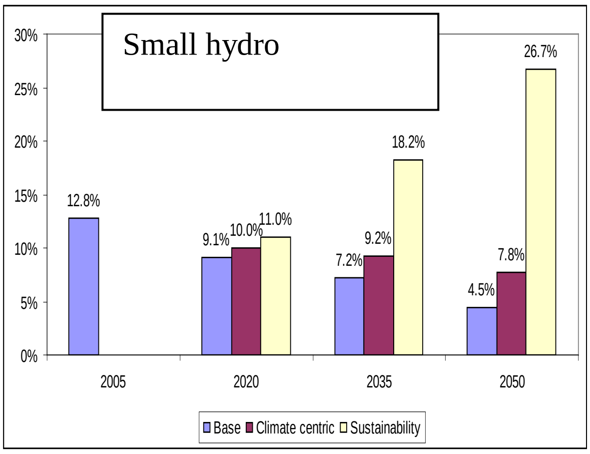
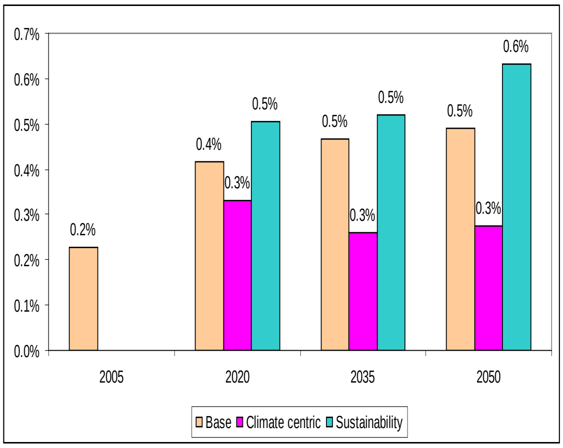


Fig 7: Large and Small hydro share – across scenarios





It is clear from the above tables that sustainability principles align the water energy nexus favorably. There are two significant aspects of the sustainability scenario: firstly, there is a reduced demand of electricity and secondly, this demand is met with from renewable and clean sources of energy. The shift in the usage of water for energy (small and large hydro) is more prominent in the large hydro sector (due to increased regional cooperation) while more pronounced penetration of small hydro is taking place in the sustainability scenario compared to climate-centric scenario. The carbon emissions target for the country is achieved from the climate-centric approach as well (i.e. alignment with global carbon regime) but the focus on climate-centric aspects has led the shift towards more of nuclear energy, which is zero-carbon source of energy but has implications for energy security in terms of the dependence on nuclear fuel. Moreover, due to measures on the demand side, there is a significant reduction in the WE nexus across all sectors. This trend is encouraging from India's energy security position and the changing nature of the electricity sub-sector in its structure, has positive impacts on the environmental side as well – carbon emissions. The reduction in the WE nexus due to a mix of supply and demand side measures help in minimizing risk to the agriculture sector and thereby decreasing vulnerabilities in the sector. It also helps in enhancing food and livelihoods security and also, helps in poverty alleviation. The reduced dependence on pump-based electricity and the clean form of the electricity used, reduces the need for encouraging price distortions in the electricity sector, reduces the subsidy burden of the government (thereby frees financial resources for other pressing needs) and also, helps in creating a uniform market in the electricity sector (removing sub-markets plagued with imperfections). The climate-centric scenario however, does result in reduced WE nexus but this reduction does not reduce power demand and has more reliance on nuclear energy to meet the energy needs of the country.

