Final Report

Integrated Modelling Study of the Food-Energy-Water Nexus in India

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...towards global sustainable development

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1 Introduction

Background

India is a growing economy with its population projected to increase well beyond 2050 (UN, 2017). Improvement of the standard of living of its people is a top agenda of the government. India's GDP and simultaneously its energy production, an essential component to the improvement in living standards has been on the rise. India will need an increasing supply of energy in the foreseeable future, and this will need to be provided to citizens using cleaner energy sources in order for it to honour its climate commitments (UNFCCC, 2015). One such resource vital to energy production is water. Water is essential not only for hydropower as is visibly the case, but vital for almost all other forms of energy from coal to natural gas to nuclear to concentrated solar (Macknick et al., 2012) (in the form of cooling water) and even to certain large-scale renewables. (Frisvold, 2013).

At the same time, India is a highly water stressed country (WRI, 2015), and it is only getting worse, with the per capita water availability falling from 1816 cubic metres as per 2001 census to 1545 cubic metres as per 2011 census (Ministry of Water Resources, Govt. of India, 2012).

Given the criticality of water for power production, its unavailability both limits power production, and also results in plants shutting down entirely. This has been the case for a number of Indian plants (WRI, 2017) due to shortage of water either due to natural reasons or increasing competition among water consuming sectors (industry, agriculture, domestic users, etc.).

Looking at Figure 1 which presents region-wise water stress index in India, and Figure 2, which shows the location of the major thermal, nuclear and hydro power plants in the country, it is evident that many of the power plants are located in high to extreme water stress belts of the country. In the context of increased climate variability in the future, this not only raises a question on the continuation of the power plants' operation, but also on the possible aggravation of water stress in already water stressed regions.

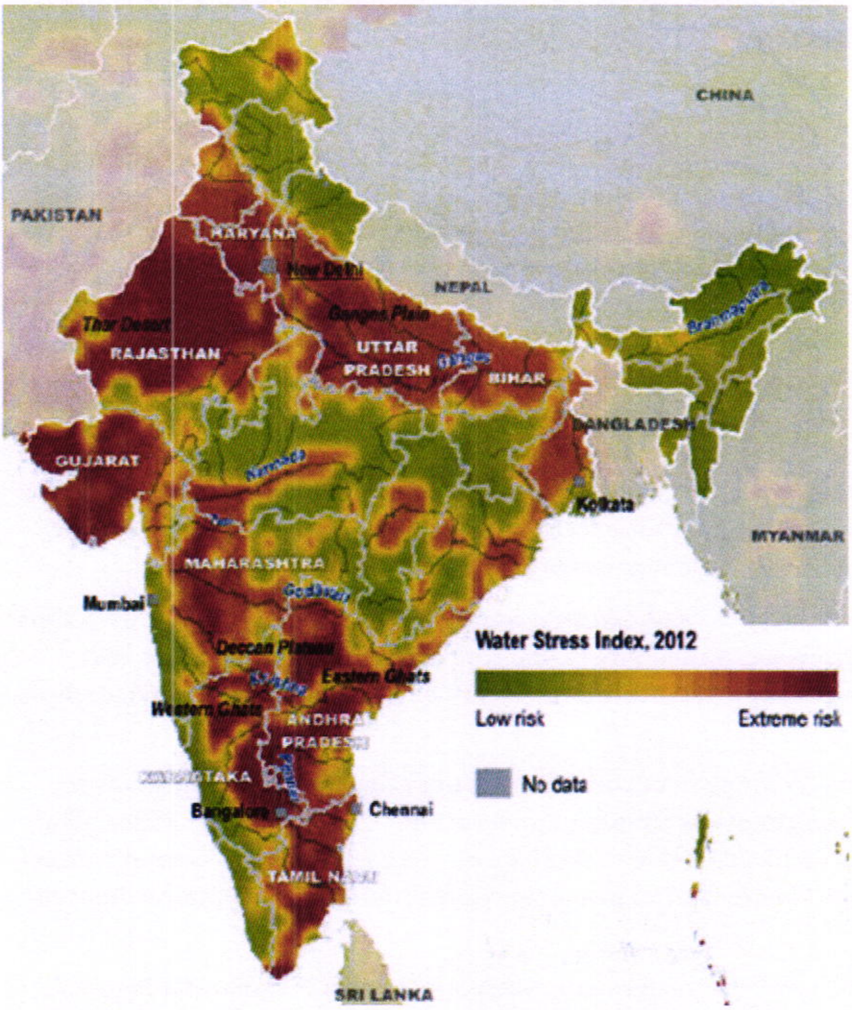

Figure 1: Region-wise water stress index of India - 2012

Source: Maplecroft, 2012 (Maplecroft, 2012)

Note: Figure 1 does not reflect the political boundary of India.

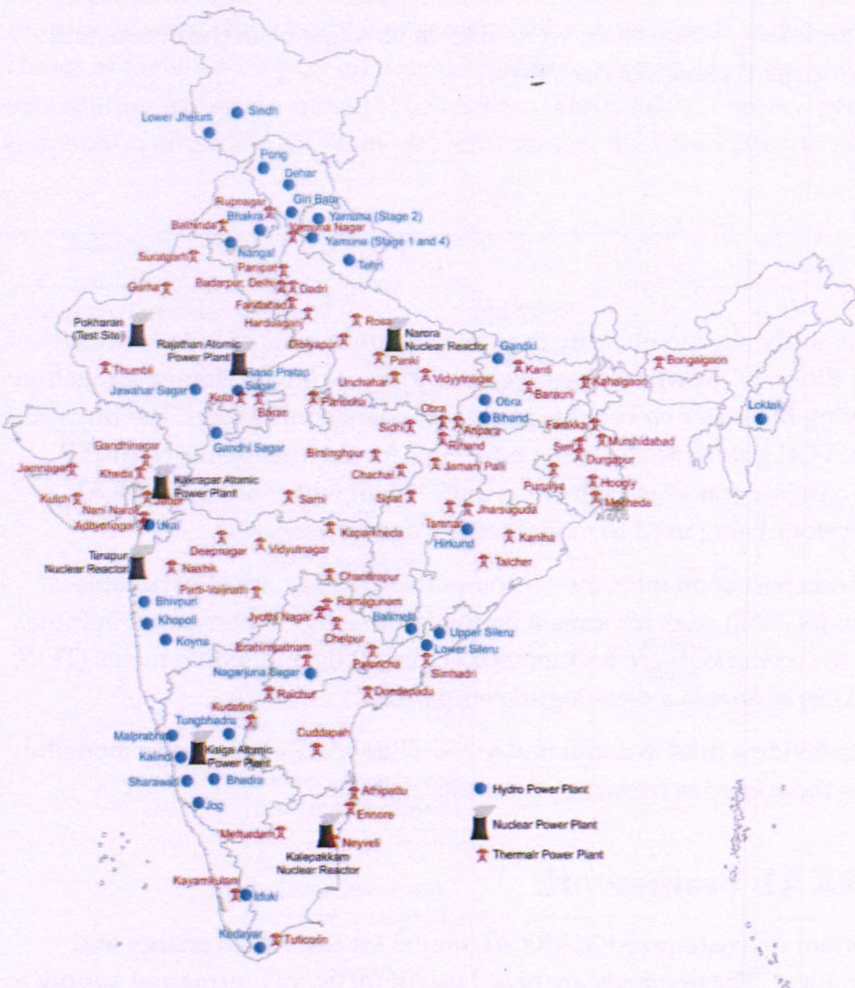

Figure 2: Location of the major thermal, nuclear and hydro power plants in India

Source: TERI compilation

It is in this context that studying the water requirements of India's energy sector both in its present form and in context of the changes envisaged as part of India's energy transition into the future, given energy security as well as climate change aims, gains utmost importance.

Aim & Scope

This study aims to quantitatively study the water requirements of the Indian energy sector under different energy scenarios up till the horizon year 2051. The energy scenarios aim to capture different levels of ambition of GHG mitigation policies, as well as different growth rates for the country through 2051. Water is often seen as a co-benefit of GHG mitigation (IRENA, 2015). This study endeavours to examine this aspect as well, and quantify the water co-benefits of GHG mitigation policy for India. Further, it also aims to quantify the implications of water efficiency policy on the water consumption of the energy sector.

The study forms part of an on-going inter-model comparison study of the Sustainable Growth Working Group (SGWG) research stream on the energy-water nexus in India. A part of the work by this consortium was also published in 2017 (Srinivasan et al., 2017). The study focuses on the electricity sector, which is the largest consumer of water in the energy requirement are presented to give insight on what the impact of changes in the growth rate may be on parameters of interest.

3.1 Energy Scenario Analysis

Given the focus on the water linkage with energy generation, this section provides a description of the scenario results focusing on key elements such as total primary energy, the energy mix and shares of various fuels and technologies contributing to the power sector specifically.

3.1.1 Reference Scenario

The total primary energy use in the Reference scenario is reflected in Figure 6. Given the objective of cost minimization and expectations of continuation of current policy trends, the resultant primary energy needs required by the MARKAL model to meet the energy demands across all the end-use sectors, viz. residential, industrial, transportation, commercial and agricultural, indicate that the total primary energy requirement would be 2971 mtoe by 2051. In the reference scenario, this is mainly composed of conventional fuels, i.e. coal and oil-based products, as well as natural gas.

