IGES Research Report 2013-01

# Water Availability for Sustainable Energy Policy: Assessing cases in South and South East Asia

Institute for Global Environmental Strategies,
December, 2013

IGES

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# Water Availability for Sustainable Energy Policy: Assessing cases in South and South East Asia





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IGES Research Report



IGES is an international research institute conducting practical and innovative research for realising sustainable development in the Asia-Pacific region.

# List of Abbreviations

| | |
|---|---|
| ADB | Asian Development Bank |
| BCM | Billion Cubic Meter |
| CCGT | Combined Cycle Gas Turbine |
| CEA | Central Electricity Authority |
| CPU | Compression and Purification Unit |
| CWC | Central Water Commission |
| DG | Diesel Generator |
| DM | Demineralized |
| DWR | Department of Water Resources |
| EJ | Exajoules |
| EPPO | Energy Policy and Planning Office |
| FAO | Food and Agriculture Organization |
| GCM | Global Circulation Model |
| GHG | Green House Gases |
| GIS | Geographic Information Systems |
| GWh | Gigawatt Hour |
| IEA | International Energy Agency |
| IGES | Institute for Global Environmental Strategies |
| IIASA | International Institute for Applied Systems Analysis |
| IPCC | Intergovernmental Panel of Climate Change |
| IWMI | International Water Management Institute |
| MCM | Million Cubic Meter |
| MoEF | Ministry of Environment and Forests |
| MW | Megawatt |
| MWh | Megawatt Hour |
| NCIWRD | National Commission on Integrated Water Resource Development |
| RCM | Regional Circulation Model |
| TLFS | Thailand's Load Forecast Sub-committee |
| TWh | Terawatt Hour |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFPA | United Nations Population Fund |
| USA | United States of America |
| WRG | Water Resource Group |
| WSL | Water Stress Level |

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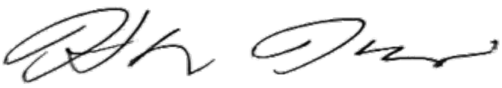
# Foreword

Water and energy play vital roles in all economic activities. Over a period of time, both water and energy have rapidly become exhaustible resources, due to rapid population growth, introduction of complex industrial processes and rapid agricultural growth. This situation will challenge sustainable development because access to these resources and their sustainable management are the basis for sustainable development. Many commitments have been made to contribute to achieve water, energy and food security for the poor, including the MDGs and related policy processes. However, despite significant progress, the security of water and energy supplies remain far from being achieved in Asia. Developing Asia in particular still faces significant challenges in ensuring water and energy security for all people.

Water and energy issues are inherently inter-linked and inter-dependent. However, until recently, the surge in demand for water, energy and food has typically been addressed through individual sectoral approaches. Conventional approaches cause tradeoff conflicts among sectors. Conflicts on water use between energy production and other users are emerging in Asia, particularly in water-scarce countries. Furthermore, in water abundant countries like Thailand, energy generation has led to a water shortage in the dry season. To mitigate the conflict among sectors, there needs to be much better understanding of the inter-resource relationship. A quantitative assessment of water for energy needs is essential in this regard. The Institute for Global Environmental Strategies has initiated a study aiming at a quantitative assessment of the water-energy nexus in South Asia and Southeast Asian countries. In this study we developed an integrated assessment framework for natural resource management, which is perhaps one of first attempts in Asia to investigate the quantitative relationship between water and energy.

It is with great pleasure that IGES publishes this research report, taking us one step closer to realising the necessity of integrated resource planning on the path to sustainable development in the Asian region.



Hideyuki Mori
President
Institute for Global Environmental Strategies

# Acknowledgement

We, the authors, are very much obliged to the Institute for Global Environmental Strategies (IGES) for providing us with financial support, under the provision of the IGES Strategic Fund 2012, to conduct this study. We are also indebted to the International Institute for Applied Systems Analysis (IIASA), especially to the Energy Group headed by Dr. Keywan Riahi, for their kind support in terms of the development of the MESSAGE Model for estimating water demand and conducting subsequent analysis which is, indeed, the backbone of this study. Furthermore, we would also like to thank our colleagues at IGES who continuously helped the team work on this very challenging task over the last year. We are especially thankful to Dr. Satoshi Kojima and Ms. Yatsuka Kataoka for their insightful comments on various technical issues of modelling and analysis. Our sincere thanks also go to Professor Hidefumi Imura and Dr. Mark Elder for their encouragement and insightful review of the report.

# Abstract

Water and energy are the two most essential resources for the survival of human beings on this planet. Since the era of industrialisation, beginning in the nineteenth century, energy and water have been utilised in industrial processes in various forms and quantities. Over a period of time, due to rapid population growth, the introduction of complex industrial processes and rapid agricultural growth, both water and energy have become exhaustible resources. Therefore these resources now require careful attention in the context of their extraction, use and disposal. As a matter of fact, water and energy are now inherently interdependent in nature. Water is an essential element in energy production while, for water use, energy is essential for providing the power to transport water from one place to another.

Understanding this fundamental principle of interdependence, we have tried to investigate the scientific relationship between these two resources in the context of energy generation and subsequently the long-term consequence of water constraints. There are ample studies available where the relationship of energy use in water extraction, distribution and consumption has been investigated. But the upper cycle of the relationship, where water is an essential input factor for energy generation, has hardly been investigated in a scientific manner. Though there are a few studies available on a global scale, which have mostly been done based on information collected from the United States, there is no such study available for regions in South Asia and South East Asia. As a matter of fact, these regions are very vulnerable with regards to water availability in the long run and thus need additional attention in terms of developing their long-term energy strategy.

Understanding the requirements of such an important assessment, we conducted two separate studies in two different geographical locations, one in India and the other in Thailand, to demonstrate the impacts of water scarcity on long-term energy supplies up until 2050. India is a major economic hot spot in Asia, and has an enormous appetite for energy, but with limited water resources, the country poses an excellent case study for us to investigate the impact of potential water scarcity on the long-term energy supply situation. We also investigated the same situation for Thailand which is conversely considered to have abundant water supplies. At the end we compared the findings of the two different cases. This further reveals the stunning truth of the potential severe conflict between the users of two resources (energy and water) and the subsequent negative impact on the overall development of these regions.

This study further corroborates the need for early action in terms of water and energy conservation and an adoption of an integrated planning approach where both of these resources can be considered together. This study also indicates further research which includes agricultural issues along with water and energy to provide a comprehensive assessment of water, food, energy and climate together. Under the extremely complex system of human society, no independent resource planning can work perfectly unless the influences of other resources are considered in a systematic manner.

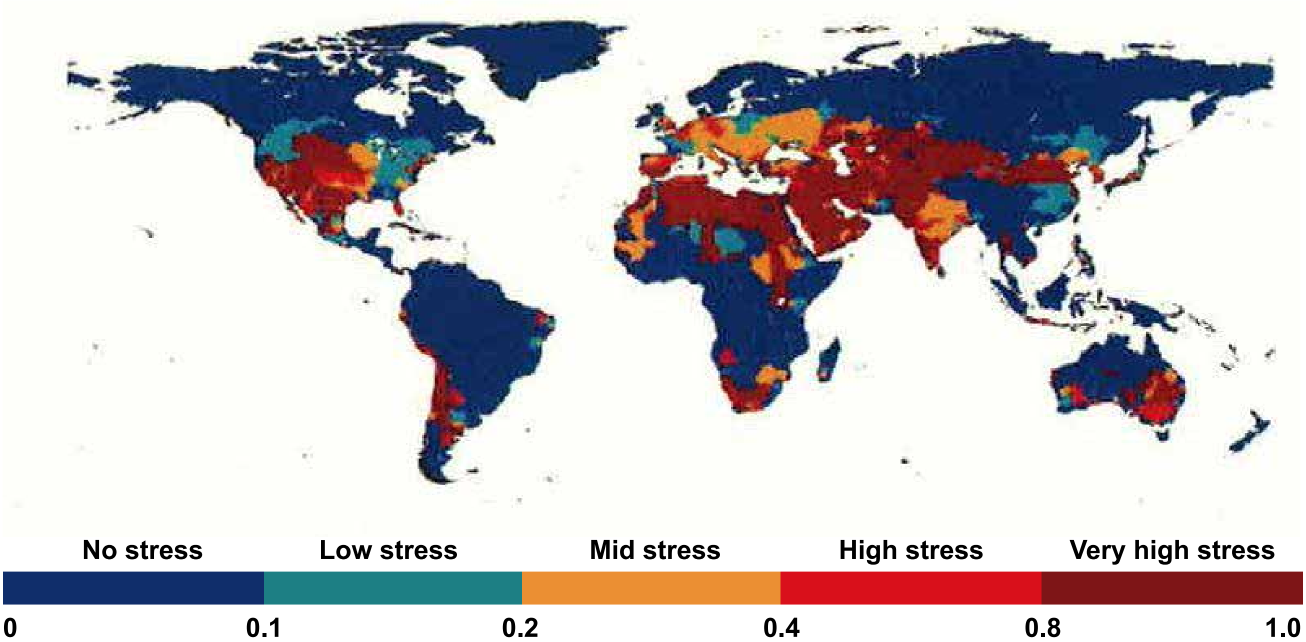
# 1. Introduction

Although water and energy are two different resources on the earth they are intrinsically interdependent on both the supply and demand sides. Water is required for extracting energy, refining and processing raw materials and finally transforming these into a usable form like natural gas, liquid fuel and electricity. On a global scale approximately 8% of the total water withdrawn is used for energy generation. In some developed countries it accounts for about 40% of the total water withdrawn (World Economic Forum, 2011; Huston et al., 2004). This water demand will continue to grow particularly in emerging countries like China, India and Brazil because there will be an increasing demand for energy as these countries develop. All three countries together will account for 30% of the total energy consumption of the world over the next 40 years (World Energy Council, 2010). Similarly energy is an integral input for modern water supplies and wastewater systems. In the United States, over 3.5% of total electricity consumed in 2005 was accounted for by municipal water supply and wastewater treatment. This report will limit its focus to discussing the water used in energy generation.

While competition for water is intensifying in the world, growing energy demands further intensify the conflict for this resource among various users. Energy policy decisions will have a significant influence on future water security. Many countries are revisiting their energy policies for sustainable energy production considering putting emphasis on carbon mitigation, costs and security (Glassman et al., 2011). However, in most cases, water is yet to be well addressed in terms of its importance as an input factor in long-term energy policies. In recent years the inter-linked nature of water and energy has been gaining special attention in regional and international platforms where the long-term challenges associated with the growing demand for these resources is being considered. The water-energy nexus is more critical for “water scarce” regions where there is emerging economic growth.

Figure 1 shows, about 25% of world’s terrestrial surface is under sever water stress if Greenland and the Antarctica is excluded (Alcamo et al., 2000). It has been estimated that by 2030 the world will face a water supply shortage of nearly 40% (WRG, 2010). Asia is the driest continent in the world in terms of the availability of freshwater. It has less than half of the global annual average of 6,380 cubic metres per inhabitant. The region also has less than one-tenth of the total water available in South America, Australia and New Zealand, less than one-fourth of North America, almost one-third of Europe, and moderately less than Africa per inhabitant (FAO, 2011). Approximately 2.1 billion people live in the water stressed river basins and 50% of them live in South Asia and China. In India the total water demand will increase by nearly 100% (750 BCM) and in China it will be around 200 BCM by 2030 compared with the current supplies of 750 BCM and 618 BCM respectively (NCIWRD, 1999; Water Resources Group, 2009).

**Figure 1: Stress on World's water resources based on criticality ratio**[1]




The problem is even more acute in countries like India in South Asia. India is one of the world's "water scarce" countries with only about 4% of the world's total utilisable freshwater resources. The National Commission for Integrated Water Resource Development (NCIWRD) (1999), estimated that India only has 1122 billion cubic metres (BCM) of utilisable water per year at the current level of supply and demand. By 2050 water demand will grow to almost 1300 BCM, compared with the current supply of about 750 BCM, which will put all development activities under threat. The per capita freshwater availability has dropped from 8192 $m^3$ early last century to 1730 $m^3$ in 2006, which is dangerously close to constituting a "water stressed" condition (1700 $m^3$) and it is projected that this availability will further drop to 1240 $m^3$ which is close to qualifying as a "water scarce" situation (1000 $m^3$) as per the Falkenmark indicator (Falkenmark 1989).

Despite there being a relatively large water endowment in South East Asia, countries like Thailand are already water stressed in particular regions and seasons. The agricultural sector faces the biggest threat since it accounts for about 90% of total water withdrawals in the region. In 2005 more than 2.1 million hectares of agricultural cropland was damaged due to drought in Thailand (Office of Natural Resources and Environmental Policy and Planning, 2010).

While the major hot spots for economic development are located in Asia, it is envisaged that this development will be challenged by the increase in water shortages. Besides the various reasons for the increasing water crisis (population growth, industrialisation, green revolution in agriculture and climate change), energy production is one of the potential major sources of water shortages in Asia. This has been ignored in water and energy policies. It is projected that electricity demand increased by 6.4% between 1980 and 2007. However about 930 million Asians do not have access to electricity; this is equivalent to about half of the world's population being without electricity (Bhattacharya, 2011). By 2050 Asia's electricity demand will account for 44% of total world demand (IEA, 2011).

1 The criticality ratio is based on average water withdrawals and water availability

It is projected that high water consuming, coal-based electricity generation is likely to be the predominant electricity supply mix in the foreseeable future in Asia and it is expected that this will put immense pressure on the freshwater resource stocks. Considering the fact that water constraints pose a severe threat to the rate of development in Asia, the very high projected ratio of electricity sector to water use implies that there is a critical trade-off among various water uses, particularly in water stressed hot spots of economic development such as India and China. It is projected that in 2050 electricity generation will account for 20% of the total water demand in India unless appropriate measures are taken to deal with the water scarcity issues from both technical and policy perspectives (Table 1).

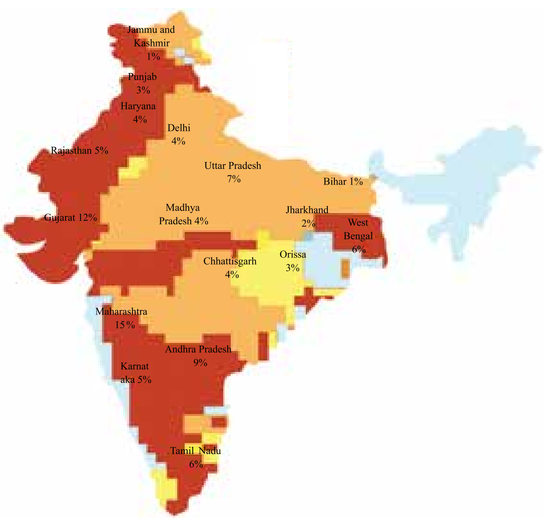
As a result, water stress will intensify in the context of water use among various demand categories. Furthermore, frequent climate induced events and longer drought events will worsen the situation. In fact some cases of conflict have already been reported in different parts of Asia (Table 2). However, the energy policies of Asian countries have so far not put enough attention on this link between water and energy, and the corresponding trade-offs. An example is the clear dichotomy in the electricity planning of India where they have been seriously ignoring the issue of water availability. More than 60% of the capacity of installed thermal plants were set up in regions where electricity demands are expected to remain very high and, ironically, all these areas are either "water scarce" or "water stressed" as per the World Resource Institute definition (Figure 2).

**Table 1: Projected rate of water use in the electricity sector as a percentage of the total utilisable water in India**

| Year | Projected rate |
|---|---|
| 2010 | 4% |
| 2025 | 9% |
| 2050 | 20% |

*Source: (Mitra and Bhattacharya 2012).*

**Figure 2: India's existing thermal power plants**




% shows installer capacity of thermal power generation

**Water stress level**

- Water scarce
- Water stressed
- Mod erate water a vailability
- Water abundant

*Source: Author generated map (not to scale) using data from World Resource Institute (2010) on Water Stress Levels in India and data on power plant installation from the Central Electricity Authority of India (2011).*

*Note: Water stress level (WSL) = Water withdrawals/Total available water-Environmental needs.*

*Water scarce: WSL>1; Water stressed: 0.6≤WSL<1; Moderate water availability: 0.3≤WSL<0.6; Water abundant: <0.3*

**Table 2: Examples of water crises for electricity generation in Asia**

| Country | Nature of water crisis | Sources |
|---|---|---|
| India | Opposition to Adani power projects is growing in the local community due to threats to drinking water and the availability of irrigation water | The Times of India, 2011 |
| | In Orissa State, farmers protested the increasing rate of water allocation for thermal power and industrial use | UNEP Finance Initiative, 2010 |
| Thailand | EGCO's Rayong plant nearly ran out of cooling water in the dry season of 2005 | Levinson, 2008 |
| | Reduced rainfall causing reduction of hydropower generation in Thailand in 2004 | Thai Press Reports, 2004 |
| Viet Nam | Severe drought caused hydropower generation to be reduced to 40% of total capacity due to water being diverted for agricultural use | Financial Times Information, 2005 |

# 2. Rationale and objectives of this study

Meeting the increasing water needs for rapid urbanisation, increased industrial and commercial activities, agriculture and municipalities for all-inclusive uninterrupted growth in emerging countries is becoming a concern among policy makers. For example the sectoral demand for water, including the power sector, by the year 2050 is expected to slightly exceed the available water resources in India in some scenarios and significantly exceed them in others. Under a water stressed situation, considering the priority given to the agricultural and domestic sectors over industrial water usage, as mentioned in the national water policies, the industrial sector (including power) may face water availability issues. Spatial and temporal distributions in water availability may further aggravate the situation.

The national average for water availability masks the wide inter-basin and state disparities stemming from anthropogenic as well as natural factors, such as spatial and temporal differentials in India's rainfall, which translate into iniquitous water distribution and access.

Asia's electricity demand will grow from 5530 TWh in 2007 to 13830 TWh by 2035 (Komiyama, No dated). Asia's power sector is heavily dependent on coal and gas based thermal power plants and is expected to continue to rely significantly on fossil fuels. Fossil fuel based power generation is water intensive. Therefore there is a need to assess the water requirements for thermal power plants in the long-term and the policy implications of water stress on thermal energy generation.

Against the above background, this study covers two case study countries in order to cover South Asia and the Southeast Asia region, namely India and Thailand. India is a "water scarce" country in terms of per capita water availability, whereas Thailand is "water abundant" but frequently faces seasonal water scarcity. it is likely that the dominant form of future electricity generation will use water intensive thermal power plants, which put pressure on water availability for other water users.

Therefore, this study on the water-energy nexus will help develop an understanding of the increasing gap between water supply and demand at the national level in these case study countries, and will demonstrate the potential impact of water scarcity on the power sector. The study is expected to provide an assessment of the availability of water resources and the requirements at the sector level and the national level. It will focus on the requirements of thermal capacity addition by 2050 and the potential of water stress/scarcity impacting on thermal power capacity addition, and will also look at the options that are available for thermal power plants including policy interventions, increasing end-use efficiency and using water efficient technologies in the power sector for meeting water requirements on a long-term sustainable basis.

## Therefore, the main objectives of this study are

(i) Establishing a resource link between water and energy at the energy supply side under the framework of a country's energy systems.

(ii) Demonstrating the importance of integrated water-energy assessments in energy planning for sustainable development.

(iii) Demonstrating the effects of water availability on the development of a long-term energy scenario and the subsequent impacts on energy technology choices.

(iv) Indicating policy changes in water supply and demand management to mitigate the impact of water shortages and increasing energy demands.

# 3. Methodology

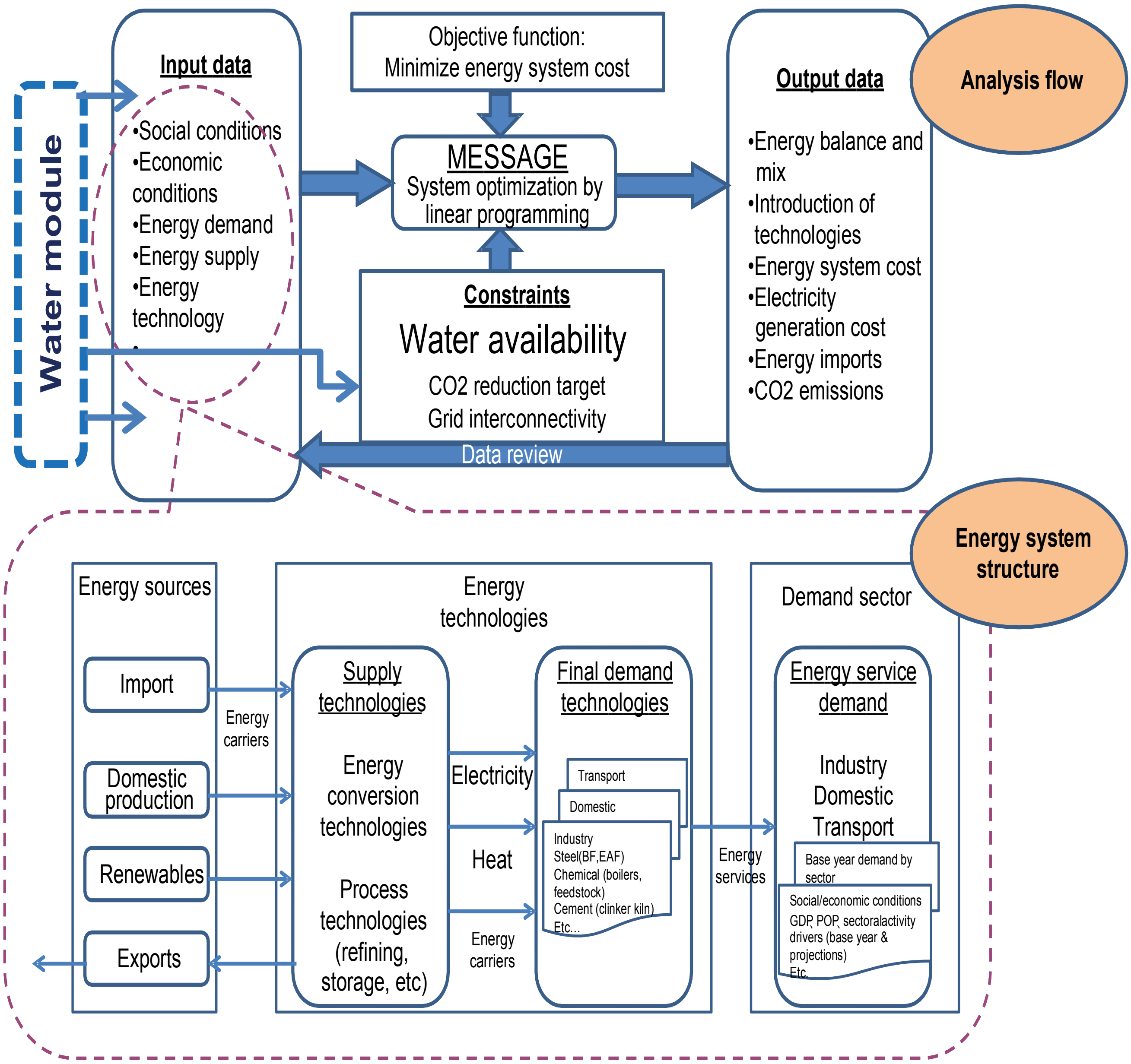
To meet the objectives of this study we depended on several tools such as a literature review, power plant survey, stakeholder consultation, three different types of assessment models dealing with issues like water, energy and climate change and their correlations. We used an energy systems model, climate forecasting model (circulation model) and hydrological model in a predetermined sequence to obtain an integrated assessment output. Nonetheless, in this study the three models are not endogenously integrated but manually linked to each other. For some of the analyses we used different methodologies for each of the case study countries (India and Thailand), particularly for water availability. We used the hydrological model together with the climate circulation model to estimate future water availability in the major river basin of Thailand. On the other hand, we relied on available literature for analysing the state of water resources in India.

## 3.1 Description of the MESSAGE model and water demand assessment for the energy sector

Besides integrating different models, a major methodological advancement has been made in this study by integrating the water demand for energy generation assessment module with the energy systems model. So far there is no global energy systems model available which can endogenously determine the water demand for the entire energy system. In this study this was the first methodological challenge which we overcame by developing a water module for the MESSAGE Model (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) developed by Messner and Strubegger in 1995. MESSAGE is a multi-region energy system model capable of estimating the cheapest supply option for energy in the long-term under different constraints including climate, resources and costs.

In the process of estimating the water demand exclusively for energy supply in the system, we used a newly developed water module, synchronised with the rest of the model. This module endogenously determines the total water demand for total energy that needs to be supplied to the system under optimal conditions. For each energy technology that needs water, a unique water use coefficient is assigned in the model which internally interacts with the corresponding technological output in terms of energy units and derives the total water demand for that particular technology in the system. Finally, each technology based water demand gets aggregated over a period of time (here we derived water demand on an annual basis). For assessing water demand we used a water use coefficient for each eligible technology and data was collected from surveys of power plants in the country. Figure 3 below shows the schematic diagram of the MESSAGE-Water model that is the basis of our water-energy Nexus assessment.

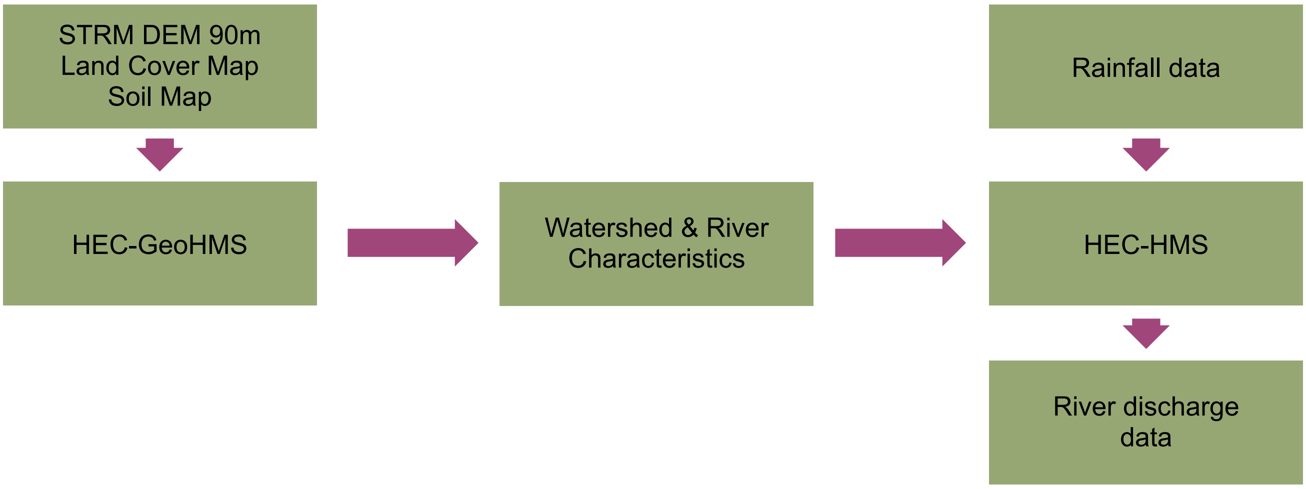
**Figure 3: Schematic diagram of MESSAGE Model with water module**




## 3.2 Selection of the Global Circulation Method (GCM) and the downscaling of GCM data

In the context of estimating long-term water availability in the region we used two different models, namely the global circulation model and hydrological model respectively. The main purpose of adopting two models was to estimate the impacts of climate variation on long term surface water availability which is the major source for energy production. Based on the regional performance and acceptance of Global Circulation Models (GCMs), climate change projections were obtained from ECHAM4. ECHAM4 was used by several regional level and river basin level studies in Southeast Asia (Chinvanno, 2009; Sharma et al., 2007; Khattak et al., 2011). The most popular two SRES scenarios A2 and B2 were chosen for this study. Figure 4 below shows the schematic diagram of the flow of the modelling analysis for the water demand assessment.