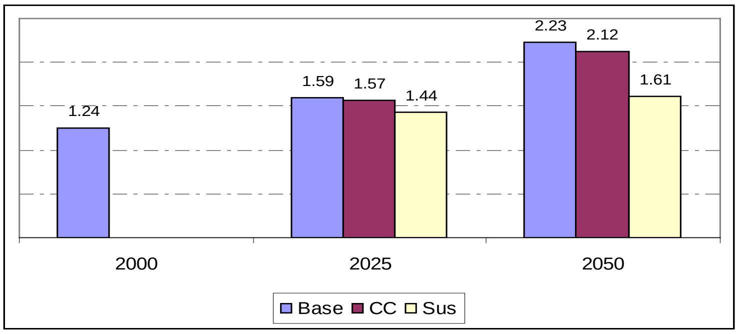
At the city level (Table 2), the climate scenario does align the WE nexus favorably and the policies that result in such a favorable alignment are centered on demand reduction, energy intensity improvements and also, at local level measures such as augmentation of water supply through restoration of water bodies & reduction in T&D losses.

Table2: Evolution of the WE nexus under various scenarios, at city level

S.No.	Indicator	Base year (2005)	2035 BAU	2035 WECC scenario	2050 BAU	2050 WECC scenario
1	Energy use in water - Domestic - Industry - Municipal - Sewage - ***Total***	9.04 0.85 0.65 11.35 ***21.89***	12.76 7.96 0.60 25.66 ***46.97***	10.47 6.52 0.49 21.04 ***38.52***	18.91 16.33 0.86 44.68 ***80.77***	8.70 7.51 0.39 20.55 ***37.16***
2	Water demand (MLD) - Domestic - Industry - Municipal - Power - ***Total***	612 81 44 33 ***771***	865 763 40 73 ***1741***	***1936***	1282 1565 58 164 ***3068***	***2252***
3	Energy intensity of GDP (ktoe/Bn INR at 2005 prices)	6.05	3.07	2.50	2.33	1.05

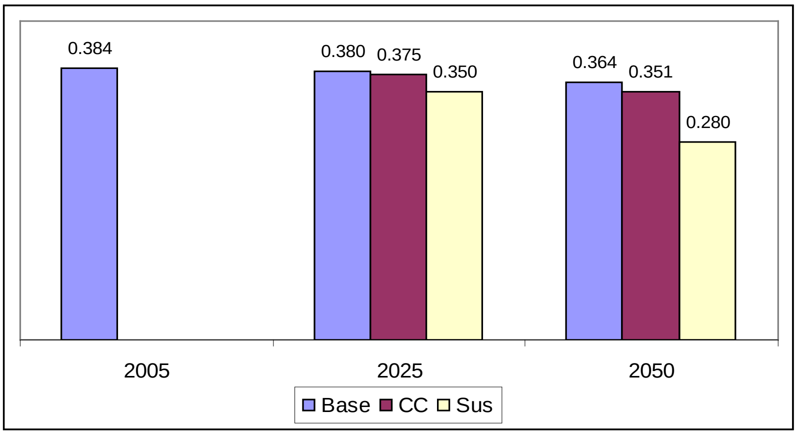
In totality, two striking aspects emerge from this analysis. The first pertains to the decomposition of the water-energy nexus under climate change scenario and the second, pertains to the emissions profile. On the former front, we find that there is a progressive decrease in the WE nexus intensity with respect to water usage across the economy. This decrease is more pronounced in the sustainability scenario due to both demand as well as supply side transitions.

Fig 8: WE intensity wrt water used - trends (PJ/BCM)