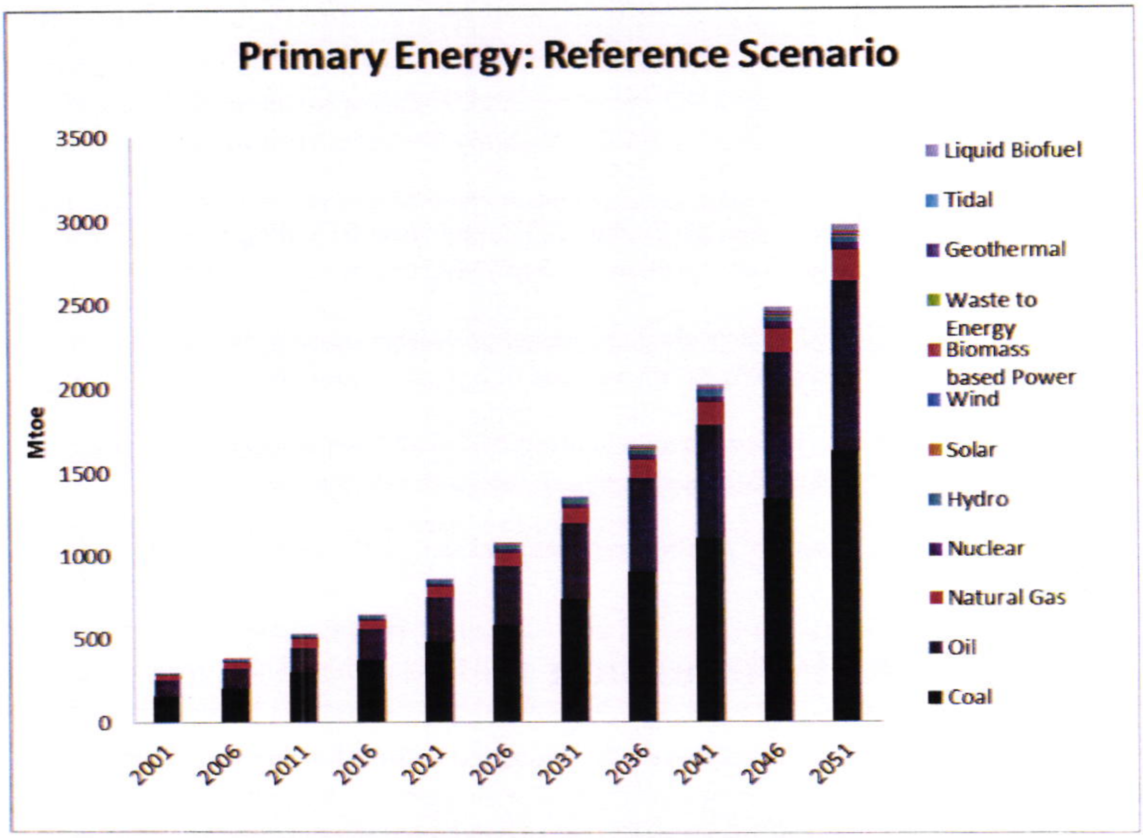

Figure 6: Reference Scenario Primary Energy

Given that the focus in this study in terms of water use in the energy sector is directed at the power sector, Figures 7 and 8 present the installed capacity and power generated in the Reference scenario.

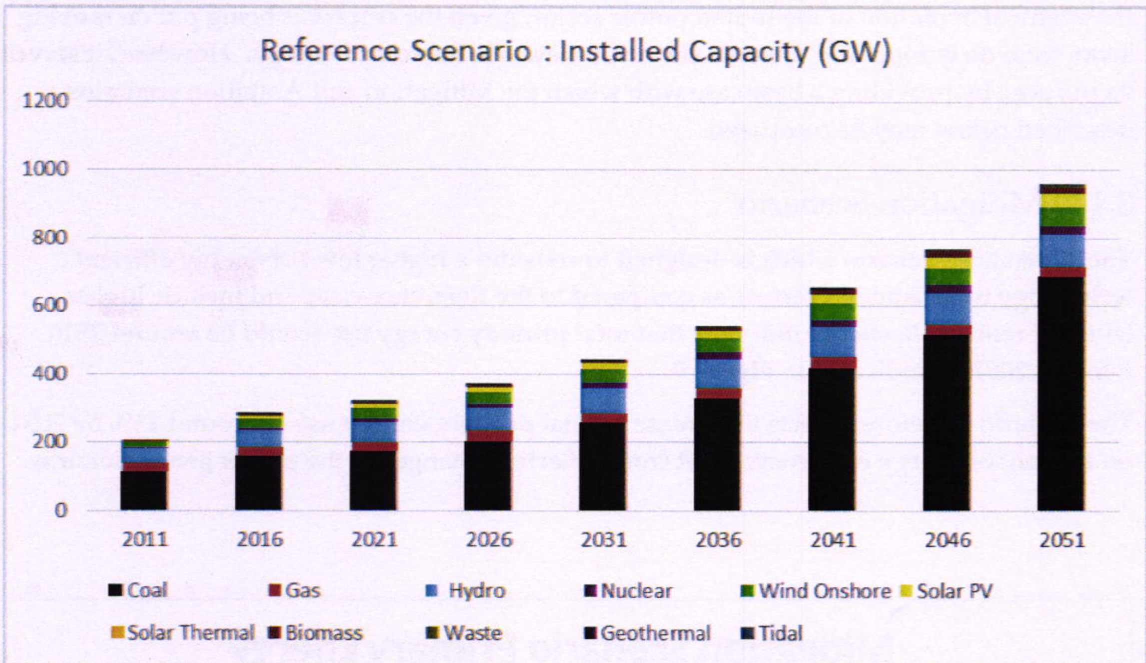

Figure 7: Reference Scenario Installed Capacity

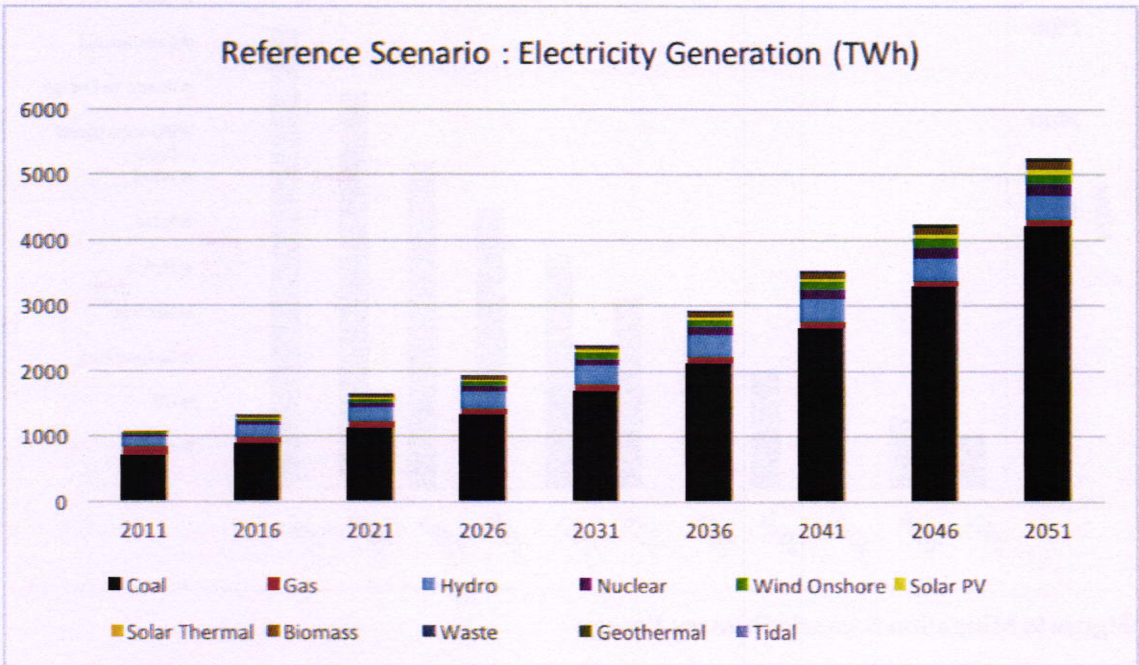

Figure 8: Reference Scenario Electricity Generation

In the Reference Scenario, the total installed capacity reaches 440 GW in 2031 and 955 GW in 2051. The corresponding generation numbers are 2375 TWh and 5235 TWh. As is evident, there is substantial coal based capacity and generation in the Reference scenario. 72% of the capacity and 80% generation in 2051 is from coal. There is some increase in penetration of limited amounts of non-fossil fuel based technologies over time, predominantly hydropower and wind. The scenario represents a BAU (Business-as-Usual) case which is unlikely to be the eventual evolution of the Indian power sector, given the emphasis being put on moving away from dirty fuels and towards cleaner, renewable sources of energy. However, it serves its purpose by providing a base case with which the Mitigation and Ambition scenarios, described below may be compared.

3.1.2 Mitigation Scenario

The Mitigation scenario which is designed to consider a higher level of energy efficient technology uptake across sectors as compared to the Reference case, and include higher levels of renewable energy indicates that total primary energy use would be around 2516 mtoe by 2051, as indicated in Figure 9.

The scenario therefore reflects a decrease in total primary energy use of around 15% by 2051 on account of energy efficiency, apart from reflecting changes in the power generation mix.

