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# Report on "Energy, Food and Water Nexus – analysis in Macroeconomic consistency framework"

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## Disclaimer:

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# Chapter 1 Introduction

Higher economic growth would require higher agricultural growth and higher energy production coupled with urbanization. All these would in addition to material and financial inputs also require water as an important ingredient. There are four major sources of demand for water. These are from 1) Agriculture 2) Residential 3) Industry 4) Power Generation. With economic growth demand for water would increase from all sources. However, Agriculture and Power are major water using sectors. Higher economic growth and larger population would imply increasing and changing agricultural consumption patterns which in turn would imply a change in cropping pattern and therefore impact the amount of water required for the agriculture sector to satisfy such a demand. At the same time higher economic growth would imply increasing power generation also resulting in rising water demand for cooling requirements. Climate change is likely to affect rainwater frequency, intensity and distribution as well as flows in rivers fed by glacier melts. This may lead to altered water availability for irrigation and also result in changes in ground water levels. The increased variability would imply higher need for irrigation through more coverage by groundwater pumps which is energy intensive and would increase the demand for power. This apart, economic growth would also result in higher water demand due to increasing urbanization through expanding cities and newly proposed smart cities and also due to increasing manufacturing base to support such an economic growth. Thus a sustainable economic growth path would require a sustainable use of water resources across sectors and by private households. To understand this would require a model based analysis of projections of water demand and supply.

## Scope of the Research study:

1) To comprehensively asses the nexus between energy, food and water and provide a policy based suggestion on the most optimal strategy for Energy sector growth and water conservation and water use efficiency. The following would be the aspects that the study would address
2) To project the changing water requirement in to the future up to 2050 accounting for changing cropping patterns due to changing food consumption patterns
3) To project the water demand due to urbanisation and growing cities
4) To incorporate the impact of climate change on water availability and hence increasing reliance on ground water irrigation
5) To assess the water requirement by industry and power generation technology wise
6) To assess the reduction in water use due to water conservation policies for the power generation sectors

## Deliverables

The deliverables for this project:

1) Scenario on water requirement till 2050 under existing water use policies and trends

2) Scenario on water needs from Power and agriculture sectors due to optimised water use policies
3) Impact of climate change agenda on water availability and demand
4) Macroeconomic impacts of the above scenario on Growth, Consumption and sectoral developments

## Objectives of the research study

1) Projection of water demand scenario for Power sector up to 2050 under existing and optimised water use policies
2) Projection of water demand scenario for Agriculture and other sectors up to 2050 under existing and optimised water use policies.
3) Impact of lowering of water availability on energy food nexus

# Chapter 2 Methodology for the Research study

Water is an essential input into various economic activities as well as for domestic requirements for drinking, cleaning and washing by households. Sectors that have a major water usage are, Agriculture for Irrigation purposes, Residential sector for domestic consumption, Power sector for cooling and ash cleaning purposes and in Industry for Industrial purposes. Water demand projections in each of these sectors are directly proportional to the output in these sectors. However each of these sectors are part of the larger economy and their growth has many common macroeconomic drivers and Inter sectoral linkages with other economic sectors. This implies that growth projections of these sectors need to be made consistent with assumed GDP growth, economic linkages and macroeconomic relations. We use a macro economic model, The IRADe-Integrated Assessment model (IRADe-IAM), based on input-output frame work to make a consistent projections of outputs of the after consuming sectors. The Input-Output frame work ensures inter sectoral consistency and the macro economic relations ensures that the sectoral outputs are feasible and economically consistent with the projected GDP growth. A brief description of the IRADe-IAM model is provided in the section below.

## Structure of the Model

The IRADe-IAM model is a multi-sectoral, inter temporal dynamic optimization model that is bottom-up in the sense that it includes alternative technology options, and top-down in the sense that it covers the whole macro-economy (similar to Parikh J and Ghosh P, 2009) and captures the characteristics considered essential by Urban et al, (2007) for models of developing countries. The model is set up in an activity analysis framework and is solved as a linear programming problem using the GAMS programme (Brooke, A., Kendrick, D. and A. Meerhaus, 1998).

The model maximizes present discounted value of the total sum of private consumption over the planning period using a real discount rate of 4 % subject to various macroeconomic, technological and resource constraints. It uses the Social Accounting Matrix (SAM) for the year 2007-08 (estimated by Pradhan, Saluja and Sharma (2013)) to represent the whole economy and the sectoral inter linkages. The SAM used in the model is aggregated to 25 commodities and 38 Production activities. The model ensures that demand and supply balance in the optimal path for each commodity for each period.

$C_{it} + G_{it} + Z_{it} + IO_{it} + E_{it} \leq Y_{it} + M_{it}$.......... (1) For each i and t

Where, $Y_{i,t}$ denotes output and $M_{i,t}$ denotes imports, $C_{i,t}$ denotes Private consumption, $G_{i,t}$ denotes Government consumption, $Z_{it}$ is vector of investment goods, $IO_{i,t}$ denotes Intermediate demand and exports is denoted by $E_{i,t}$. Intermediate demand ($IO_{i,t}$) is determined using the Input-output coefficients from the SAM.

The private household consumption is disaggregated into ten expenditure classes each for urban and rural areas. The per capita household demand function of each commodity by each consumer class is empirically estimated as a Linear Expenditure System (Stone, R., 1954) based on an underlying common nonlinear expenditure system (Swamy, G., Binswanger, H.P., 1983 and Parikh K. et al, 2014).

$C_{iht} = \alpha_{ih} + \beta_{ih0}(E_{ht} - \sum_i \alpha_{ih})$......................(2) for each i,h and t

Where, $C_{iht}$ = per capita consumption of the $i^{th}$ commodity by the $h^{th}$ household group in $t^{th}$ time period,

$\alpha_{ih}$ =minimum per capita consumption of the $i^{th}$ commodity by the $h^{th}$ household,

$\beta_{ih\ ih}$ = share of the $i^{th}$ commodity in the super numerary expenditure (total per capita expenditure less the expenditure for minimum consumption) of the $h^{th}$ household and

$E_{ht}$ = Total per capita consumption expenditure of the $h^{th}$ household.

The total number of people in each expenditure class is projected using an estimated log normal distribution for a given the level of total per capita consumption. As incomes rise, per capita consumption increases, which results in people moving from lower expenditure classes to higher classes and adopting the consumption patterns of the higher expenditure classes. This is particularly relevant for energy commodities as with higher income levels people adopt more energy intensive lifestyles for mobility, electricity and petroleum products. The Linear Expenditure System and the lognormal distribution together provide the estimate of $C_{i,t}$.

The output of any production activity $X_{j,t}$ is constrained by available capital stock in the activity. As incremental capital output ratio, ICOR, changes due to technical progress incremental output is related to incremental capital stock.

$(X_{j,t} - X_{j,t-1}) \leq (K_{j,t} - K_{j,t-1})/ICOR_{j,t}$...........for each j,t...........(3)

Where, $X_{j,t}$ = domestic output of the $j^{th}$ sector at time t, $K_{j,t}$ = capital of the $j^{th}$ sector at time t and $ICOR_{j,t}$=incremental capital output ratio of the $j^{th}$ sector in period t.

The total output of a commodity is the sum of output of all production activities that produce that commodity. Thus $Y_{i,t} = U_{ij}*X_{jt}$ where $U_{ij}$ is a matrix with a entry of 1 if jth sector produces the ith commodity and zero otherwise.

Capital stock in sector j at time t depends upon the rate of depreciation, and investment at time t.

$K_{j,t} = DEL(J) * K_{j,t-1} + I_{j,t}$ ............................(4)

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

Aggregate investment resource available in the economy depends on aggregate domestic investible resources (domestic savings determined by the marginal savings rate) and foreign investments in the economy (net capital inflow).

$\sum_i \sum_j P_{i,j} * I_{j,t} \leq Z_0 + S * (VA_t - VA_0) + (FT_t - FT_0)$.....................(5)

Investment goods, are identified separately from other commodities and are also allocated to different sectors as fixed proportions $P_{i,j}$ (which reflect the share of $i^{th}$ capital good in the $j^{th}$ sector) of the total investment ($I_{i,t}$) in $j^{th}$ sector at time t subject to the availability of Investment goods.

$\sum_j (P_{i,j} * I_{j,t}) \leq Z_{i,t}$.........................................(6)

Where, $Z_{i,t}$ = demand of commodity i for investment at time t, $VA_t$ = value added at time t, S = exogenously specified maximum marginal savings ratio, $Z_0$= investment in the base year (2007-08).

The foreign investments in the economy (net capital inflow) is modelled as a positive but decreasing function of GDP (value added) to allow for developing economies to reduce their reliance on foreign investments over time with development as shown in equation 7

$FT_t = (a - b * t) * VA_t$......................(7) Where $FT_t$ = foreign investment at time t

The balance of payment constraint requires that the foreign exchange earnings through net capital inflows, $FT_t$ and total export earnings are used to meet the foreign exchange requirement from the total import bill. The balance of payment constraint is imposed on the model solution using equation 8. Trade, exports and imports are endogenous to the model. Upper and lower limits on trade levels are exogenously specified for the model to optimise export and import levels within a reasonable range.

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

The model also imposes monotonicity constraints on outputs and per capita consumption to simulate a smoother pathway. Resource constraints as incorporated for fossil fuel coal, crude oil and natural gas.

Overall, the model's projections for commodity demand and production is sectorally consistent and it satisfies all macroeconomic relationships. This feature helps the model to assess the energy economy and resource linkages in a more consistent manner and hence provides a more consistent assessment of the environmental GHG emissions due to activities in the economy. The IRADe- IAM Model is thus able to give a detailed and comprehensive picture of feasible production levels for each sector given the availability of a scarce resource for which all sectors have a competing demand. In this case the constrained resource is water and the IRADe-IAM model can be used to make an assessment for the feasible levels for agricultural and energy sector growth given the water resources available in India and the kind of water conservation strategy required to optimise growth.

The IRADe-Integrated Assessment Model (IRADe-IAM) was used to assess the Water demand for power sector in India and the impact of energy efficiency and water use efficiency measures in Power sector.

## Model Assumptions

The following are some of the key assumptions valid for all the selected scenarios:

### a) Population

All the scenarios use the UN medium variant population for India. The population of rural and urban areas assumed under the scenarios is given in Table 2.1.

**Table 2.1 Total, Rural and Urban Population Projection**

| Population* (in millions) | | | | |
|---|---|---|---|---|
| **Year** | Total | Rural | Urban | Urbanisation (in %) |
| **2007** | 1158 | 812 | 346 | 30% |
| **2010** | 1206 | 833 | 373 | 31% |
| **2020** | 1353 | 883 | 471 | 35% |
| **2030** | 1476 | 893 | 583 | 39% |
| **2040** | 1566 | 864 | 701 | 45% |
| **2050** | 1620 | 806 | 814 | 50% |

***Population UN Medium Variant**

### b) Resource Reserves and Growth Assumptions

Reserves of natural resources such as coal and lignite, crude oil and natural gas grow over the years with exploration for new resources. For scenarios, the growth rate assumption for natural resources is provided in Table 2.2.