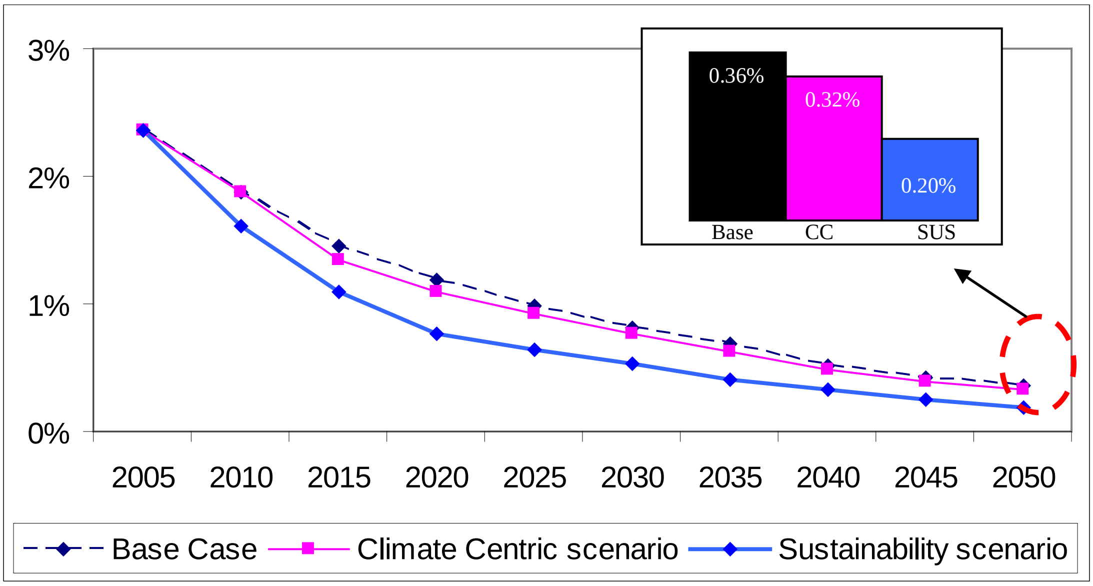
Secondly, it is found that the sustainability scenario results in a greater de-carbonization with respect to water use vis-à-vis the base case and climate-centric scenario. The policies and programmes of the GoI result in a decreasing trajectory of emissions due to energy use in the water. The sustainability scenario aligns well with the global carbon regime as well as provides a wider option in managing the WE nexus in the Indian context.

Fig 9: Carbon intensity of energy use for water across scenarios (mt-CO2/BCM)



As shown in the graph, the WE intensity improves at a CAGR of 4.1% under the BAU scenario and improves at a CAGR of 4.34% in the climate-centric scenario but in the sustainability scenario, it improves at a rate of 5.34% CAGR (aligning the nexus favorably with climate change).

Fig 10: Energy intensity of water wrt GDP (PJ/billion INR at 2005 prices)



Pursuance of policies on the 'sustainability' dimension helps in achieving a transition in the carbon emission due to WE nexus through widening of the options; with the total cumulative mitigation potential of 4.24 bt-CO2 during the analysis period. From the perspective of water consumption and the overall perspective of enhancing water security, the following figure depict the water consumption trends in the power sector, owing to the imposition of the alternate scenarios.

Fig 11: Trends in water consumption for power sector across scenarios (BCM)