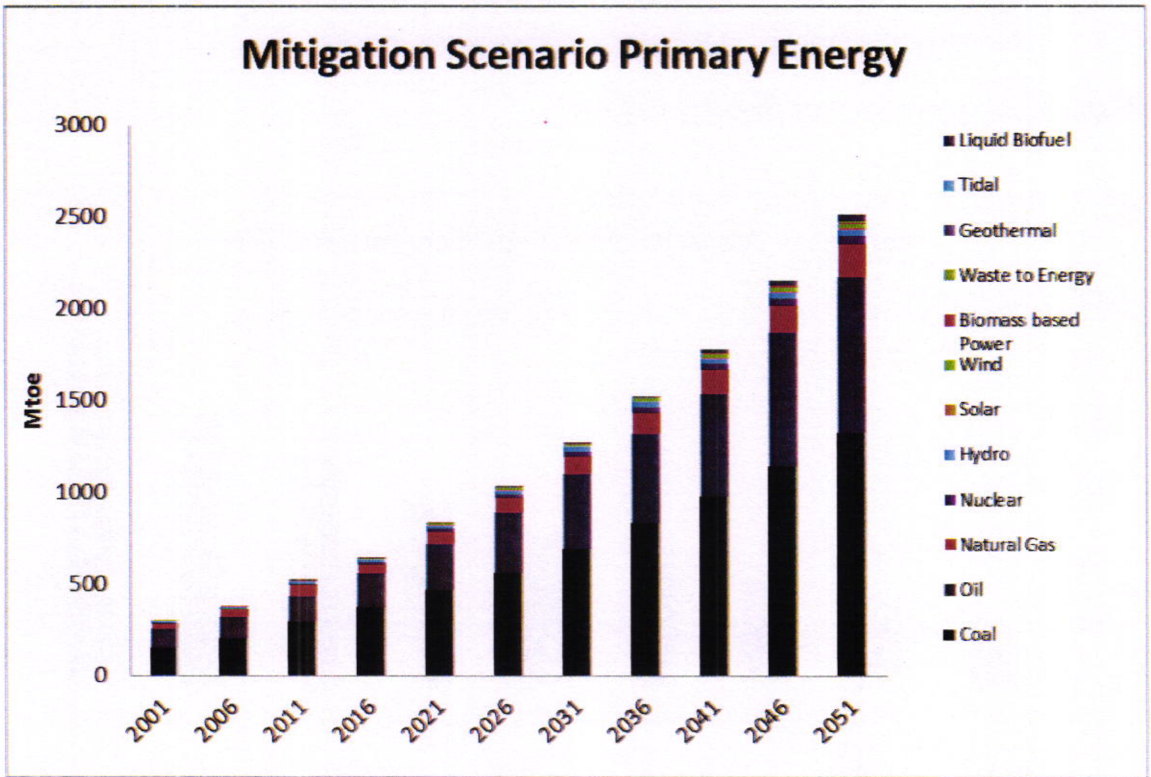

Figure 9: Mitigation Scenario Primary Energy

The electricity sector mix in the Mitigation scenario is presented in Figures 10 and 11.

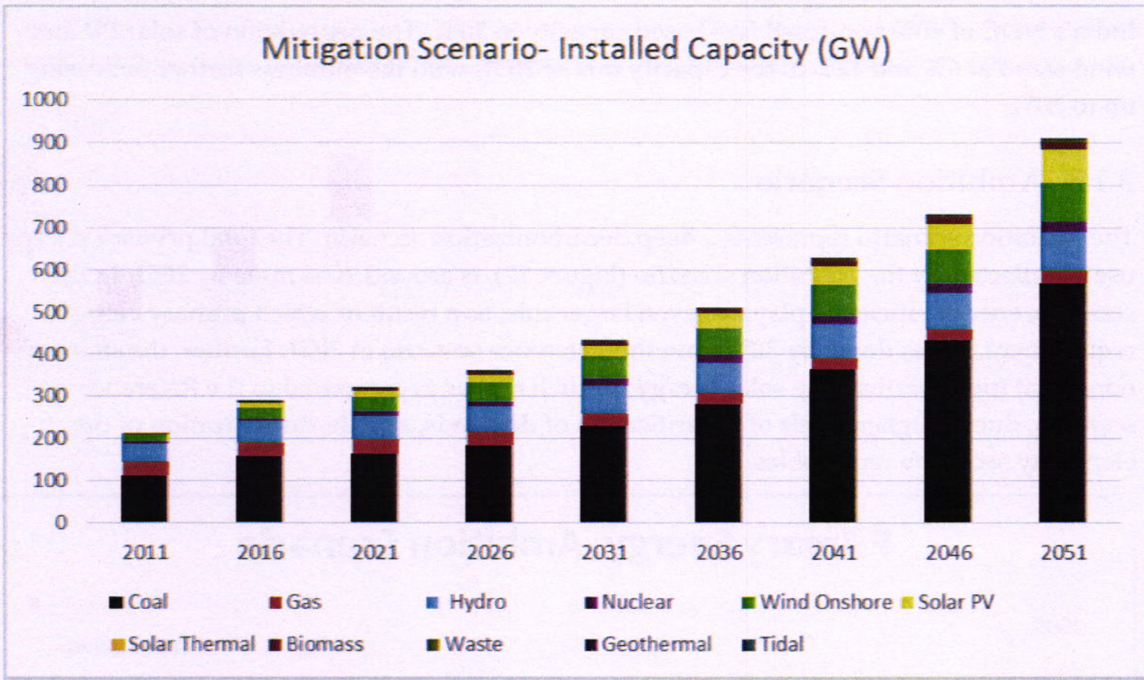

Figure 10: Mitigation Scenario- Installed Capacity

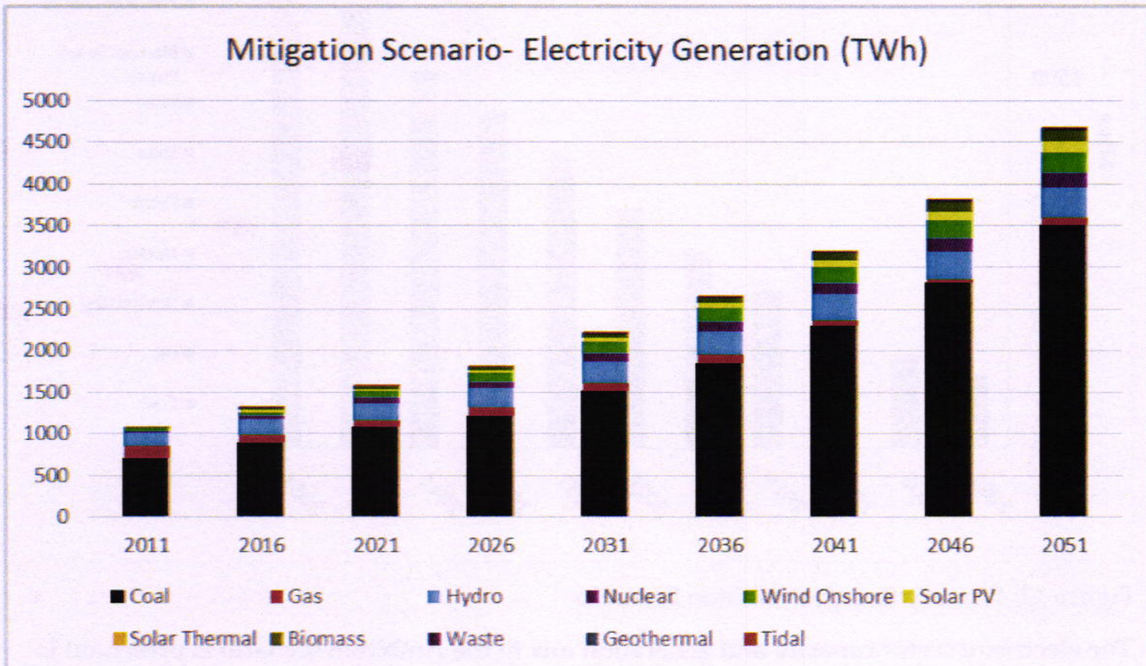

Figure 11: Mitigation Scenario- Electricity Generation

Here, the total installed capacity reaches 430 GW in 2031 and 906 GW in 2051. The corresponding generation numbers are 2214 TWh and 4770 TWh. As compared to the BAU or Reference case scenario, the Mitigation scenario, which is designed to align with India's NDC commitments, has a higher penetration of non-fossil fuel based energy, and consequently has a lower share of coal and natural gas in the mix. This scenario meets

India's NDC of 40% non-fossil fuel based capacity in 2031. The penetration of solar PV and wind stand at 6% and 12% in the capacity mix of 2031, with the numbers further increasing up to 2051.

3.1.3 Ambition Scenario

The Ambition scenario represents a deep decarbonization scenario. The total primary energy use as reflected by the Ambition scenario (Figure 12), is around 2008 mtoe by 2051. In this scenario, energy efficiency plays an even larger role, as a result of which primary energy requirement comes down by 32% from the Reference scenario in 2051. Further, the share of non-fossil fuels, particularly solar energy is much higher as compared to the Reference scenario, due to higher levels of electrification of demands, and de-carbonization of the electricity sector by renewables.