**Table 2.2 Resource Growth Assumptions**

| Resource | Reserves in 2007 | Growth Rate in Reserves |
|---|---|---|
| **Coal and lignite (million tonnes)** | 153,103 | 1.0% |
| **Crude petroleum (million tonnes)** | 725 | 0.0% |
| **Natural gas (billion cubic meter)** | 1,055 | 1.1% |

Source: http://www.coal.nic.in/content/coal-reserves

Energy sector policy assumptions made in the model are, normal cost reduction for renewables (solar PV and wind) due to the efficient use of production factors, no investment in capacity and no fall in costs due to factor productivity for sub-critical coal are assumed from 2017. India has announced its intended nationally determined contributions (INDCs) and commitment towards low carbon growth. The government has announced various low carbon measures through support schemes and programme targets and these announced plans in power, energy efficiency, buildings and transport sector have been incorporated. The share of buildings complying with Energy Conservation Building Code (ECBC) is specified to grow 0.1% per annum. In transportation higher vehicular efficiency, switch from conventional oil-based transport to gas- and electricity-based transportation and shift from private vehicle use to public transportation are assumed.

**Table 2.3 Assumptions of Exogenous Parameters for DAU scenario**

| Parameter | Sectors | |
|---|---|---|
| TFPG | Agriculture and power | 1% |
| | Rest of the economy | 1.5% for all except new technologies in power sector |
| AEEI for non-power sectors | Coal | 1.5% per year |
| | Petroleum products | 1.5% per year |
| | Natural gas | 1.5% per year |
| | Electricity | 1.5% per year |
| AEEI for power sectors | Coal | No AEEI for coal use in power sector technologies assumed |
| | Petroleum products | No AEEI for diesel use in power sector technologies assumed |
| | Natural gas | No AEEI for gas use in power sector technologies assumed |
| | Electricity | Reduction in transmission and distribution losses assumed |
| Reduction in energy use by government and households | Petroleum Products | 1% reduction in marginal budget share of expenditure on petroleum products by household due to use of more efficient vehicles |
| | Electricity | 1.5% reduction in marginal budget share of expenditure on electricity by households due to use of efficient appliances |

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

### c) Energy Sector Policies

**Table 2.4 Power Sector Policies Scenario**

| Power Sector Policies | |
|---|---|
| Costs for renewable | cost reduction due to recent fall in solar and wind energy prices |
| Growth of renewable | A minimum share for renewable of 8% by 2030 and 10% by 2050 is prescribed |
| Minimum share of solar | A minimum penetration rate for solar power is prescribed to allow for minimum share of 1.4% in 2030 and increases to 1.6% in 2050. |
| Nuclear power | Nuclear generation capacity is projected to reach up to 8 GW by 2050 |
| Thermal coal | No investment in capacity and no fall in costs due to factor productivity for sub critical coal assumed from 2017 |
| Hydropower | constrained to grow by 1.% in keeping with the government plans |
| Gas-based power generation | Maximum of 40% of domestic production of Gas is used for Power Generation |
| Minimum penetration rate for ECBC buildings | The share of ECBC is specified to increase by 1%. |

**Table 2.5 Transport Sector Policies in DAU Scenario**

| Transport Sectors Policies | |
|---|---|
| Share of railways in total freight movement | Stipulated to increase by 1.5% per year, from around one-third in 2015 to almost two-thirds by 2050 |
| Greater use of public and non-motorised transport | Reducing marginal budget shares for petroleum products by 0.2% per year beginning 2015 |
| Change in fuel mix in road transportation sector | Reducing petroleum product inputs in the transport sector by 0.5% per year, and replacing them by increasing inputs of natural gas and electricity in the ratio 60:40 respectively from 2015 |

### d) Macroeconomic Assumptions

The 78×78 sector Social Accounting Matrix for 2007 (Pradhan, Saluja and Sharma, 2013) forms the reference for the base year data of the model. The base year of the model is 2007–08 and the sectors from the 78×78 sector Social Accounting Matrix for 2007–08 is aggregated to 25×41 sectors for the most appropriate representation of energy sector and its linkages with the overall economy. There are 7 agricultural sectors, 10 industrial sectors (excluding energy sectors) and 3 services sectors. There are three primary energy sectors and two secondary energy sectors as shown in the table 6 below. The other major macroeconomic assumptions are provided in the table2.7 & table 2.8 below.

**Table 2.6 Sectoral Classifications**

| | Commodity Name | Production Activity Name |
|---|---|---|
| **Non-energy sectors** | | |
| **Agriculture** | | |
| | Food grains | Food grains |
| | Sugarcane | Sugarcane |
| | Oil seeds | Oil seeds |
| | Other Crops | Other crops |
| | Animal husbandry | Animal husbandry |
| | Forestry | Forestry |
| | Fishing | Fishing |
| **Industry** | | |
| | Mining and quarrying | Mining and quarrying |
| | Agro-processing | Agro-processing |
| | Textiles | Textiles |
| | Fertiliser | Fertiliser |
| | Cement | Cement |
| | Non-metallic minerals | Non-metallic minerals |
| | Steel | Steel |
| | Manufacturing | Manufacturing |
| | Construction | Construction |
| | Water supply and gas | Water supply and gas |
| **Services** | | |

| | | |
|---|---|---|
| | Railway transport services | Railway transport services |
| | Other transport | Other transport |
| | Other services | Other services |
| | | Other services with ECBC |

| | Commodity Name | Production Activity Name |
|---|---|---|
| **Energy Sectors** | | |
| **Primary energy sectors** | | |
| | Coal and lignite | Coal and lignite |
| | Crude petroleum | Crude petroleum |
| | Natural gas | Natural gas |
| **Secondary Energy Sectors** | | |
| | Petroleum products | Petroleum products |
| | Electricity | Sub-critical coal |
| | | Gas combined cycle |
| | | Hydropower |
| | | Super-critical coal |
| | | Onshore wind |
| | | Solar photo voltaic without storage |
| | | Solar thermal without storage |
| | | Biomass |
| | | Nuclear |
| | | Diesel |
| | | Solar photo voltaic with storage |
| | | Solar thermal with storage |
| | | Offshore wind |
| | | Ultra-super critical coal |
| | | Integrated gasification combined cycle coal |
| | | Gas open cycle |

**Table 2.7 Macroeconomic Assumptions**

| Parameter | Assumption |
|---|---|
| **Maximum growth rate of per capita consumption** | 8% |
| **Government consumption growth rate** | 7% |
| **Maximum savings rate** | 40% |
| **Discount rate** | 4% |
| **Post-terminal growth rate** | 3% |

**Table 2.8 Trade, Exports & Imports Assumptions**

| | Commodity | Export Upper Bound | Import Upper Bound | Import Lower Bound |
|---|---|---|---|---|
| 1 | Food grains | 10 | 10 | 0 |
| 2 | Sugarcane | 10 | 10 | 0 |
| 3 | Oil seeds | 10 | 10 | 0 |
| 4 | Other crops | 10 | 10 | 0 |
| 5 | Animal husbandry | 10 | 10 | 0 |
| 6 | Forestry | 10 | 10 | 0 |
| 7 | Fishing | 10 | 6 | 0 |
| 8 | Coal and lignite | 1 | 30 | 20 |
| 9 | Crude petroleum | 2 | 98 | 80 |
| 10 | Mining and quarrying | 99 | 45 | 0 |
| 11 | Agro-processing | 10 | 20 | 1 |
| 12 | Textiles | 50 | 30 | 0 |
| 13 | Petroleum Products | 20 | 20 | 5 |
| 14 | Fertiliser | 20 | 33 | 20 |
| 15 | Cement | 10 | 0.6 | 0.3 |
| 16 | Non-metallic minerals | 10 | 10 | 1 |
| 17 | Steel | 20 | 10 | 1 |
| 18 | Manufacturing | 40 | 30 | 1.5 |
| 19 | Construction | 0 | 0 | 0 |
| 20 | Electricity* | 0 | 0 | 0 |
| 21 | Water supply and gas | 0 | 0 | 0 |
| 22 | Railway transport services | 30 | 0 | 0 |
| 23 | Other transport | 30 | 20 | 3 |
| 24 | Other services | 20 | 10 | 6 |
| 25 | Natural gas | 0 | 80 | 20 |

** Imports and Exports of Electricity specification is explained in the methodology sections.*

## Calculation of Water Demand

Water demand is calculated for four categories 1) irrigation 2) Domestic 3) Industry 4) Power generation using coefficients. The methodology of calculating water demand for each category is provided below.

Agriculture: Water in agriculture is required for irrigation purposes and depends on the area under irrigation coverage and the type of crops grown. The model projects output of each agricultural sector including food and non-food crops from irrigated and unirrigated areas. The Gross irrigated area and Gross Cropped Area for each crop sector for the year 2007-08 is provided in the Table 2.9 below.

**Table 2.9 Crop wise Area under cultivation and Irrigation (000 Hectares) for the year 2007-08**

| | Crop | Gross cropped Area | Gross Irrigated Area |
|---|---|---|---|
| 1 | Paddy | 43623 | 25199 |
| 2 | Wheat | 28596 | 26101 |
| 3 | Coarse Cereals | 28669 | 4227 |
| 4 | Grams & Pulses | 24820 | 3925 |
| 5 | Sugarcane | 5151 | 4844 |
| 6 | Oilseeds | 28686 | 7811 |
| 7 | Fibres | 10431 | 3487 |
| 8 | Plantations | 1352 | 196 |
| 9 | Fruits | 4151 | 2560 |
| 10 | Vegetables | 5944 | 3666 |
| 11 | Other Crops | 13711 | 5968 |

Source: land use statistics at a glance 2000-01 to 2009-10 Directorate of Economics & Statistics, Department of Agriculture & Cooperation' Ministry of Agriculture, Government of India.