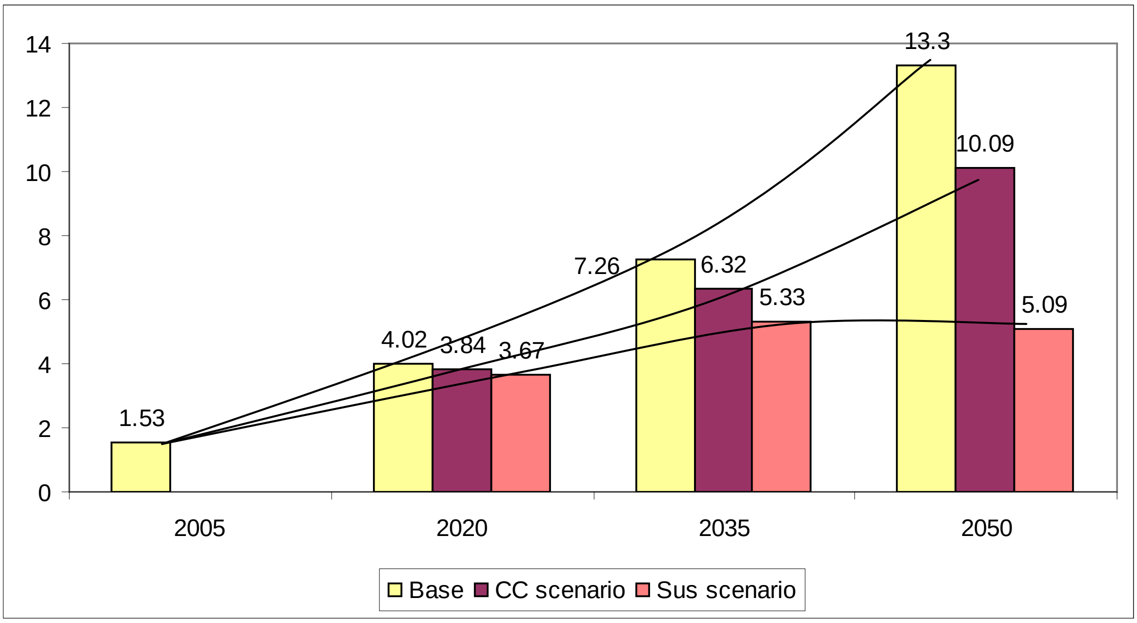
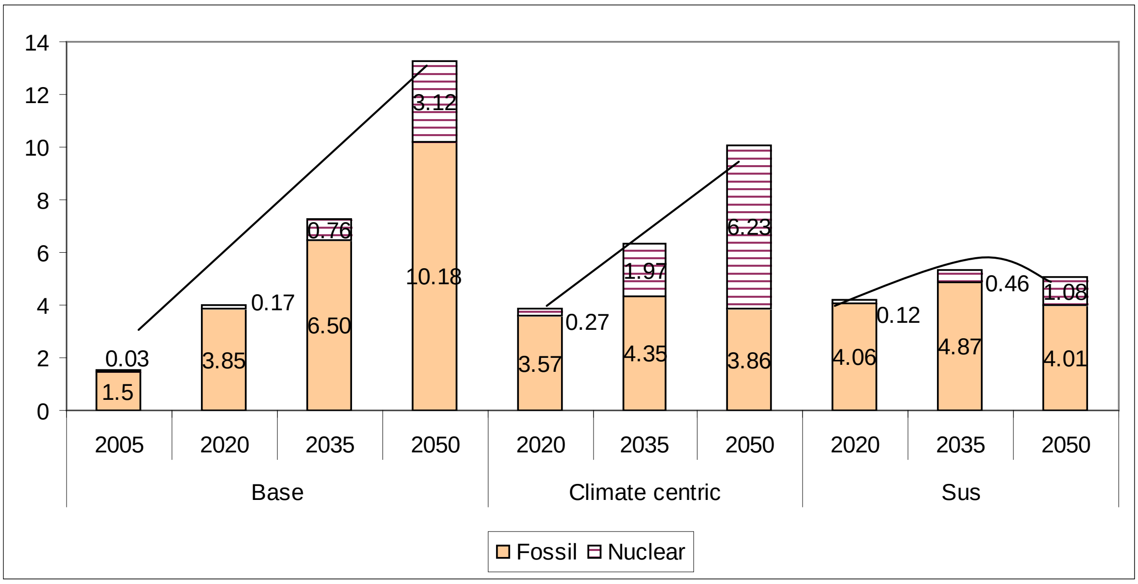


Fig 12: Trends in water consumption in power sector across scenarios (BCM)



The sustainability scenario aligns the water consumption in the power sector favorably from the water resources perspective. There is a decrease of nearly 62% of water requirements in the power sector in the sustainability scenario over the base case, owing to the changing nature of the power sector structure with less fossil-based power generation dependency. The changing nature of the electricity structure has a significant impact on the WE nexus that emerges – both from the water as well as energy perspective.