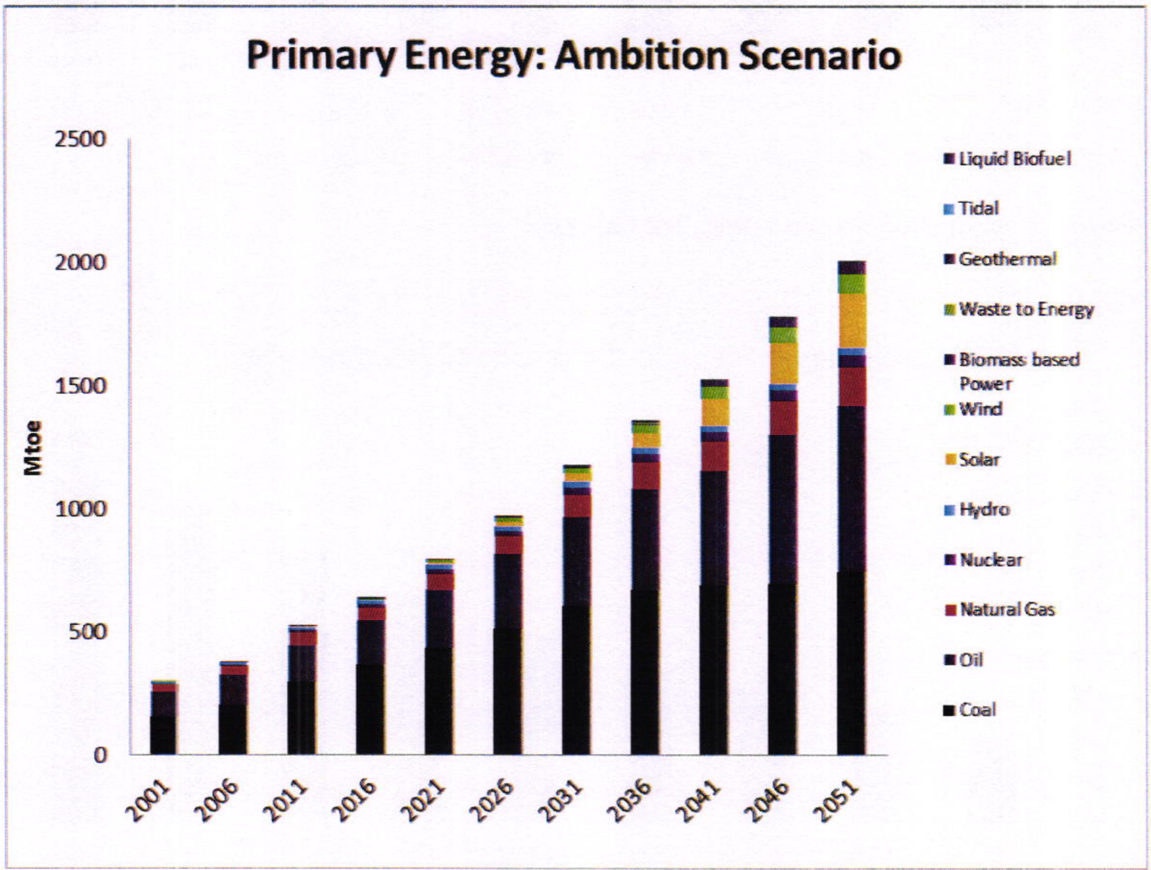

Figure 12: Primary Energy Ambition Scenario

The electricity sector capacity and generation mix in the Ambition scenario is presented in Figures 13 & 14.

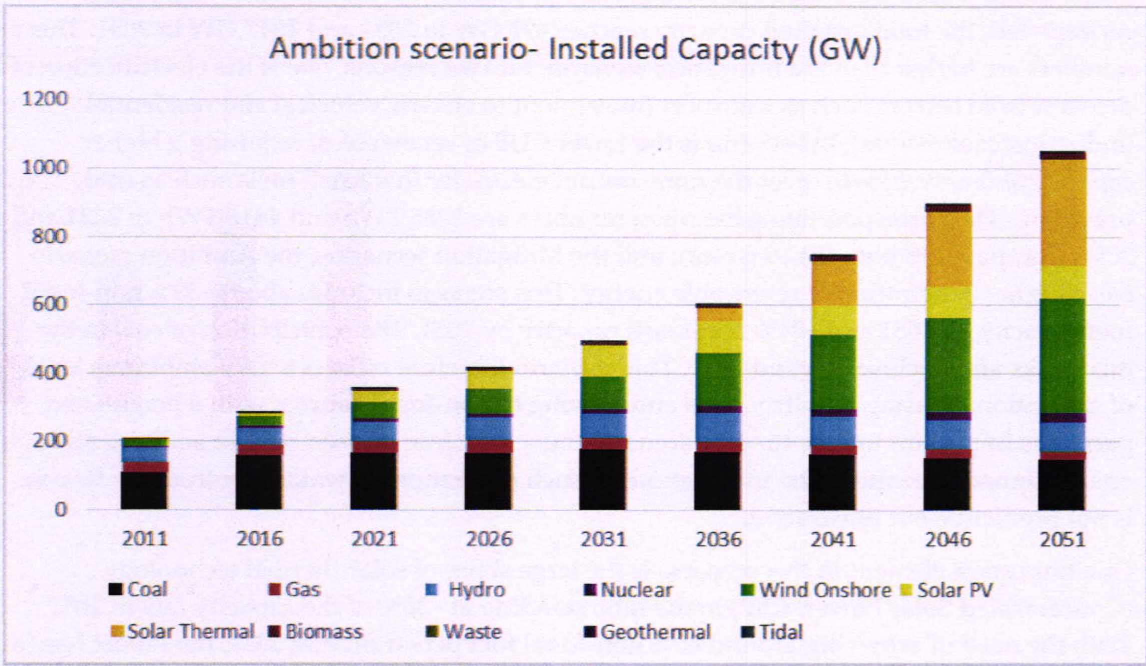

Figure 13: Ambition scenario Installed Capacity

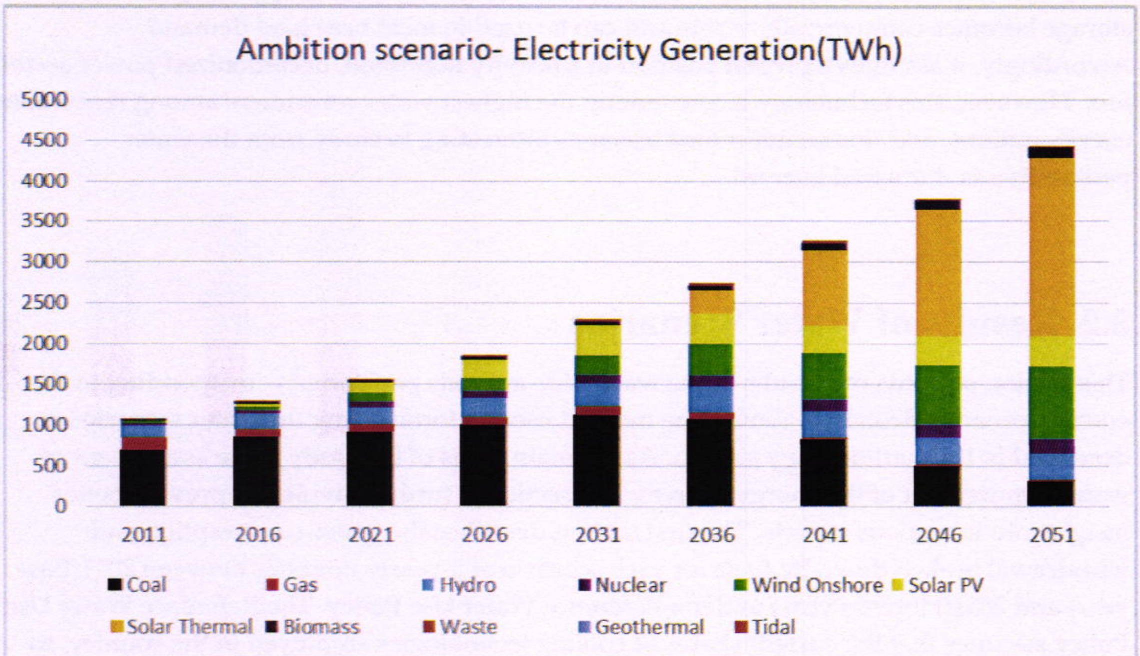

Figure 14: Ambition Scenario Electricity Generation

As depicted, the total installed capacity reaches 491 GW in 2031 and 1047 GW in 2051. These numbers are higher than the mitigation scenario, for two reasons, one is the electrification of demand from sectors such as transport (movement to electric vehicles) and residential (induction cook stoves), the second is the lower CUF of renewables, requiring a higher capacity of renewables to meet the same output electricity that fossil fuels such as coal provided. The corresponding generation numbers are 2285 TWh and 4416 TWh in 2031 and 2051. Compared to both the Reference and the Mitigation scenarios, the Ambition scenario has a higher penetration of renewable energy. This scenario includes about ~59% non-fossil fuel capacity by 2031 and ~84% non-fossil capacity by 2051. The contribution of coal in the mix peaks and declines beyond 2031. This scenario therefore reflects a very ambitious level of mitigation, phasing out dirty fuels and moving to non-fossil sources with a heightened pace. It is important to note that the scenario must therefore be seen only as an illustrative one, designed to examine the implications of such mitigation on water requirement. Its role is not predictive but illustrative.