**Figure 4: Flow chart for the water availability assessment exercise**



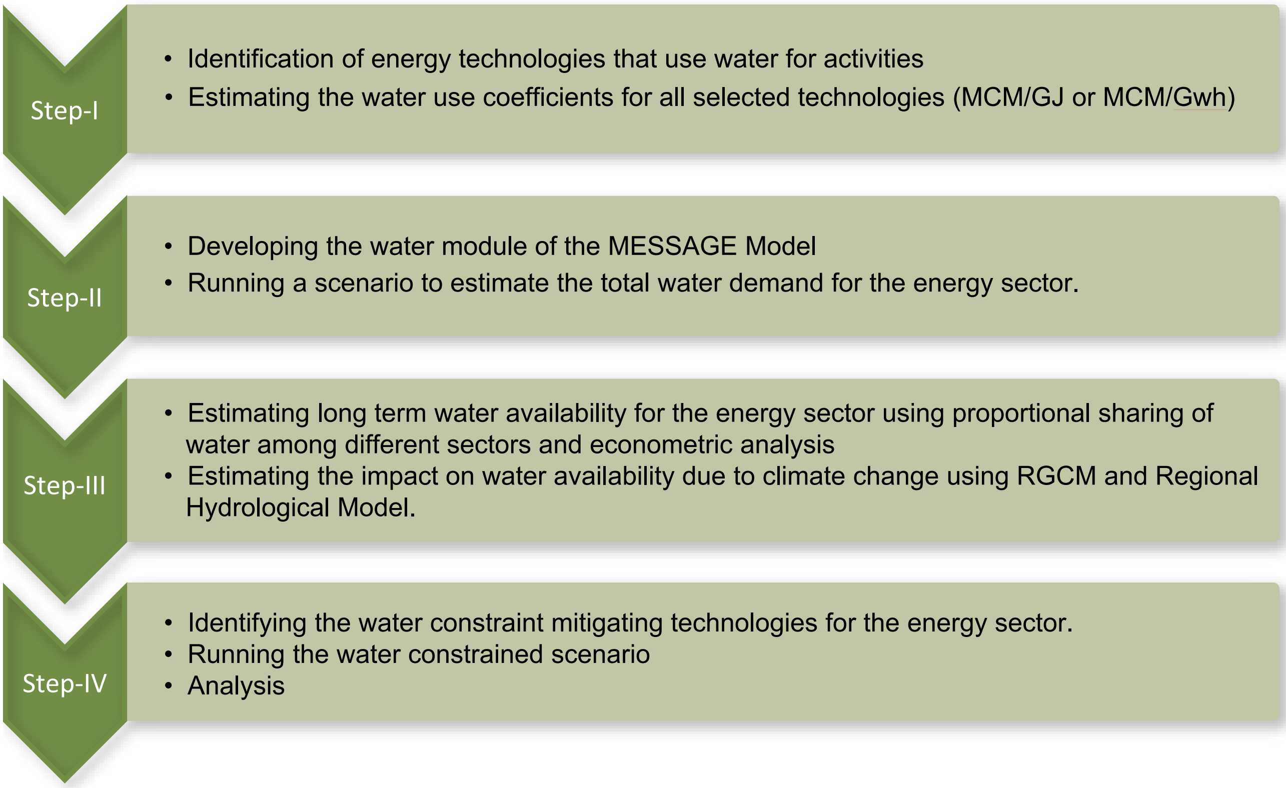

## 3.3 Activity sequence

There were four major steps taken to complete the entire quantitative assessment part of this study. In the first step, we compiled a list of all the energy technologies that use water as one input for process activities. We mainly identified around 70 different energy technologies that are in use in the energy systems in this region. This covers the technologies used for energy extraction, refining and use. Power generating technologies are given priority here as they are the major water consumers in the South and South East Asia region. Our next task was to estimate the water use coefficients for each selected energy technology. Here we only considered how much water is withdrawn from the source for energy extraction, refining and conversion (electricity generation). The major problem was the availability of region specific data. The only source of secondary data was available from the USA Department of Energy, which was based on the US power plant and energy sector. To overcome this problem, we conducted power plant surveys in both India and Thailand and collected water use data which was finally converted into water coefficients that could be used in the model.

In the second step, we developed the water module for the MESSAGE global model and ran a reference scenario for energy systems to estimate the base water demand.

The third step was to estimate the long term water availability for the energy sector. There were hardly any projections available from a reliable source on the energy sector's future water demands. The major classifications of water demand categories are agricultural, residential and industrial. In most of the cases the energy sector is aggregated under either the industrial category or agricultural demand category. In this study we first conducted a literature survey to assess the water demand in different sectors and then performed certain statistical analyses using our model to determine an estimate of the water demand in the energy sector.. As we were also observing the impacts of climate change on water availability, it was assumed that climate change will also impact on the water that is available for energy generation in the future. Therefore, we conducted a hydrological simulation of net utilisable water in the study region under no climate impact, IPCC A2 and IPCC B2 scenarios. However, we could only conduct this assessment for Thailand at this time due to a lack of time. For India we used a purely statistical method to project the energy sectors' water availability until 2050.

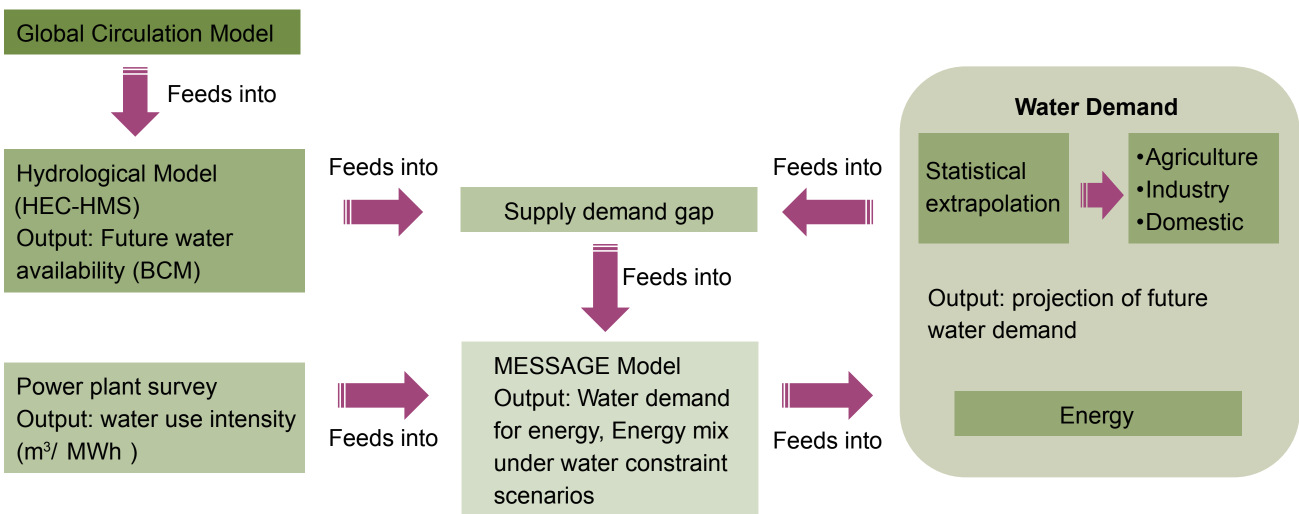
**Figure 5: Steps in the process of analysis**




In the last step of this assessment, we used these water availability constraints to estimate the impacts on the long-term energy scenario in the study region in terms of technology variation, investment patterns and environmental issues. We also investigated the supply- demand management options to mitigate the water shortage problem in the region. Figure 5 describes the steps of analysis in sequence.

In this study, we conducted the above mentioned analysis separately for two countries: India and Thailand. Due to certain methodological constraints we could not link the regions under the same model. However, this juxtaposed assessment brings out some common messages which are, indeed, relevant to policies for the entire region. The following diagram (Figure 6) shows how this integrated assessment model was developed and how each part is linked.

**Figure 6: Links between the different models and tools used in this study**



# 4. Water demand in the energy sector

Water is needed throughout the energy chain. Water is required in every step in various quantities, starting from energy resource extraction, processing, transportation, refining and conversion up until energy use. However, the quantity of water required varies among different energy commodities as well. Thus long term water resource availability can affect all forms of energy production including electricity generation and can lead to price volatility in wholesale electricity markets due to the wide variation in supply and demand.

## 4.1 Water requirements for primary energy production

Water consumption in primary energy production varies from fuel to fuel depending on whether it is a fossil fuel or renewable. More or less, all types of energy production need water at some point in the production cycle. As a matter of fact, the water footprint of energy commodities is significant on a global scale. In developed countries assessing the water foot print for various energy types is predominant when compared to developing countries. Moreover, developing countries are still largely dependent on biomass and solar which are difficult to measure. In the following section we will briefly describe the water foot prints of commonly used energy commodities like crude oil, natural gas, coal and biomass. However, as biomass consists of food and other agricultural residue, which has uses other than for energy utilisation, it is very complicated to attribute the water demand exclusively to energy production from biomass. As a result, we avoided using the water footprint of biomass as a primary energy source. Table 3 below shows the global average water coefficient per unit of energy generation from crude oil, natural gas and coal. However, there are now new types of fossil fuels, like shale oil, shale gas etc., appearing on the 2059 horizon which have high water demands. Here in our study region there has been no such proven reserve found of such non-conventional fossil fuels and thus we did not include them in our estimation of the water demands for energy production in the region.

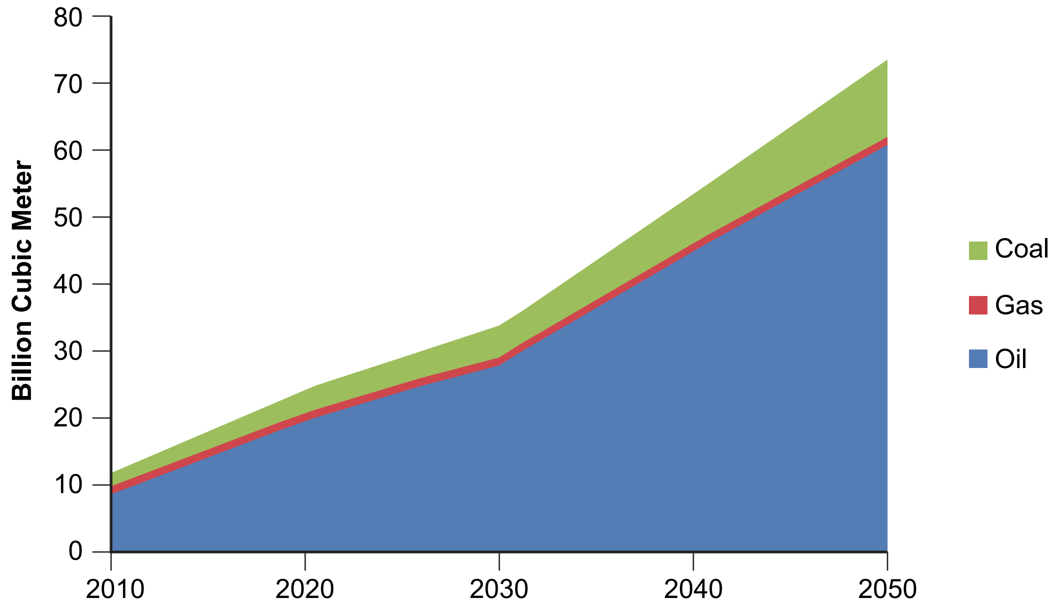
**Table 3: Water requirements for primary energy production in Asia**

| Fuel Type | Water requirement ( BCM/EJ) |
|---|---|
| Crude Oil production | 1.058 |
| Natural gas production | 0.109 |
| Coal production | 0.164 |

*Source: Compiled from World Energy Council report 2010*

Based on projections of long-term energy supply requirements it has been estimated that in the South Asia region (mainly India) the total water required for primary energy production and supply will be around 75 BCM per annum by 2050. Figure 7 below shows the total water requirements for this region to produce primary energy.

**Figure 7: Water demand in South Asia for primary energy production**




## 4.2 Water requirements in thermal power plants

The water requirements in power plants depends on the type of technology employed for power generation, the type of cooling systems employed, the quality of raw water, the quality of coal and the ash disposal system. The typical power plant water requirements for a coal based thermal power plant can be broadly divided into the following categories.

a) Cooling water – Cooling water is required for condensing steam in the condenser to convert steam back to water. The cooling water has other applications in the thermal power plant including (1) cooling water for the heat exchanger and (2) cooling water for auxiliary equipment.

b) Demineralized (DM) water makeup – DM water makeup represents the water that is lost due to blow down. The reject water from a DM plant can be used for applications such as dust suppression.

c) Evaporation from reservoir – A reservoir is created to store water for use in the power plant. The evaporation rate for a reservoir depends upon the ambient conditions and the surface area.

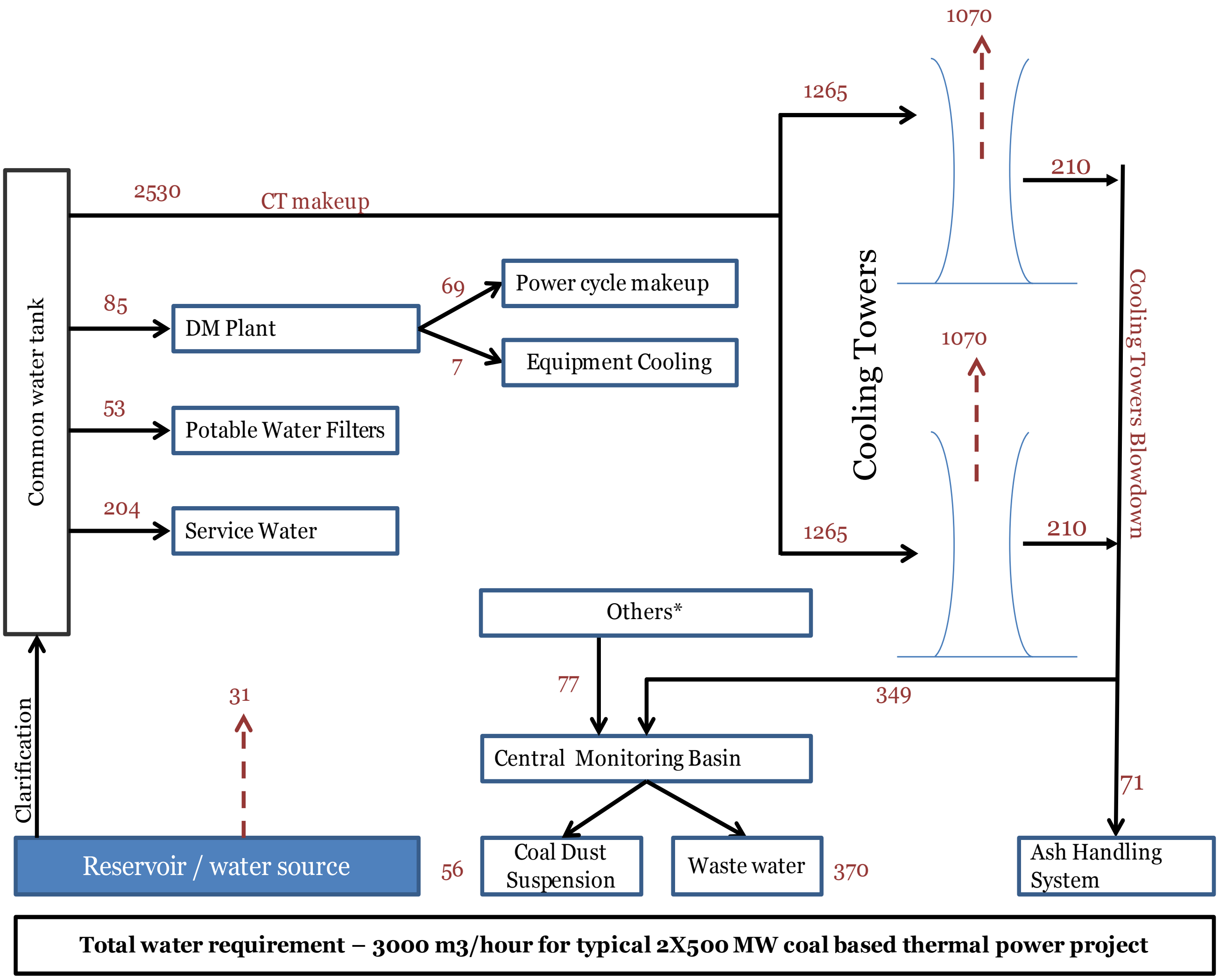
d) Effluent discharge.

e) Ash handling in the case of coal based power plants – The burning of coal results in bottom ash and fly ash being generated by coal based power plants. Fly ash and bottom ash can be transported to an ash pond by using a wet slurry system. Methods such as water recirculation may be adopted to optimise the water required for fly ash disposal. The use of a high concentration slurry disposal system can reduce the amount of water required for the disposal of fly and bottom ash. Other systems include a dry ash disposal system. A dry ash disposal system may be employed for disposing of fly ash but this system is not suitable for bottom ash. Therefore for the bottom ash the water requirement for disposal may be minimised by using a high concentration disposal system. As per the notification by MoEF dated November 03, 2011 the new power plants should achieve 100% utilisation of fly ash by the fourth year of operation.

f) Coal dust suppression in the case of coal based power plants – The low grade water from cooling tower blow down can be used for coal dust suppression at crushing areas and belt conveyers.

The schematic (Figure 8) of water consumption for a typical 2 x 500 MW coal based thermal power plant is provided in the figure below. The water intake for power plants can be broadly divided into two categories - cooling requirement and power cycle requirement.

**Figure 8: Water requirements in a typical 2 x 500 MW coal based thermal power plant (CEA, 2012)**



# 5. Case study on India

## 5.1 Context and objective

India is one of the “water scarce” countries in the world with only about 4% of the world’s total utilisable freshwater resources. The National Commission for Integrated Water Resource Development (NCIWRD) (1999), India estimated that only 1122 billion cubic meters (BCM) of water is utilisable per year at the current level of supply and demand. Eighty per cent of the geographical area in India currently faces varying degrees of water stress or scarcity according to a commonly used water stress indicator developed by Falkenmark (1989). The per capita freshwater availability has dropped from 8192 m3 early last century to 1730 m3 in 2006, which is dangerously close to a “water stressed” condition (1700 m3). Rapid urbanisation, the growth of agriculture and industrial development will put further stress on water resources. It is projected that this availability will further drop to 1240 m3 which is close to a “water scarce” situation (1000 m3) as per the Falkenmark indicator (Falkenmark 1989). Irrigation has an 85% share of the total water consumption in the country. While the water requirement for thermal power generation currently constitutes 1%-2% of the total water demand in the country, thermal power generation is critically dependent on water for its operations. Water is a key resource for thermal power generation and instances of thermal power plant shut down caused by a lack of available  cooling water have been reported (UNEP Finance Initiative, 2010) .

With the growth in thermal power generation, its share of the water requirement is expected to rapidly increase. Thermal power capacity has increased by more than 75% in the last decade and is expected to grow by a further 90% in the coming decade. The current planning and approval process for thermal power plants do not appear to take into account long-term water availability and the competing water uses associated with its water source. This poses a potential risk to power plant operations in the medium to long-term, especially if they are located in the river basins that face water stress or water scarcity. Further, the draft National Water Policy 2012 prioritises water allocation to the domestic and irrigation sectors over industrial/power generation. If a situation of water conflict arises, thermal power plant operations may be at risk if the water resources are diverted to higher priority sectors (Rajput, 2013).

In order to ensure that the country’s electricity needs do not come into conflict with the irrigation and domestic water needs, an assessment of the risks related to water availability  for future thermal power plants needs to be made. The statistics on national level water availability and requirements masks the regional differences that in turn are critical to understanding the effect of water stress on thermal power plants.

The technical life of thermal power plants is 15 years (for gas based power plants) to 25 years (for coal based power plants). With renovation and modernisation, the technical life can be further extended by another 15 to 20 years.

Planning decisions on power generation taken today will lock in the fuel, technology and location of the thermal power plants for the next 30–40 years. Therefore, it is important to understand and analyse the policy implications of such decisions in the context of water stress.

For this study, the reference year of 2050 has been chosen in consideration of the 30–40 year time horizon which means that policy decisions relating to setting up of new thermal power plants taken today can mitigate water related risks by the year 2050. This study estimates thermal power capacity additions up to this reference year (2050). It assesses water scarcity at the river basin level up to 2050 and evaluates the thermal power capacity that can be at risk based on the forecasted geographical distribution of thermal power plants. It examines some of the key business drivers of cooling technologies and concludes with recommendations for de-risking thermal power plants from water stress.





## 5.2 Study approach

This study primarily relies on national planning documents and research studies supplemented with limited primary data collection and modelling. Thermal power capacity (MW) estimates for a period up to 2050 are developed based on projections contained in national planning documents and extrapolated where there are gaps. In order to assess if the thermal power capacity exposed to water stress in 2050 can be significantly different in the event that there is a shortfall in planned capacity additions, an alternate scenario of lower thermal power capacity by 2050 has also been evaluated. Coastal plants have been excluded from this study as they do not impact freshwater sources.

Research studies on river basin water availability and requirements, as well as climate change impacts have been reviewed and adapted to the requirements of this study. In examining water stress, the Falkenmark water stress indicator (Falkenmark 1989) and IWMI water stress indicator (Smakhtin et al. 2004) have been used. The Falkenmark water stress indicator views the water issue from a per capita availability perspective while IWMI views the water issue from a water balance perspective.

The location of thermal power plants in 2050 is a key determinant for assessing how thermal power capacity will be exposed to water stress. National planning documents do not contain information on the location of future capacity additions. A methodology has been developed to forecast future power plant locations based on the current pattern of development but subject to the availability of fuel reserves in the river basin. The methodology does not consider other parameters relevant to siting like transmission availability, local environment and forest issues, mine locations, fuel transportation, load centres, market arrangements, etc. Information has been collated from the state and central environment approval process to develop another scenario of distribution of thermal power plants. The location analysis is superimposed on the water stress/water scarcity of river basins to examine the percentage of thermal power capacity that may be exposed to water stress.

As cooling technologies are expected to play a key role in mitigating the water risks to thermal power plants, the key business drivers of cooling technologies have been examined. Limited primary data collection on the current performance of cooling technologies and financial modeling of coal and gas based power plants to assess the impact of cooling technologies have been carried out.

## 5.3 Overview of the power sector in India

The total installed capacity at the end of the XIth Plan (2012) was 211,766 MW including 141,714 MW from thermal power plants (coal, lignite, gas, diesel, oil and naphtha), 39,416 MW from hydro power plants, 4,780 MW from nuclear and 25,856 MW from renewable energy plants.

Table 4 below shows the installed capacity break-up by fuel/technology.

**Table 4: Installed capacity by the end of the 11th Plan**

| Fuel/technology | Installed Capacity (MW) |
|---|---|
| Coal and lignite / subcritical | 114,871 |
| Coal / supercritical | 6,740 |
| Natural gas / CCGT | 18,903 |
| Diesel and fuel oil | 1,200 |
| Hydro | 39,416 |
| Nuclear | 4,780 |
| Renewable Energy Sources | 25,856 |

*(Source: CEA, MNRE, MOP)*

In addition, captive power capacity of 32,900 MW was operational by 31 March 2011 according to the National Electricity Plan 2012. The fuel/technology break-up for captive power capacity is not available and therefore this has not been examined further.

### 5.3.1 Thermal power capacity expansion plan up to 2050

In the National Electricity Plan, CEA projects the thermal power capacity additions under three scenarios during the XII$^{th}$ Plan (2012 to 2017) from 64,486 to 67,686 MW while thermal capacity additions during the XIII$^{th}$ Plan (2017 to 2022) are expected to be 47,000 to 49,200 MW. This study considers the "low renewable, low gas" scenario among the three scenarios developed by CEA, as it is the base case scenario of the National Electricity Plan and it is more likely given the current uncertainties surrounding the availability of gas and prioritisation of gas use for the fertiliser sector.

The Working Group on Power for the XII$^{th}$ Plan considered capacity additions from coastal power plants and, accordingly, the coastal power plants have been considered as a percentage of the thermal capacity additions for the period 2017 to 2050. Coastal power plants are not expected to impact on freshwater resources. For the period up to 2032, CEA has made annual projections of electricity demand in the draft 18th Electric Power Survey. On the assumption that the technology mix will remain constant from 2022 onwards, CEA's electricity demand forecast is expected to translate into a total installed capacity (including thermal and other power generation sources) of 718,456 MW by the year 2032. As there are no estimates available in the national planning documents beyond 2032 a simple extrapolation of total electricity demand, assuming that the same technology mix (as in 2022) will be maintained, is used to arrive at an estimate of the installed capacity by 2050. The projected installed capacity under a business as usual scenario is presented in Table 5 below.

**Table 5: Projected installed capacity in MW (2017 – 2050) under a business as usual scenario**

| Generation technology | Year | | | |
|---|---|---|---|---|
| | 2017 | 2022 | 2032 | 2050 |
| Coal – coastal | 28,232 | 35,612 | 61,142 | 99,660 |
| Coal – inland | 159,979 | 201,799 | 346,474 | 564,739 |
| Gas | 19,989 | 19,989 | 34,320 | 55,940 |
| Hydro | 48,620 | 60,620 | 104,080 | 169,646 |
| Nuclear | 7,580 | 25,580 | 43,919 | 71,586 |
| Renewable Energy Sources | 44,356 | 74,856 | 128,522 | 209,486 |
| Total | 308,756 | 418,456 | 718,456 | 1,171,056 |

### 5.3.2 Underachievement of capacity expansion targets

It is important to understand whether the thermal power capacity exposed to water stress would be significantly different in the event of lower than expected power capacity additions. Actual power plant capacity additions on average have been at the 65% level compared to the plan targets. The lower capacity scenario therefore assumes that the projected installed capacity up to 2050 will be 65% of the capacity projected in a business as usual scenario.