5. Conclusions

Traditionally; policies aimed at water, energy and climate change sectors have been pursued in an independent framework with very little co-ordination between them. However, due to the impending challenges of climate change; it becomes imperative to understand the 3-way nexus in an integrated and comprehensive framework. Policies aimed at mitigating carbon may have direct influence on other sectors and therefore it becomes necessary to harmonize the three-way interaction favorably. For eg, a global carbon price of $ 200/ t-CO2 in 2050 may translate into a per unit electricity cost of INR 10.00, which would make coal-based power technologies less competitive and if we are unable to avoid technological lock-ins, it would translate into a huge electricity cost burden on to the consumer and in the case of farmers, less competititive product. But a response mechanism of expanding the surface irrigation ex-ante might prove to be a better strategy to cope with such imminent realities into the future. Similar would be the case of building advance hydro power capacity so as to avoid lock-ins in possible future obsolete technologies.

This research analyses the water-energy-climate change nexus in an integrated framework so as to understand the interaction comprehensively and understand unambiguously the implications of policy change in one sector and its impacts on the other sectors. This gives us an advantage over the more traditional modes of analysis wherein the sectors are analysed in isolation.

This analysis has followed two approaches. The first approach is to conduct the 3-way assessment at two scales (national and local-city) and the second approach is to bring in the implications of a global perspective on climate change, wherein the aspirational target of stabilizing the GHG emissions to such a level so as to limit temperature rise to 2 deg C has gained in popularity and acceptance. At the least, this target has received political acceptance and therefore the importance of bringing in this perspective in the overall analysis.
At the next level, this research touches upon the interventions necessary on the demand as well as the supply side; so as to provide a comprehensive menu of policy options (quantitatively estimated). Although quantitative estimates regarding water savings need to be enhanced further in integration with the physical sciences, but some calculations are done to suggest the magnitude of water savings after pursuance of certain policies on the demand as well as the supply side. Finally, it provides an integrated policy road map for policy makers so as to address the water-energy sector conjointly.

As an output, this research proposes an integrated policy road map to address the water-energy-climate change nexus (Table 3), both in the short to medium term and medium to long term. The table explicitly mentions the co-benefit in terms of water savings potential as well as managing the climate mitigation agenda.

Table 3: Integrated Policy road map for India

S.No.	Sector	Policy (short-medium term, till 2035	Water savings (BCM)	Mitigation potential (mt-CO2)	Policy (medium-long term, till 2050)	Water savings (BCM)	Mitigation potential (mt-CO2)
1	Agriculture	P1: Low input (water), high yielding crops	45.1	13.5	P1: Low input (water), high yielding crops	47.7	18.2
2		P2: Expansion of surface irrigation	63.2	17.9	P2: Expansion of surface irrigation (beyond UIP)	69.1	24.3
3		P3: Diffusion of micro-irrigation	47.8	13.5	P3: Diffusion of micro-irrigation, large scale	50.1	18.2
4		P4: Pump infrastructure & motor standards	69	16.2	P4: Reducing motor connections, expand surface irrigation	71.5	21.9
5		P5: Reusing waste water	5.2	1.81	P4: Zoning for mandatory use of waste water	7.2	2.42
6		P6: Strengthening institutions		-	P7: Strengthening institutions		-
7	Domestic	P7: Appliance efficiency and behavior	13.3	5.4	P1: Appliance efficiency and behavior	15.8	7.2
8		P8: Recycling of waste water	11.2	7.2	P2: Recycling of waste water, zero discharge levels	12.3	9.7
9	Industry	P9: Motor standardization	4.3	2.2	P1: Reducing specific energy consumption in water	4.5	2.9
10		P10: Process improvements leading to demand reduction	13	12.2	P2: Process improvements leading to demand reduction	13.6	16.5
11	Power	P11: Expanding domestic large-hydro	1.9	38.1	P1: Expanding large-hydro through regional co-operation	8.2	42
12		P12: Promotion of renewable		36.1	P2: Promotion of renewable		24.8

REFERENCES:

1. ABARE. (1999). User Manual: ANSWER MARKAL an Energy Policy Optimization Tool, version 3.3.4. Canberra: The Australian Bureau of Agricultural and Resource Economics
2. AMC. (2007). Annual Report of Ahmedabad Municipal Corporation, Ahmedabad. Retrieved from http://www.egovamc.com/amc_budget/Ahewal_2006-07.pdf on 20th July, 2009
3. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., (2008): Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.
4. Bohringer, C. and Thomas F. Rutherford. (2006). Combining Top-down and Bottom-up in Energy Policy Analysis: A Decomposition approach. ZEW Discussion Paper no. 06-007, Mannheim
5. Briscoe, J. and Malik, R.P.S. (2007). Handbook of Water resources in India: development, management and strategies. Oxford University Press, India
6. CDP. (2006). City Development Plan Ahmedabad: 2006-2012.Ahmedabad Municipal Corporation and Ahmedabad Urban Development Authority, Ahmedabad
7. CEA. 2008. Hydro Development Plan for 12th five year period (2012-2017), Hydro Planning and Investigation Division, September 2008, GoI
8. Chopra, K. (2003). Sustainable Use of Water. Economic and Political Weekly, Vol. 38(32), August 9-15
9. CMIE. (2010). Energy and Agriculture. Centre for Monitoring Indian Economy
10. Dhar, S. (2008). Natural Gas Market in India: Evolution and Future Scenarios. Doctoral thesis , Indian Institute of Management Ahmedabad, India
11. Diary. (2009). Ahmedabad Municipal Corporation Diary, 2009-10. Ahmedabad Municipal Corporation, Ahmedabad. Retreived from http://www.egovamc.com/amcdiary/diary_09-10.pdf on 20th July, 2009
12. Edmonds, J.A. (2007). Personal communication on global carbon price trajectories for various stabilization scenarios. P.R.Shukla (Ed.)
13. Edmonds, J.A., Pitcher, H.M., Baron, R. and Wise, M.A. (1992). Modeling future greenhouse gas emissions: The second generation model description
14. Fisher-Vanden, K., P.R. Shukla, J.A. Edmonds, S.H. Kim and H.M. Pitcher. (1997). Carbon Taxes and India. Energy Economics, 19, 289-325
15. Garg, A. 2000. Technologies, Policies and Measures for Energy and Environment future. Doctoral thesis, Indian Institute of Management Ahmedabad, India
16. Garg, A., Menon-Choudhary, D., Kapshe, M. and Shukla, P.R. (2004a), “Carbon Dioxide Capture and Storage Potential in India”, in E.S.Rubin, D.W.Keith and C.F.Gilboy (eds.), Proceedings of 7th International Conference on Greenhouse Gas Control Technologies. Volume 1: Peer-Reviewed Papers and Plenary Presentations, IEA Greenhouse Gas Programme, Cheltenham, UK
17. Garg, A., Shukla, P.R., Kapshe, M. and Menon, D. (2004b), Future methane and nitrous oxide emissions and mitigation flexibility, Atmospheric Environment, 38 (2004) 1965–1977
18. GoI (2007). Report of the Steering Committee on Water Resources for Eleventh Five Year Plan (2007-12). Planning Commission, Government of India
19. GoI (2008a). Preliminary consolidated report on effect of climate change on water resources. Government of India, New Delhi
20. 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
21. GoI (2008c). Eleventh Five Year Plan 2007-2012. Vol I. Planning Commission, Government of India. Oxford University Press, New Delhi
22. GoI (2008d). Eleventh Five Year Plan 2007-2012. Vol II. Planning Commission, Government of India. Oxford University Press, New Delhi
23. GoI (2008e). Eleventh Five Year Plan 2007-2012. Vol III. Planning Commission, Government of India. Oxford University Press, New Delhi
24. GoI (2008f). National Hydro Power Policy. Ministry of Power, Government of India
25. GoI. (2010). Mid-term Appraisal of the 11th five-year Plan: Water Resources. Planning Commission, Government of India
26. Gosain, A.K., Rao, S. and Basuray, D. (2006). Climate change impact assessment on hydrology of Indian River basins. Current Science, Vol 90 (3), February
27. Integrated Energy Policy (IEP). (2006). Planning commission, Government of India
28. IPCC (1990). IPCC First Assessment Report. Cambridge University Press, UK
29. IPCC (1995). IPCC Second Assessment Climate Change 1995: A Report of the Intergovernmental Panel on Climate Change. UNEP and others, 64 pp.