We use data from land use statistics at a glance 2000-01 to 2009-10 to compute area under irrigation for each crops for the year 2007-08, which is the base year for the model. The ratio of area under irrigation to the irrigated output for each crop for the year 2007-08 is computed and used to calculate irrigated area based on irrigated production level for each crop for subsequent years up to 2050. We use crop wise projection of water requirement in mm /hectare of irrigated area for entire growing period of each crop to project total water demand aggregated over all crops for each period. Crop wise water requirement data is collected from the website of Food and Agriculture Organisation and presented in Table 2.10 below

**Table 2.10 Crop wise water needs for irrigation**

| Crop | Crop water need | |
|---|---|---|
| | (mm/total growing period) | Average |
| Alfalfa | 800-1600 | 1200 |
| Banana | 1200-2200 | 1700 |
| Barley/Oats/Wheat | 450-650 | 550 |
| Bean | 300-500 | 400 |
| Cabbage | 350-500 | 400 |
| Citrus | 900-1200 | 1050 |
| Cotton | 700-1300 | 1000 |
| Maize | 500-800 | 650 |
| Melon | 400-600 | 500 |
| Onion | 350-550 | 450 |
| Peanut | 500-700 | 600 |
| Pea | 350-500 | 425 |
| Pepper | 600-900 | 750 |
| Potato | 500-700 | 600 |
| Rice (paddy) | 450-700 | 575 |

| | | |
|---|---|---|
| Sorghum/Millet | 450-650 | 550 |
| Soybean | 450-700 | 575 |
| Sugar beet | 550-750 | 650 |
| Sugarcane | 1500-2500 | 2000 |
| Sunflower | 600-1000 | 800 |
| Tomato | 400-800 | 600 |
| Tobacco* | 400-600 | 500 |

Source: http://www.fao.org/docrep/s2022e/s2022e02.htm#TopOfPage
*https://agriculturalinformation4u.blogspot.in/2016/02/irrigation-water-requirement-for.html

**Table 2.11 crop wise Irrigation water demand (BCM) in 2007-08**

| Model Cropping Sectors | Irrigated Area (IA) | Water Consumption (WC) | Water demand for total irrigated Area (IA) of the crop |
|---|---|---|---|
| | (000 hectares) | (mm/hectare) | (BCM) |
| Paddy | 25199 | 575 | 145 |
| Wheat | 26101 | 550 | 144 |
| Coarse Cereals | 4227 | 583 | 25 |
| Grams & Pulses | 3925 | 400 | 16 |
| Sugarcane | 4844 | 2000 | 97 |
| Oilseeds | 7811 | 600 | 47 |
| Fibres | 3487 | 1000 | 35 |
| Plantations | 196 | 500 | 1 |
| Fruits | 2560 | 1083 | 28 |
| Vegetables | 3666 | 521 | 19 |
| Other Crops | 5968 | 831 | 50 |

Based on the technical water requirement coefficient from the above table 2.10 the water demand for the year 2007-08 is computed as shown in the table 2.11. The ratio of water demand in Billion cubic meter to irrigated area in thousand hectares is calculated for each crop for the year 2007-08. The calculated ratio is then used to compute water demand in billion cubic meter for subsequent years using the model projected Irrigated area as discussed above.

Domestic: Water demand from the domestic sector is on account of water requirements by domestic households for their drinking, cleaning and bathing purposes. In the IRADe-IAM model, the household residential is disaggregated into 10 expenditure classes each for rural and urban areas. Water consumption depends on the households living standards which in the IRADe-IAM model is captured by the expenditure levels of the household classes. We estimate water demand for each expenditure class using water consumption per capita per day coefficients from Shaban and Sharma (2007). The estimated coefficients used is presented in the table 2.12 below.

**Table 2.12 Area-wise consumption of water per capita per day (In litres)**

| Resident household status | Model expenditure class in Rural & Urban Areas Mapped to | Mean |
|---|---|---|
| High income group (HIG) areas with well planned building | H10, H9 | 99.9 |
| Middle income group (MIG) areas with well planned building | H8, H7, H8 | 94.2 |
| Low income group (LIG) areas with well planned building | H3, H4, H5 | 90.2 |
| Slum areas | H2 and H1 | 81.9 |
| Others (mixed areas) | | 91.3 |
| Total | | 91.6 |

Source: Shaban and Sharma (2007) H1,H2,..., H10 refer to households in different expenditure classes in rural and urban areas

The model projects endogenously the household consumption expenditure for each expenditure class and number of people in each expenditure class. With growth and prosperity, per capita consumption increases and people shift from lower expenditure classes to higher expenditure classes. With increasing economic prosperity the households water consumption patterns increases more towards the patterns of high income groups. We have applied the household water consumption coefficients (as mapped for each expenditure class) per person per day on the number of people in each expenditure classes and aggregated it to get the total water demand from domestic sector for each year from 2007-08 to 2050.

Industry: Water is required by Industry in various production processes. we use the Centre for Science and Environment (CSE, 2004) report that estimates water demand for the year 2004 from major industrial sectors. The report mentions that water to industry is not priced appropriately as it is provided either by municipalities or through extraction from ground using subsidized energy. This leads a lot of inefficient use of water in the industry sector. The report also shows that the industrial water productivity which is represented by the ratio of Industrial GDP to water consumption is one of the lowest among major industrialised countries. Over time with increase in growth and industrial output, water demand from industry is likely to increase and make industrial growth critically dependent on water. To project water consumption from Industry sources, the sectors and their water demand from the report are presented in table 2.13 below. Each of the industry sectors considered by the report which has a significant water demand in its production process is considered in the IRADe-IAM model either explicitly or as a part of a larger aggregated sector. We compute the ratio of water consumed to output in 2004 and multiply the ratio to output growth of the sectors for all the years from 2007-08 to 2050.

**Table 2.13 Wastewater Generation and Water use by Different Industries in India, 2004**

| Industrial Sector | Annual consumption |
|---|---|
| | (million cubic metres) |
| Engineering | 2019.9 |
| Pulp and paper | 905.8 |
| Textiles | 829.8 |
| Steel | 516.6 |
| Sugar | 194.9 |
| Fertilizer | 73.5 |
| Others | 314.2 |

Source: CSE (2004)

## Power Generation:

Water demand in power sector is because of thermal power generation. Thermal power generation technologies require water for cooling purposes. Coal based thermal power generation in addition requires water for ash cleaning. The IRADe-IAM model is an economy wide model and covers all sectors of the economy of which power is one of the sectors. In this sense it is a top down model. However, the power sector is disaggregated into 13 technologies as shown in table 2.6. In this sense the model has bottom up specifications of technologies. The IRADe-IAM model is a integrated model that combines top down macroeconomic and inter sectoral linkages with bottom up technological specifications. The models output for each power generation technology is provided in value terms and in physical terms. This thermal power generation technologies include sub critical coal, super critical coal, ultra-super critical coal, IGCC coal, Gas, Nuclear, biomass, solar PV, solar thermal with and without storage. We use India specific water use coefficients of power generation technologies from CEEW (2017) to project water withdrawal and consumption from power sector. The CEEW (2017) provides fuel technology wise water coefficients for cooling tower (CT) and once through cooling (OTC) technology separately. The IRADe-IAM model however does not have technologies disaggregated cooling technology wise and hence we assume a weighted average of the water coefficients of CT and OTC for each fuel technology. The weights being the installed capacity with OT and OTC cooling technology under each power generation technology. The average water use coefficients for each technology is reported below in table 2.14

**Table 2.14 Technology wise water withdrawal per unit generation**

| Technologies | Water Withdrawal ($m^3$/Mwh) | | | |
|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 |
| Coal | 41.87342 | 22.69972 | 3.5 | 3.5 |
| Gas | 1.62 | 1.62 | 1.62 | 1.62 |
| Nuclear | 152.7726 | 78.58846 | 3.5 | 3.5 |
| Refined liquids | 68.3 | 68.3 | 68.3 | 68.3 |

| | | | | |
|---|---|---|---|---|
| CSP | 2.845 | 2.845 | 2.845 | 2.845 |
| PV | 0.1 | 0.1 | 0.1 | 0.1 |
| Biomass | 4.35 | 3.925 | 3.5 | 3.5 |

Source: weighted average from CEEW (2017)

## Scenarios

The analysis tries to address the issue of water demand and water constraints to power sector growth and agricultural growth. In analysing the nexus between Food, water and Energy we try to answer three questions 1) Impact of Economic Growth on water demand from each sector 2) Impact of water conservation policies and low carbon scenario in power sector on water demand in power sector 3) impact of implementing Government schemes and INDC targets on water demand.

The first question is answered using a set three scenarios each representing different rate of GDP growth rate.

**Low Growth rate scenario**: GDP growth rate is simulated to 5.88% from 2011-12 to 2047 by appropriately adjusting parameters and assuming MOEFCC guidelines on water conservation policies in power plants.

**Medium Growth rate scenario**: GDP growth rate is simulated to 6.70% from 2011-12 to 2047 by appropriately adjusting parameters and assuming MOEFCC guidelines on water conservation policies in power plants.

**High Growth rate scenario**: GDP growth rate is simulated to 7.40% from 2011-12 to 2047 by appropriately adjusting parameters and assuming MOEFCC guidelines on water conservation policies in power plants.

The second question of impact of power sector policies on water demand and power sector water conservation policies is answered by another set of two scenarios

**Reference Scenario (REF):** we use the Medium Growth rate scenario with MOEFCC guidelines on water conservation in power plants.

**Water Conservation Policy Failure (WCF)**: The scenario assumes Medium Growth rate scenario without MOEFCC guidelines on water conservation in power plants.

The Water Conservation Policy Failure scenario shows the additional water demand in the power sector if the MOEFCC guidelines are not adhered to.

The third question of impact of government's announced power sector plans and capacity build up and NDC commitments made in Paris is addressed by comparing the REF scenario with two additional scenario

**INDC Scenario (INDC)**: The scenario considers announced government policies of 175 GW of renewable power capacity, Nuclear and Hydro plans and attainment of the INDC targets.

**AMBLC Scenario (AMBLC)**: The scenario considers announced government policies of 175 GW of renewable power capacity, Nuclear and Hydro plans and attainment of more ambitious targets of nearly 60% non-fossil fuel capacity by 2030.

# Chapter 3 Impact of Growth on Water Demand

Higher growth leads to increase in production and consumption activities in the economy. Agricultural production rises resulting in higher irrigation requirements and hence more water demand for irrigation. Industrial production also rises which increases the demand for water in industrial processes. Higher GDP growth leads to higher income growth for domestic households and hence higher level of economic standards of living which also results in higher levels of water use. Higher GDP growth also increase Power demand and generation. A major share of power generation is from Thermal technologies which require water for cooling requirements and for ash cleaning in coal based thermal technologies. Thus Higher GDP stimulates economic activity and competing demand for water from the above discussed sectors. The impact of GDP growth on water demand is explained using three scenarios 1) Low Growth rate scenario 2) Medium Growth rate scenario and 3) High Growth rate scenario.

The GDP levels across the three scenarios are provided in Figure 3.1 below.