Power plant must assess the water risk in terms of water quality, quantity and the timing of water availability. Many parts of India face high water stress and scarcity largely due to uneven availability and distribution of water resources, both geographically and seasonally. Therefore, it is important to analyse water availability at the river basin level. This has been done in the next section.

## 5.4 Water stress at the river basin level

This chapter analyses water availability and sectoral water demand at the national level. It assesses water availability and requirements at the river basin level, analyses some of the issues related to climate change and examines the water stress in river basins.

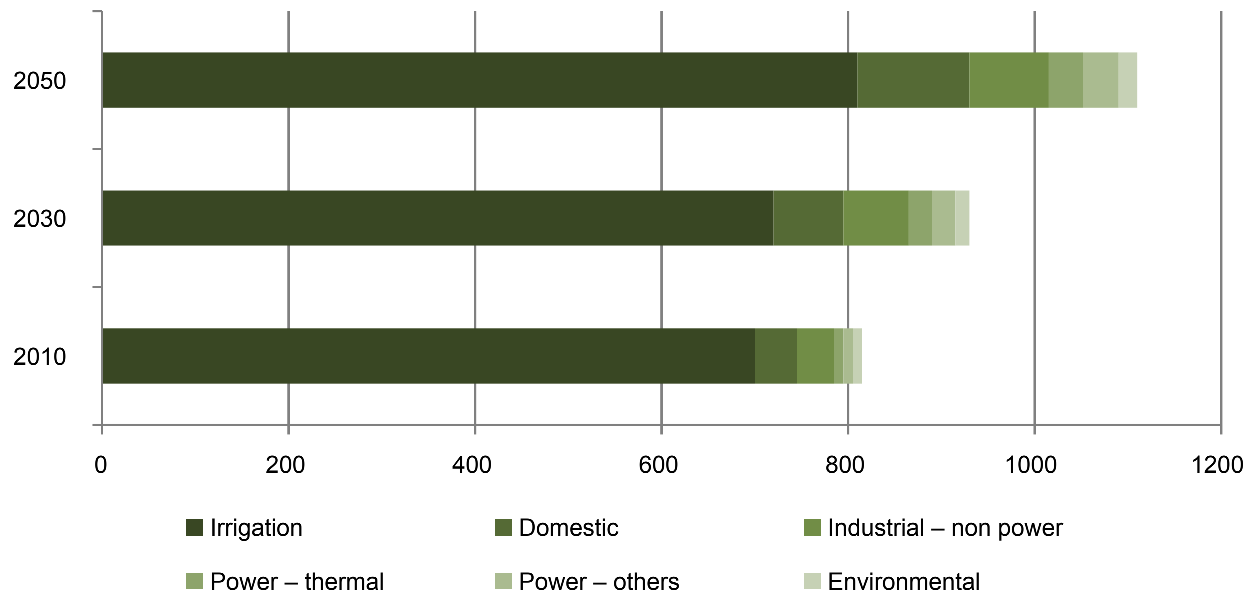
### 5.4.1 National water availability and sectoral water requirements

The total annual water resource potential in India is estimated to be in the range of 1870 to 1950 BCM, considering both surface and ground sources. Groundwater recharge is estimated to be 22-23% (CWC 2010; CGWB 2011, Amarasinghe et al. 2008). However, all available natural freshwater, surface water or ground water resources are not accessible for use. Utilisable water resources have been assessed as being in the range of 1030-1160 BCM of which 60-65% is from surface water sources and the remaining is from groundwater sources (CWC 2010; ADB 2011). The utilisable water resources at the national level are expected to be 1141 BCM (CWC 2010; NCIWRD 1999; ADB 2011) by 2050.

The current annual water requirement is estimated to be in the range of 635-815 BCM out of which the irrigation sector accounts for 85% of the total requirement, followed by the industrial and domestic sectors, which together account for the remaining 10-15% of total water use (NCIWRD 1999; ADB 2011; CWC 2010; Planning Commission 2009; Amarasinghe et al. 2008). By 2050, the water requirement is projected to be in the range of 895-1110 BCM out of which the irrigation sector is expected to account for 70-75% of the total requirement, followed by the industrial and domestic sectors (NCIWRD 1999; ADB 2011; CWC 2010; Planning Commission 2009; Amarasinghe et al. 2008).

The water requirement of the industrial sector, including power, is estimated to be in the range of 145-160 BCM by 2050 (NCIWRD 1999, ADB 2011, Amarasinghe et al. 2008). The power sector's share of the water requirement is estimated to be 45% of the total water demand in the industrial sector (ICID 2005; CWC 2010; ADB 2011). Further, the water requirement for thermal power generation is expected to be close to half of the total water demand of the power sector and the remaining half is for other power generation technologies including hydro. Figure 9 below provides a summary of the overall water requirement and sectoral distribution in detail.

**Figure 9: Water requirements and sectoral distributions for different sectors in BCM**




*Source: NCIWRD 1999; Planning Commission 2009; Amarasinghe et al. 2008; Author's estimates*

### 5.4.2 Water availability and requirements at the river basin level

Studies have estimated the utilisable water resources and total water requirements up to 2050 (CWC 2010; NCIWRD 1999; ADB 2011). These have been synthesised and adapted to develop a water resource and requirement forecast for the year 2050 which is set out in Table 6 below.

**Table 6: Water availability and requirements at the river basin level in 2050**

| River basins | Per capita water available [2010] | Per capita water available [2050] | Utilisable water resources [BCM] | | | Total water requirement in 2050[2] [BCM] | | | Water gap[2] in 2050 |
|---|---|---|---|---|---|---|---|---|---|
| | | | Surface water | Ground water | Total (1) | Surface water | Ground water | Total (2) | Net (1) - (2) |
| Indus | 1242 | 915 | 46 | 26.5 | 72.5 | 47.24 | 29.88 | 77.12 | -4.62 |
| Ganga | 1039 | 621 | 250 | 171.57 | 421.57 | 311.96 | 182.11 | 494.07 | -72.50 |
| Brahmaputra and Barak | 11782 | 885 | 24 | 26.55 | 59.07 | 28.46 | 27.37 | 55.83 | 3.24 |
| Subernarekha | 935 | 484 | 6.81 | 1.8 | 8.61 | 7.43 | 2.62 | 10.05 | -1.44 |
| Brahmani-Baitarni | 2063 | 1,206 | 18.3 | 4.05 | 22.35 | 17.53 | 3.59 | 21.12 | 1.23 |
| Mahanadi | 1786 | 1,322 | 49.99 | 16.5 | 66.49 | 36.5 | 24.46 | 60.96 | 5.53 |
| Godavari | 1454 | 1,145 | 76.3 | 40.6 | 116.9 | 56.45 | 42.33 | 98.78 | 18.12 |
| Krishna | 912 | 734 | 58 | 26.4 | 84.4 | 60.88 | 30.64 | 91.52 | -7.12 |
| Pennar | 462 | 642 | 6.86 | 4.93 | 11.79 | 9.93 | 3.92 | 13.85 | -2.06 |
| Cauvery | 518 | 576 | 19 | 12.93 | 31.93 | 20.08 | 15.1 | 35.18 | -3.25 |
| Tapi | 714 | 813 | 14.5 | 8.27 | 22.77 | 13.31 | 4.88 | 18.19 | 4.58 |
| Narmada | 2205 | 1,629 | 34.5 | 10.8 | 45.3 | 23.81 | 6.9 | 30.71 | 14.59 |
| Mahi | 746 | 358 | 3.1 | 4 | 7.1 | 7.18 | 3 | 10.18 | -3.08 |
| Sabarmati | 257 | 258 | 1.93 | 3.2 | 5.13 | 5.77 | 2.89 | 8.66 | -3.53 |
| West flowing rivers[3] | 4879 | 962 | 36.21 | 17.7 | 53.91 | 40.73 | 10.35 | 51.08 | 2.83 |
| East flowing rivers[4] | 937 | 1125 | 29.84 | 37 | 66.84 | 40.27 | 17.58 | 57.85 | 8.99 |
| Luni | 486 | 627 | 14.98 | 11.23 | 26.21 | 16.98 | 11.75 | 28.73 | -2.52 |
| Minor rivers draining into Myanmar (Burma) | 14,679 | 6,633 | | 18.8 | 18.8 | 2.54 | 1.21 | 3.75 | 15.05 |
| **Total** | | | | | | **1141.6** | | **1167.6** | |

*Source: CWC 2010; NCIWRD 1999; ADB 2011*

2 A water gap is calculated as a difference between utilisable water resources and water requirements. Positive values indicate utilisable water resources exceed the water requirements. Negative values indicate that utilisable water requirements exceed utilisable water resources.
3 (Tapi to Tadri and Tadri to Kanyakumari)
4 (between Mahanadi and Pennar and between Pennar and Kanyakumari)

### 5.4.3 Impact of climate change on water availability at the river basin level

Changes in rainfall due to global warming will influence the hydrological cycle and the pattern of stream-flows and demand. Studies on the impacts of climate change on river runoff in various river basins in India indicate that the quantity of surface runoff due to climate change will increasingly vary across river basins as well as sub-basins in the future. Climate change is expected to result in an increase in average temperatures that may affect water availability in terms of high evaporation rates, melting of glaciers and changes in precipitation factors. The melting of glaciers due to increasing temperatures may result in changes in the water flow of glacier fed river basins. Ganga, Indus, Brahamaputra and Barak are likely to be impacted by climate change due to the recession of the Himalayan glaciers.

**Table 7: Changes in precipitation at river basin level**

| Basin | Annual precipitation average (mm) | % change in Percipitation (MC scenario) | | |
|---|---|---|---|---|
| | | Mean | Low | High |
| Baitarni | 1417.3* | -2.5 | -15.7 | 4 |
| Brahmani | | -8.1 | -12 | 0 |
| Brahmaputra | 2589.2 | 2.3 | -30 | 12 |
| Cauvery | 1031.7 | 1.7 | -8.5 | 5 |
| Ganga | 1051.2 | -2.5 | -2 | 2 |
| Godavari | 1106.8 | -16.1 | -34 | 24.6 |
| Indus | 1097.1 | -16.6 | -26 | 16 |
| Krishna | 838.1 | -1.5 | -15 | 12 |
| Luni | 397 | -13.8 | -31 | 15 |
| Mahanadi | 1344.4 | -13.3 | -18 | 21.6 |
| Mahi | 1002.6 | -11.5 | -15 | 21.8 |
| Meghna | 2171.8 | -25 | -50 | 5 |
| Narmada | 1108.7 | -17.4 | -26 | 21.7 |
| Pennar | 719.8 | 3.5 | -17.5 | 7 |
| Sabarmati | 654.5 | -13.7 | -21 | 15.1 |
| Subernrekha | | -1.1 | -5 | 6 |
| Tapi | 764.6 | -17.5 | -30 | 18.1 |

*Source: Gosain et al 2011; Jain and Kumar 2012; MoEF 2010*

Changes in precipitation will result in changes in the flow of water in the river basins. Under the climate change mid-century (MC) scenario (2021-2050) using the IPCC SRES A1B scenario, the majority of the river systems will witness increased variability in precipitation levels at the basin level (Gosain et al. 2011). In another study by Jain and Kumar (2012), 25% of the river basins were expected to have variable but increasing trends in annual rainfall, 70% of the river basins were expected to have a decreasing trend, with the Ganga basin showing no trend.

The Mahanadi and Krishna river basins might experience decreasing trends in annual rainfall, which implies that droughts may become more recurrent in Krishna (an already water stressed basin). Similarly, in the monsoon season, Barak, an east flowing river might experience increasing rainfall and decreasing rainy days, which implies that floods may become more intense (Jain and Kumar 2012). The changes in precipitation from various studies are synthesised in Table 7. The impact of changes in precipitation on water availability is outside the scope of this study.





### 5.4.4 Water stress at the river basin level

There are two commonly used approaches for assessing water scarcity at the river basin level – the Falkenmark water stress indicator (Falkenmark 1989) and the IWMI water stress indicator ((Smakhtin et al. 2004)). The Falkenmark water stress indicator is based on the per capita availability of utilisable water resources. It categorises river basins according to the following categories: no stress, stress, scarcity and absolute scarcity. Experts opine that the levels of scarcity and absolute scarcity indicate water conflicts and significant risks to water availability.

**Table 8: Falkenmark stress indicator**

| Category/Condition | Water Availability ($m^3$ per capita) |
|---|---|
| No Stress | >1,700 |
| Stress | 1,000-1,700 |
| Scarcity | 500-1,000 |
| Absolute Scarcity | <500 |

**Table 9: IWMI water stress indicator**

| Category/Condition | WSI = Withdrawals/(Total water availability – Environmental needs) |
|---|---|
| Slightly exploited | WSI<0.3 |
| Moderately exploited | 0.3<WSI<0.6 |
| Heavily exploited | 0.6<WSI<1 |
| Overexploited | WSI>1 |

The IWMI water stress indicator is based on the ratio of total withdrawals to utilisable water. According to the IWMI water stress indicator, the river basins can be classified as slightly exploited, moderately exploited, heavily exploited or overexploited. The IWMI indicates that the term “heavily exploited” indicates environmentally water stressed basins and the term “overexploited” indicates environmentally water scarce basins. The thresholds for the two indicators are set out in Table 8 and Table 9.

Applying the Falkenmark water stress indicator and the IWMI water stress indicator to the river basins, we find that most of the river basins in India are likely to face some degree of water stress. Table 10 provides the results of the analysis:

**Table 10: Classification of river basins in terms of water stress**

| Sl. No. | River basin | Falkenmark water stress indicator in year 2050 | IWMI water stress indicator in year 2050 |
|---|---|---|---|
| 1 | Brahmaputra and Barak | No stress | Heavily exploited |
| 2 | Western flowing rivers | No stress | Heavily exploited |
| 3 | Brahmani-Batarni | Stress | Heavily exploited |
| 4 | Mahanadi | Stress | Heavily exploited |
| 5 | Godavari | Stress | Heavily exploited |
| 6 | Narmada | Stress | Heavily exploited |
| 7 | Indus | Scarcity | Overexploited |
| 8 | Ganga | Scarcity | Overexploited |
| 9 | Subernarekha | Scarcity | Overexploited |
| 10 | Tapi | Scarcity | Heavily exploited |
| 11 | Mahi | Scarcity | Overexploited |
| 12 | Krishna | Scarcity | Overexploited |
| 13 | Pennar | Absolutely Scarcity | Overexploited |
| 14 | Cauvery | Absolutely Scarcity | Overexploited |
| 15 | Sabarmati | Absolutely Scarcity | Overexploited |
| 16 | Eastern flowing rivers | Absolutely Scarcity | Heavily exploited |
| 17 | Luni | Absolutely Scarcity | Overexploited |

For the purpose of this study, the river basins that are classified with the term “Scarcity” or “Absolute Scarcity” by Falkenmark and with the term “overexploited” by IWMI are expected to face serious water risks to thermal power plant operations. The river basins can be seen to broadly follow this pattern except for the Tapi and Eastern flowing rivers. In order to understand the degree of water stress that thermal power capacity may face in 2050, it is necessary to project the geographical distribution of thermal power capacity on a river basin level. This is analysed in the next chapter.

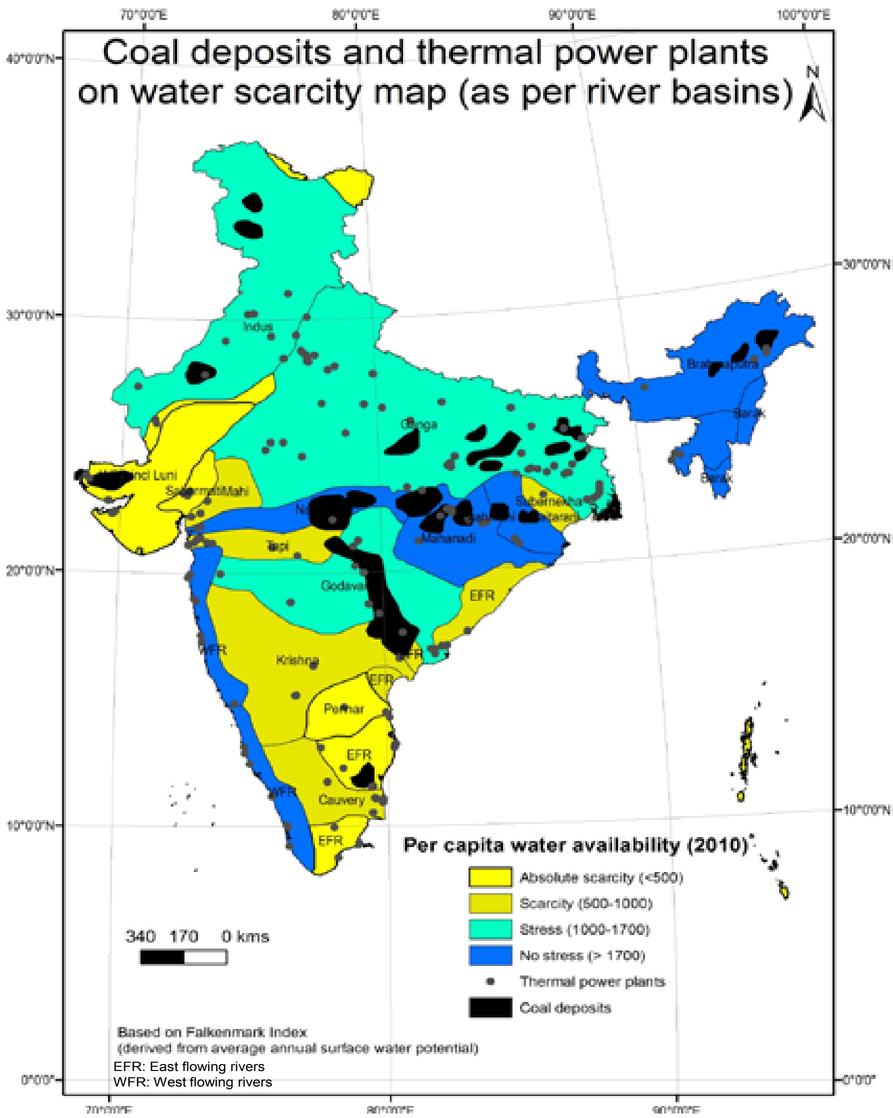
## 5.5 Thermal power capacity exposed to water stress

There are no studies or planning documents that provide guidance on the location for thermal power plants up to 2050. However, a methodology has been developed to project the geographical distribution of thermal power plants at the river basin level.

### 5.5.1 Mapping future power plants to river basins

The currently installed capacity and location of power plants has been mapped using GIS (geographic information system) on a river basin level. Further, the coal/lignite reserves have been mapped on the river basin level. A map showing locations of the power plants on a water scarcity map is provided in Figure10 below.

**Figure 10: Coal deposits and plant locations on water scarcity map (2012)**




*Source: 1) Water scarcity map developed by Water and Resources Institute using Central Water Commission (2010) and IDFC (2011) data; 2) Power plant location plotting done by IGES using Global Energy Observatory database.*

Table 11 below shows the distribution rate of thermal power installed capacity across the country along the major river basins.

**Table 11: Installed thermal power capacity distribution (2012)**

| River basin | Thermal power capacity distribution (MW) |
|---|---|
| Ganga | 34.9% |
| Indus | 6.6% |
| Luni | 6.2% |
| Sabarmati | 1.0% |
| Mahi | 1.5% |
| Narmada | 1.0% |
| Mahanadi | 8.6% |
| Brahmani and Batarni | 3.2% |
| Subernrekha | 0.3% |
| Godavri | 10.5% |
| Tapi | 5.6% |
| Krishna | 4.6% |
| Pennar | 0.8% |
| Cauvery | 1.2% |
| EFRs | 7.1% |
| WFRs | 6.1% |
| Brahmaputra | 0.4% |
| Barak | 0.2% |
| Total | 100% |

*Source: Created by the author based on information from CWC and CEA 2011.*

The location of future thermal power plants will be influenced by multiple factors including fuel reserves and mine locations, fuel transport infrastructure, transportation costs, water availability, transmission and evacuation infrastructure, policy and regulatory frameworks, market and institutional arrangements, local environment and social considerations. The cases of inland coal/lignite capacity coastal power plants and gas based power plants have been separately examined.

For the inland coal/lignite power plants, the current pattern of development is expected to continue, i.e. based on historical trends, inland coal power plants will continue to be located in river basins. This is subject to sufficient fuel (coal/lignite) reserves being present in the river basin such that it is able to support a coal/lignite power plant for 25 years after 2050. This means that any thermal power plant that is installed in 2050 should have access to sufficient reserves to last for 25 years of power plant operations. Some of the river basins like Ganga, Indus, Luni, Tapi, Krishna, Pennar and western flowing river basins are expected to reach the limits of their fuel reserves during the forecast period the balance capacity is assumed to be located in river basins that have surplus fuel reserves.

Coastal power plants have been excluded from this study as these are not expected to impact on freshwater availability. Once-through cooling systems have been prevalent for coastal located power plants. However, once-through cooling systems contribute to thermal pollution due to the difference in inlet and outlet temperatures and it is possible that future regulations may prevent the use of once-through cooling systems for coastal power plants. Coastal thermal power plants may be mandated to use desalination technology or closed loop wet cooling systems or dry cooling technology.

Future gas-based capacity addition has been assumed to be the same rate at inland locations as the current gas-based capacity at each of the river basins. This is because the availability of gas transportation infrastructure rather than the location of upstream gas wells is expected to be the driver for deciding the locations of gas based power plants. The study does not consider the development of a gas infrastructure network on a river basin level or other considerations that may influence gas plant locations such as locating them close to load centres. Table 12 shows the inland thermal power capacity by river basin in 2050 based on the business as usual scenario. A similar geographical distribution of thermal power capacity for the lower capacity scenario has also been completed.

**Table 12: Inland thermal power capacity in MW by 2050**

| River basins | Inland coal power plants [2050] | Gas-based power plants [2050] | Total thermal power plants [2050] |
|---|---|---|---|
| Ganga | 150,000 | 12,500 | 162,500 |
| Indus | 17,000 | 344 | 17,344 |
| Luni | 17,000 | 0 | 17,000 |
| Sabarmati | 731 | 1,905 | 2,636 |
| Mahi | 686 | 3,970 | 4,656 |
| Narmada | 8,934 | 2,034 | 10,967 |
| Mahanadi | 157,056 | 0 | 157,056 |
| Brahmani and Batarni | 59,177 | 0 | 59,177 |
| Subernrekha | 428 | 0 | 428 |
| Godavri | 55,449 | 8,177 | 63,625 |
| Tapi | 26,049 | 6,496 | 32,545 |
| Krishna | 27,000 | 0 | 27,000 |
| Pennar | 1,050 | 0 | 1,050 |
| Cauvery | 840 | 2,090 | 2,930 |
| Eastern flowing rivers | 39,085 | 4,772 | 43,857 |
| Western flowing rivers | 4,255 | 11,213 | 15,469 |
| Brahmaputra and Barak | 0 | 2,440 | 2,440 |
| Total | 564,739 | 55,940 | 620,679 |

The central and state environment approval process contains information on thermal power plants that are in various stages of environmental approval. This information has been collated and analysed. The total thermal power capacity that is in various stages of the environmental approval process is in excess of 700,000 MW, which is comparable to the projected thermal power capacity in 2050. The thermal power capacity distribution based on information from the environmental approval process has been developed into an environment scenario and analysed together with the business as usual scenario and lower capacity scenario.

### 5.5.2 Different scenarios whereby thermal power plants are exposed to water scarcity

In this section we would like to describe the situation concerning water stress levels under three different potential cases of thermal power capacity addition in the Indian power market by 2050. The business as usual scenario assumes the 2010 level built-rate of thermal power plants in the country, the lower capacity addition scenario assumes that there will be around 65% of total planned capacity addition and finally the environment scenario assumes that there will be an implementation of all environmental regulations in terms of water use. Information on the water stress and thermal power capacity distribution on a river basin level under these three scenarios (business as usual, lower capacity and environment) has been analysed and summarised in Figures 11 and 12 below. To normalise the effect of different capacity projections under different scenarios the percentage of thermal power capacity under each scenario has been used rather than the absolute capacity in MW. With the inherent uncertainties both on the power and water sides, it is important to understand the percentage of thermal power capacity that may face water stress rather than absolute amounts.