30. IPCC (2001). Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (Eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.
31. IPCC (2007a). Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22
32. IPCC (2007b). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E.Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp
33. Kanudia, A. (1996). Energy-Environment Policy and Technology selection: Modeling and Analysis for India. Doctoral thesis, Indian institute of management Ahmedabad, India
34. Khan, S.S. (2009). Managing climate change risks in cities: A study of mitigation and adaptation strategies. Doctoral thesis , Indian Institute of Management Ahmedabad, India
35. Kumar, R., Singh, R.D. and Sharma, K.D. (2005). Water resources of India. Current Science, Vol 89 (5), September
36. Loulou, R., P.R. Shukla and A. Kanudia. (1997). Energy and Environment Strategies for a Sustainable future: Analysis with the Indian MARKAL Model
37. Malik, R.P.S. (2002). Water-Energy nexus in resource poor economies: The Indian experience. World Resources Development, Vol. 18(1), pp. 47-58
38. MNRE. (2010). Annual Report 2009-10. Ministry of New & Renewable Energy, Government of India
39. MoEF. (2010). Presentations made at the National Consultation Workshop on State Action Plans on Climate Change, Government of India
40. Nakicenovic, N. and Swart, R. (Eds). (2000). IPCC Special Report on Emissions Scenarios, Cambridge University Press, Cambridge, 599 pp
41. NAPCC. (2008). National Action Plan on Climate Change. Government of India
42. NCIWRD. (1999a). Report of the Working group on Water availability for use. Ministry of Water Resources, Government of India, New Delhi
43. NCIWRD. (1999b). Report of the Working group on perspective of water requirements. Ministry of Water Resources, Government of India, New Delhi
44. Personal Communication with Mr. Tarun Lad, Special City Engineer of AMC on 31st July, 2009
45. Rana, A. (1999). Energy, Economy and Emissions in India: Analysis using Equilibrium models. Doctoral Thesis, Indian Institute of Management Ahmedabad, India
46. Reidhead, W. (2001). Achieving agricultural pump set efficiency in rural India. Journal of International Development, Vol. 13, pp. 135-151
47. Roy, J. (2006). The Economics of Climate Change: A Review of Studies in the Context of South Asia with a special focus on India. Report submitted to the Stern Review
48. Shukla, P.R. (2006). India's GHG emission scenarios: Aligning development and stabilization paths. Current Science, 90(3), pp. 384-395
49. Swart, R., Robinson, J. and Cohen, S. (2003). Climate change and sustainable development: expanding the options. Climate Policy, 3, S19-S40
50. TERI. (2009). TERI Energy Data Directory & Yearbook. The Energy & Resources Institute, New Delhi
51. The Stern Review. (2006). The Economics of Climate Change. Cambridge University Press
52. UNDP (United Nations Development Program). (2003). Human Development Report, Oxford University Press, New York, 365 pp
53. Vision 2010. (1999). Gujarat Infrastructure Agenda: Vision 2010. Vol. II Sector Reports. Gujarat Infrastructure Development Board, Government of Gujarat
54. Water requirements for Existing and Emerging Thermoelectric Plant Technologies. (2005). National Energy Technology Laboratory, US
55. WPD. (2009). Ahmedabad Municipal Corporation: Water Project Department Proactive disclosure. Ahmedabad Municipal Corporation, Ahmedabad. Retrieved from http://www.egovamc.com/right_info/PRO/Pro_Water_Dept.pdf on 20th July, 2009
56. Yoshimoto, K. and Simson, J.J. (2009). Background paper of Low-Carbon city 2025 Sustainable Iskandar Malaysia. Atmospheric and Thermal Environmental Engineering Laboratory, Department of Urban and Environmental Engineering, Graduate School of Engineering, Kyoto University, Japan