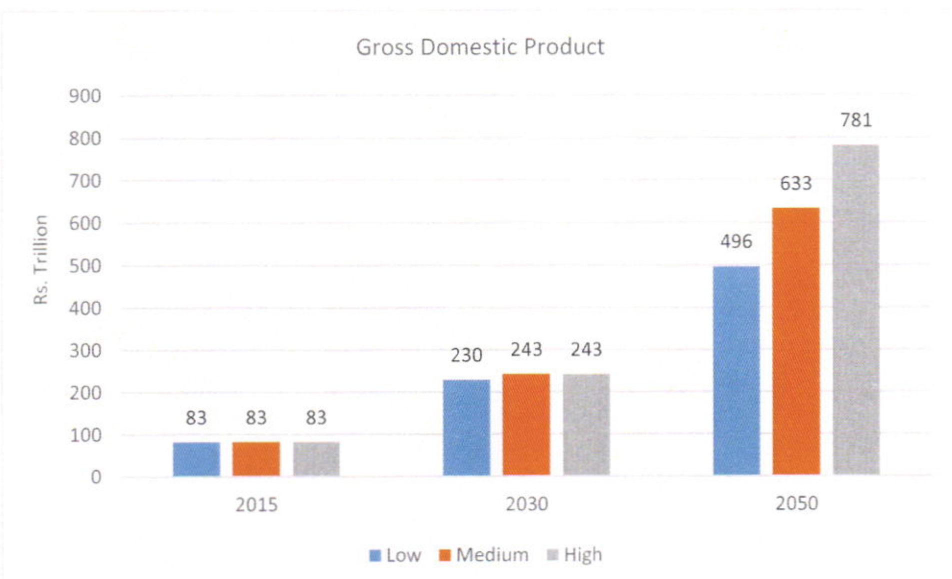



**Figure 3.1 Gross Domestic Product under different scenarios**

The Increase in Per capita consumption levels, which is an indicator of the improving levels of standards of living of households is provided in Figure 3.2 below. Increase in average per capita household consumption results in people moving from lower expenditure classes to higher expenditure classes which increases their per capita consumption. Thus the per capita consumption is a driver of domestic water consumption

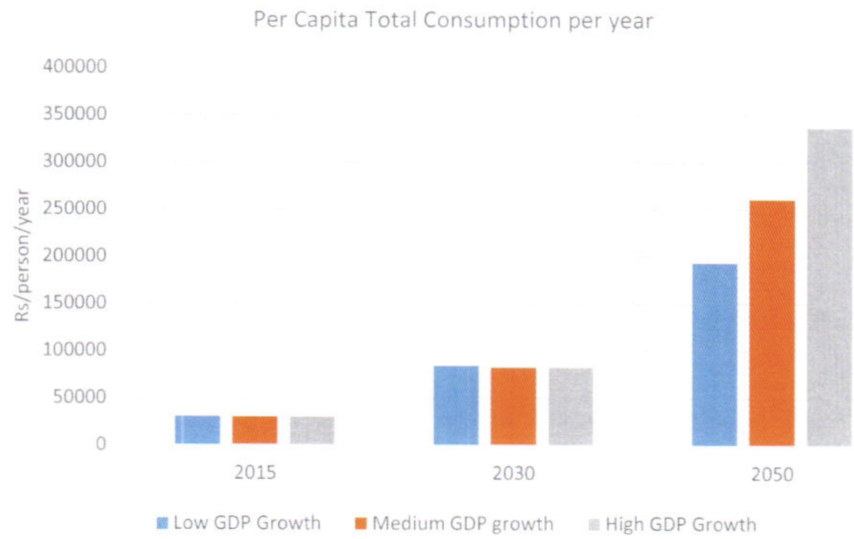



**Figure 3.2 Per capita aggregate Consumption**

Increase in Consumption increases demand for Agricultural commodities including food, Industrial products and Electricity. Figure 3.3 gives the Agricultural GDP Growth corresponding to the three scenarios of GDP growth

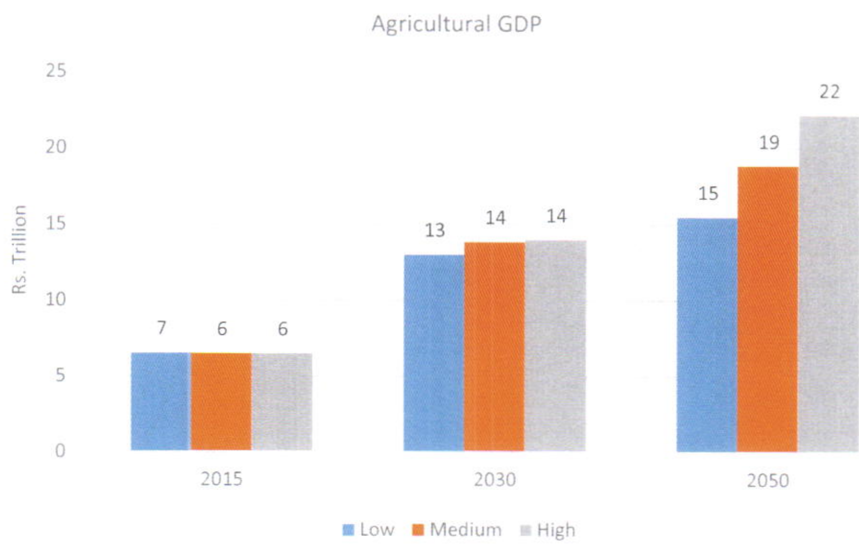



**Figure 3.3 Agriculture GDP**

The increase in Agricultural GDP results in higher production of food and non-food crops, requiring increase in irrigation coverage over time.

The water requirement for agriculture would depend on the area covered by irrigation. Figure 3.4 gives the crop wise Irrigation Area.

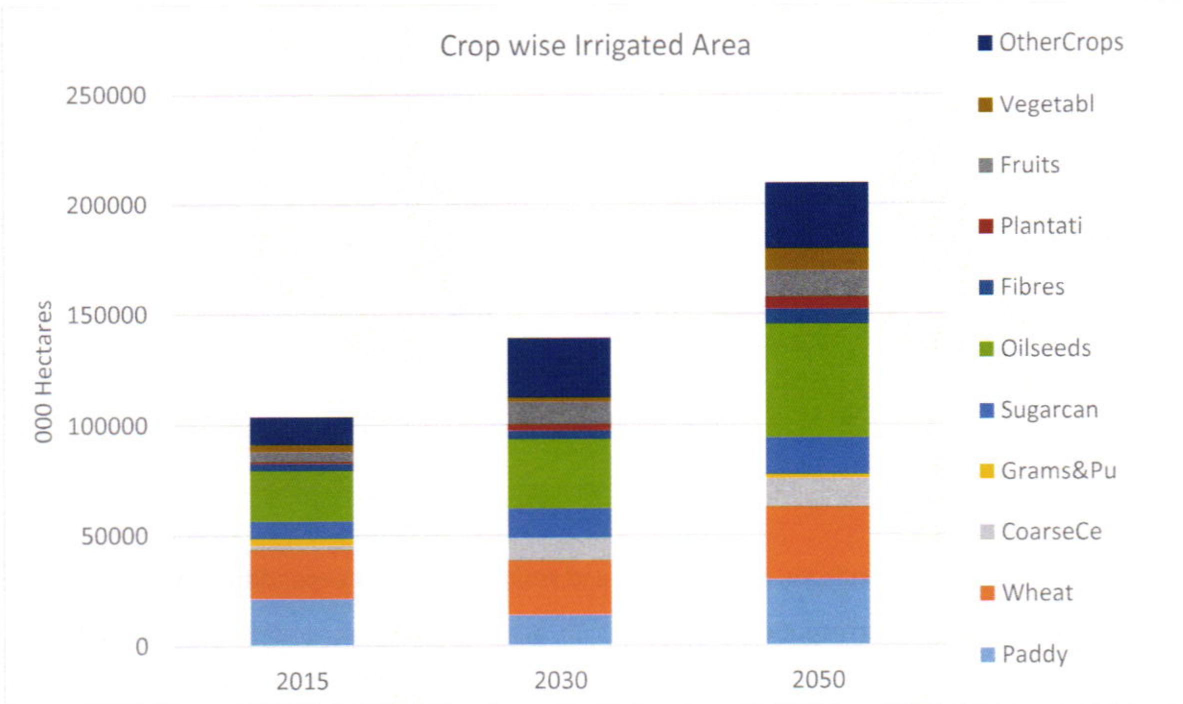



**Figure 3.4 Crop wise Irrigated Area in thousand hectares in Reference Medium growth scenario**

Gross irrigated area increase is exogenously prescribed and is assumed same across all scenarios although its distribution across crops may vary by production choices. Gross irrigated area increases at a growth rate of 2% from 88 million hectares to 139 million hectares in 2030 and to 209 million hectares in 2050. Paddy, Wheat, Coerce Cereals, sugar cane, Oilseeds and other crops have significant share in Gross Irrigated Area. The share of crops in gross irrigated area changes, driven by changing consumption pattern and availability and cost competitiveness of imports.

Increase in Industrial Growth corresponding to the three GDP growth scenarios is shown in Figure 3.4 below. Industry includes sectors like Engineering, pulp and paper, Textiles, Steel, Sugar and Fertilizers and others miscellaneous manufacturing sectors

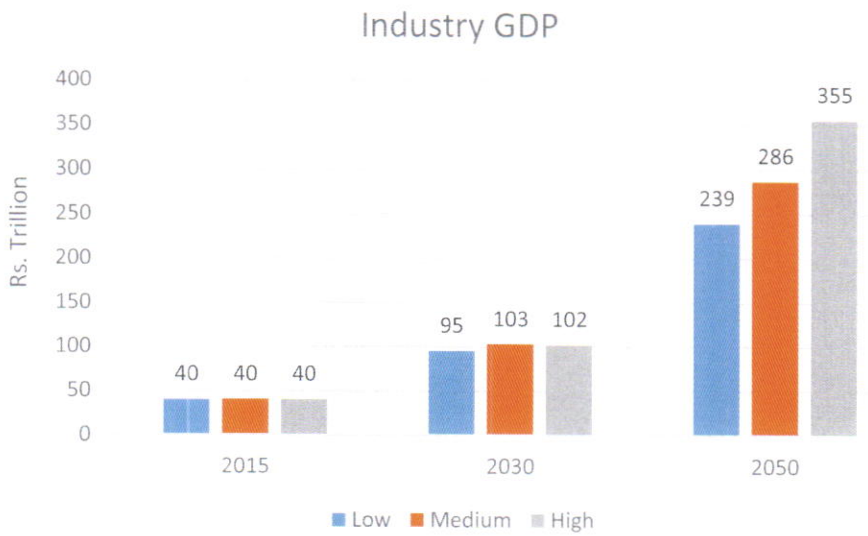



**Figure 3.5 Industrial GDP**

Increase in GDP growth, Agriculture, Industry GDP and residential sector expenditure results in higher demand for Power and corresponding increases in generation from various technologies. The technology wise generation is provided in Figure 3.6 , 3.7 and 3.8 below