**Figure 11: Thermal power capacity (%) facing water stress (Falkenmark indicator) in 2050**

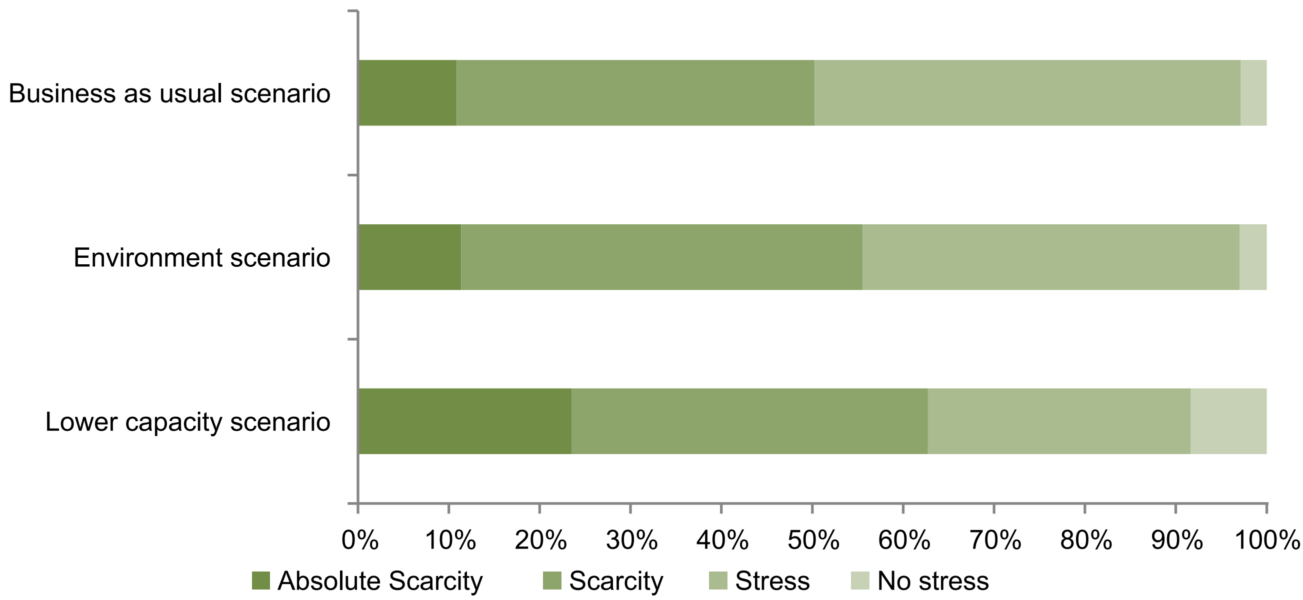
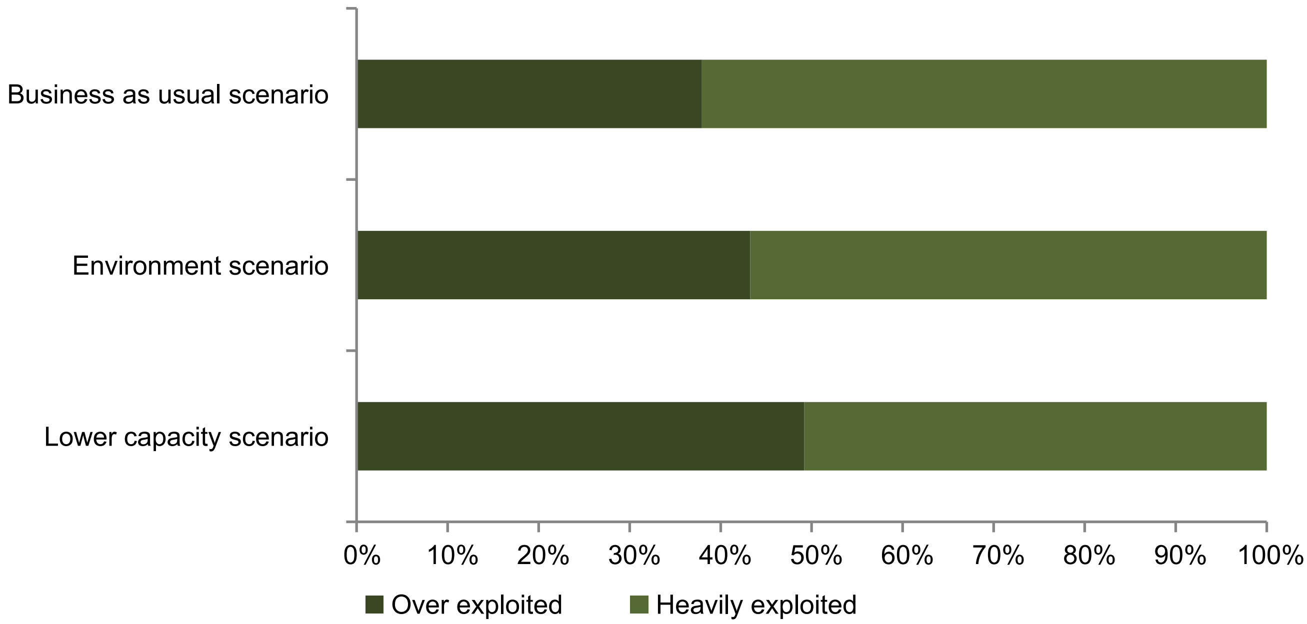


**Figure 12: Thermal power capacity (%) facing water stress (IWMI water stress indicator) in 2050**




Thermal power capacity in river basins that face "scarcity" or "absolute scarcity" on the Falkenmark indicator and are described as "overexploited" on the IWMI indicator comprise 45% of the total thermal power capacity in a business as usual scenario and 50% in the environment scenario. In other words, about half of the installed thermal power capacity is likely to face severe water stress if there are no policy interventions and the planned projects (based on environmental approvals) continue to be developed in the proposed locations. The percentage of capacity facing severe water stress increases to 60% in the lower capacity scenario and this is understandable as some of the river basins that face water scarcity also have lower coal/lignite reserves. In the business as usual scenario, these become fuel constrained and future capacity spills over to river basins with more fuel reserves (which often have lower water stress).

**Table 13 : Water stress and thermal power capacity distribution – all scenarios**

| River basin | Falkenmark water stress indicator in 2050 | IWMI water stress indicator in 2050 | Thermal power capacity distribution in 2050 | | |
|---|---|---|---|---|---|
| | | | Business as usual scenario | Lower capacity scenario | Environment scenario |
| Brahmani-Batarni | Stress | Heavily exploited | 9.5% | 8.1% | 9.0% |
| Brahmaputra and Barak | No stress | Heavily exploited | 0.4% | 0.4% | 0.7% |
| Cauvery | Absolute Scarcity | Overexploited | 0.5% | 0.5% | 2.7% |
| Eastern flowing rivers | Absolute Scarcity | Heavily exploited | 7.1% | 7.1% | 10.4% |
| Ganga | Scarcity | Overexploited | 26.2% | 30.0% | 24.6% |
| Godavari | Stress | Heavily exploited | 10.3% | 10.3% | 5.5% |
| Indus | Scarcity | Overexploited | 2.8% | 3.2% | 4.5% |
| Krishna | Scarcity | Overexploited | 4.4% | 4.9% | 3.5% |
| Luni | Absolute Scarcity | Overexploited | 2.7% | 3.2% | 5.7% |
| Mahanadi | Stress | Heavily exploited | 25.3% | 21.5% | 10.2% |
| Mahi | Scarcity | Overexploited | 0.8% | 0.8% | 2.4% |
| Narmada | Stress | Heavily exploited | 1.8% | 1.6% | 4.3% |
| Pennar | Absolute Scarcity | Overexploited | 0.2% | 0.2% | 3.7% |
| Sabarmati | Absolute Scarcity | Overexploited | 0.4% | 0.4% | 1.1% |
| Subernarekha | Scarcity | Overexploited | 0.1% | 0.1% | 1.0% |
| Tapi | Scarcity | Heavily exploited | 5.2% | 5.2% | 3.2% |
| Western flowing rivers | No stress | Heavily exploited | 2.5% | 2.6% | 7.6% |

The river basins of Narmada, Mahanadi, Godavari, Brahmaputra, Barak, Brahmani-Batarni and western flowing rivers, are expected to have a per capita availability of more than 1000 $m^3$. The river basins of Narmada, Mahanadi, Godavari, Brahmaputra and Barak, and Brahmani-Batarni have coal reserves in excess of 152 billion tonnes and water availability which will exceed the water requirement by 42.71 BCM in 2050. It is expected that the power plants in these river basins are likely to be better placed for dealing with water risks as compared to the ones in "water scarce" or "absolute water scarce" regions. On the other hand, there are likely to be negative impacts due to climate change on account of changes in precipitation levels (see Table 7) and these would need to be modelled to determine the impact on water availability.

Given the context that a significant proportion of the thermal power capacity is likely to face significant water risks, it becomes important to examine the status of cooling technologies in power plants and their financial viability. Cooling technologies are likely to play a significant role in mitigating the impact of water risks.

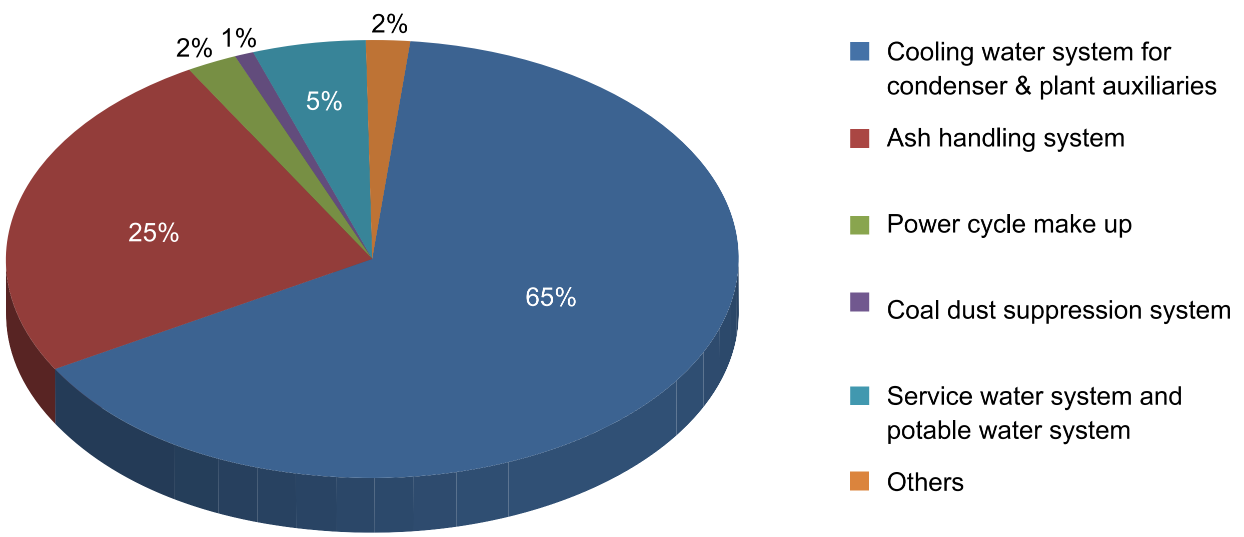
## 5.6 Water requirement for thermal power generation in India

For thermal power generation in India, water is a crucial input factor. Water is even more critical for the coal-fired power plants where India is using mostly domestic low grade coal with high ash content. Water is required at every important stage of power plant operations from coal handling plant to fly ash disposal to the cooling tower. Water is used in almost all areas and facilities of thermal power stations in one way or other. A typical list of plant systems/ applications requiring consumptive water is indicated as below:

- Cooling water system for condenser & plant auxiliaries
- Ash handling system
- Power cycle make-up
- Equipment cooling system & CPU regeneration, if applicable
- Air conditioning and ventilation system
- Coal dust suppression system
- Service water system and potable water system
- Evaporation from raw water reservoir

In the case of Indian thermal power generation, around 80% of the consumed water is used by the plants' cooling system followed by ash handling activities. In the context of total water withdrawal or intake for the power plant, the cooling system takes around 65% of the total water withdrawal. Figure 13 below shows the percentage rate of distribution for total water use in a typical thermal power plant in India. In general, ash handling water comes from the cooling water blow-down and thus is not part of the consumptive water for the power plant.

**Figure 13: Percentage distribution of water use by different activities in a typical thermal power plant in India**

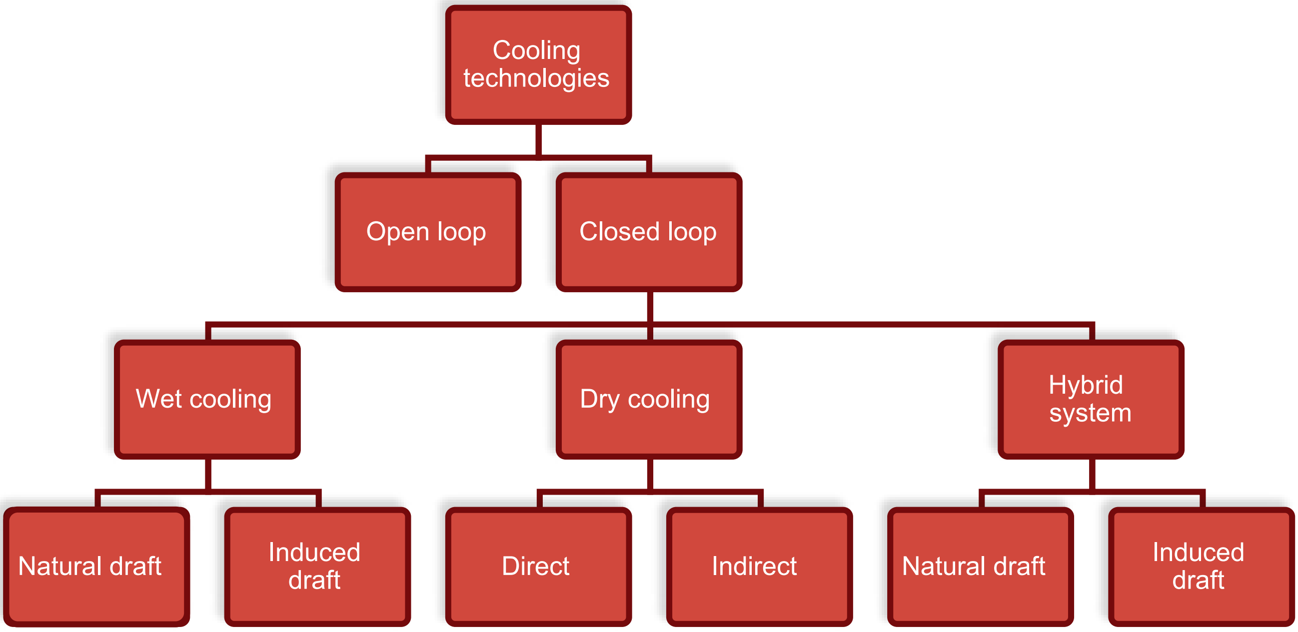



*Source: Data obtained from Central Electricity Authority report, 2012*

### 5.6.1 Different cooling technologies used in India

Cooling technologies can be broadly classified as open and closed loop cooling systems and further to dry, wet and hybrid cooling systems. The subsets of wet cooling systems are induced draft or natural draft cooling systems. Further there are cooling technologies that employ both wet and dry cooling at the same time and are better known as hybrid systems.

**Figure 14: Classification of Cooling Technologies**




Open loop cooling systems entail water being circulated through the condenser for condensing steam and returned back to the water body from where the water was drawn. Open loop cooling systems are also known as once-through cooling systems. This type of cooling system creates thermal pollution as the temperature of water discharged is more than the temperature of water intake. Open loop cooling systems were outlawed by MoEF in its Stipulation dated 2 January 1999 for power plants that were expected to be commissioned after 1 June 1999. This was done to prevent thermal pollution (CEA, 2012).

Closed loop cooling systems can be classified into three categories: dry cooling systems, wet cooling systems and hybrid cooling systems. Wet cooling systems employ cooling tower technologies for condenser cooling. Wet cooling systems can be classified as:-

a) Natural draft

b) Induced draft

Water in a wet cooling system is circulated in the cooling tower where part of it is evaporated, resulting in cooling of the circulated water. Makeup water for the cooling tower includes loss due to evaporative cooling, drift and blow-down.

Dry cooling systems can be classified into direct cooling systems and indirect cooling systems. In a direct dry cooling system, water is directly cooled by a system of finned tubes that push ambient air using mechanical draft fans or natural draft towers. In case of an indirect dry cooling system, the heat from a low pressure turbine is condensed in the condenser by circulating water which in turn is cooled by pushing ambient air using mechanical draft fans or natural draft.





### 5.6.2 Estimates of water use coefficients in thermal power generation in India

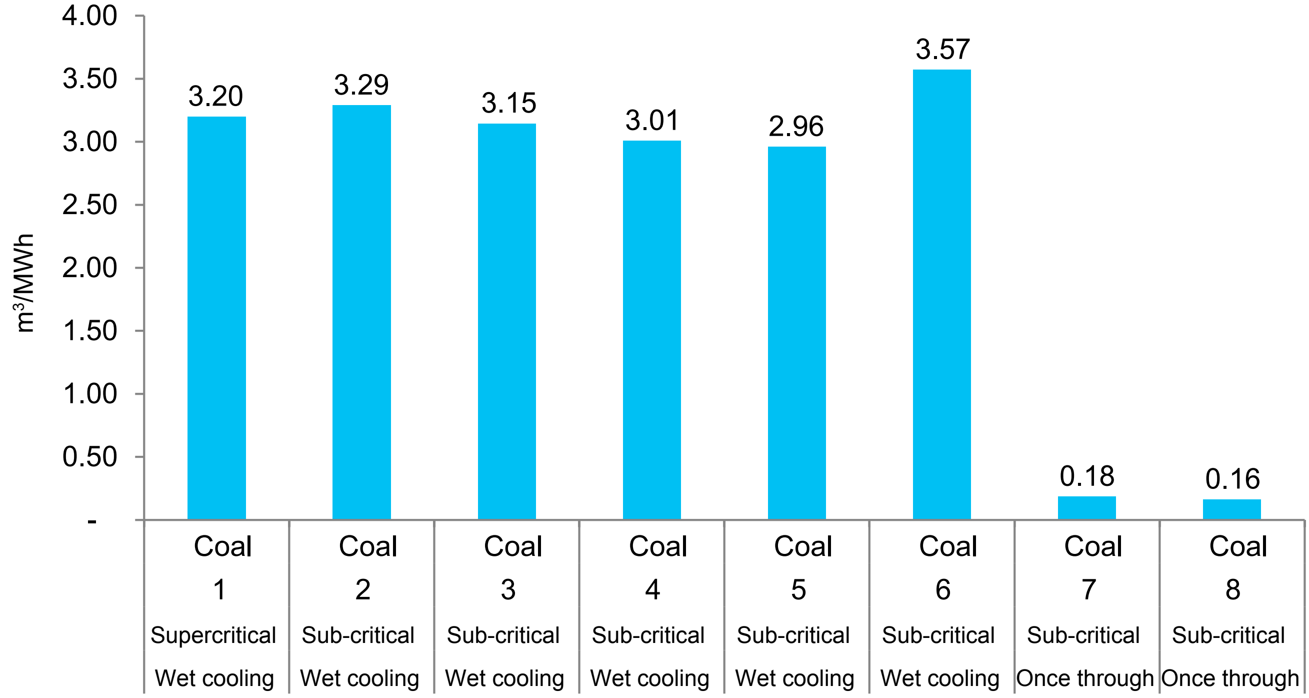
The power plants with different generation and cooling technologies were selected when collecting the primary data. The primary data collected from 14 units covers different power generation technologies and employs different cooling technologies (wet open loop, wet closed loop cooling and dry cooling system). The primary data has not been independently audited or verified (See Table 14).

**Table 14: Primary data collection matrix**

| Fuel | Technology | Wet cooling (Open through) | Wet cooling (Close loop) | Dry cooling |
|---|---|---|---|---|
| **Coal** | Subcritical | √ (2) | √ (5) | Data not available |
| **Coal** | Supercritical | Data not available | √ (1) | Data not available |
| **Natural gas** | CCGT | √ (1) | √ (2) | √ (1) |
| **Diesel** | DG Set | √ (1) | Data not available | Data not available |
| **Oil** | Subcritical | √ (1) | Data not available | Data not available |

The primary data collected for coal-based thermal power plants indicated water consumption intensity for subcritical and supercritical plants based on wet cooling technology is in the range of 2.96 $m^3$/MWh to 3.57 $m^3$/MWh. Water consumption in once-through cooling systems is in range of 0.16 $m^3$/MWh to 0.18 $m^3$/MWh. A once-through cooling system is permitted only if sea water is used for condenser cooling. Sea water is not counted towards water consumption by the power plant.

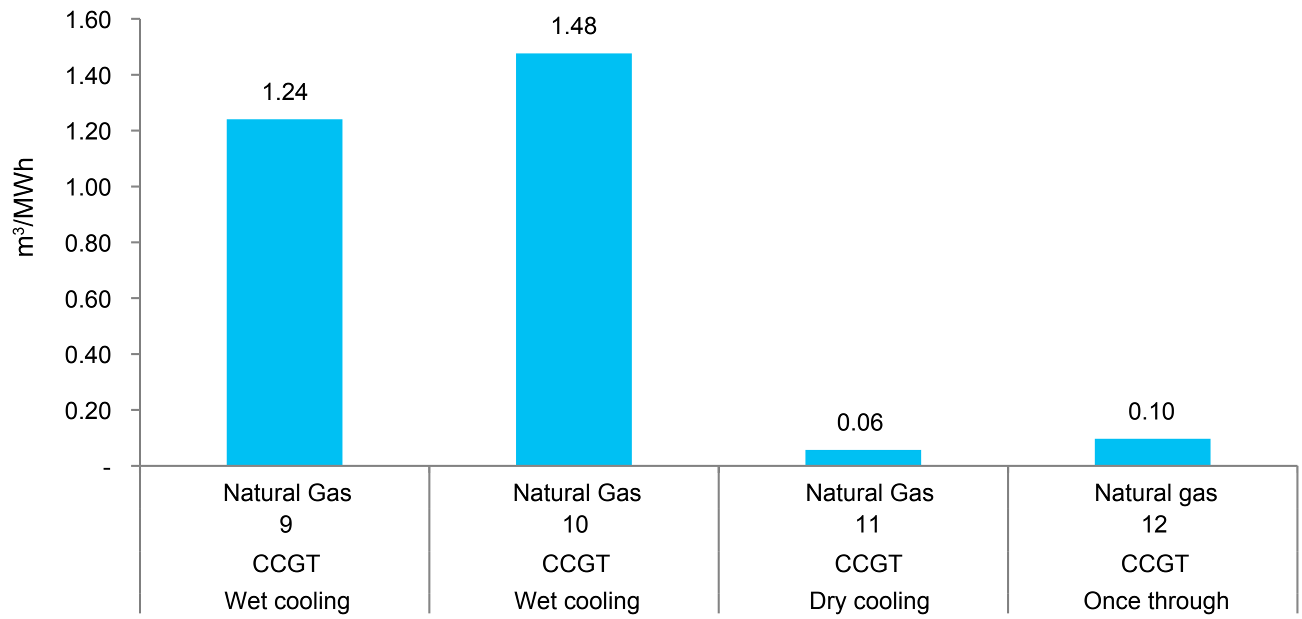
**Figure 15: Water requirements in coal based thermal power plants**




*Source: Power plant survey by IGES, 2012*

The primary data collected for gas fired thermal power plants indicated water consumption intensity for wet cooling technology is in range of 1.24 to 1.48 $m^3$/MWh and for dry cooling technology is 0.06 $m^3$/MWh and for once-through cooling system is 0.10 $m^3$/MWh.

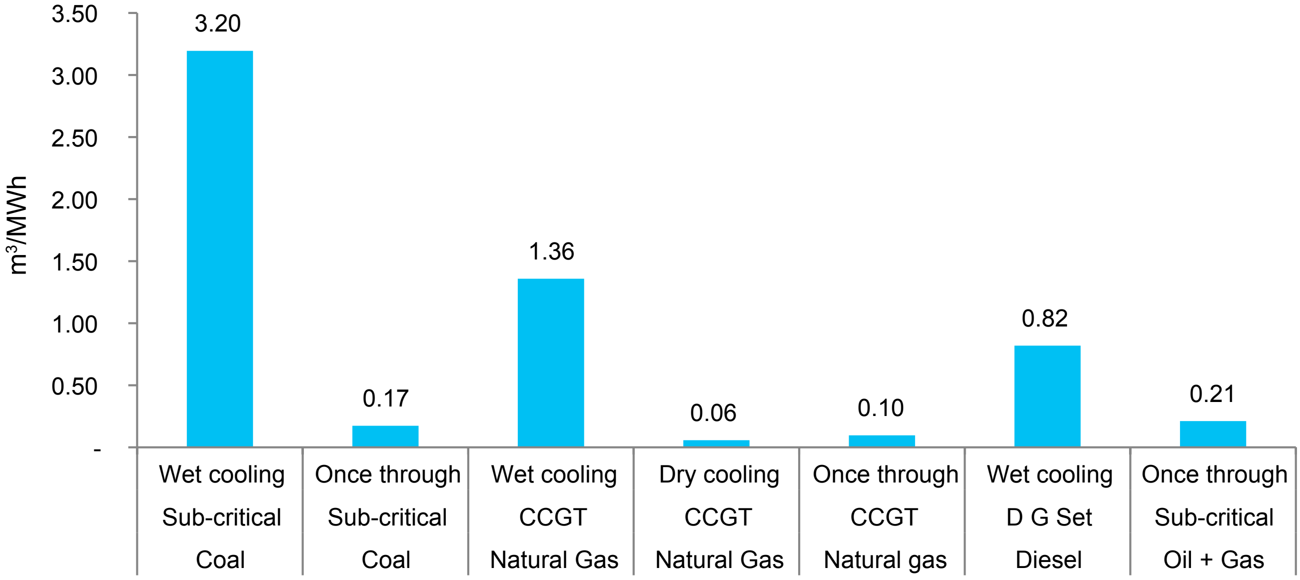
**Figure 16: Water requirements by combined cycle generating stations**




*Source: Power plant survey by IGES, 2012*

The primary data collected for diesel and oil fired thermal power plants indicates that water consumption intensity for once-through cooling systems is 0.82 m³/Mwh and 0.21 m³/Mwh respectively. The average water consumption for different technologies where primary data is available is shown in Figure 17.

**Figure 17: Average water requirements for different cooling technologies**




*Data Source: Power plant survey by IGES, 2012*

The data collected above corroborated with data sourced from CEA (2012) on minimisation of water requirement in coal-based thermal power plants. The data available in the report published by CEA includes data on water requirements at coal-based thermal power plants employing wet and dry cooling and is shown in Table 15 below.

**Table 15 : Water requirements by coal-fired generating stations (supercritical/Subcritical)**

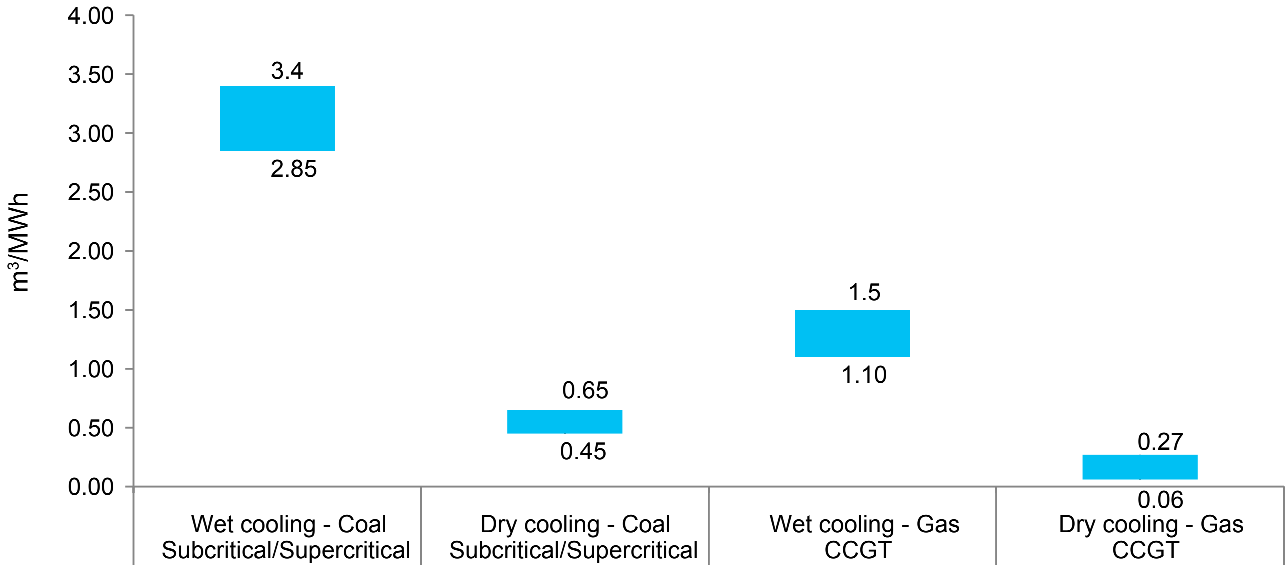
| Particular | Water requirements for wet cooling system (m³/ MWh) | Water requirements for dry cooling system (m³/ MWh) |
|---|---|---|
| Water requirements for the first year | 3.6[5] | 0.75[6] |
| Water requirements for the subsequent years | 3.0 | 0.55[7] |

*Data source: CEA, 2012*

Finally, Figure 18 below shows the range of water coefficients from different water cooling technologies used in the power plants.