One important element in this scenario is the large share of solar thermal technology (Concentrated Solar Power, CSP) in the mix, standing at ~30% of the capacity mix in 2051. With the need of achieving around 80% non-fossil fuel penetration in 2051, the model has to resort to solar thermal apart from the other existing renewable alternatives, in order to overcome the issue of intermittent renewable supply, especially for meeting base load demand. This scenario therefore presumes that solar thermal technology along with thermal storage becomes commercially viable and can be used to meet base load demand. Accordingly, it assumes a pivotal position in a heavily non-fossil, decarbonized power sector mix. However, this technology is also among the highest water consumers among renewable energy options, and this scenario thus becomes interesting to study from the water perspective as discussed later on.

3.2 Results of Water Scenarios

This section presents the results of the water side analysis performed corresponding to the energy scenarios described above. The method used in formulating the water scenarios is described in the methodology section. As the main focus of the study is the assessment of water requirement of the energy sources, this section is further divided to provide better insight into its various aspects. The first section describes the water consumption and withdrawal broken down by fuels for each scenario at 5-yearly intervals between 2011(Base year) and 2051(Horizon year) under a Reference Water Use Policy. The Reference Water Use Policy assumes that the current shares of cooling technologies employed in the country, as well as the water withdrawal and consumption intensities (described in the methods section) remain the same for the entire duration of the model runs. These numbers thus showcase the impact of purely mitigation policy on water requirement, in the absence of any water efficiency policy. A section delving further into this, quantifying the water co-benefits of GHG emission reduction follows thereafter. An analysis of the water requirement (withdrawal as well as consumption) scenarios in the case of an active Water Efficiency Policy (detailed in the methodology section), follows in the end.

3.2.1 Reference Water Policy Results

As described above and in the methodology section, the Reference Water Policy case assumes a continuation of the existing cooling shares and cooling efficiencies; all through the years 2011-2051.

3.2.1.1 Reference Scenario

In the Reference scenario (described along with the other energy scenarios in the previous section), as seen in Figure 15, the trend of water withdrawal is seen to be steadily increasing. Water withdrawal reaches a value of 137 bcm in 2051, up from 29 bcm in 2016. By far the largest share of this water withdrawal comes from the power plants utilizing coal. This fraction stands at ~95% in 2051.

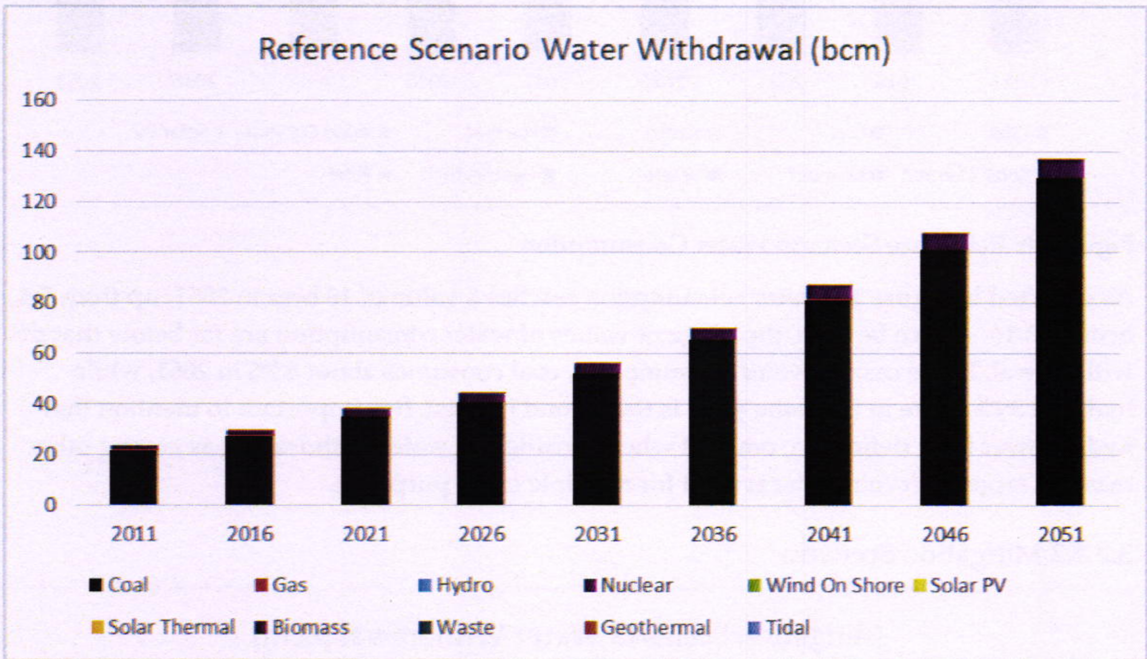

Figure 15: Reference Scenario Water Withdrawal

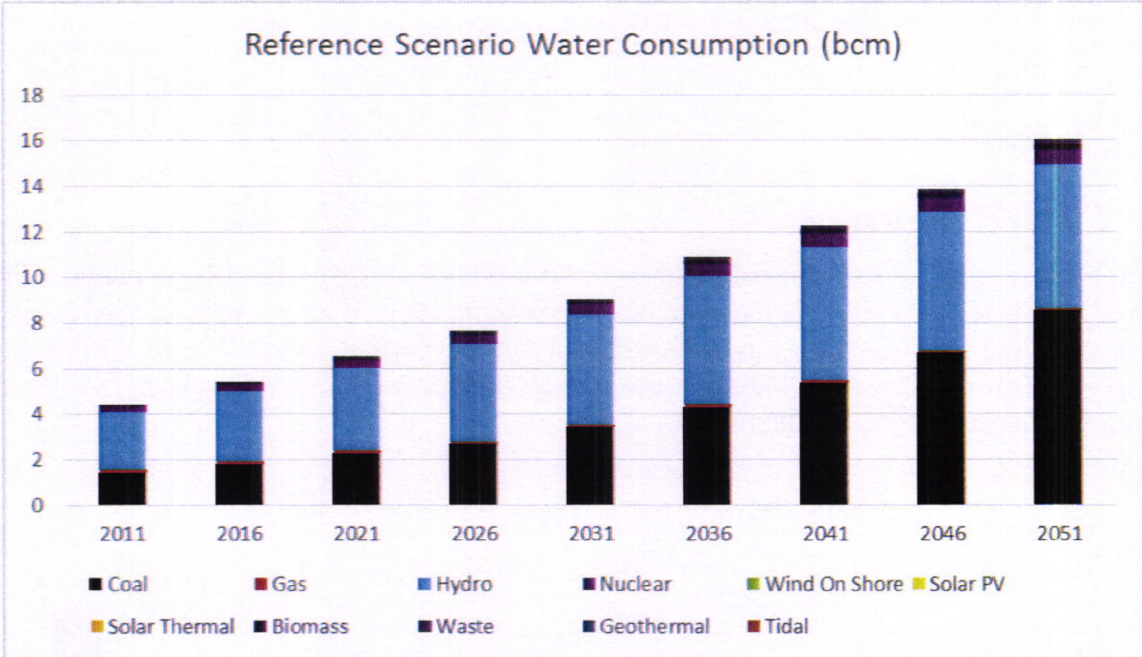

Figure 16: Reference Scenario Water Consumption

As depicted in Figure 16, water consumption reaches a value of 16 bcm in 2051, up from 5.4 bcm in 2016. As can be seen, the range of values of water consumption are far below that of withdrawal. In the case of water consumption, coal consumes about 53% in 2051, while hydro at 39% share in the same year, is the second highest. It is important to mention that hydropower is by definition, omitted when considering water withdrawal; as among other reasons, large reservoir water is used for multiple other purposes.