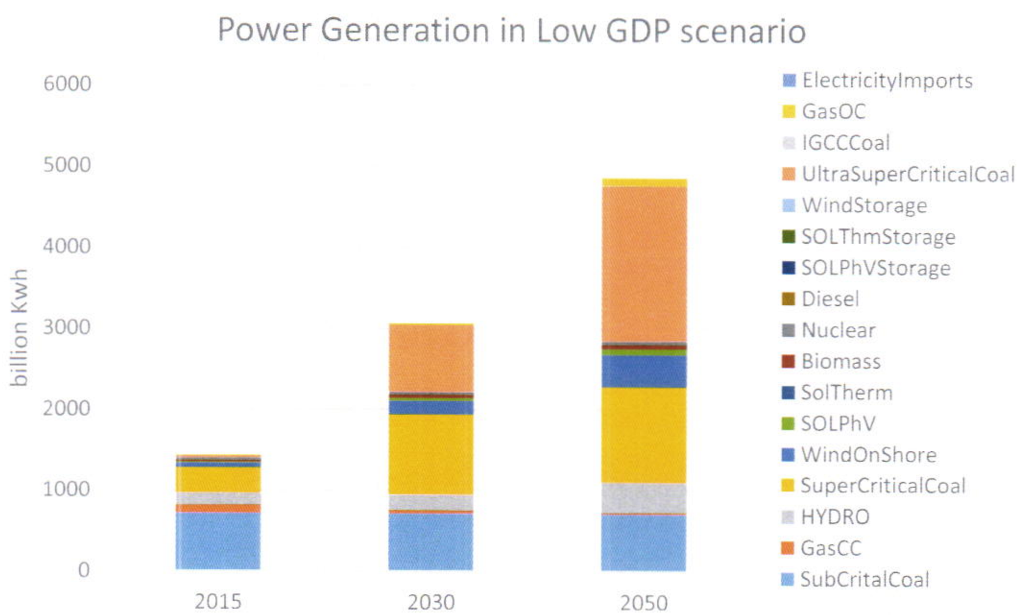



**Figure 3.6 Power Generation in Low GDP growth scenario**

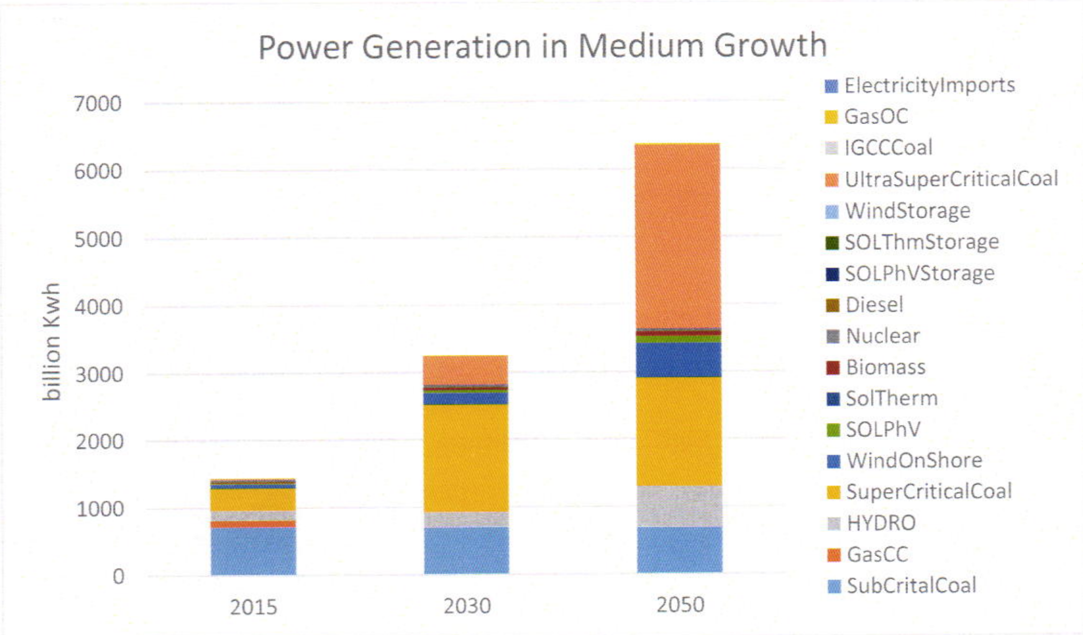



**Figure 3.7 Power Generation in Medium GDP growth scenario**

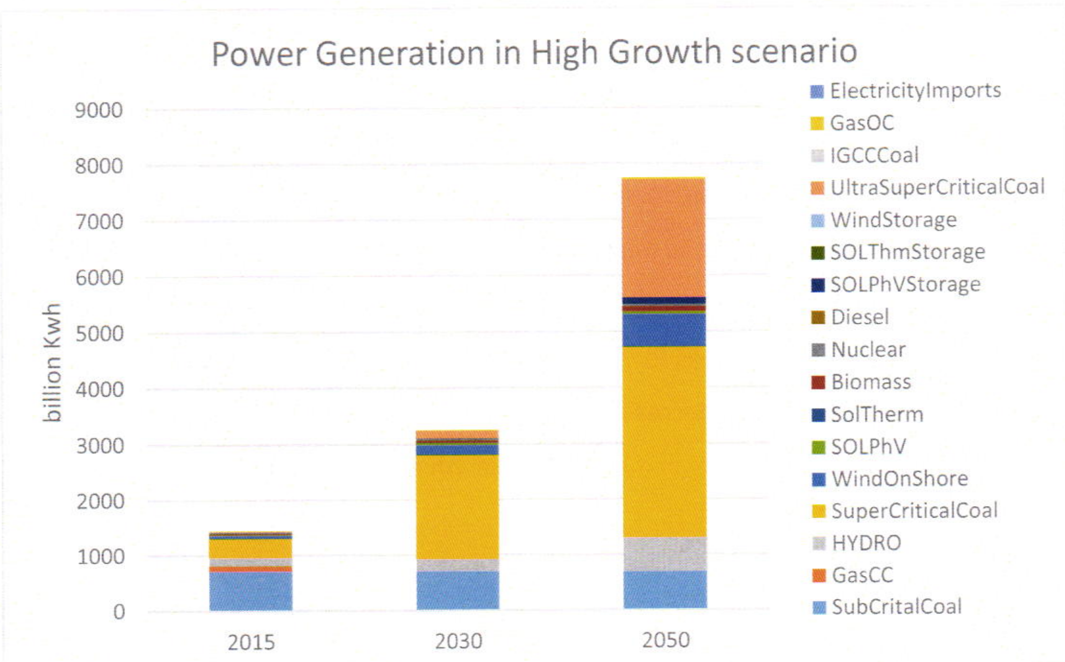



**Figure 3.8 Power Generation in High GDP growth scenario**

Power generation is projected to increases from 1074 billion Kwh in 2011-12 to 4857, 6365 and 7746 billion Kwh by 2050 at a growth rate of 4.18%, 4.97% and 5.51% for Low, Medium and High GDP growth scenarios respectively. Coal based thermal power generation is the most preferred choice of generation. The share of sub critical coal decreases due to governments stated policy of not having any new sub-critical based plants after 2017. However coal based thermal power generation still remains the preferred choice as generation shifts to super critical coal and ultra super critical coal despite its higher capital cost. Thermal power generation will have a major impact on water demand as thermal power generation, would require water for cooling purposes and coal based thermal power generation would require water for ash cleaning. The water demand by various sectors based on the growth of the above mentioned drivers for the three GDP growth scenarios are provided below.

**Table 3.1 Impact of economic growth on water demand (billion cubic meters)**

| | 2015 | | | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| Irrigation | 764 | 768 | 768 | 1069 | 1110 | 1125 | 1604 | 1600 | 1602 |
| Domestic | 43 | 43 | 43 | 52 | 52 | 52 | 59 | 59 | 60 |
| Industry | 7 | 7 | 7 | 16 | 17 | 17 | 27 | 36 | 47 |
| Power Generation | 50 | 50 | 50 | 9 | 10 | 10 | 14 | 18 | 22 |
| Total | 864 | 868 | 868 | 1145 | 1189 | 1203 | 1703 | 1713 | 1731 |

Total water demand in 2015 is estimated to be at 868 bcm, of which irrigation demand is of about 768 bcm and demand for power is about 50 bcm. Industry has a very small share of 7 bcm and domestic demand is at 43 bcm. The total demand increases to 1145, 1189 and 1203 bcm in 2030 in the low, medium and High Growth rate scenarios respectively. In 2050 the total water demand increases to 1703, 1713 and 1731 bcm for the low, medium and High GDP scenarios. Demand from irrigation increases from 768 bcm in 2015 to 1069, 1110 and 1125 bcm in 2030 and to 1604, 1600 and 1602 bcm for Low, Medium and High GDP growth scenario. The demand for water from Power of course decreases as we assume MOEFCC guidelines for water conservation in power plants are adhered to. The demand from water in power sector decreases from 50 bcm to 9, 10, 10 bcm in 2030 and to 14, 18 and 22 bcm in 2050 for the low, medium and high GDP growth rate scenario respectively.

# Chapter 4 Impact of Low carbon pathway on Water Demand

Coal based thermal generation is the cheapest and optimal source of power generation in India. However low carbon pathway and initiatives of the government of India is likely to shift away India's power generation from being coal based to other technologies like Gas, Hydro, Solar, Wind, Nuclear and Biomass. Many of the alternative technologies have significant water requirement, though may be much less than coal based thermal power generation. Thus, low carbon pathways would reduce $CO_2$ emissions and may also reduce water demand in the power sector. This chapter deals with the extent to which low carbon pathways reduce the water stress in the economy and secure energy from any likely future water scarcity.

The government of India has come out with many low carbon policies in the recent past. These include no subcritical plants after 2017, 175 GW of renewable energy capacity by 2022, The ambitious Nuclear energy program and Hydro power plans. In one of the most significant announcements, the Indian Government announced at the Paris COP, its INDCs to reduce emissions intensity by 33-35%, to increase its non-fossil fuel capacity to 40% of its total capacity by 2030. We assess the impact of the announced government plans and policies on water demand in the power sector by comparing the REF scenario with INDC and AMBLC scenario as defined in chapter 2 section for scenarios.

Low carbon scenario requires investment in non-fossil power generation capacities like Renewables, Nuclear and Hydro technologies. Coal is the cheapest source of power generation in India is also confirmed from the choice of super critical and ultra-super critical as the preferred technology Low, Medium and High GDP growth scenarios. A low carbon path would imply a shift towards more costly technologies like renewable, Nuclear and Hydro then compared to coal. Shift away from coal based thermal technologies is going to reduce water demand in power generation but on the other hand, technologies like Nuclear, Solar thermal technologies also use water. Thus, the net impact on water demand in power sector may be of interest to policy makers.

To assess the impact of low carbon pathway and Government of India's proposed power sector policies on water demand we provide a comparative analysis of three scenarios 1) Ref-Medium GDP Growth rate 2) INDC Scenario and 3) AMBLC scenarios as described in chapter 2 in the section for scenarios. Figure 4.1 below shows the impact on macroeconomic variables of GDP (income generation in the economy) and per capita household consumption expenditure. The results show that impact on GDP is insignificant, but household consumption decreases in the low carbon scenarios.