5 In cases where fly ash disposal systems using high concentration slurry disposal are employed from the first year – the water requirement will be 3.0 m³/MWh from the first year of operation.
6 In cases where the HSCD system is used rather than the dry fly ash disposal –there will be additional raw water requirement of 0.15 m³/ MWh.
7 In cases where the HSCD system is used rather than the fly ash disposal –there will be additional raw water requirement of 0.15 m³/hour/MW.

**Figure 18: Range of water requirements by coal and gas-fired generating stations**




*Data source: Power plant survey by IGES, 2012*

Based on the above-mentioned data and information collected during primary data surveys and interviews at various power plants in India, we can derive the following critical information to be used in the model simulation:-

a) The water consumption is highest for coal-fired power generation employing wet cooling technology. Water consumption for coal-fired power generation employing wet cooling systems is expected to be in range of 2.85 to 3.40 $m^3$/MWh.

b) Water consumption for coal-fired power generation technology employing dry cooling system is expected to be in range of 0.45 to 0.65 $m^3$/MWh.

c) Water consumption for gas-fired power generation employing wet cooling system is expected to be in range of 1.10 to 1.50 $m^3$/MWh

d) Water consumption for gas-fired power generation employing dry cooling system is expected to be in range of 0.06 to 0.27 $m^3$/MWh.

e) Once-through cooling systems have low water intensity but can be employed only in the case of coastal power plants. Once-through cooling systems are not permitted in thermal power plants as directed by MoEF according to a stipulation dated 2 January 1999 except for coastal power plants using sea water. The water intensity for coal-fired power generation using once-through systems is 0.17 $m^3$/MWh (as sea water used for condenser cooling is not counted towards water consumption) and for CCGT is 0.10 $m^3$/MWh.

### 5.6.3 Regulatory issues of cooling technologies in thermal power plants in India

Open loop cooling systems were disallowed by the MoEF for inland thermal power plants according to a stipulation dated 2 January 1999 for power plants commissioned after 1 June 1999. This was done to prevent thermal pollution (CEA, 2012). Currently, a number of inland thermal power projects use wet cooling systems. Dry cooling technologies reduce the water requirements by up to 80% for both coal and gas-based power plants. In the CEA report on minimisation of water requirement in coal power plants, it was concluded that dry cooling systems, as such, are costly technologies and are not comparable to wet cooling systems on techno-economic considerations. However, for sites where adequate quantity of water is just not available, dry cooling systems offers a possible solution for power plant installation with much reduced water requirement.

Current dry cooling technologies are reported to be more expensive than wet cooling. For pithead coal power plants, the levelised cost of generation under a set of assumptions is estimated at INR2.79/kWh for dry cooling compared to INR2.60/kWh for wet cooling system (CEA, 2012). The levelised cost of generation is approximately 7.3% higher for dry cooling system. If the coal power plant is located some way from the mines (distance from mine assumed as 2000 kms), the levelised cost of generation is estimated at INR4.16/kWh for dry cooling system compared INR3.88/kWh for wet cooling system. The levelised cost of generation is again 7.3% higher for dry cooling system.

In a situation where there is flexibility when locating a power plant close to the mine mouth where water is scarce, or close to a water source which would involve coal transportation, dry cooling technology offers an interesting option to power plant developers. The decrease in cost of transporting coal versus increase in cost due to dry cooling provides an equilibrium point at approximately 300 kms under a set of assumptions. In other words, if the abundant water source is available at a site more than 300 kms away from the mine mouth, it is economical to set up a mine mouth based power plant with dry cooling provided that sufficient water is available for dry cooling at the mine mouth.

For inland gas based power plants, the levelised cost of generation under a set of assumptions is estimated at INR3.40/kWh for dry cooling compared to INR3.30/kWh for wet cooling. The difference in levelised cost of generation is sensitive to the price of water that is charged to the power plant and is inversely proportionate, i.e. the difference in levelised cost reduces if water tariffs increase. With a water tariff of INR61.0 /$m^3$, the levelised cost of generation based on dry cooling is estimated to be equal to wet cooling.

It is expected that a number of policy measures will be required to address the water risk for thermal power plants. These are detailed in the next chapter. It is expected that use of efficient cooling technologies will play a key role in mitigating water related risks as technologies mature and become competitive while water scarcity and variability increases.

### 5.6.4 Projected water demand for electricity generation

Ultimately, our plan is to conduct a national-scale hydrological assessment of surface water availability which can supply the required amount of water for energy production and generation. However, in this study we used the relatively simpler method of proportional allocation to determine the long-term water availability for the energy sector in the country (See Figure 19).

Data on water withdrawal for electricity generation is not systematically available in India. Therefore, data has been compiled from various sources to project India's total water requirement for electricity generation until 2050 (Table 1). If the current technologies for coal-based thermal power plants are continued ( i.e. open loop (once-through) cooling systems), the projected electricity generation in 2050 will require approximately 227 BCM of freshwater which is about 20% of the total annual utilisable water in the country (1122 BCM).

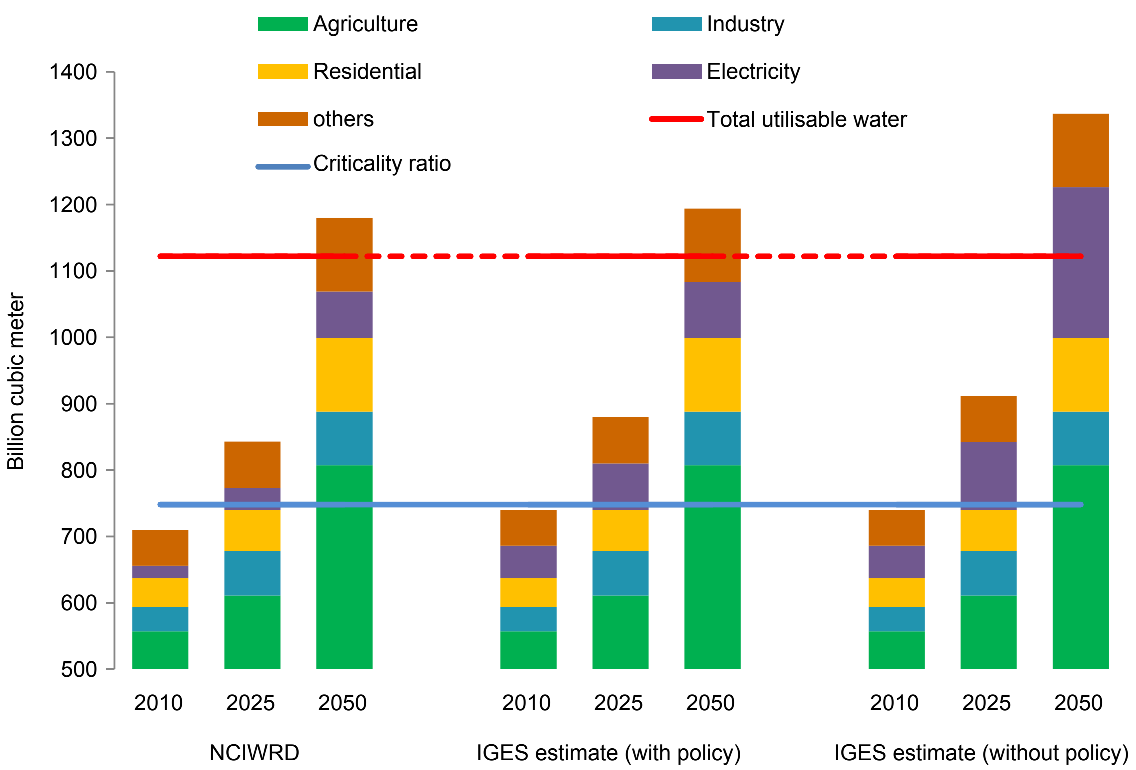
The National Commission on Integrated Water Resources Development (NCIWRD) projected that water requirements for electricity generation of the same period will be around 70 BCM using the government estimate of water intensity and demonstrated that the total water demand will be less than that of the total utilisable water resources in 2050. Based on our model estimate, the total water demand exclusively for electricity generation will be around 227 BCM by 2050, which will create a deficit of around 100 BCM (exceeding the total annual utilisable water by 10%) in terms of annual water supply and demand gap. Such significant difference in water use could be further attributed to the heavy dependence on coal-based power plants, operating with low quality coal, and with high water intense cooling tower technologies.

Although regulations for cooling systems set out in 1999 were primarily to control thermal pollution, they inherently also acted as a check point for the volume of water use by thermal power plants in the country. It has been estimated that around 50% of existing operational thermal power plants in India were set up before 1999 and half of those are using open loop wet cooling systems. Therefore, around 20-25% of the total thermal power installed capacity in India, is still using open loop wet cooling (there is no exact number available but this figure was obtained from experts' interview). This means that more than 30 GW of installed capacity still uses fresh water at a rate of 80 -160 $m^3$/MWh and around 100 GW of remaining capacity is using fresh water or sea water in the closed loop wet cooling system at a rate of 2.8 to 3.4 $m^3$/MWh. However, the open loop plants are very old and are expected to be retired within the next decade or so.

It also appears that retrofitting of the closed loop cooling systems in these old plants is not economical. We have therefore estimated two different water demands based on both the pre-1999 and post-1999 regulatory situation. It indicates that if India were to continue pre-1999 open loop wet cooling system, the country would require a maximum of 227 billion cubic meters (BCM) of water per year just for thermal power generation by 2050 which would be 20% of the total utilisable water in the country by that time. However, with policy intervention, such a huge water demand could be reduced to around 85 BCM per year for electricity generation by 2050.

This estimate considers gradual retirement of the old power plants (set up before 1999) and no new thermal plants to be set up with open loop wet cooling systems. This also indicates that India's electricity sector will also remain extremely water-intensive for the next couple of decades, if not beyond. Retrofitting of old power plants are not considered in this estimate as there is no existing regulation to mandate R&R activities to change the open loop cooling system.

**Figure 19 : Projected water demand for electricity generation and impacts on total utilisable water**




[1]*Criticality ratio is defined as extraction of 40% of total renewable water resources for human use*

*Note: 1) Base year of IGES model study was set at 2005 and water demand projection for electricity generation was estimated for 2010, 2025 and 2050 to compare with NCIWRD projection; 2) IGES estimates water demand for electricity sector only based on water use intensity of power plants. Electricity sector's water demand with policy intervention is basically considering the closed loop wet cooling system installed after 1 June 1999 and without policy water demand is a reference estimate of continuation of use of open loop wet cooling system in the thermal power stations. All other sectoral water demand projections follow NCIWRD projections.*

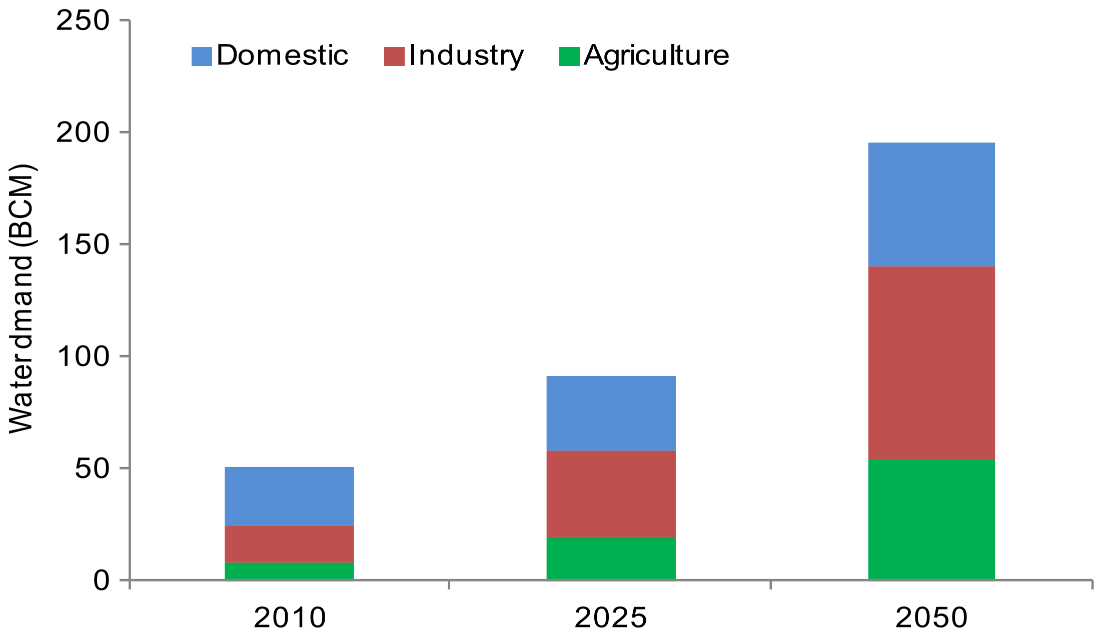
The current water allocation for new thermal power plants setting up in India is fixed at 3 $m^3$/Mwh, with provision of a four-year maturity time period. Furthermore, no permission is given unless the developers ensure and satisfy the authorities about the availability of the required amount of water. These stricter regulations and restrictions aim to bring water efficiency into power plant operations. Water efficiency can thus be achieved in coal handling, fly ash handling, boiler operation and cooling systems. Figure 19 demonstrates the comparison of different estimates of total water demand for electricity generation in India and their corresponding impact on utilisable water resource. Our scenario projection (considering medium-level economic and technological development with no stringent climate target) shows that by 2050, Indian electricity generation together with other sectors will exceed the total utilisable annual water availability in the country, even with proper enforcement of MoEF regulations, i.e. achieving around 3 $m^3$/Mwh standard.

### 5.6.5 Impacts on total utilisable water and deriving water availability constraint for energy sector in India

It is suspected that by 2030 India as a whole will become more or less water scarce due to various hydrological, demographic, climatic and environmental reasons. However, 135 $m^3$ of per capita utilisable water (664 $m^3$) will be needed additionally for electricity generation by 2050. This is the expected water footprint per capita for electricity generation in India by 2050 which is approximately 20% of per capita total utilisable water. This instigates trade-off and conflict among other water users in the country especially among agricultural use and residential use. Figure 20 below shows the increasing water demand in residential and industrial sectors due to increasing level of electrification.

It is estimated that the rate of electrification in India will increase by more than 6% per annum, substituting the use of other primary energy resources like coal, kerosene and oil. As a matter of fact, electricity generation will not only increase water intake for its own use but will also increase the embedded water use for other sectors using electricity as source of energy (See Figure 20). By 2050 the incremental water demand in domestic, industry and agriculture sectors corresponding to electricity used in those sectors will be 41 BCM, 63 BCM and 40 BCM, respectively. It is estimated that direct and indirect incremental water demand related to electricity use by the sectors will create water scarcity for 7.25 million ha of irrigated cropland and about one third of projected total population (650 million) will face difficulties in accessing water for domestic use by 2050. However, the relative severity will vary by region depending on the availability of local renewable water, the type of dominant water users, population density, and indeed trends in land use change and political power of the water user groups.

**Figure 20: India's sectoral water demand corresponding to electricity demand**



It has also been estimated that if India continues to consume water at the rate of 80 $m^3$/Mwh for its electricity generation then by 2050, per capita water demand will exceed per capita water availability. However, situation gets slightly better when India introduces stricter standards of water utilisation in energy sector especially in power generation (3 $m^3$/Mwh). Table 16 below shows the comparison of the long-term per capita water availability situation in India under two different water use standards in Indian power sector.

**Table 16: Impact of water for energy on per capita water availability**

| Year | Population (Billion) | Per capita available water ($m^3$)/ year | Per capita Utilisable water ($m^3$)/ Year | Per capita water consumption ($m^3$)/year | | | |
|---|---|---|---|---|---|---|---|
| | | | | **NCIWRD** | **IGES Estimates** | | **DOE** |
| | | | | | **@ 80 $m^3$/MWh** | **@3 $m^3$/MWh** | |
| 2025 | 1.46 | 1280 | 768 | 529 | 576 | 560 | 510 |
| 2050 | 1.69 | 1106 | 664 | 633 | 725 | 643 | 597 |

*Source: National Commission for Integrated Water Resource Development, 1999; Department of Energy, US Govt., 2006*

*Note: The estimated per capita water consumption includes the embedded water consumption for electricity use*

This estimate indicates that India's long-term per capita water availability is in marginal condition even with high efficiency of water use technologies in its power sector. It has been further estimated that around 15% or more of the thermal power plants currently operating in India use once-through wet cooling system which consume about 80-160 $m^3$/Mwh of water, and these plants are expected to continue operating until 2050. As a matter of fact, per capital water consumption in India by 2050 is expected to be more than 650 $m^3$/year while the per capital water availability remains at 664 $m^3$/year. Finally it has been estimated that in India, the maximum amount of water that could be available for energy sector until 2050 is around 90 BCM per annum.

## 5.7 Model estimates

In this study we used the MESSAGE_Water as the key modelling tool for estimating how much water is required in the energy systems of the country as a whole. The main purpose of this model is to assess the interlinkages between water resource availability and electricity generation in the region and how the energy supply mix could be affected due to water scarcity in the long run. As described earlier, a module to estimate water demand has been created for the standard MESSAGE model and thus it becomes capable of estimating endogenous water demand for the entire energy systems of the region,. Therefore, we have used two scenarios to observe the impacts of water availability constraints on energy systems[8]. In the following section we briefly describes these scenarios.

8 Here we use the South Asia region of MESSAGE Model as proxy for India, as India consists of 90% of the total electricity supply of the entire region and also carries out intra-regional power trading between Bhutan, Nepal. In 2010 out of 1100 Twh of regional generation India produces around 1000 Twh of electricity.

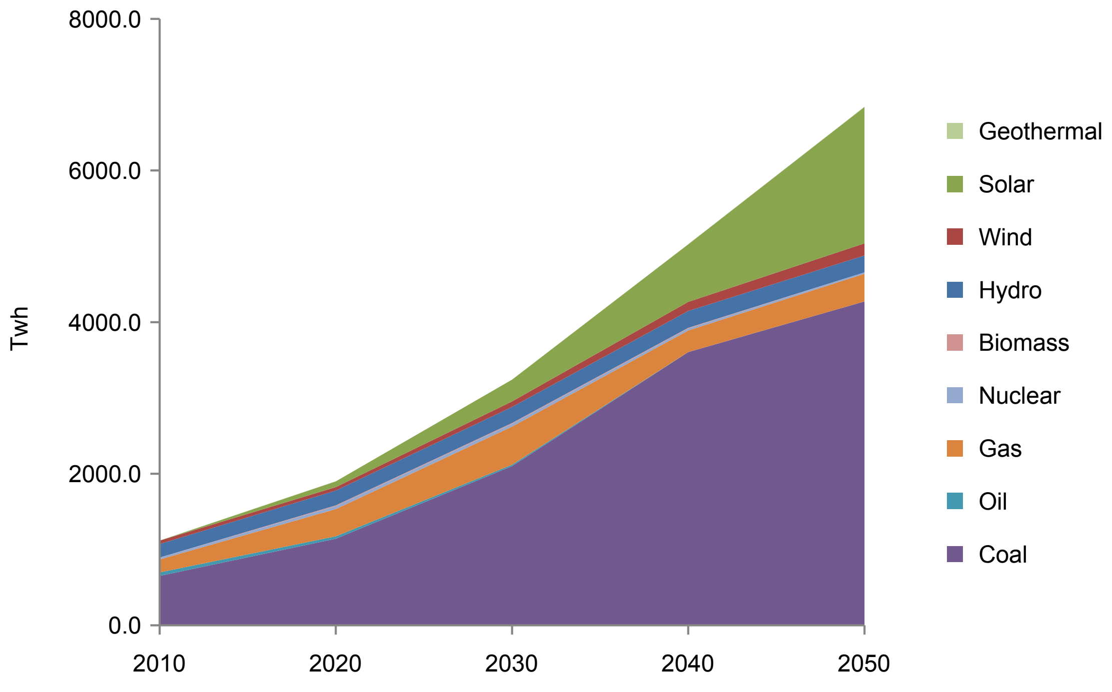
## 5.7.1 Reference scenario without water constraint but with stringent GHG emissions reduction objective

In this scenario we considered all possible advance technologies to pitch in the system to reduce emissions as much as possible. The main reason for selecting such scenario is to provide maximum possible leverage to the energy system to reduce the water load by selecting more renewable energy like solar PV and wind which are less water intensive. It is assumed that this scenario can achieve around 70% of the maximum feasible emissions reduction in the system.

### Electricity Generation

Our reference scenario shows an optimistic future of renewable energy deployment which is indeed inherently less water intensive. However, coal, natural gas, oil and hydro will remain the major sources of electricity generation until 2050. This further corroborates the need of for a significant amount of water to produce the required amount of power from thermal sources even with high renewable energy penetration and low-carbon technology development. Thus the target of emissions reduction does not in fact gurantee reduction of water dependence in power sector.

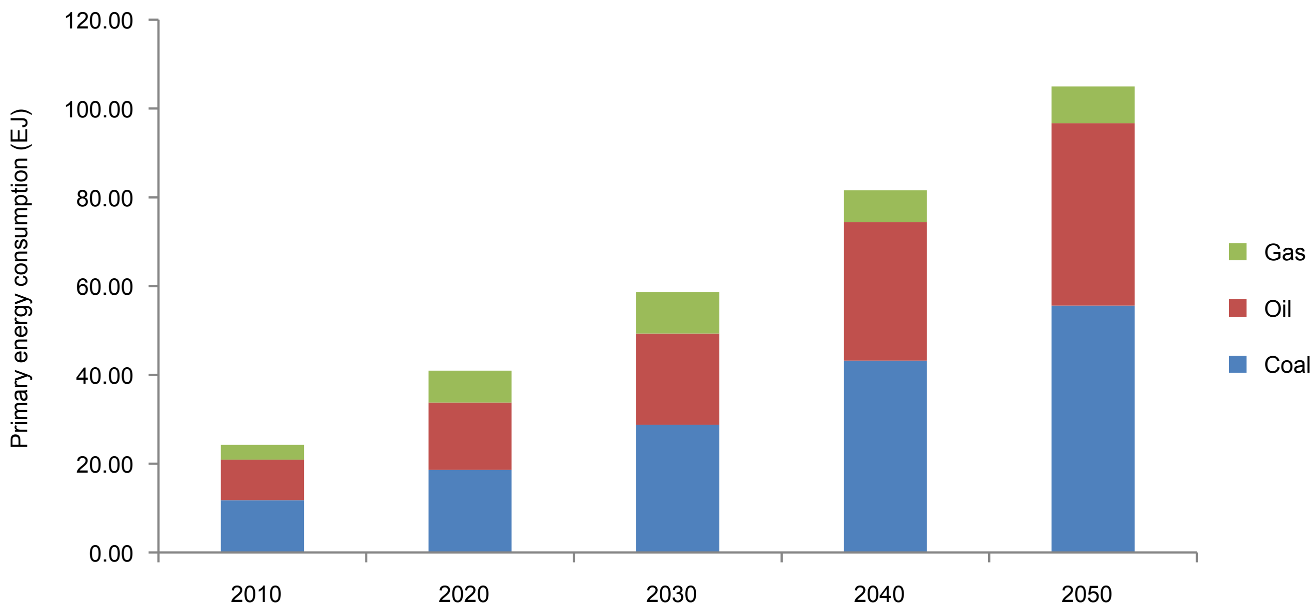
**Figure 21: Electricity supply scenario trend of India**




### Primary Energy Consumption

In the context of primary energy consumption, the long-term energy mix also depends on major water-consuming fuels like coal, natural gas and oil. Figure 22 shows the long-term primary energy consumption trends under no water availability constraints. It assumes that given all other considerations, the energy system will not face any water shortage in the future to fullfill the target of heavy renewable energy penetration.

**Figure 22: Primary energy consumption trend of India without water constraint**



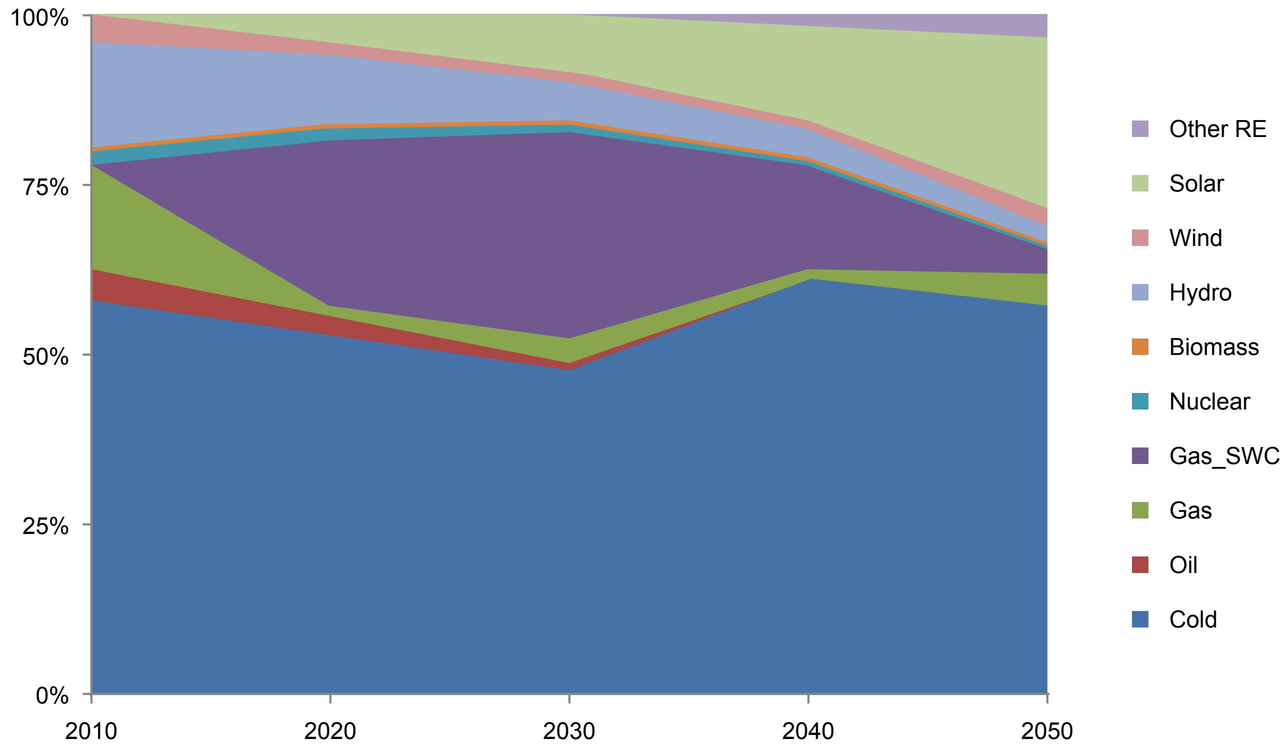

### 5.7.2 Water constrained scenario

In this scenario we introduced the maximum constraints on water availability ( up to 90 BCM per year) for the energy sector along with other conditions that remain the same as before. However, we also introduced several alternative technologies to mitigate the impact of water constraints like dry cooling and sea water cooling. Though these technologies are more expensive than conventional wet cooling systems, they are adopted by the system in case of water constraints. This further indicates that if meeting the energy demand is absolutely essential in the system, deployment of alternative cooling technology penetration is a must. However, the additional costs of these cooling technologies are adjusted in the standard O&M costs of corresponding power generating technologies. It is therefore assumed that systems under the global optimal conditions will pick up certain alternative cooling technologies to mitigate the water shortage and to maintain the optimal energy supply amount.