3.2.1.2 Mitigation Scenario

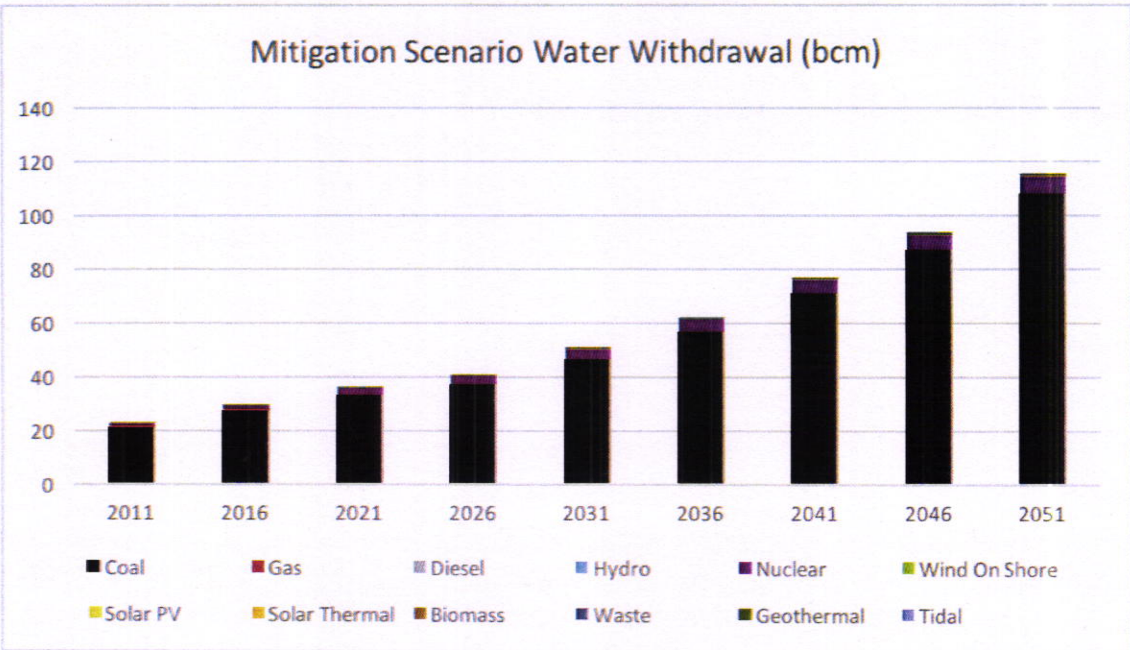

Figure 17: Water Withdrawal Mitigation Scenario

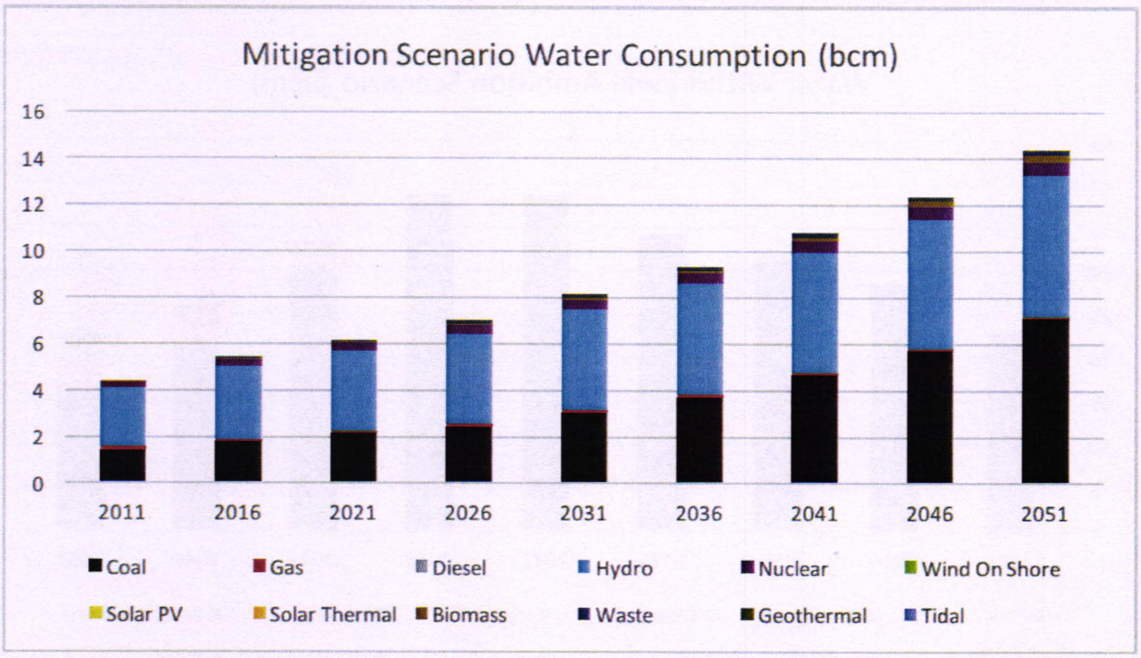

Figure 18: Water Consumption Mitigation Scenario

In the mitigation scenario, as is clear from figures 17 and 18, the overall water withdrawal and consumption reaches values of 115 bcm and 14.3 bcm in 2051, lower than corresponding values of the Reference scenario by 16% and ~10% respectively. In terms of water withdrawal, coal is still the dominant fuel but in terms of water consumption, hydropower at 42% also forms a large fraction as the role of hydropower is a crucial component of the energy mix for the mitigation of GHG emissions.

3.2.1.3 Ambition Scenario

From figure 19 below, it is evident that the Ambition scenario withdraws far less water (the scales of the charts are different across scenarios). The value for withdrawal in 2051 is 22.4 bcm, a reduction of 84% with respect to the Reference scenario. Further, there is a fall in water withdrawal in this scenario, 2036 onwards. Within the water withdrawals, the fraction of solar thermal stands at 25% in 2051, a substantial amount. The heavy penetration of solar thermal in this scenario to meet base load needs, as explained earlier, and the comparatively large footprint of this technology within the renewable technologies is the cause for this.

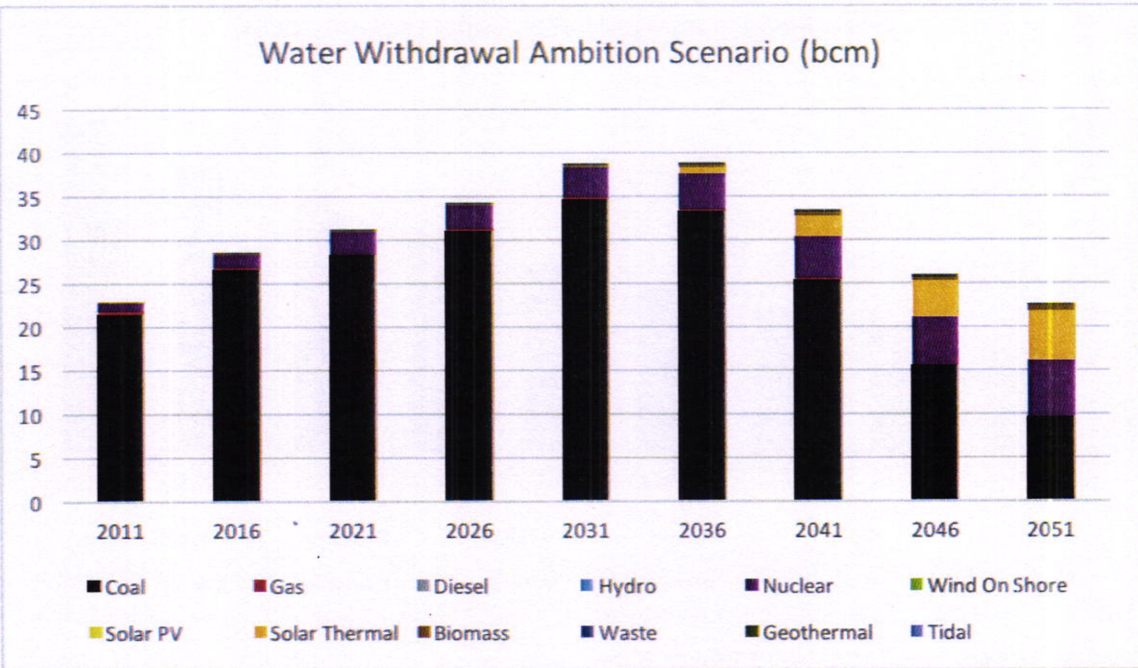

Figure 19: Water Withdrawal Ambition Scenario

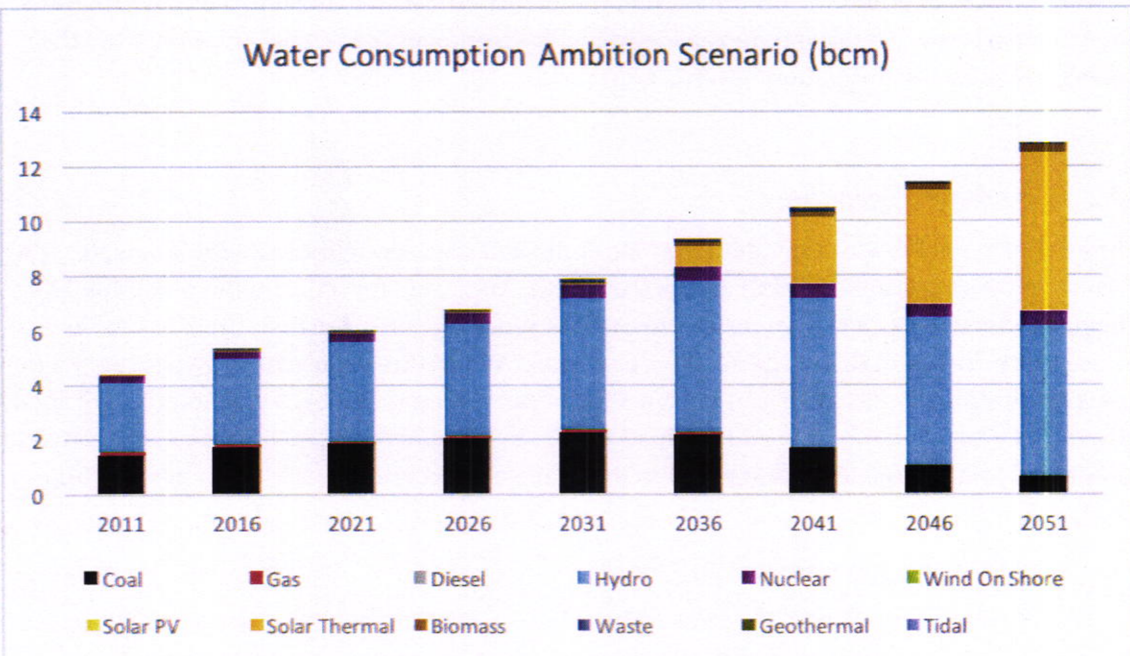

Figure 20: Water Consumption Ambition Scenario

From Figure 20, it can be seen that the water consumption in this scenario is also far lower that the Reference scenario, and it is lower by 20% in 2051, standing at a value of 12.8 bcm. Solar thermal power and hydropower are the dominant consumers of water, at 45% and 43% of the total in 2051, respectively.