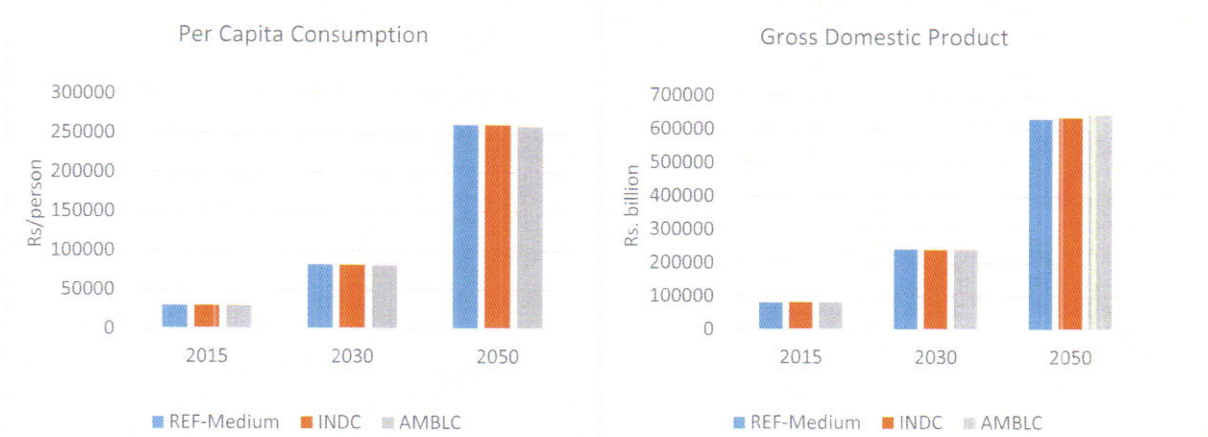



**Figure 4.1 Macro economic impact of Low carbon pathways on per capita consumption and GDP**

There is not much impact on irrigational requirement as irrigated area is same across scenarios and increases through governmental efforts. However, the power generation decreases in the low carbon scenario due to feedback effect. Figure 4.2 below provides the impact on Aggregate irrigated area (Food) and power generation (energy) due to low carbon pathways.

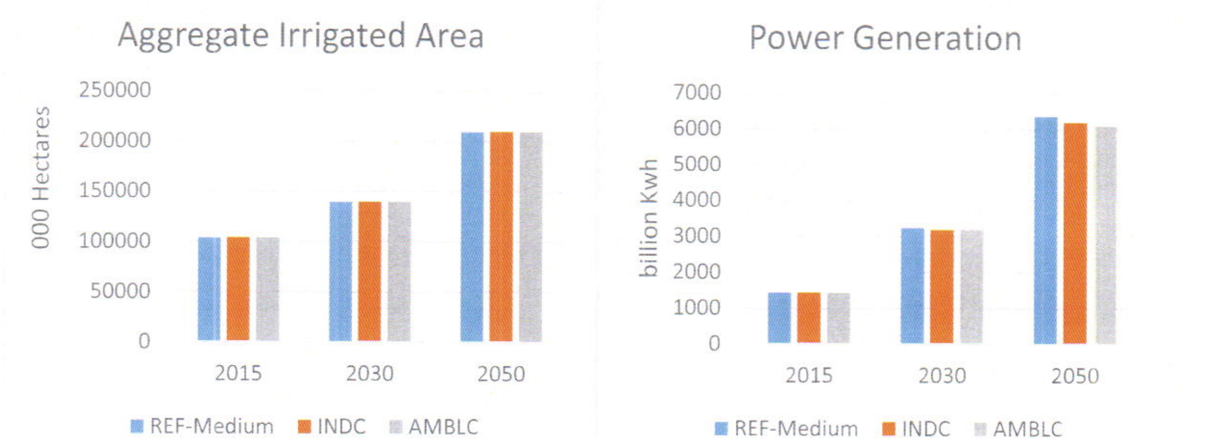
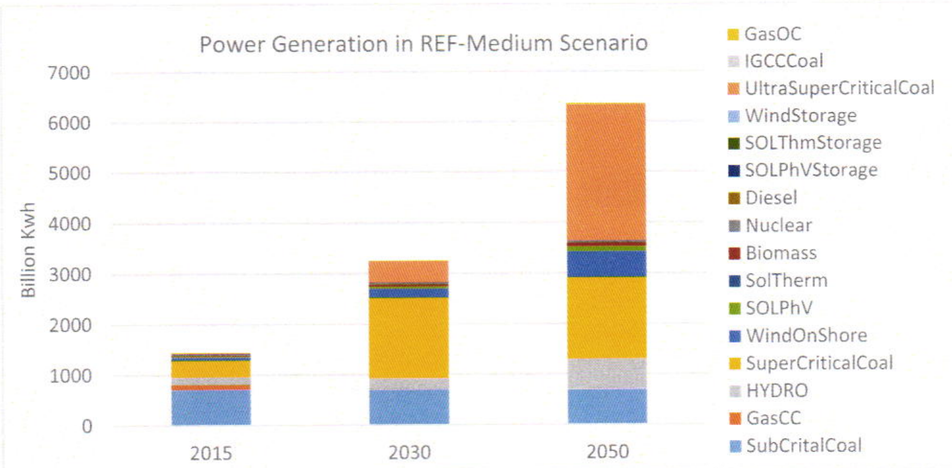



**Figure 4.2 Low carbon pathway impact on Food (irrigated area) and Energy (power generation)**

As shown above, power generation increases from 813 BU in 2007 to 3247 BU and 6365 BU, an increase of 4 times and nearly 8 times in 2030 and 2050 respectively in the Reference Medium GDP growth scenario. The INDC scenario which assumes the 175 GW by 2022 target and the INDC commitments of the government of India in COP at Paris and the AMBLC scenario which represents a more ambitious low carbon scenario with 60% non-fossil fuel capacity by 2030 brings down power generation. The figure 4.3, 4.4 and 4.5 below shows the Power generation and Capacity mix for REF-medium, INDC and AMBLC scenario respectively.

In the medium growth reference scenario (figure 4.3 below), Coal is the dominant source of power generation and has the most major share in capacity. Within coal, subcritical coal has a falling share as it is phased out based on government policy. Super critical coal and ultra supercritical coal are the major contributor to generation and capacity. Among Non-fossil fuel technologies Hydro, wind on shore are the major contributors in generation. In terms of capacity also Hydro, Wind onshore technologies are major contributors in addition to Solar Photo voltaic. The share of solar photo voltaic is insignificant in generation because it has a low PLF.



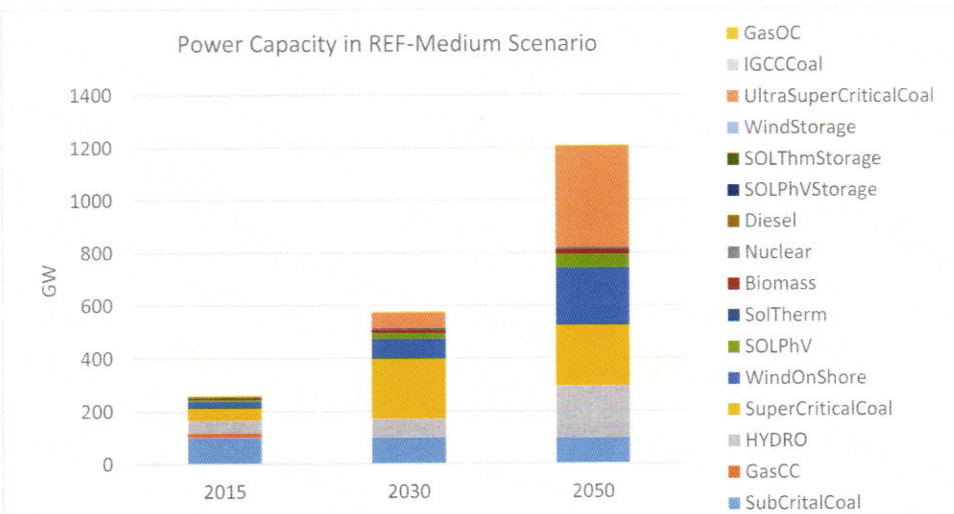
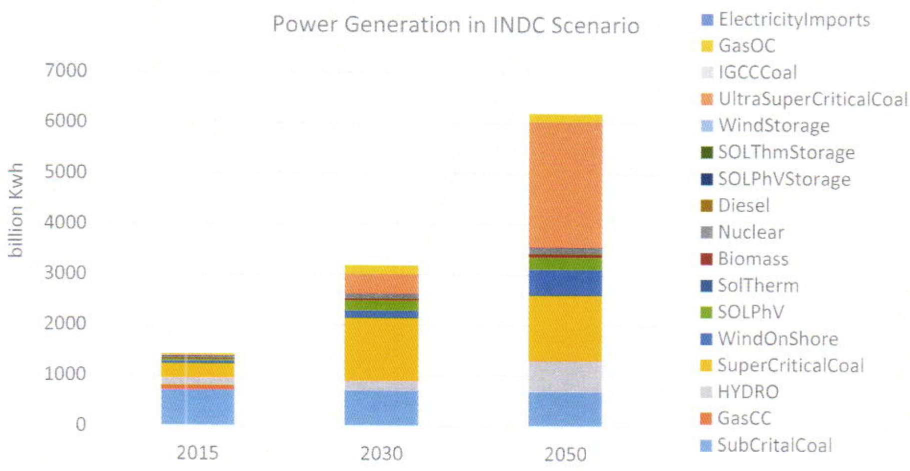




**Figure 4.3 Power Generation and Capacity in Reference-Medium Scenario**

Coal based thermal power technologies share in generation is 84% (sub critical :22%, super critical: 49%, ultra-super critical:13%) in 2030 and reduces to 79% in 2050 (sub critical :11%, super critical: 25%, ultra-super critical:42%). Among Non-fossil fuel technologies, share of hydro is 7% and 9%, share of wind on shore is 5% and 8% and solar Phv is 1% and 2% in total generation in 2030 and 2050 respectively. total capacity increases from 146 GW in 2007 to 575 GW and 1208 GW in 2030 and 2050 respectively. Coal share in total capacity decreased from 68% in 2030 (sub critical :18%, super critical: 40%, ultra-super critical:10%) to 59% in 2050 (sub critical :8%, super critical: 19%, ultra-super critical:32%). Share of hydro increases to 12% and 16%, share of wind on shore to 13% and 18% and solar Phv is 4% in 2030 and 2050 respectively.