### Impact on electricity generation

Under water constrained conditions, the energy system behaves conservatively and deploy technologies which need less or no fresh water. As a matter of fact, sea water cooling in gas technology becomes predominant in this case. It has been observed that unless there are alternative technologies available to mitigate the impact of water scarcity for electricity generation, the system also fails to meet the required energy demand. As a matter of fact, water availability is absolutely critical to maintain the balance of energy supply and demand in the market. Figure 23 shows the new electricity supply mix for the region under water constrained conditions.

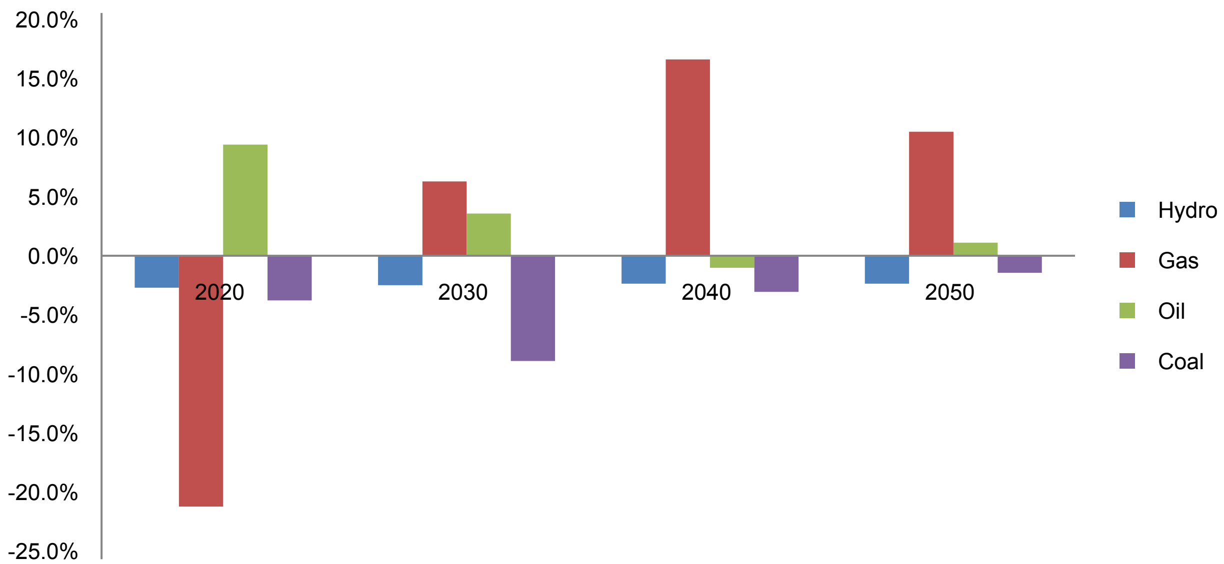
**Figure 23: Electricity supply scenario trend of India under water availability constraints**




## Impact of primary energy consumption

It has been observed that the issue of water availability also affects countries' primary energy consumption. We find that coal and oil consumption decreases along with hydropower due to water scarcity, and gas consumption increases to compensate for the decrease in other fuel consumption.

**Figure 24 : % Change in primary energy consumption due to water constraints**



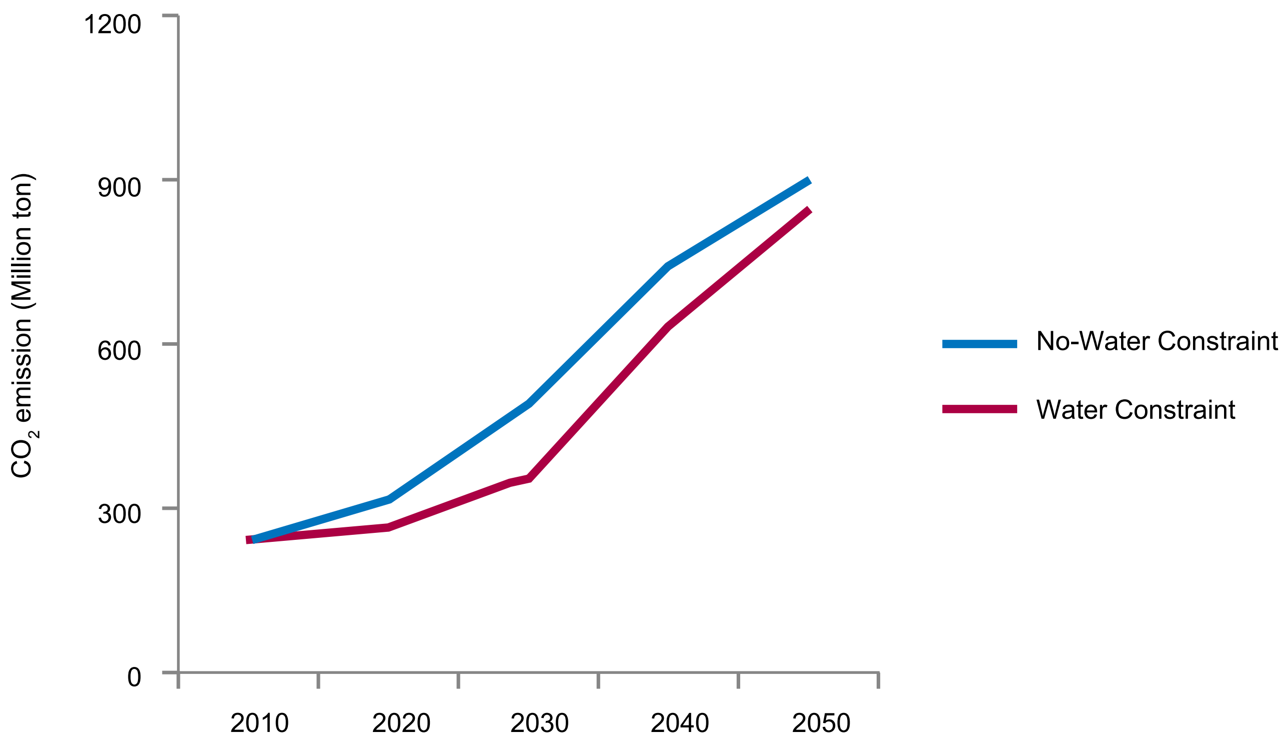
### 5.7.3 Other impacts of water constraints in the energy sector

In this study we also investgated how water scarcity affects various other issues, looking at environmental impacts, trade of energy commodities and also investment in the energy sector, all of which are crucial matters for this region in the future.

### Impact on GHG emissions

It has been observed that water scarcity and its limited use, does in fact bring some extra benefits to society in terms of reduction in $CO_2$ emissions from the energy sector. Due to increasing use of relatively less polluting fuels in energy generation (*viz.* natural gas ) which also consume less water, net $CO_2$ emissions will see a reduction of around 6% by 2050.

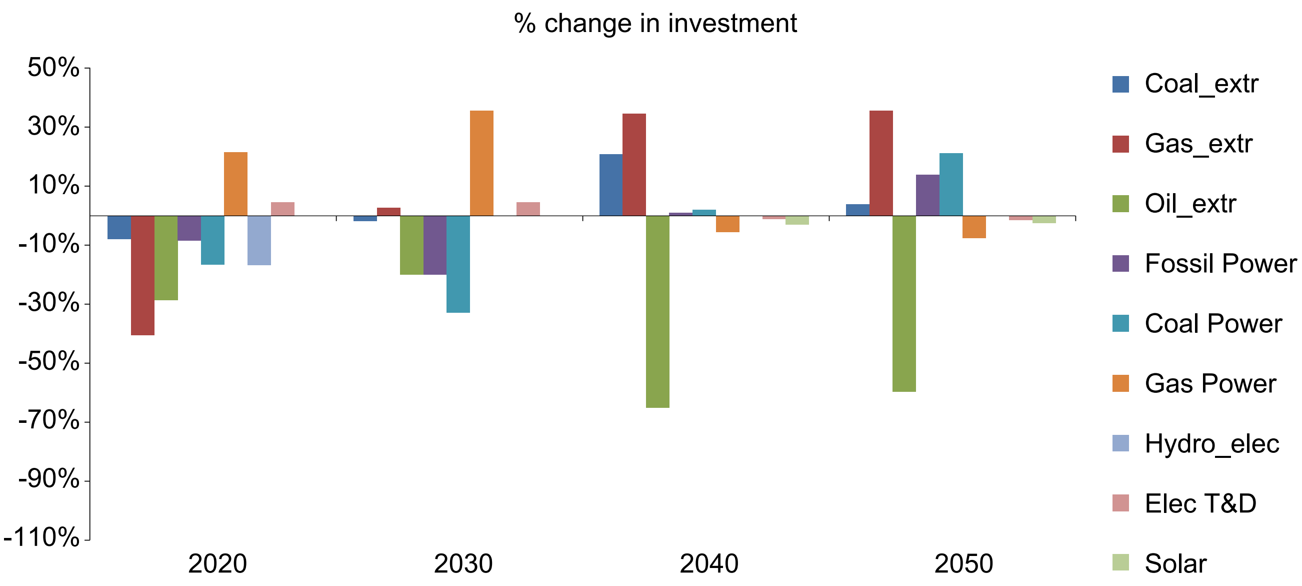
**Figure 25: Impact of water constraints on $CO_2$ emission from the power sector**




### Impact on energy sector investment

It has been observed that long-term energy sector investment is also being affected by water constraints. It is suspected that technologies with high water-use coefficients like non-conventional oil and gas exploration (shale gas, tar oil etc) will be affected in terms of reduced investment in the region. These technologies need more than average water compared to conventional fossil fuel extraction.

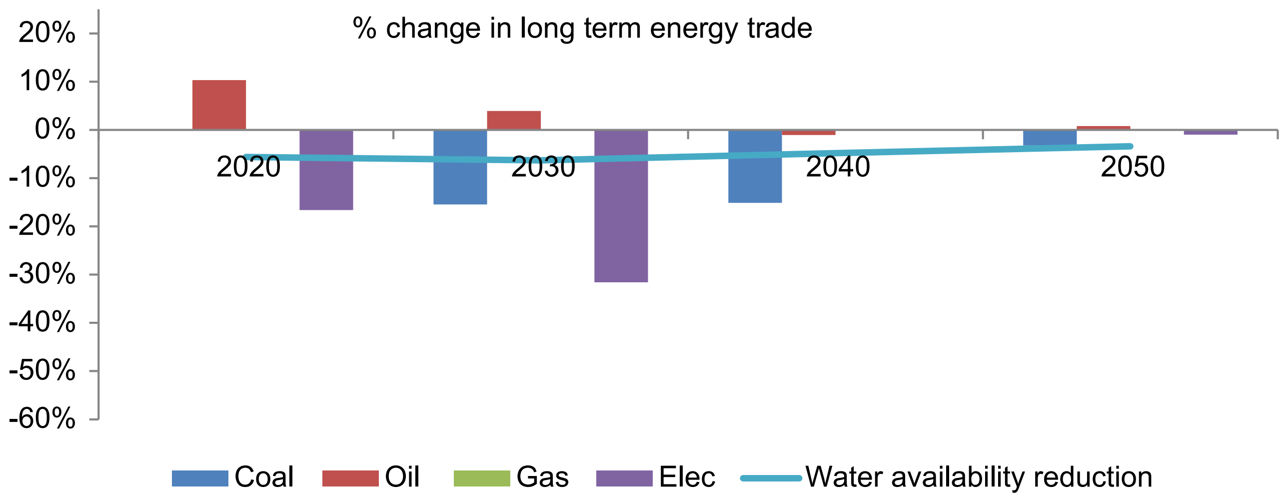
**Figure 26: Impact of water constraints on energy sector investment**




## Impact on cross border energy trade

Another important parameter of judgement in the regional energy market is energy trade. The South Asian region, especially India, has various long-term energy trade projects either using grid interconnection or by building hydropower projects in neighbouring countries like Bhutan, Nepal and Afganistan. It has been observed that such energy trading is suspected to be affected adversly due to water constraints. The figure below shows that out of all other energy commodities, electricity trade gets affected most; the main reason being reduced hydropower generation. There will be a reduction of around 30%in electricity trade in the region by 2030. Coal is another energy commodity whichwill be affected in the near future due to water scarcity, mainly due to lack of water for coal washing. Dirty coal has a lower international price than washed coal and thus the volume of trade decreases.

**Figure 27: Impact of water constraints on cross-border energy trade**



## 5.8 Possible options to mitigate water shortage in the future

This section provides recommendations for addressing water risks to thermal power plants including amendments in the planning criteria, measures related to plant site, demand-side management, and measures to improve water availability. These measures should not be seen in isolation or be seen to override other equally important economic, environmental and social considerations. The measures should be integrated in the long-term water availability and competing water-use planning, approval and implementation process of thermal power plants. The use of appropriate cooling technologies is expected to play an important role in terms of mitigating the risk of power plant operations even under a scenario whereby all measures to address water stress, water variability and water conflict issues have been undertaken.

### 5.8.1 Planning criteria for inland thermal power plants

The planning criteria for geographical distribution of inland thermal power plants should include long-term water availability and competing water use, in addition to load centres, fuel availability, transportation, evacuation, local environment considerations, etc. The planning process should encourage locating thermal power plants in river basins that are expected to be at relatively lower water stress in 2050 – for example, locating power plants in no stress areas or locations where water is stressed according to the Falkenmark water stress indicator. Narmada, Mahanadi, Godavari, Brahmaputra and Barak and Brahmani-Batarni have per capita water availability of more than 1000 $m^3$/capita and hold coal reserves that are likely to be sufficient to meet the projected growth in inland thermal power capacity by 2050. Based on the model and other analytical assessment, it has been estimated that by 2050 India will come under severe necessity for water to meet the overall demand including that of the power sector (See Figure 19). The situation will be further exacerbated if we consider only surface water availability. Indian thermal power plants are mostly fed by surface water and thus reductions in surface water availability will seriously affect energy generation.

### 5.8.2 Plant site related measures

The risk arising out of water variability is expected to increase, particularly due to the impacts of climate change. Assessing the requirements of additional water storage at plant sites and acquiring sufficient land for storage at the time of plant siting may reduce water variability risks. As per capita water availability decreases, the possibility of water conflicts with local communities is likely to increase. Engaging with the local communities and government in local watershed management to replenish watersheds will reduce the possibility of water conflicts. Such measures should be made part of the plant approval process by the MoEF and by the appropriate state government / central government that approves the investment.

Depending on the long-term availability at the plant site and the competing water use, the appropriate government authorities should require the power plant developers to assess the appropriateness of cooling technology that is proposed to be employed while approving the project. Equally, the appropriate authorities should require an assessment that the power plant location has been optimised considering long-term water availability and competing water use, among other things. State power generators own 42% of the current thermal power capacity followed by central sector (36%) and private sector (22%). The state power generators may face institutional barriers in implementing thermal power plants outside their home state. If the state power generators are expected to continue to play a significant role in thermal power generation in the year 2050, the state power generators should be incentivized to implement thermal power plants outside the home state in case the home state does not have sufficient water resources in the long term. Equally, states that have sufficient water resources should encourage joint development of thermal power plants.

### 5.8.3 Demand side management

The end-use efficiency improvement in water consumption is targeted at 20% under National Water Mission through incentive mechanisms for water efficient technologies, engaging NGOs in activities related to water resources management (planning, capacity building and mass awareness), promote water conservation measures and expediting renovation and restoration of water bodies (Ministry of Water Resources, 2011). An increase of 20% water efficiency in irrigation sector has the potential to release 125 to 160 BCM of water at the national level. The IWMI water stress indicator is expected to change from ‘overly exploited’ to ‘heavily exploited’ for Indus, Krishna, Cauvery and Luna river basins if there is a 20% increase in water efficiency in the irrigation sector.

The agriculture sector is a good representation of the water-energy nexus of a different kind. Subsidised / free power to the agriculture sector has been stated to cause over exploitation and inefficient use of utilisable water resources. On the other hand, inefficient agriculture pump-sets are said to cause significant energy losses – both in the pump-sets as well as in the rural electricity distribution. Strengthening the agriculture sector through good agriculture practices, efficient irrigation techniques, efficient agriculture pump-sets and increasing rural electricity distribution will not only reduce local water requirements but also bring down the electricity generation requirements.

Power plant developers should be encouraged to take a proactive role in promoting good agriculture practices in their nearby communities as part of their corporate responsibility activities.

### 5.8.4 Improving water availability

One project that has emerged is the river inter-linking project, which envisages linking the water surplus river basins in India to the water deficit river basins. This project aims to provide a long-term solution to maintain equilibrium in availability and demand. This project is capital intensive and therefore it is important that it is viewed as a win-win situation by the concerned states (ADB 2011). Local linking projects are expected to provide multiple benefits such as flood control, water for irrigation and electricity generation (ADB 2011). The dynamics for per capita water availability for thermal power plants may significantly change as a result of implementation of the river inter-linking project.

The per capita water storage in India (225 $m^3$/capita) is the lowest in the world relative to comparable countries and the world average (e.g. 1960 $m^3$/capita for the United States and 1100 $m^3$/capita for China; and world average of 900 $m^3$/capita) (CWC 2010; Narula and Lall 2010; ADB 2011). Building water storage facilities is critical in addressing water availability and variability.

# 6. Case study on Thailand

## 6.1 Introduction

Thailand is a water abundant country according to the Falkenmark indication. Total renewable water resources come to about 210 BCM. However, Thailand is the driest country in Southeast Asia in terms of per capita water availability. It ranked 85th in the world for per capita water availability, whereas neighbouring countries like Lao PDR, Cambodia and Viet Nam ranked 18th, 30th and 62nd, respectively (UNESCO, 2003). According to Department of Water Resources, Thailand has a water shortage of about 15 BCM with current water storage capacity to satisfy total water demand. The degree of water shortage will intensify over the coming decades. An increase in water demand has resulted in the construction of water storage bodies. Current water storage capacity is about 71 BCM and only 60% of total water can be used for water users (DWR, 2007).

Water availability in Thailand varies throughout the year, depending on the temporal distribution of rainfall. The average annual rainfall in Thailand is 1420 mm. However, the country receives about 70% of its total rainfall during the wet season starting from May until October. Dry season rainfall (November to April) accounted for only 30% of the total annual rainfall. During the past decade, weather patterns in Thailand have fluctuated from severe droughts to severe floods, leaving residential and agricultural areas reeling. Between 1990 and 1993, rainfall was below normal levels, causing water shortages in 1993 (Kisner, 2008). Between June and October 2011, five tropical storms and three strong low-pressure systems caused historical levels of flooding and the worst recorded damage in Thailand (Kure and Tebakari, 2012). All these are indicative of the negative impacts of climate change on Thai water resources.

While a negative impact of climate change on water resources is to be expected, water demand will increase exponentially to ensure drinking water for food security for people and to fuel economic growth. According to the current statistics of Department of Water Resources (DWR) (2007), the cumulative water demand of domestic, agriculture, and industry is 57 BCM, which indicates a water shortage situation if we look at current water demand and utilisable water storage. The DWR estimate showed that water demand will increase to 80 BCM by 2025.

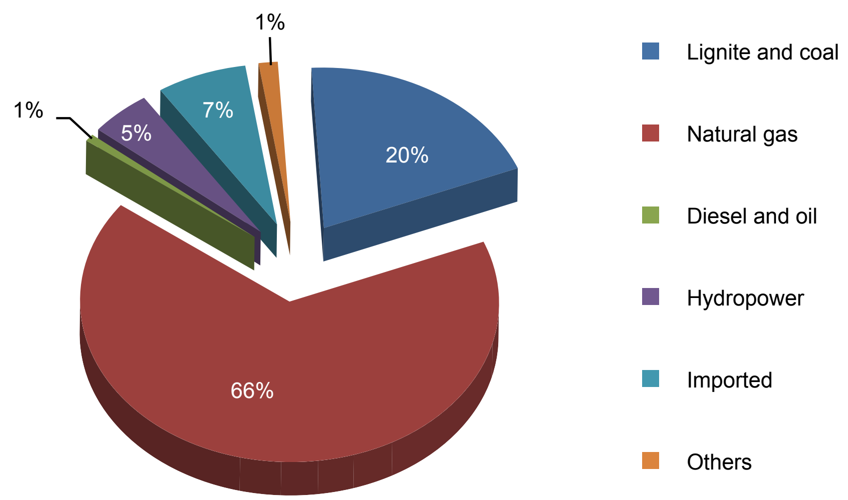
Power generation is highly water intensive, a fact which is generally ignored when estimating national water demand projections by the DWR. In recent years a number of reports have been published on water use in power generation. However the discussion was made based on water use co-efficients for US power plants which were derived by Department of Energy. In fact, the water use co-efficient not only depends on fuel types but also power generation technology, cooling technology and also on the climatic nature of the region since most of the water is used for cooling purpose. While regional variability of water requirement for power generation is obvious, no information is available on water use in this particular sector of Thailand, which is an emerging economic nation. No studies have been carried out on water demand for the energy sector.. Considering that water demand for electricity generation is quite significant in terms of water security and energy security, this study was conducted with the following objectives:

I. To quantify future water availability under different SRES scenarios (A2 and B2)
II. To estimate water demand for electricity generation and impacts on national water demand
III. To explore comparative advantages for water demand and supply management option toward mitigation of water shortages

## 6.2 Overview of electricity sector and future plan for Thailand

Electricity is an important catalyst for the development of emerging countries like Thailand. The growth rate of peak electricity demand was 12% in the mid-1990s to late 2000s, but this fell to nearly 4% between 1998 and 2006 (EPPO, not dated). Against this background, the Thai government formulated a power development plan to support sustainable development over the coming decades. It is projected that electricity demand will increase at a rate of 6% between 2007 and 2021 (TLFS, 2007). According to the power development plan, power generation capacity will be increased to 70686 MW by 2030 which is more than twice the current capacity. Existing power generation capacity is dominated by gas-based power plants. Currently, 70% of total generation comes from gas-based power plants, 11% from lignite-based power plant, 8% from imported coal and 6.6% from renewable sources. Furthermore about 7% of electricity is imported from neighbouring countries such as Lao PDR and Malaysia. Future power plant development will emphasise fuel diversification to reduce over dependency on natural gases. Figure 28 demonstrates the power supply portfolio of Thailand in 2012.

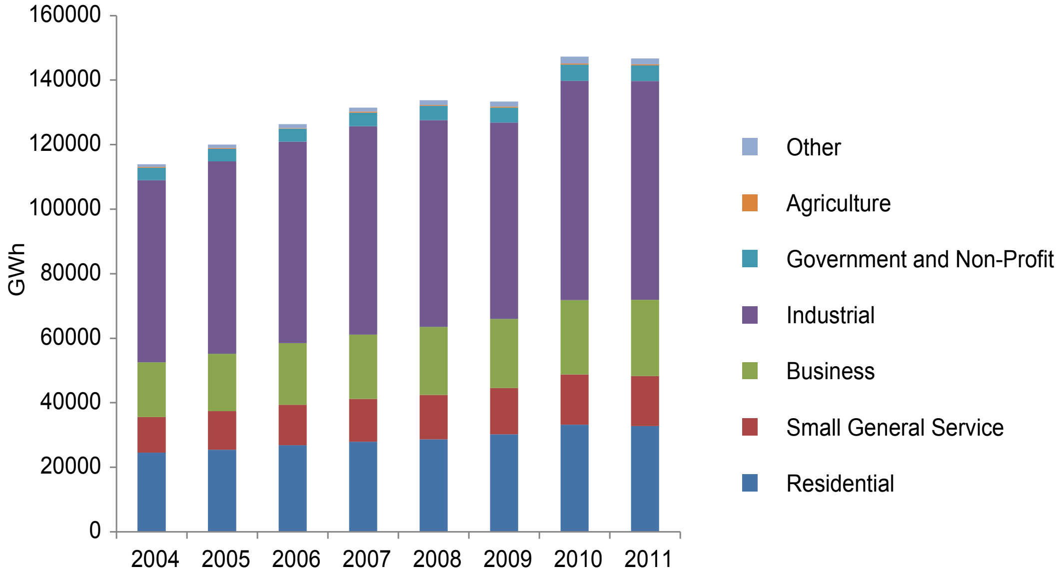
**Figure 28 : Power generation by fuel types as of 2012 in Thailand (Source: EPPO)**



## 6.3 Demand trend of electricity in Thailand

Demand for electricity has increased to fuel economic growth in Thailand. Figure 29 illustrates the trend of electricity demand over the last few years. The industrial sector is the biggest consumer of electricity followed by the residential sector. In contrast with the situation in India, agriculture consumes only 0.2% of the total electricity generated. According to government projections, electricity demand will increase to 360112 GWh by 2030.