3.2.1.4 Comparative Analysis

Although the individual scenario-wise results of water withdrawal and consumption provide a good idea of the numbers (a decreasing trend is evident when increasing the level of mitigation); a comparative analysis helps make this more concrete. Figures 21 and 22 below offer a comparative picture of water requirement by the three energy scenarios between 2011 and 2051.

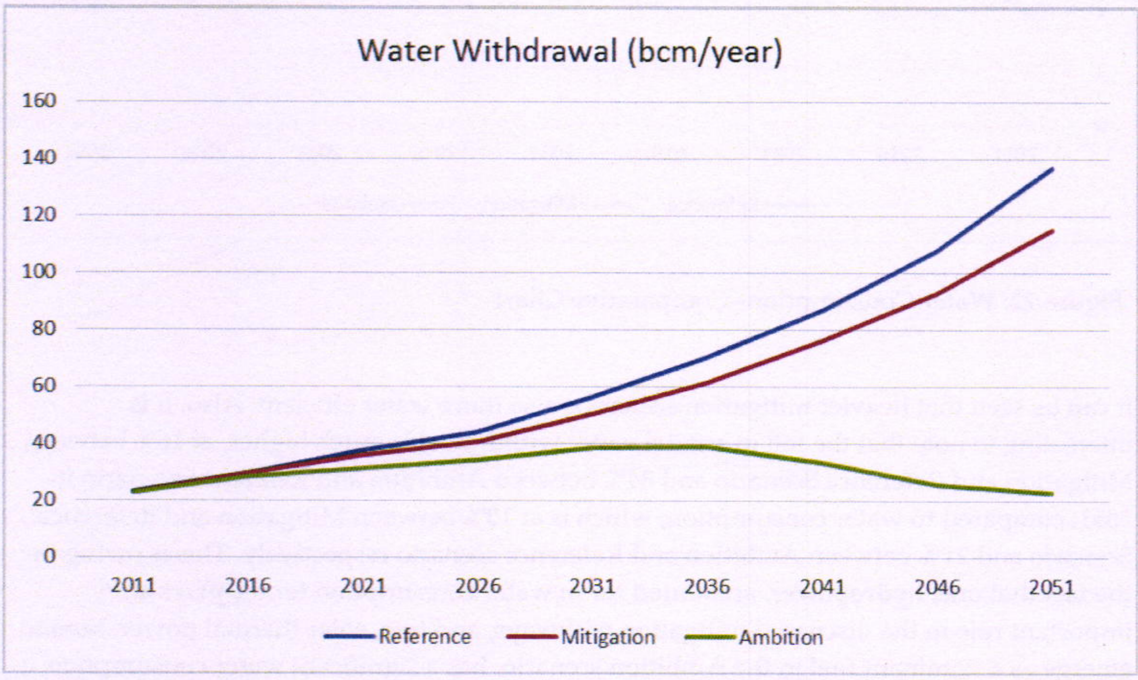

Figure 21: Water Withdrawal- Comparative Chart

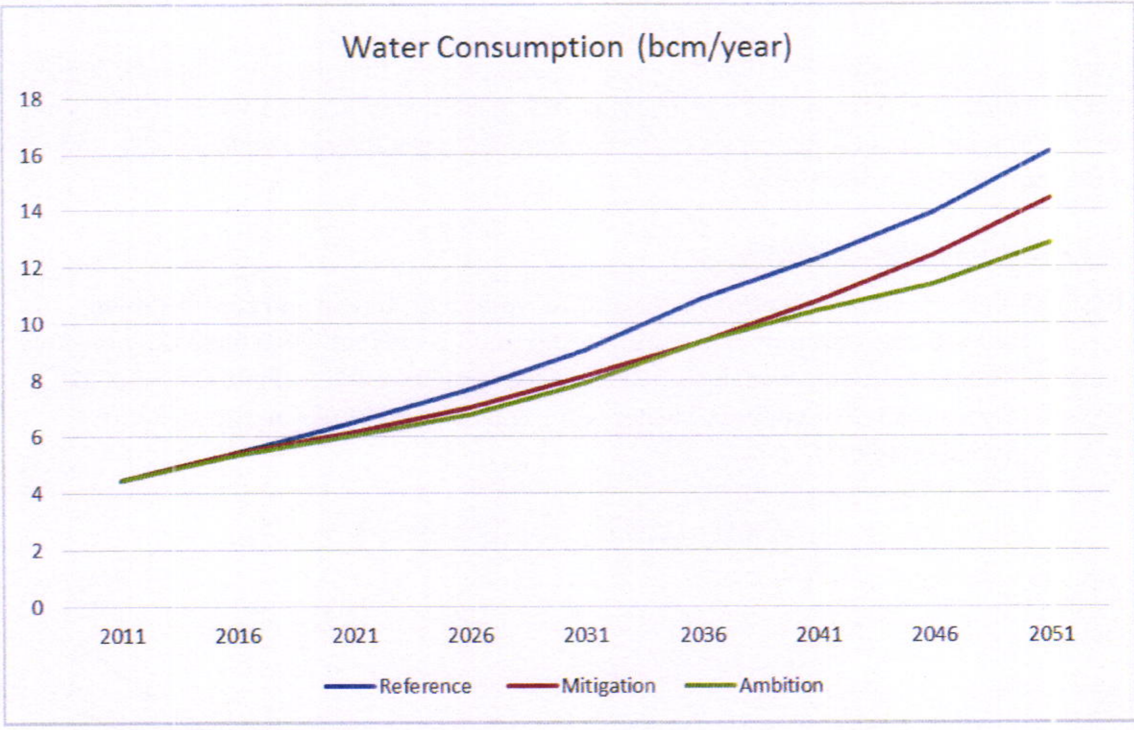

Figure 22: Water Consumption- Comparative Chart

It can be seen that heavier mitigation scenarios also more water efficient. Also, it is interesting to note that the fall in annual water withdrawal is much higher, at 16% between Mitigation and Reference Scenario and 84% between Ambition and Reference scenario in 2051; compared to water consumption, which is at 10% between Mitigation and Reference Scenario and 21% between Ambition and Reference scenario respectively. This is owing to the fact that one, hydropower, accounted for in water consumption terms, plays an important role in the discussed mitigation pathways, and two, solar thermal power, seen to emerge as a dominant fuel in the Ambition scenario, has a significant water consumption intensity.

It is also interesting to note that in case of the Ambition scenario, the water withdrawal flattens out between 2031 and 2036, and falls thereafter, and the water withdrawal in 2051 is lower than the value in 2016, a net reduction of 20% between these years, even with a power production increase of nearly 2.5 times between the same years. Evidently, water co-benefits of mitigation action are significant, and the following section aims to delve a little deeper into this.

3.2.1.5 Water Co-benefits of Mitigation Action

The previous section raised the important point that mitigation action has water co-benefits. This section endeavors to quantify this, by calculating the cumulative water savings (done separately for withdrawal as well as consumption) as a function of the cumulative reduction in carbon dioxide emissions.

Cumulative water withdrawal refers to the summed-up water withdrawal between 2016 and 2051, all in-between years included. These values are 1777 bcm, 1575 bcm and 857 bcm for the Reference, Mitigation and Ambition scenarios respectively. The respective numbers for water consumption are 262 bcm, 235 bcm and 225 bcm.

The carbon dioxide emission numbers taken from the TERI-MARKAL model are shown in Figure 23 and added up for all the interim years between 2016 and 2051 to get the cumulative emission numbers. These numbers were 131 Gt, 118 Gt, 94 Gt respectively for the Reference, Mitigation and Ambition scenarios.

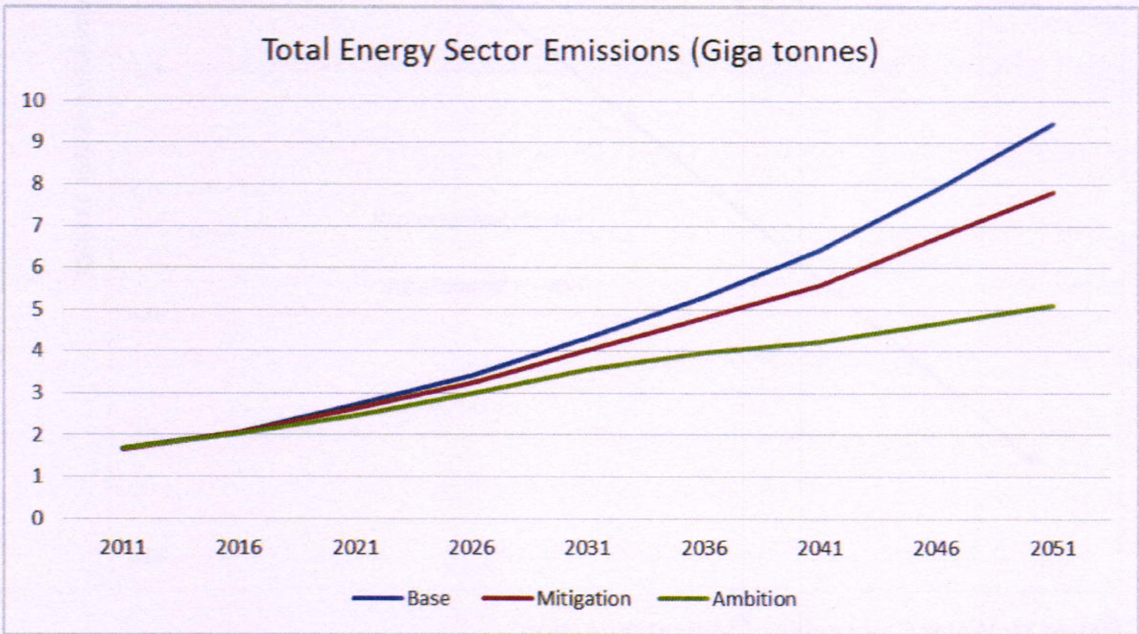

Figure 23: Total Energy Sector Emissions

The reduction in cumulative emissions are ~10% and 28% for the Mitigation and Ambition scenarios respectively, with respect to the Reference scenario.