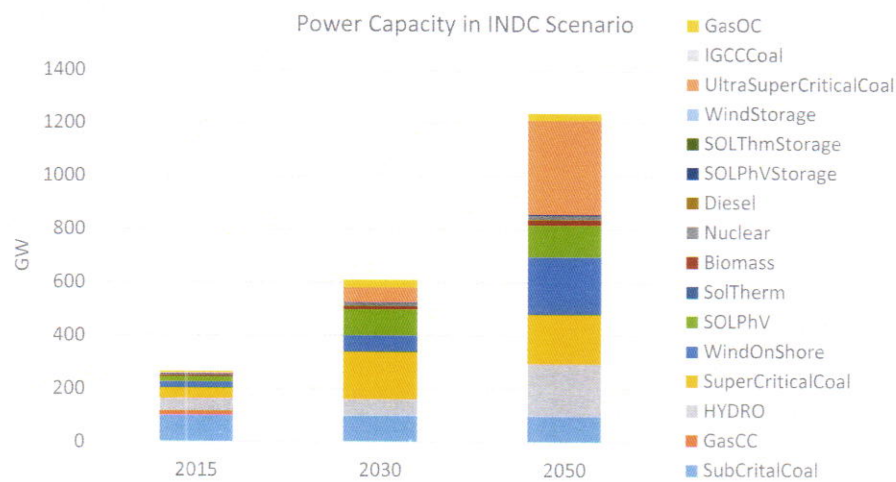
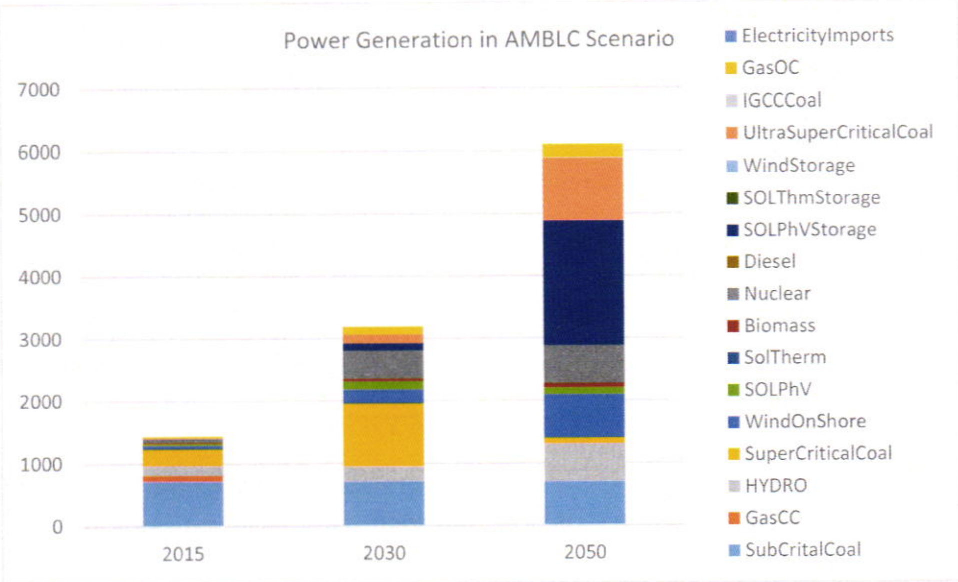




**Figure 4.4 Power Generation and Capacity in INDC Scenario**

Figure 4.4 above shows the technology wise generation and capacity in the INDC scenario. INDC scenario reduces power generation in 2030 to 3177 BU and in 2050 to 6188 BU. The share of Non-fossil fuel in power generation and capacity increases mostly because of Solar Photovoltaic without storage. The share of super critical coal in total generation decreases to 39% and 21% in 2030 and 2050 respectively. Solar Photo voltaic increase its share to 6% and 4% and Nuclear to 3% and 2% respectively in 2030 and 2050. Total capacity requirement increases to 609 GW and 1237 GW in 2030 and 2050 respectively. Share of super critical coal in total capacity decreases to 29% and 15%. Solar Photo Voltaic share increases to 16% and 10% in 2030 and 2050 respectively.



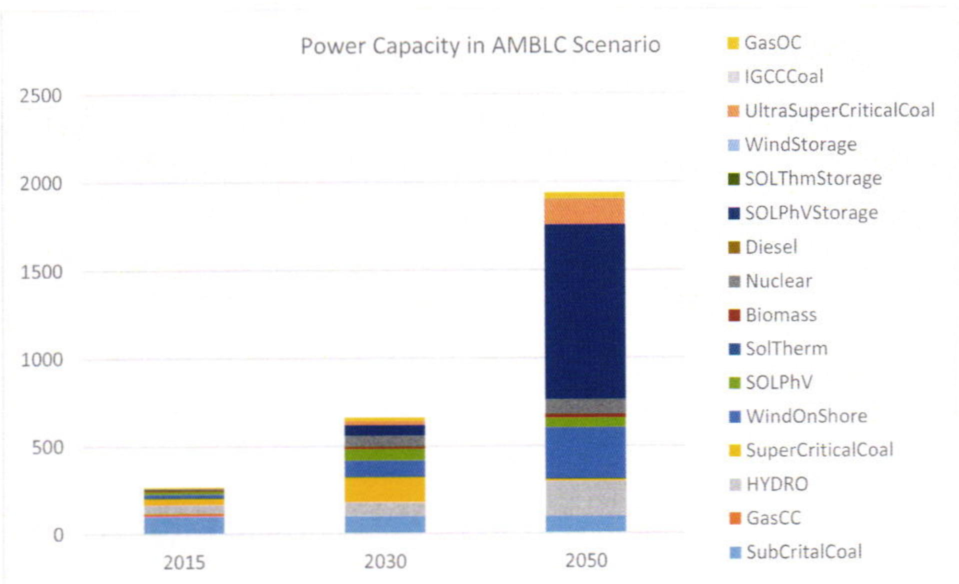




**Figure 4.5 Power Generation and Capacity in AMBLC Scenario**

In AMBLC scenario the power generation in 2030 is 3186 BU and in 2050 it is 6094 BU. The share of super critical coal in 2030 and 2050 decreases to 32% and 2%, ultra-super critical also decreases to 4% and 16%, share of solar Phv is 4% and 2%, wind onshore increases to 7% and 11%, Nuclear increases to 14 and 10% and Solar Phv with storage increases to 4% and 33% respectively. Total capacity requirement increases to 660 GW and 1936 GW in 2030 and 2050 respectively. The share of super critical decreases to 22% and 1% and share of ultra-super critical coal decreases to 3% and 7% in 2030 and 2050 respectively. The share of wind onshore increases 14% and 15%, Nuclear increases to 10% and 5% and Solar Phv with storage increases to 9% and 51% respectively in 2030 and 2050.

Thus, Low carbon pathways and government's announced policy and programs seems to shift power generation from coal based thermal power technologies to more of wind onshore, solar Photo voltaic, solar photo voltaic with storage and nuclear technologies all which have much less water requirements and hence is likely to reduce water demand in power sector. However, Low carbon pathways are expected to increase industrial demand due to higher investment requirement of low carbon technologies. Higher industrial demand, will increase water demand from the industrial sector.

The impact on water demand for each sector is provided in table 4.1 below. The drivers of water demand for each sector have been discussed earlier. The water demand from irrigation and domestic residential households is not affected. Water demand by the Industry too is not much affected except for 2 bcm increase in the case of AMBLC scenario in 2050. Water demand from power sector is in general decreasing however INDC reduces it by 1 bcm in 2030 and 2050, while AMBLC decreases water demand in power sector by 2 bcm in 2030 and by 9 bcm in 2050.

**Table 4.1 Impact of low carbon pathway on water demand (billion cubic meters)**

| | **2015** | | | **2030** | | | **2050** | | |
|---|---|---|---|---|---|---|---|---|---|
| | REF-Medium | INDC | AMBLC | REF-Medium | INDC | AMBLC | REF-Medium | INDC | AMBLC |
| **Irrigation** | 768 | 768 | 769 | 1110 | 1109 | 1108 | 1600 | 1600 | 1600 |
| **Domestic** | 43 | 43 | 43 | 52 | 52 | 52 | 59 | 59 | 59 |
| **Industry** | 7 | 7 | 7 | 17 | 17 | 17 | 36 | 36 | 38 |
| **Power Generation** | 50 | 49 | 50 | 10 | 9 | 8 | 18 | 17 | 9 |
| **Total** | 868 | 867 | 869 | 1189 | 1186 | 1186 | 1713 | 1712 | 1706 |

Thus, Overall water conservation policies for power sector and low carbon policies is likely to reduce the dependence on water for the power sector and is likely to make the sector less susceptible to water scarcity in future.

# Chapter 5 Impact of Low carbon pathway on Water Demand

In the earlier chapter we discussed the impact on water demand of announced government low carbon programs and policies for power sector. Till now all scenarios discussed assumed that water conservation policy announced by the ministry of environment, forests and climate change (MOEFCC) are implemented. In this chapter we analyse the impact of policy failure of not being able to implement MOEFCC guidelines on power sector water conservation policies. The MOEFCC guidelines issued in 2015 is briefly mentioned box 5.1 below.

Box 5.1: MOEFCC Guidelines on water conservation policies in power sector

**Standards for Water Consumption vide Notification No. S.O. 3305(E) dated 07.12.2015**

**1. All plants with Once Through Cooling (OTC) shall install Cooling Tower (CT) and achieve specific water consumption up to maximum of 3.5m3/MWh by 07/12/2017.**

**2. All existing CT-based plants reduce specific water consumption up to maximum of 3.5m3/MWh by 07/12/2017.**

**3. New plants to be installed after 1st January,2017 shall have to meet specific water consumption up to maximum of 2.5 m3/MWh and achieve zero waste water discharged.**

Policy failure for water conservation would imply continuation of water use technologies as existing in 2015. Hence referring to table 2.14, to model a policy failure scenario we assume the water withdrawal coefficients in 2015 continue subsequently for all years. Since policy failure of implementing water conservation policies in power sector will only impact the power sector alone hence we restrict the discussions here only to the power sector. We analyse the impact of policy failure here by comparing the Reference medium growth rate with water conservation policy (Ref-Medium) with Reference medium growth rate without water conservation policy (WCF).