**Figure 29: Trend of sectoral electricity demand in Thailand**

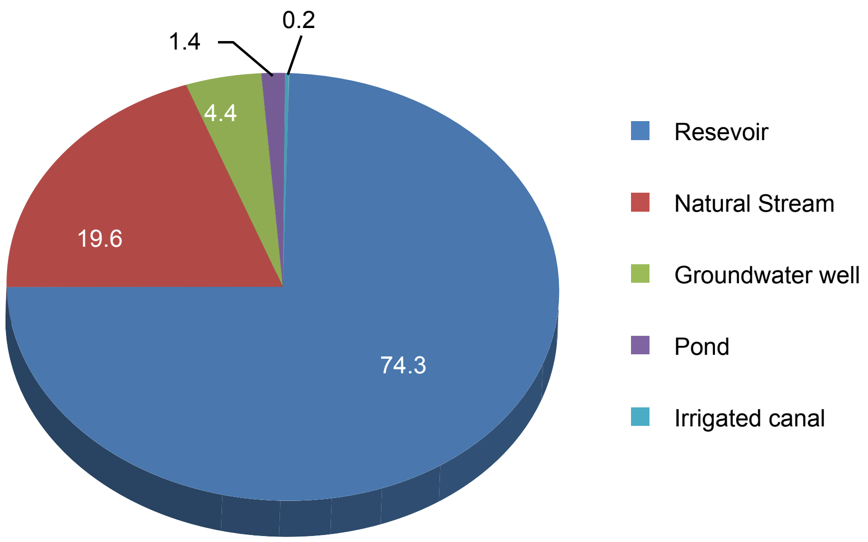



**(Adapted from EPPO)**

## 6.4 National water availability and sectoral water demand

Thailand is a water-abundant country and its water resources are mainly fed by monsoon rains between May to October. Thailand receives 732 BCM water from its annual rainfall. A large proportion of received water is lost due to the evaporation process which accounts for the loss of 75% of total water received. About 213 BCM of water flows into rivers as run-off. This is equivalent to 3500 m$^3$ per capita water, showing the water abundant status of Thailand. The country has constructed a number of reservoirs to capture water so as to meet the demands of various water users. Such water storage has a capacity of 76 BCM. Figure 30 illustrates the share of various water resources in relation to water supply. Water supply mainly depends on reservoirs which constitute 74% of supply water. Natural streams also contribute to water supply, accounting for 20% in 2007. Groundwater contributes 4% to the water supply. This shows that storage is the single largest source of water supply in the country followed by natural streams. As a matter of fact, this situation envisages the importance of run-offs of rainwater and building storage capacities.

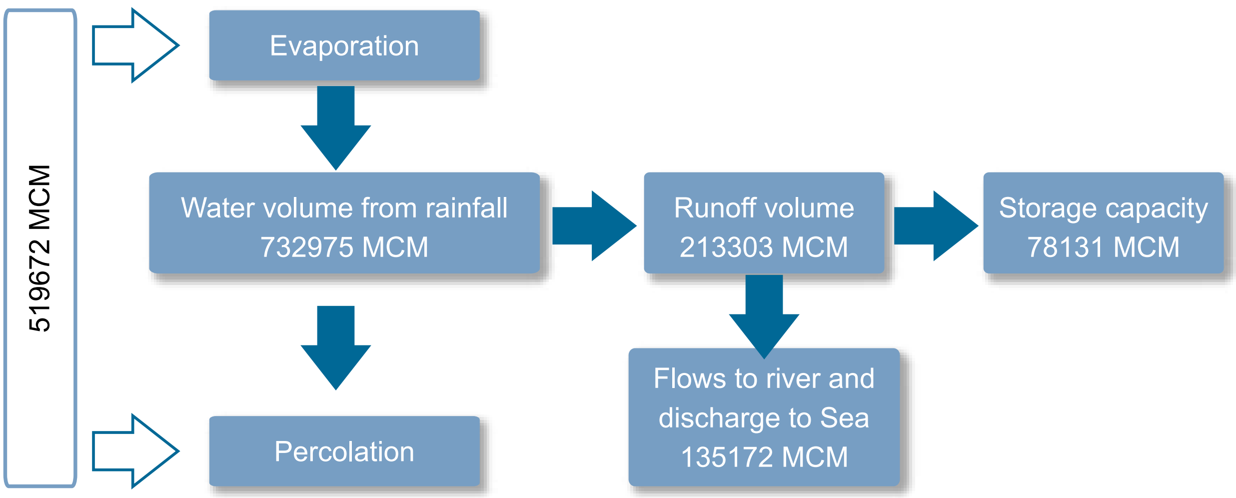
**Figure 30: Contribution of different water sources in the water supply, 2007**




*Source: Chulalongkorn University, 2012*

As agriculture is the main economic activity in Thailand, it is likely that agriculture is the major sector for water consumption. The agricultural sector uses 60% of abstracted water, followed by ecosystem water use (28%) (Chulalongkorn University, 2012). The domestic sector and industrial activities use 7% and 5% of the total water supply respectively.

**Figure 31: Surface water balance in Thailand**




**(Adapted from DWR, 2007)**

Although the national water level of Thailand is classified as water abundant, the water supply has a shortage of 3 BCM in relation to total water demand. It is expected that the water shortage will intensify over the coming decades with the expansion of irrigated land and industrial growth. Furthermore, climate change will have a negative impact with intense rainfall over a short period and a longer drought period. A number of studies were conducted to look at the possible climate change impact on water resources in Thailand, which mainly focused on major river basins like Chaophraya River basin and Mekong River basin. Studies found that river discharge is likely to increase (Kure and Tebakari, 2012; Hunukumbura and Tachikawa, 2012; Kiem et al., 2008). However, the impact of climate change on national water availability has yet to be assessed and impact may vary at the sub-national level.

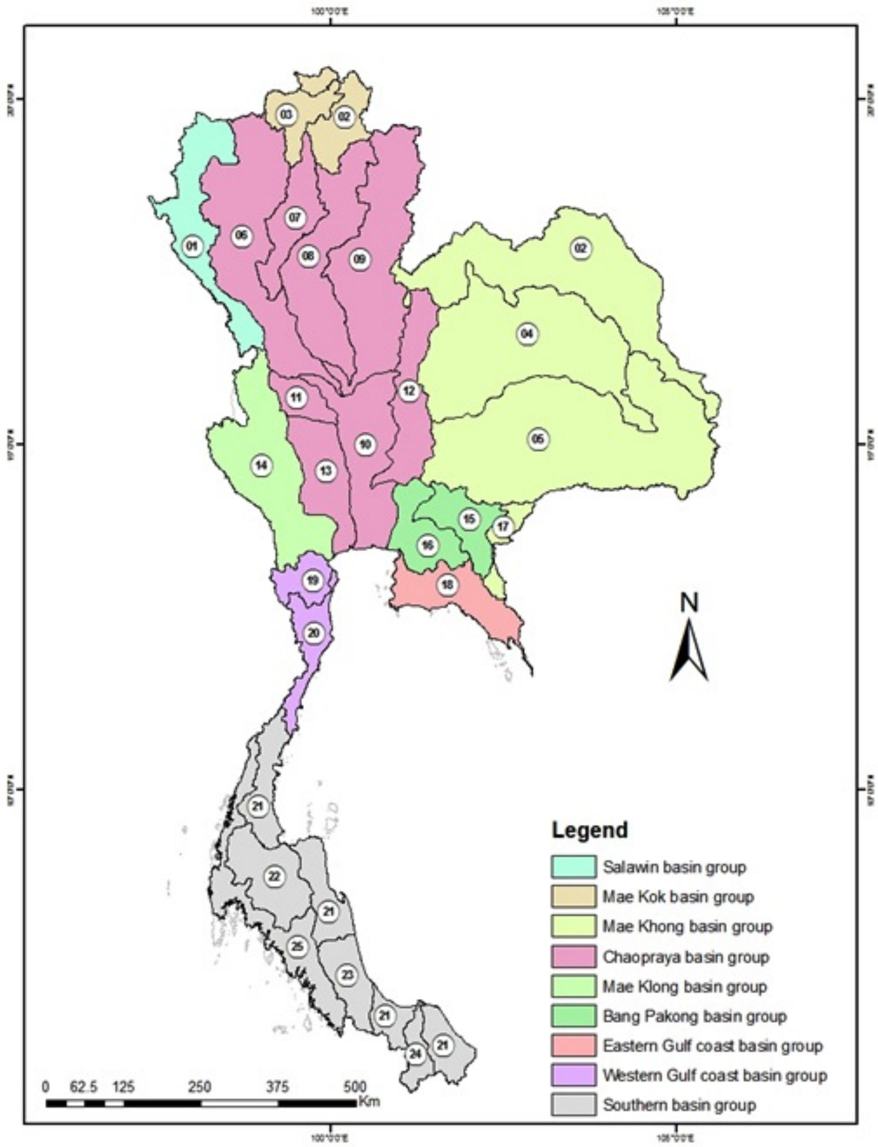
## 6.5 Method of projecting future water availability

There are 25 major river basins in Thailand. Water resources in Thailand are plentiful due to the abundant river flow into these basins. In this study, 25 river basins are grouped into nine Hydrological Response Units (HRUs) based on homogenous watershed characteristics to develop water availability projection using the hydrological model (HEC-HMS). Seasonal variation of water availability is very important for Thailand because of the distinct rainfall variation during the wet and dry seasons. Hence this study has developed a way to project water availability for both wet and dry seasons.

### 6.5.1 Data collection

Countrywide historical data of daily precipitation from 95 meteorological stations was collected from the Thai Meteorological Department and data of the stream flows of 25 river basins collected from the Royal Irrigation Department. A digital elevation map, soil type data and land use data were taken from the SRTM digital elevation database. Figure 32 shows nine different river basins that are assessed using the hydrological model to derive a national-scale projection for long-term water availability.

**Figure 32: Boundaries of Hydrological Response Units**



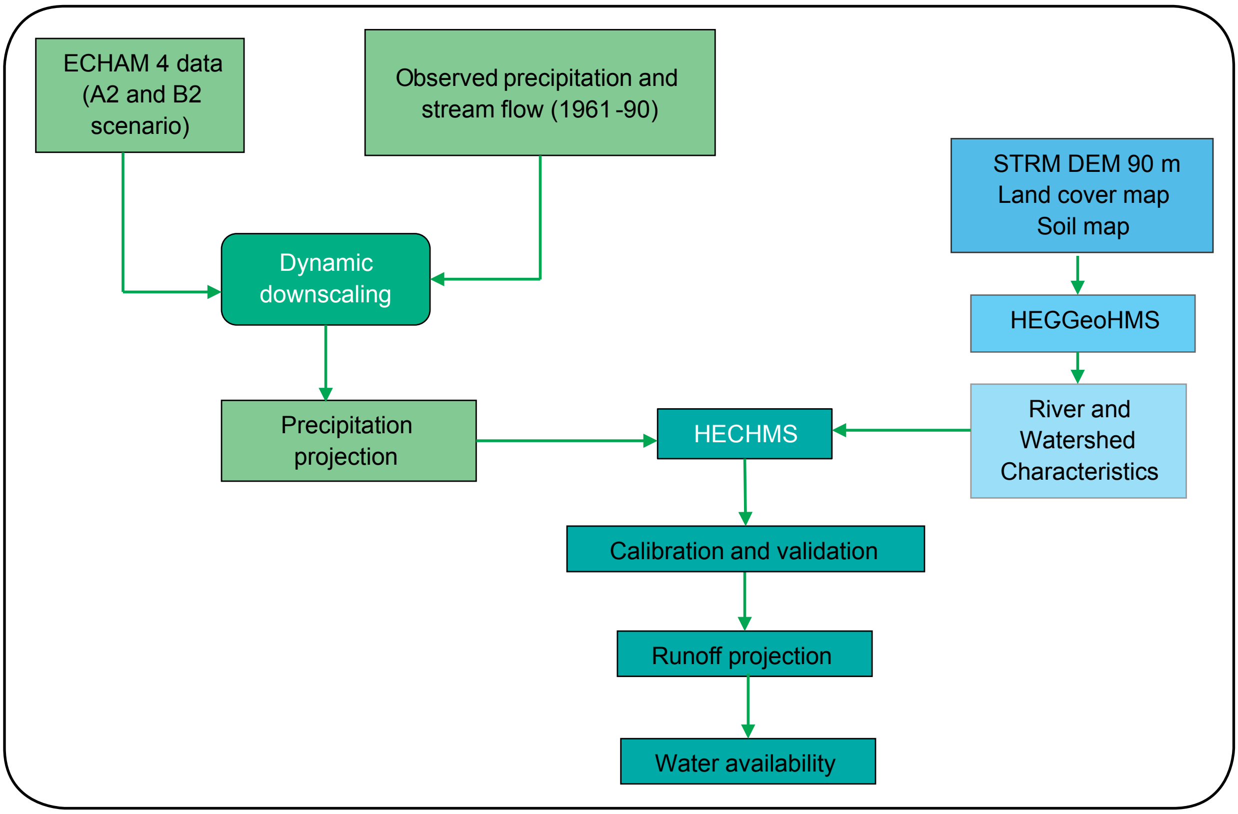
### 6.5.2 Selection of Global Circulation Model (GCM) and downscaling of GCM data

Based on the regional performance and acceptance of Global Circulation Models (GCMs), climate change projections were obtained from ECHAM4. ECHAM4 was used by several regional level and river basin level studies in Southeast Asia (Chinvanno , 2009; Sharma et al., 2007; Khattak et al., 2011). The two most popular SRES scenarios A2 and B2 were chosen for this study. First of all, dynamic downscaling of ECHAM4 data was performed to obtain RCM output. This RCM data was then further downscaled to a basin scale using the appropriate ratio method. The results revealed that RCM data represents only rough results which differ significantly from the actual situation. The variation between RCM results and observed data ranges from -23.6% to 33.0%, whereas the difference was -4.9% to 5.6% in the case of the downscaled RCM results. Therefore RCM data was downscaled to minimise error when forecasting precipitation.

### 6.5.3 Description of Hydrological modelling

Hydrological model HEC-HMS, developed by the United States Army Corps of Engineers was used to assess the impact of climate change on the future availability of water in Thailand. The model setup includes the development of a basin model for nine Hydrological Response Units (HRUs), a meteorological model, control specification and the time series data input.  Watershed characteristics were determined using HEC-GeoHMS software. The digital elevation model, soil types and land use data were used as input data into the HEC-GeoHMS. The model calibration and validation were done respectively for the time periods 1998 – 2003 and 2004 – 2010,  comparing simulated and observed daily flow at nine gauging stations in the country for the nine HRUs. The calibrated model was run for present and future time periods, and analysis was carried out on relative changes in river flow hydrograph and  changes in amount of water availability. To analyse the climate change impact on water availability, seasonal and decadal variations were calculated for all future  time periods, namely the 2010s, 2020s, 2030s, 2040s, 2050s, 2060s, 2070s, 2080s and 2090s, relative to the base period.

**Figure 33: Methodological framework for projecting water availability**



## 6.6 Approach of long-term to project water demand

water demand was estimated for major water users such as agriculture, industry, and the domestic and power sectors. The estimation primarily relies on government projections of water demand until 2024 and then develops a way to project water demand up to 2050 using the extrapolation method. Extrapolation was based on projected population growth by UNFPA (2012) and an estimate was carried out for domestic water demand. For the agricultural sector, extrapolation was based on the expansion of irrigation in mid and long-term development scenarios as reported by Young (2009). The study depended on the CAGR method for Industrial water demand projection. Water demand for electricity generation is available through government projections as well as from secondary sources. The study estimated water demand for electricity generation based on water use intensity in power plants and future electricity generation projections. For this estimation we used the MESSAGE model integrated with the water module.

## 6.7 Electricity generation projection

In this study we developed the national Thai MESSAGE model to conduct the long-term energy scenario assessment. The Thai MESSAGE model is developed based on the data provided in the National Power Development Plan and other relevant information sources. We also used the basic Thai MESSAGE model developed by the Thammast University[9]. This study also relied on a document of the Thai national power development planning for electricity generation projection beyond 2030. The MESSAGE model for Thailand was mainly developed to estimate and assess long-term scenario in the energy sector and thus does not focus on detailed demand sectors in the economy.

## 6.8 Power plant survey and assessment of water coefficients

Maximum portion of supplied water is used as coolant in thermal power plants. No systematic estimation has been done on water use intensity of Thai power plants. We conducted surveys in selected power plants to collect primary data on water use intensity in existing power plants. Power plants were selected based on fuel types and technologies that employ different cooling technologies: open loop cooling system and closed loop cooling system. Among the selected power plants, one is fuelled by lignite and the other four are gas-based. A detail description of the surveyed power plants is shown in Table 17. Performance evaluation of existing cooling technologies was carried out to assess the impact of the power sector on the future water supply-demand gap.

9 IGES MESSAGE Model for Thailand is based upon the model developed by Prof. Bundit Limmeechokchai, from Sirindhorn International Institute of Technology, THAMMASAT UNIVERSITY.

**Table 17: Basic information of surveyed power plants**

| Name of power plant | Fuel type | Current capacity (MW) | Cooling system | Water use co-efficient ($m^3$/MWh) | Source of water for power plants |
|---|---|---|---|---|---|
| Mae Moh | Lignite | 2400 | Closed loop | 2950 | Mae Kham reservoir and Mae Chang reservoir |
| Bang Pakong | Gas | 3720 | Closed loop | 900 | Bangpakong River |
| | | | Open loop | 5700 | |
| South Bang-kok | Gas | 2593 | Closed loop | 1950 | Chaophraya River |
| | | | Open loop | 5500 | |
| Chana | Gas | 746 | Closed loop | 1500 | Poma canal and Bang-ped canal |

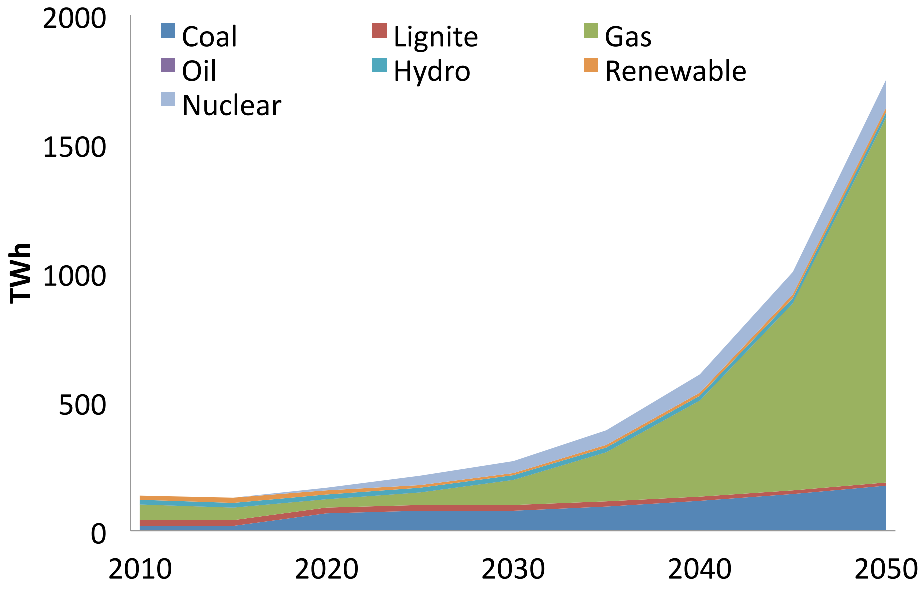
*Source: Power plant survey by IGES, 2012*

## 6.9 Results and discussions

### 6.9.1 Long-term electricity scenario

Thailand experienced increased energy demand, including electricity, for much of the decade between 2000 and 2010, driven by its high GDP growth rates. Projected electricity generation in Thailand shows impressive growth from 2010 and 2050 as shown in Figure 34. According to the power development plan, electricity demand will increase to 338 TWh by 2030. To meet this increasing demand it is expected that electricity generation will reach 270 TWh and our model study further projects that electricity generation will reach 1750 TWh by 2050, which is 12 times that of 2010 levels. The projected electricity generation portfolio also demonstrates the continued dominance of gas-based thermal power generation in the total electricity supply mix of Thailand until 2050. The contribution of gas-based electricity generation increases significantly to about 80% by 2050. Similarly generation of nuclear based electricity generation is also expected to increase significantly. Figure 34 shows nuclear based electricity will reach 110 TWh by 2050 which is about 6% of total generation.

**Figure 34: Estimated electricity generation projection in Thailand**

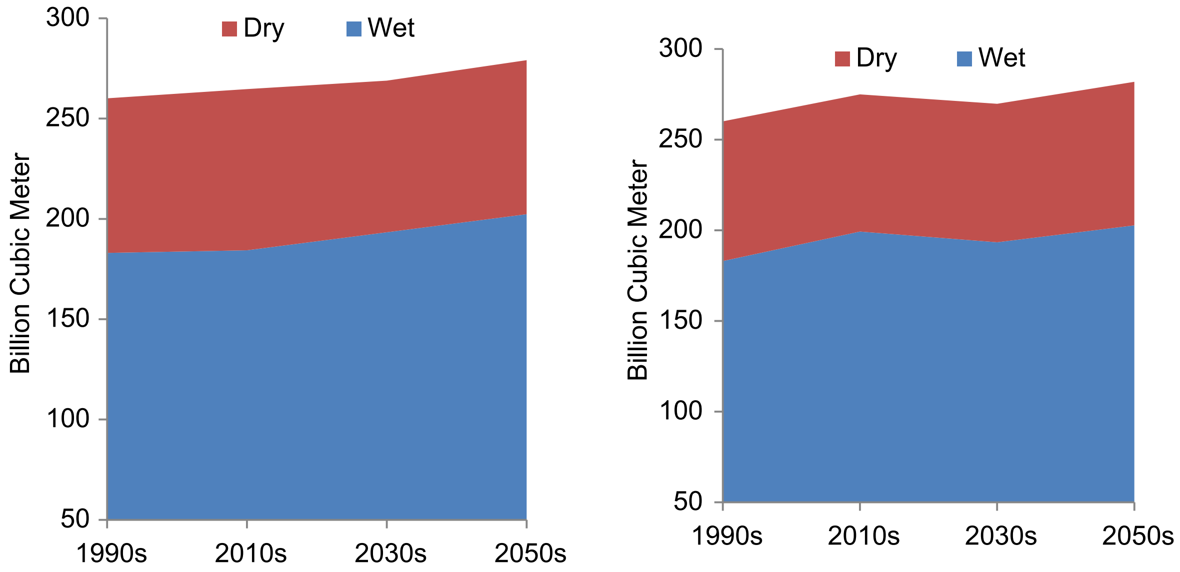



## 6.9.2 Water availability projection

Water availability projection for Thailand is presented in Figure 35. Under both A2 and B2 Scenarios, the annual water availability in Thailand will increase by 10% and 12% respectively in 2050 compared with water availability in 1990 (260 BCM). While annual water availability is expected to increase over the coming decades, seasonal variability of water availability will intensify under SRES A2; consequently water availability in the wet and dry seasons will increase and decrease respectively. Intensification of seasonal variability of water availability is attributed to increasing rainfall in the wet season and decreasing rainfall in the dry season. Looking at SRES B2, water availability in the wet season will increase to 12% in 2050 compared to 1990. This is in contrast with SRES A2, whereby dry season water availability is expected to increase in the coming decades.

The increased water availability in the wet season will not have any positive impact on agricultural and economic activities in the basins unless storage capacity of access runoff is improved. This is because the amount of water available in the wet season in the basins already greatly exceeds demand at the present time. Instead it will have a severe negative impact on the socio-economic situation as well as on environmental and ecological activities in the basins. Moreover, increased availability of water in the wet season will aggravate flooding in the country. This is already a major problem in the basins and there has been a huge loss of property and life in the past. Floods triggered by excessive wet season water availability will increase landslides and soil erosion in the upper watersheds and inundate the southern plain regions of Thailand.

**Figure 35: Water availability projection under SRES A2 (a) and SRES B2 (b)**




(a) (b)

Although national water availability is expected to increase over the coming decades, the situation at the river basin level might be different, particularly with regards to seasonal variation. In most of the river basins, dry season water availability will increase in the coming decades. However, southern river basins, Eastern Gulf Coast basin river basins and Western Gulf Coast river basins show a negative trend of water availability during the 2050s. It is expected that water availability will decrease by 12% in Western Gulf river basin groups during the dry season compared to the base year 1999. The results of projections revealed that water scarcity in the dry season will worsen in some particular river basins and sub-regional development plans should take this matter seriously.

**Table 18: Percentage changes in the future seasonal water availability in river basins under A2**

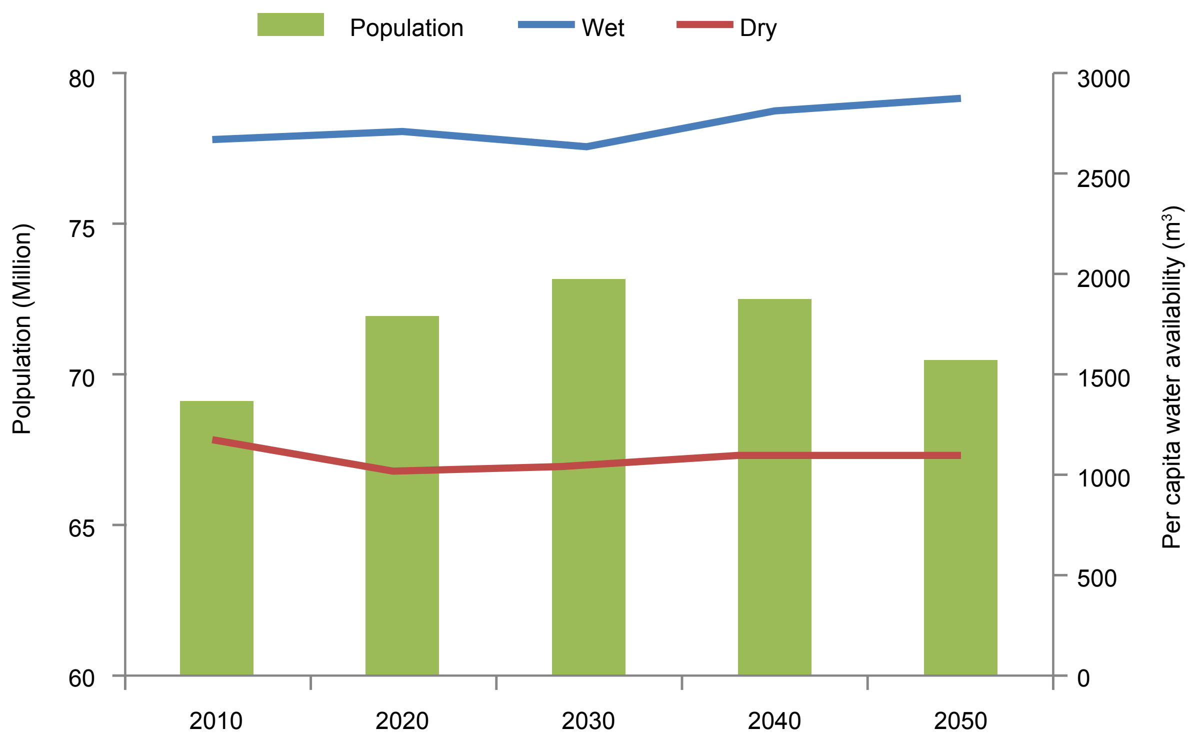
| River Basin group | 1990 (Base year) | | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|
| | Water in wet (MCM) | Water in wet (MCM) | % change in wet season to base year 1999 | | | % change in dry season to base year 1999 | | |
| Salawin Basin Group | 11023 | 3327 | -5.24 | -0.28 | 6.24 | 4.42 | -4.33 | 1.81 |
| Mae Kok Basin group | 7993 | 2123 | 7.82 | 12.53 | 19.51 | 21.53 | 11.45 | 17.9 |
| Mae Khong Basin Group | 30426 | 10112 | 8.08 | 17.58 | 24.85 | 6 | 10.34 | 17.47 |
| Chaopraya Basin group | 27001 | 7993 | 0.83 | -0.69 | 7.3 | 5.87 | -0.58 | 6.56 |
| Mae Klong Basin group | 15673 | 5376 | 2.21 | 7.56 | 14.57 | -0.88 | -9.19 | -3.37 |
| Bang Pakong basin Group | 7112 | 2129 | 6.01 | 17.15 | 14.64 | 23.11 | 24.57 | 27.76 |
| Eastern Gulf Coast Basin Group | 7598 | 2312 | -2.11 | 3.01 | 9.7 | 7.62 | -1.35 | 4.89 |
| Western Gulf Coast Basin Group | 7992 | 2731 | -7.47 | -2.63 | 3.72 | -9.85 | -17.43 | -12.13 |
| Southern Basin Group | 68232 | 40958 | -2.12 | 2.54 | 4.63 | 3.09 | -5.12 | -7.8 |

**Table 19: Percentage changes in the future seasonal water availability in river basins under B2**

| River Basin group | 1990 (Base year) | | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|
| | Wet | Dry | % change in wet season to base year 1999 | | | % change in dry season to base year 1999 | | |
| Salawin Basin Group | 11023 | 3327 | 8.2 | -0.06 | 5.05 | -4.33 | 1.66 | 7.91 |
| Mae Kok Basin group | 7993 | 2123 | 23.1 | 13.29 | 19.12 | 10.51 | 18.85 | 26.01 |
| Mae Khong Basin Group | 30426 | 10112 | 7.75 | 17.94 | 18.68 | 5.59 | 17.41 | 21.8 |
| Chaopraya Basin group | 27001 | 7993 | 7.7 | 0.59 | 7.21 | -3.7 | 4.7 | 10.94 |
| Mae Klong Basin group | 15673 | 5376 | 16.69 | 7.79 | 13.29 | -9.18 | -3.5 | 2.42 |
| Bang Pakong basin Group | 7112 | 2129 | 2.65 | 4.65 | 19.42 | 22.83 | 24.19 | 29.17 |
| Eastern Gulf Coast Basin Gropu | 7598 | 2312 | 11.73 | 3.23 | 8.48 | -1.35 | 4.76 | 11.16 |
| Western Gulf Coast Basin Gropu | 7992 | 2731 | 5.64 | -2.42 | 2.56 | -17.4 | -12.23 | -6.89 |
| Southern Basin Group | 68232 | 40958 | 7.25 | 3.07 | 7.58 | -3 | -8.23 | -6.32 |

Figure 36 demonstrates that per capita water availability in the wet season will increase in 2030 and beyond. This is attributed to negative population growth beyond 2030. In 2050, the per capita wet season water availability will rise to 2900 $m^3$, whereas projected per capita water availability in the dry season is 1100 $m^3$ in the same year.

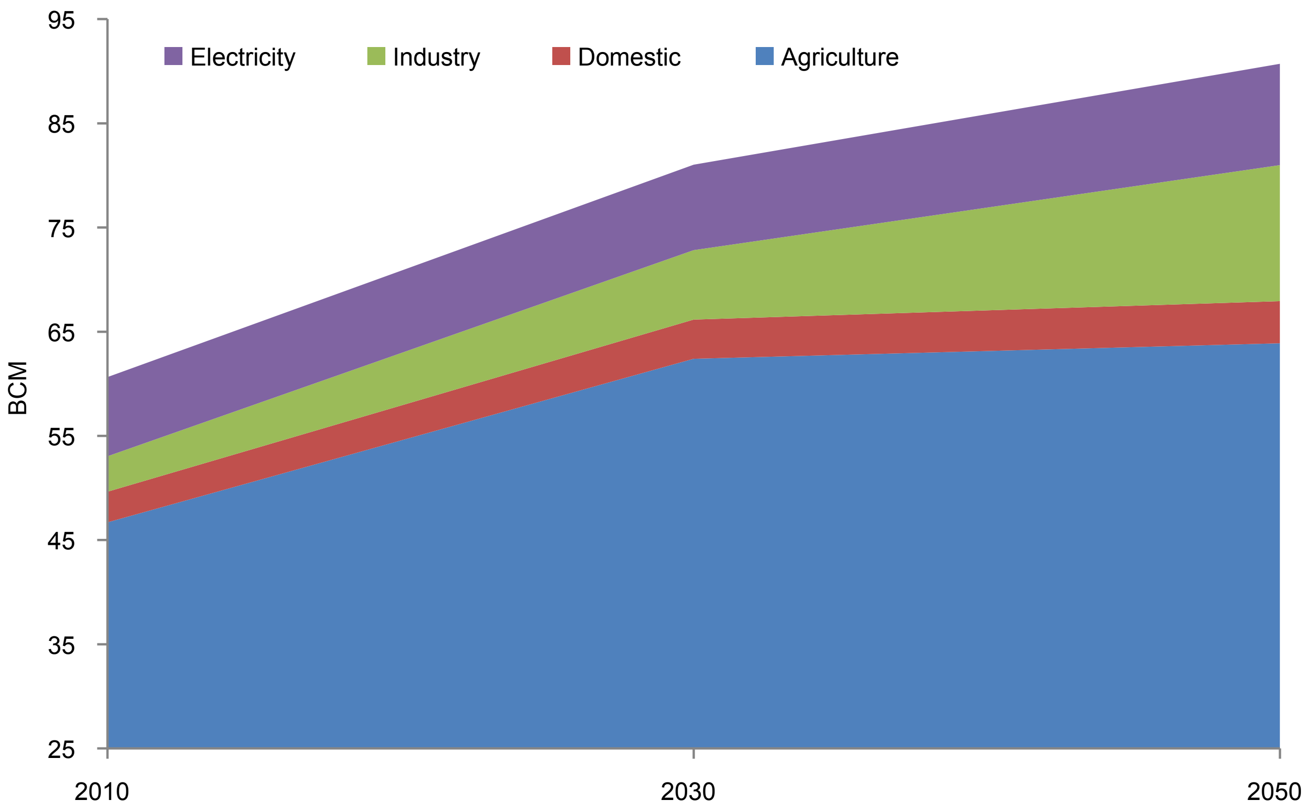
**Figure 36: Projected seasonal variation of per capita water availability in Thailand**



### 6.9.3 Trend of sectoral water demand and impact on supply -demand gap

Although per capita water availability will decrease to 3500 m$^3$/year by 2050, Thailand is catagorised as water abundant according to the Falkenmark indicator. However, at the same time water availability will increase in order to secure water for growing population, securing food and fuelling economic growth. Government reports state that Thailand has a water deficit of about 16 BCM considering current storage capacity against total water demand. The situation will worsen over the coming decades if appropriate measures are not taken in a timely manner. The results of our model demonstrate that water demand will reach 90 BCM in 2050, which is double the current capacity of usable storage. Like other developing countries in Asia, agriculture is the sector that consumes the most water. It was found that electricity generation requires the second highest volume of water, but government projections ignore this water requirement for electricity generation. Our results show that power sector water demand will rise to 10 BCM in 2050, which is about 20% of current useable water storage capacity. Such huge water requirements for the power sector will increase the water-energy trade off conflict in Thailand, particularly in the dry season.

**Figure 37: Sectoral water demand projection for Thailand**




*Note: 1) Agricultural water demand was estimated based on growth of irrigation areas*

*2) Domestic water demand was estimated based on population growth*

*3) Industrial water demand was estimated using CAGR method*

*4) Water demand for electricity generation was derived using the MESSAGE model.*

*5) Water use efficiency improvement is not considered in this estimate.*

### 6.9.4 Threat of climate change variability on water security for electricity generation

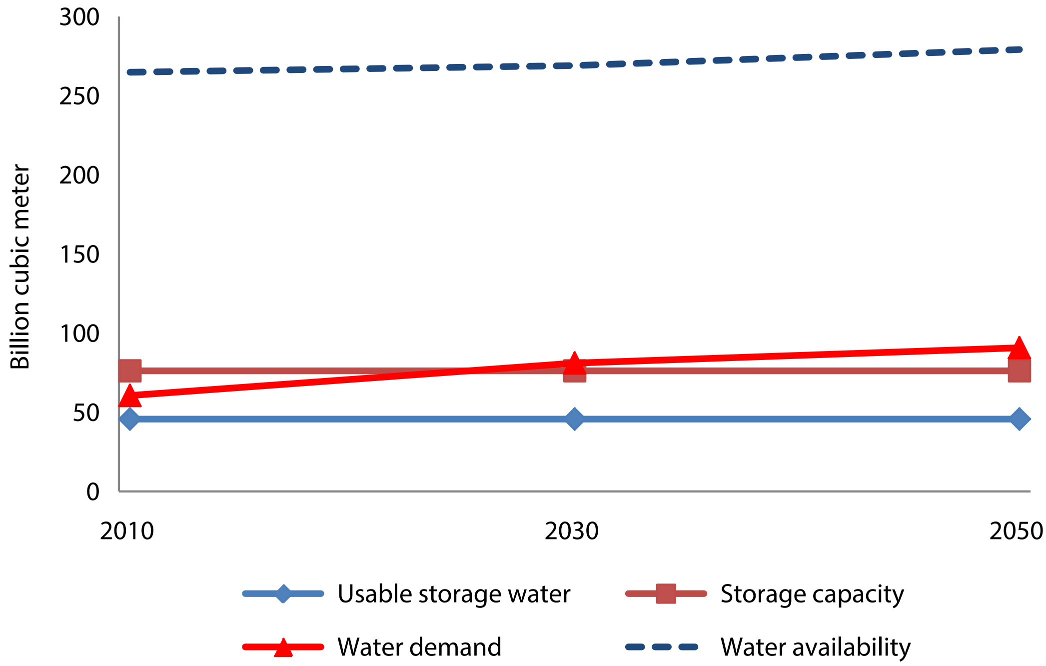
According to our hydrological model study, it is expected that total water availability will increase in coming decades due to intense rainfall during the wet season. In contrast, water availability in the dry season will decrease. Surveys of power plants revealed that electricity generation requires huge amounts of water for cooling purposes and that most of the plants depend on rain-fed reservoir for water. Mae Moh power plant, the largest power plant in northern Thailand withdraws the necessary volume of water from two rain-fed reservoirs, Mae Kham reservoir and Mae Chang reservoir which have a capacity of 34 million cubic meters (MCM) and 105 MCM respectively. Chana power plant is an important power plant in southern Thailand which collects water from Poma canal and Bang-ped canal. Annually, a maximum of 0.9 MCM of water can be withdrawn to operate the Chana power plant. Although the current water supply is sufficient to cool the Chana power plant, increased salinity of the source water during the dry season reduces the concentration cycles which cause more water to be required in the dry season. The high salinity levels in the dry season are also reported for Bangpakong power plant and South Bangkok power plant which take water from the mouths of the Bangpakong River and Chaophraya River, respectively. While water demand will increase for cooling of power plants, dry season water availability is expected to decline over the coming decades.

The drought in 2005 sent a warning to the Thai power sector about possible threats of a shortage for electricity generation. EGCO a key power plant company in Rayong nearly ran out during the dry season of 2005 because the capacity of the cooling water reservoirs fell to 9% of actual capacity (JP Morgan, 2008). Our model study demonstrates that dry season water availability will decrease by 8% by 2050 in southern Thailand. Dry season water shortages may well become a major hindrance for future development of the electricity sector and Thailand may not be able to meet the huge level of energy demand to fuel the desired level of economic growth particularly in the dry season. Apart from the impacts of climate change on thermal power generation, it is also quite likely that hydropower generation will be affected due to changes in rainfall pattern over the coming decades. The neighbouring country of Viet Nam was forced to reduce hydroelectricity generation in 11 plants in 2005 due to a three month-long drought (EVN website as cited in WRI 2010). Decreasing water availability in the dry season may negatively affect planned electricity generation, and other water use may be compromised unless supply and demand side management is improved.

### 6.9.5 Mitigation options for water shortage

Above discussion reveals that unless certain mitigation measures are taken, water shortages will intensify in the coming decades. Measures to cope with water supply-demand gap can have structural and non-structural options. Figure 38 shows the existing situation regarding the water supply and demand gap with its continuation until 2050. This shows that water demand will surpass storage capacity which indicates that in spite of having a good supply, it will be a lack of storage that results in Thailand not being able to meet the required demand for water. Here it is important to understand that water supply does not mean that water is actually available, because without storage, most of the water will flow through the river basins.

**Figure 38: Long term scenario of water supply and demand in Thailand (BAU case)**




The study analyses structural and non-structural measures toward coping with the water supply-demand gap. Priority options are improving the structure of water storage capacity and improving water use efficiency in agriculture. Improving water storage will contribute to reducing flood risk during the intense rainfall of the wet season and can be used to store water for the dry season. Improving water use efficiency in agriculture has huge potential for water savings that would complement water for other users. The study attempted to identify the best options considering technical feasibility and economic viability. Figures 39 and 40 show that the current capacity to store usable water is not sufficient to meet current water demand, with a gap of about 15 BCM. The gap will reach 45 BCM by 2050 unless supply-side management and demand-side management are strengthened. To maintain the current water supply-gap in the future (which is otherwise considered as a water sufficient situation in Thailand without much trouble) Thailand needs to expand storage capacity to 126 BCM which is almost double the current storage capacity, as shown in the Figure 39. Such a massive expansion of storage capacity might not be technically feasible and would need huge investment. Demand-side management with improved water use efficiency would be an attractive option. Figure 40 demonstrates that a water use efficiency rate of 33% in agriculture by 2050 could maintain the current gap between water supply and demand (case 3).

**Figure 39: Scenario of increasing storage capacity by dam construction (Case II)**

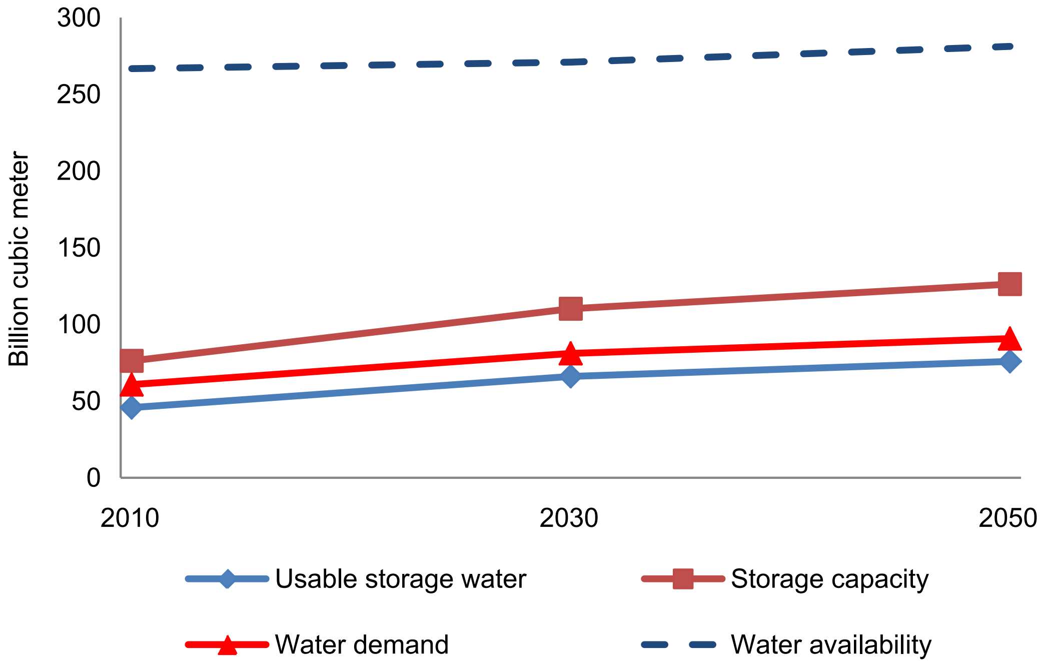
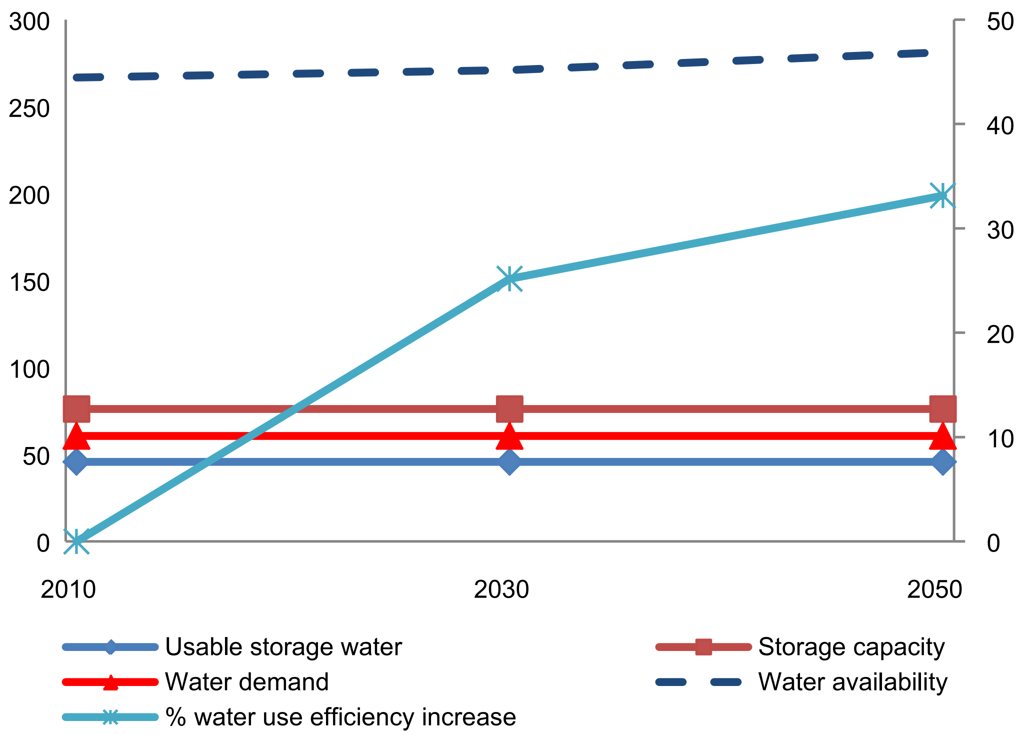
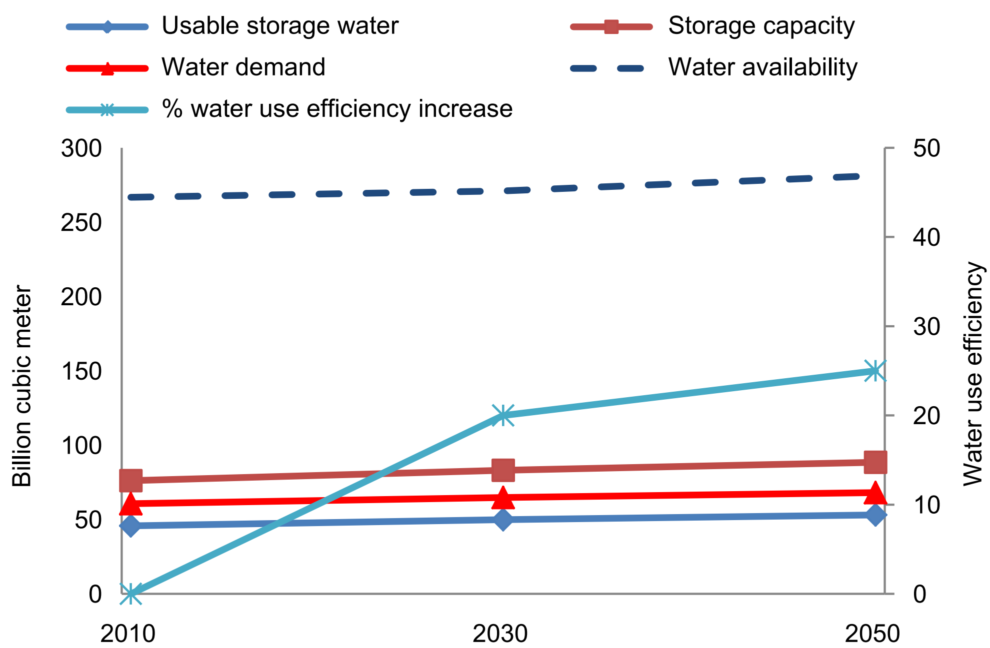



**Figure 40: Scenario of increasing water use efficiency (Case III)**




However, the impacts of climate change will result in more rainfall during the wet season and this would increase the risk of flooding in Thailand. To cope with climate change impacts on water resources, Thailand needs to increase its storage capacity. Therefore we considered a combination of increasing storage capacity and improving water use efficiency as feasible options for Thailand to maintain its current water supply demand gap over the coming decades. Figure 41 shows that a 25% improvement of water use efficiency could reduce water demand by 22 BCM in 2050 with actual water demand coming to 68 BCM.

**Figure 41: Scenario of combined mitigating actions (storage capacity increase and efficiency improvement) (Case-IV)**




To maintain the current water supply demand gap, additional 8 BCM water will be needed. The required volume of water can be captured during the wet season by expanding water storage structure. To do so, an additional 22 BCM of storage capacity needs to be constructed by 2050.

### 6.9.6 Mitigation cost analysis to reduce impacts of water constraints

It is likely that water demand will increase mainly due to expansion of irrigation areas and the rapid increase in industrial growth. However the current supply capacity will not be able to meet future water demand in Thailand. A number of mitigation options are available that can help to reduce future water shortages including supply-side and demand-side management. The choice of the options heavily depends on the required investment cost. Estimate made in this study require an investment cost under the above discussed scenarios based on construction costs required for expanding the capacity of water reservoirs and on the costs of improving water use efficiency in the agricultural sector. The costs of water reservoir construction were derived from the total construction costs of Bhumibol Dam and Sirikit Dam. Water use efficiency costs were adapted from Manero (2011). Table 20 illustrates the cost of mitigation options to cope with increasing water demand in years to come. Relying solely on supply-side management with the construction of storage dams is the most expensive option and will require a USD250 billion investment by 2050. Such a huge investment is a major challenge for a developing country like Thailand. In contrast, a 33% improvement in water use efficiency is the option requiring the least investment, and will cost USD1.3 billion by 2050. However, implementation of a 33% improvement in water use efficiency would require favourable institutional arrangements, political willingness and the active participation of farmers. Relying solely on a particular mitigation option cannot ensure long-term sustainability considering the risk of climate-induced water disasters and the increasing water demand. Under Case IV, a combination of structural and non-structural measures would require investment of USD62.6 billion which cuts investment costs to a quarter of those for scenario II and improves the sustainability of such actions.

**Table 20: Economic comparison mitigation options for water supply-demand gap**

| Required investment cost (billion $USD_{2010}$) | | | |
|---|---|---|---|
| | **Case-II** | **Case-III** | **Case-IV** |
| 2030 | 169.9 | 0.9 | 35.5 |
| 2050 | 250.6 | 1.3 | 62.6 |

*Note: Required investment cost is estimated based on construction cost for dam ranges from USD3.5/m$^3$ for earth-filled Sirikit Dam to USD7.5/m$^3$ for concrete-filled Bhumibol Dam at 2010 prices (Ngo Quoc Trung, 1978). Investment of water use efficiency is estimated based on the highest cost (USD0.43/m$^3$) of agricultural water efficiency in California*

# 7. Summary and way forward

This study tries to identify the initial issues of the water energy nexus by determining the demand for water by the energy sector to meet the needs of the economy. It also estimates for certain countries the total water available in the long term for the energy sector. It has been observed that there is no such systematic approach taken by the regional governments to assess the long-term water availability exclusively for the energy sector. Water for human and commercial consumption is more or less monitored and reported but there is a large gap when carrying out estimations for the energy sector. However, the energy sector in south Asia is heavily water-dependent and more precisely water-inefficient in the context of specific water consumption for energy. As a matter of fact, Asian developing economies especially countries like India are very vulnerable to long-term water availability for energy production. Such countries are heavily dependent on thermal technologies especially coal and natural gas for cheaper, reliable power generation and thus more dependent on water compared to other countries which have alternative technologies.

By 2050, thermal technologies for energy generation and subsequently dependence on fossil fuels like coal and natural gas will be predominant in Asia. Our assessment shows that even under the most optimistic scenario of emissions reduction by deploying renewable technologies, thermal technology dependence will continue to such an extent where water scarcity may disrupt the long-term energy planning of the countries. India is one of the fastest growing economies in the world, and thus a reliable energy supply is the most important issue that the country faces. However, the study found that currently available long-term energy planning (mainly under the 12$^{th}$ Five Year Plan) hardly considers the issue of constraints in water resources.

The Central Electricity Authority and Federal Regulators are concerned about it, but efforts have yet to be pushed up as far as policy-makers. The study demonstrated that in the decade between 2040 to 2050, there will be serious conflict among various water users which may dampen economic and social development significantly for the country. Increasing water demand for electricity generation will intensify inter-sectoral conflicts for freshwater. Thus, to mitigate such conflicts, appropriate policies should be taken in a timely manner. Such policies could be the introduction of water-efficient technologies in power plants, promoting low water-consumptive renewable energy (wind, solar photovoltaic) and the implementation of water demand management approaches for major water users.

In case of Thailand water demand for electricity generation is ignored in national water allocation plan, despite electricity sector will require 10 BCM water annually by 2050. In general, water abundant country like Thailand may not face water shortage for electricity generation. However, climate induced seasonal change of water availability may negatively affect water supply for power plants

The developing nations of Asia including India and Thailand are currently in the stage of economic growth and prosperity, and thus are in an advantageous position to avoid long-term technology and investment lock-in by taking prudent decisions with regards to sustainable investment in the energy sector. Consideration of the water energy nexus while building long-term planning for energy could well be thought of as a risk-hedging measure for investment.

This study tries to make quantitative measurements as accurately as possible to determine the specific water consumption of different energy technologies used in this region, but plenty of assumptions are still taken to cover the data gap. It has been observed that in most cases, government and the energy companies do not estimate such water coefficients. Therefore, an important task ahead is to build a reliable regional database for specific water consumption for energy technologies to further improve this assessment with more accuracy. It is also important to consider intersectoral conflicts of water use among various other demand categories in a long-term manner to gain precise estimations of sectoral allocation of water. Finally, it is also important to consider the reuse and recycling of waste water for the energy sector to mitigate the impact of water shortage.

# Limitations of the study:

This study is meant to examine the water-energy nexus issue at a national level to establish if there is *prima facie* case for further investigation by the policymakers. The recommendations made in this study are directional in nature and should be implemented after undertaking detailed studies specific to the context. River basin level assessment of water energy nexus is crucial for integration of water and energy policies. Furthermore, the impacts of climate change on water availability are expected to be significant in the future, and the study could cover this issue for Thailand. This study takes note of these important issues but could not take them into account while conducting the model assessment due to time and data constraints. However, improvements are required in the near future for this kind of study.

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IGES Research Report 2013-01

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ISBN 978-4-88788-139-6