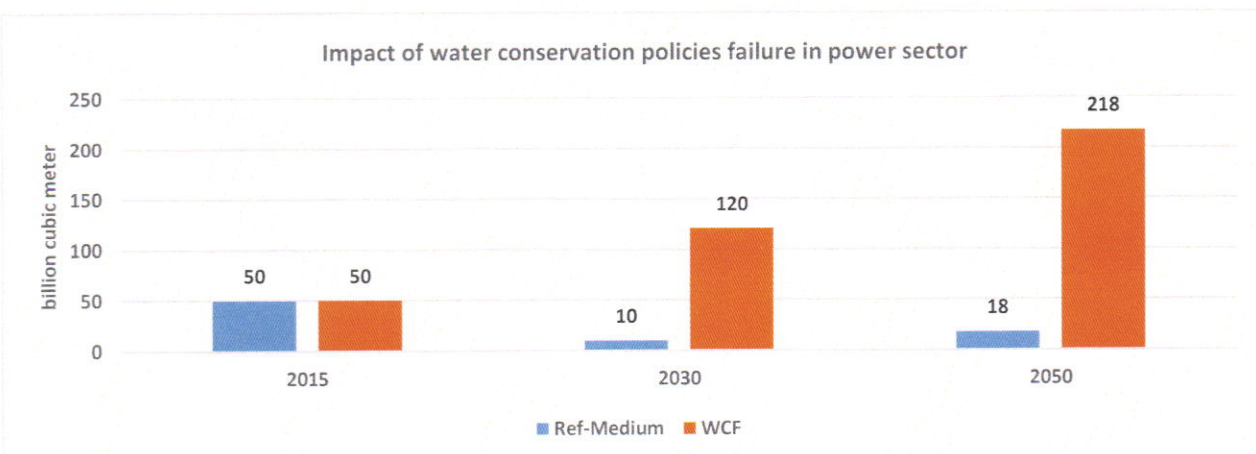



**Figure 5.1 Impact of water conservation policies failure in power sector in the medium scenario**

Figure 5.1 above shows the impact on water demand if water conservation policies of MOEF are not implemented. The comparison of water withdrawal under the two policies from power sector shows a significant impact. In the scenario of a policy failure, water withdrawal demand from power sector would be nearly 12 times in 2030 and nearly 20 times in 2050. Implementation of water conservation policies in power sector is essential to make the power sector growth secure from uncertainties of water availability in future. This will also make power generation more sustainable.

# Chapter 6 Summary and Conclusions

Water demand for the entire economy is projected using a macro economic model that takes care of macroeconomic relationships, inter sectoral linkages and production relationships. The water demand calculated is consistent with the economic growth suggested and the structural change that accompanies such a growth. There have been other researchers' and official estimations of water demand in India. The Table 6.1 below provides two such official projections of sectoral and total water demand.

**Table 6.1 Government of India agencies projection of water demand**

| Projected Water Demand in India in BCM (Billion Cubic Meter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Standing Sub-Committee of MOWR | | | NCIWRD | | | | | |
| Sectors | 2010 | 2025 | 2050 | 2010 | | 2025 | | 2050 | |
| | | | | Low | High | Low | High | Low | High |
| Irrigation | 688 | 910 | 1072 | 543 | 557 | 561 | 611 | 628 | 807 |
| Drinking Water | 56 | 73 | 102 | 42 | 43 | 55 | 62 | 90 | 111 |
| Industry | 12 | 23 | 63 | 37 | 37 | 67 | 67 | 81 | 81 |
| Energy | 5 | 15 | 130 | 18 | 19 | 31 | 33 | 63 | 70 |
| Other | 52 | 72 | 80 | 54 | 54 | 70 | 70 | 111 | 111 |
| Total | 813 | 1093 | 1447 | 694 | 710 | 784 | 843 | 973 | 1180 |

Source: Basin Planning Directorate, CWC, XI Plan Document., Report of the Standing Sub-Committee on "Assessment of Availability & requirement of Water for Diverse uses-2000", Note: NCIWRD (1999): National Commission on Integrated Water Resources Development, BCM: Billion Cubic Meters, MOWR: Ministry of Water Recourses.

**Table 6.2 Summary Projection of water demand from various scenarios analysed**

| | 2015 | | | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| Irrigation | 764 | 768 | 768 | 1069 | 1110 | 1125 | 1604 | 1600 | 1602 |
| Domestic | 43 | 43 | 43 | 52 | 52 | 52 | 59 | 59 | 60 |
| Industry | 7 | 7 | 7 | 16 | 17 | 17 | 27 | 36 | 47 |
| Power Generation | 50 | 50 | 50 | 9 | 10 | 10 | 14 | 18 | 22 |
| Total | 864 | 868 | 868 | 1145 | 1189 | 1203 | 1703 | 1713 | 1731 |
| | INDC | AMBLC | WCF | INDC | AMBLC | WCF | INDC | AMBLC | WCF |
| Irrigation | 768 | 769 | 768 | 1109 | 1108 | 1110 | 1600 | 1600 | 1600 |
| Domestic | 43 | 43 | 43 | 52 | 52 | 52 | 59 | 59 | 59 |
| Industry | 7 | 7 | 7 | 17 | 17 | 17 | 36 | 38 | 36 |
| Power Generation | 49 | 50 | 50 | 9 | 8 | 120 | 17 | 9 | 218 |
| Total | 867 | 869 | 868 | 1186 | 1186 | 1299 | 1712 | 1706 | 1913 |

The official projections from Table 6.1, if compared to the projections in this report under various scenarios provided in table 6.2 above, we can conclude that the total demand projection using the

IRADe-IAM model is in the close range of projections by official government agencies for the starting year. The projections in this report in 2015for irrigation and Domestic use are not too far from the projections for 2010. However, there are differences in estimates between the projections by Ministry of water resources (MOWR) and National commission on integrated water resources (NCIWRD).

In the longer run for 2030 and 2050, the IRADe model estimates of water demand projected in this report are higher than those of either MOWR or NCIWRD. The highest projection of water demand in 2050 is of 1447 bcm by MOWR. This is still lower than the lowest projection of all scenarios considered in this report of 1703 bcm for Low GDP growth scenario. This can be attributed to two factors. First, in this report we have assumed water conservation policies only for the power sector and not for other sectors like irrigation and industry. Secondly, we have assumed 100% irrigation coverage by 2050 on the basis of Government's slogan of '*har khetme paani*' (water in every field), which increases water requirement for irrigation. Also if one were to assume that sprinkler and drip irrigation would be widely used, the water requirement for irrigation can be reduced by 30 %, in which case in 2050, IRADe projection of water needed for irrigation will be around 1120 BCM close to MOWR projection of 1060 BCM.

IRADe estimate of domestic water is also much smaller than those by MOWR and NCIWRD. The current norm for supplying water to urban households is 140 litres/day/person, which is higher than the norm of around 90 litres/day/person taken here. Given the severe water crisis faced by Cape Town and similar ones staring in the face of other cities, such as Bengaluru, underscores the need for water conservation in households. India where much of the housing is yet to be built has an opportunity to make them water efficient and build in as much of recycling as possible.

Official estimates (water and related statistics 2010) suggest that India's estimated annual precipitation including snowfall is 4000 bcm. The estimated annual average potential in rivers is 1869 bcm. The utilisable water is estimated to be around 1123 bcm. Climate change is likely to further reduce the utilisable water availability. Both MOWR (1447bcm) and the scenarios in this report project higher water demand (around 1700 bcm ) than the estimated utilisable water. This further highlights the importance of water conservation in major sectors like irrigation and industry.

The lowest total water demand is of 1703 bcm for low GDP growth scenario and the highest water demand is of 1913 bcm for water conservation policy failure in power sector scenario. The result underscores the importance of water conservation in power sector. If water conservation policies suggested by the MOEFCC are not implemented, then it can increase water demand in the power sector by almost 200 bcm. Implementing MOEFCC guidelines for water conservation would secure future power generation from uncertainties related to water availability.

The scarcity of water is far more serious than indicated by these projections that exceed estimate of utilizable water as water is distributed unevenly in space and time. Thus not only conservation and efficiency but also storage and transport of water need highest priority.

# Chapter 7 References


Abdul Shaban and Sharma R. N. (2007): "Water Consumption Patterns in Domestic Households in Major Cities", Economic and Political Weekly June 9, 2007.

Baljinder Kaur, Kamal Vatta and R.S. Sidhu (2015), "Optimising Irrigation Water Use in Punjab Agriculture: Role of Crop Diversification and Technology", Ind. Jn. of Agri. Econ Vol.70, No.3, July-Sept. 2015

Pratap S. Birthal1, Md. Tajuddin Khan, Digvijay S. Negi and Shaily Agarwal (2014), "Impact of Climate Change on Yields of Major Food Crops in India: Implications for Food Security", Agricultural Economics Research Review Vol. 27 (No.2) July-December 2014 pp 145-155 DOI: 10.5958/0974-0279.2014.00019.6

Centre for Science and Environment [CSE] (2004), 'Not a Non-Issue', Down to Earth, Vol. 12, No. 19, February.

Pradhan, Saluja and Sharma (2013), "Institute of Economic Growth" Working paper _ 325

MoEF (2009), "India's GHG Emissions Profile: Results of Five Climate Modelling Studies", *Climate Modelling Forum, supported by Ministry of Environment and Forests, Government of India, New Delhi, India.* <http://www.moef.nic.in/downloads/home/GHG-report.pdf>, September, 2013.

Parikh J. and Ghosh P. (2009), "Energy Technology Alternatives for India till 2030" *International Journal of Energy Sector Management,* 3(3), pp 233–250.

Parikh K.S., Binswanger-Mkhize H.P., Ghosh P., D'Souza A. 2011. Double Digit Inclusive Growth: Not Without Robust Agricultural Growth. Background Paper to Centennial Group, *India 2039: Transforming Agriculture*, Washington DC

Parikh K. S., Karandikar V., Rana. A., and P. Dani. August (2009), "Projecting India's Energy Requirements for Policy Formulation."*Energy - The International Journal* 34(8): pp 928-941

Parikh Kirit S, Parikh Jyoti, Ghosh Probal, (2010), "Indian perspectives on global energy scenarios till 2050", IRADe-PR-26-2010

Parikh Kirit S, Parikh Jyoti, Ghosh Probal, Khedkar Gayatri, (2012), "Maps India study on Poverty and low carbon strategy", IRADe-PR-35 (2012)

Parikh Kirit S, Parikh Jyoti, Ghosh Probal, Khedkar Gayatri, (2014), "Low-Carbon Development Pathways for a Sustainable India", IRADe-PR-41 (2014), a collaborative partnership between WWF India, CEE, LAYA, CASA, Bread for the world and Welthungerhilfe.

Parikh Kirit S and Ghosh Probal, (2014), "Economy wide Model for Low Carbon Strategy", IRADe-PR-42-2014, prepared for the Planning Commission (2014), "Final report of the expert group on Low Carbon Strategy for Inclusive Growth" Planning Commission, Government of India, 2014.

Parikh, Kirit S; Ghosh, Probal; D'Souza, Alwin; Binswanger-Mkhize, Hans P,"Consumer Demand System for Long Term Projections", Indian Journal of Agricultural Economics; Apr-Jun 2016; 71, 2; pg. 113-136.

Parikh, Kirit S; Ghosh, Probal; Binswanger-Mkhize, Hans P, "Rapid Economic Growth in India: Technical Change in Agriculture, Irrigation and Food Security", The Indian Economic Journal, Indian Economic Association, SAGE Publications, 64(1&2) 115–136, 2016, DOI: 10.1177/0019466216652530.

RamFishman, Naresh Devineni and Swaminathan Raman (2015), "Can improved agricultural water use efficiency save India's groundwater?" Environ. Res. Lett. 10 (2015) DOI:10.1088/1748-9326/10/8/084022