Figure 24 below shows the results of this cumulative water savings vs. carbon dioxide emissions analysis. On the abscissae are plotted the reduction in % of carbon dioxide emissions vis-à-vis the Reference scenario; while the ordinates show the% reduction in the water requirement (either withdrawal or consumption) vis-à-vis the Reference scenario.

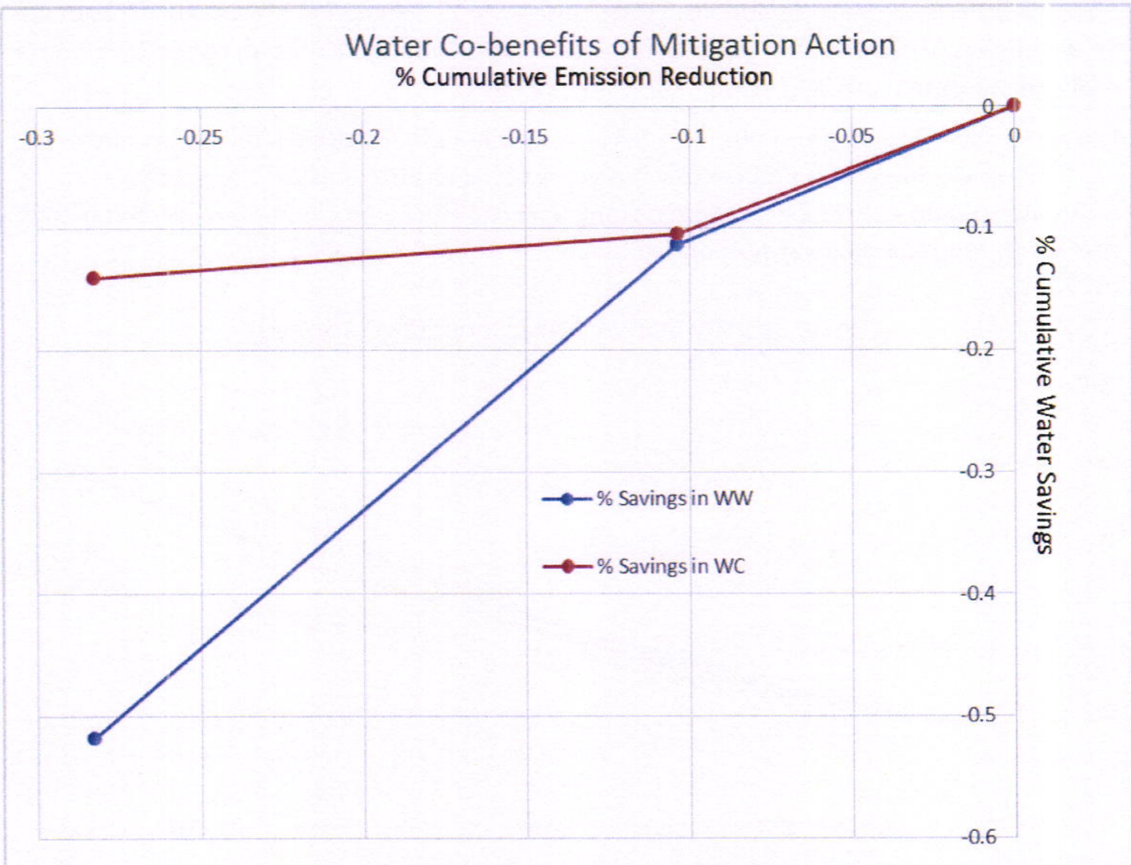

Figure 24: Water Co-benefits of Mitigation Action

This graph helps take a step towards quantifying the relationship between mitigation of carbon dioxide emissions from the energy sector and the co-benefits of this action on water savings. On the withdrawal side, the values show that a 10% reduction in carbon dioxide emissions result in a ~11 % fall in water withdrawal; while a 28% fall in emissions in a ~52% cumulative saving of water withdrawal. In the case of water consumption, the numbers for the same levels of cumulative emission reduction (10% and 28%) correspond to a cumulative reduction in water consumption of ~10% and ~14% respectively. These numbers would of course vary depending on the pathway taken for the mitigation action-in this case due to largely heavier penetration of renewables and hydropower, and further if other life-cycle components of the energy sector are also considered, but they provide some insight into quantifying the water co-benefits of mitigation. The fall in water withdrawal is higher compared to water consumption, and its fall steeper with increased mitigation, as the water consumption is substantial for some important low carbon fuels, like hydropower, nuclear, solar CSP and biomass, while water withdrawal is much lower in low-carbon fuels (barring nuclear), as compared to coal or natural gas.

3.2.2 Water Efficiency Policy Results

In this section, results of water withdrawal and consumption are presented in the case when there is strict application of The Water Efficiency Policy on the cooling of thermal power plants. The policy itself was described earlier on, in the Methodology section.

3.2.2.1 Reference Scenario

As is evident from Figure 25, under the Water Efficiency Policy, the water withdrawals witness a significant fall between 2016 and 2021 (by ~86%). This may not in reality be achieved 100%; due to the slow nature of technology change, but this scenario gives a 'what-if' idea as to what could be the result if the policy were enforced strictly. Further, 2021 onwards the water withdrawals see a gradual rise; as the scenario does not take into account any continuous water efficiency measures, and strictly adheres to the present MOEFCC guidelines. Thus, an increase in energy demand is naturally met by an increase in power production and consequently water withdrawals. Further, the largest share of the water withdrawals comes from coal fired power plants.

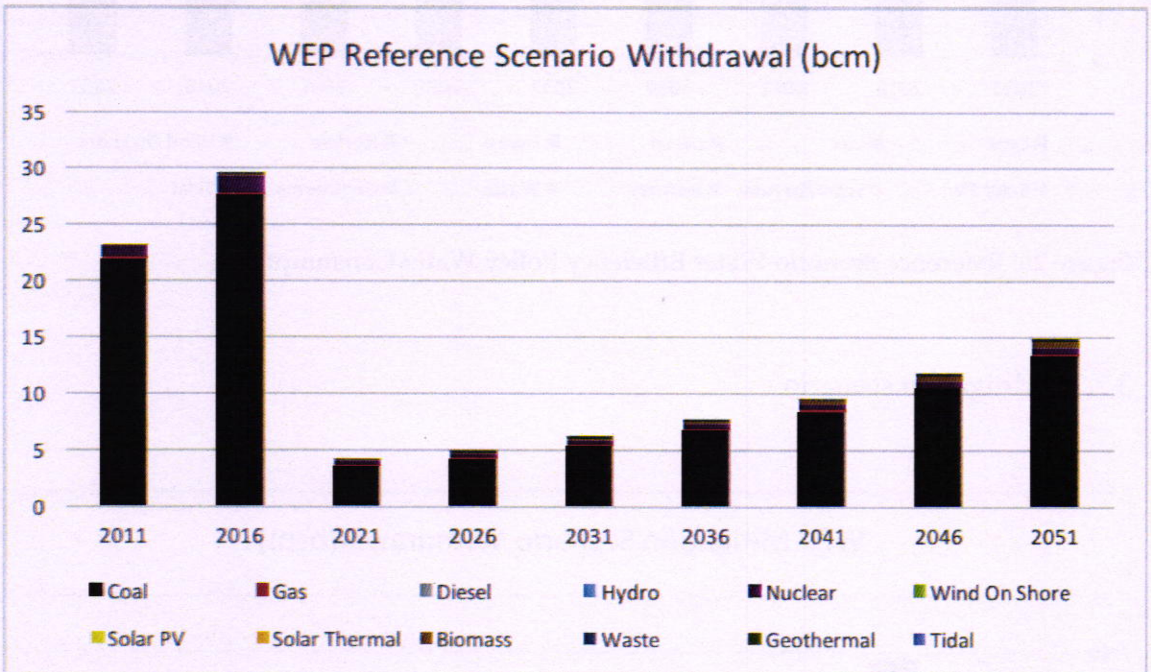

Figure 25: Reference Scenario Water Efficiency Policy Water Withdrawal

In the case of water consumption (Figure 26), there is a steady increase in the numbers, and no significant fall is seen, because whereas recirculating cooling, the point of emphasis of the Water Efficiency Policy, withdraws far less water; it consumes more water per energy unit, as can be seen for any of the energy technologies in Table 2. Still, the overall impact of the policy is positive, as there is a significant reduction in water withdrawal, which is not offset by an equivalent increase in consumption, but only marginal. The increase is less than 2% w.r.t. Reference No-WEP Scenario in 2051. Coal and hydropower remain the largest consumers of water in 2051.

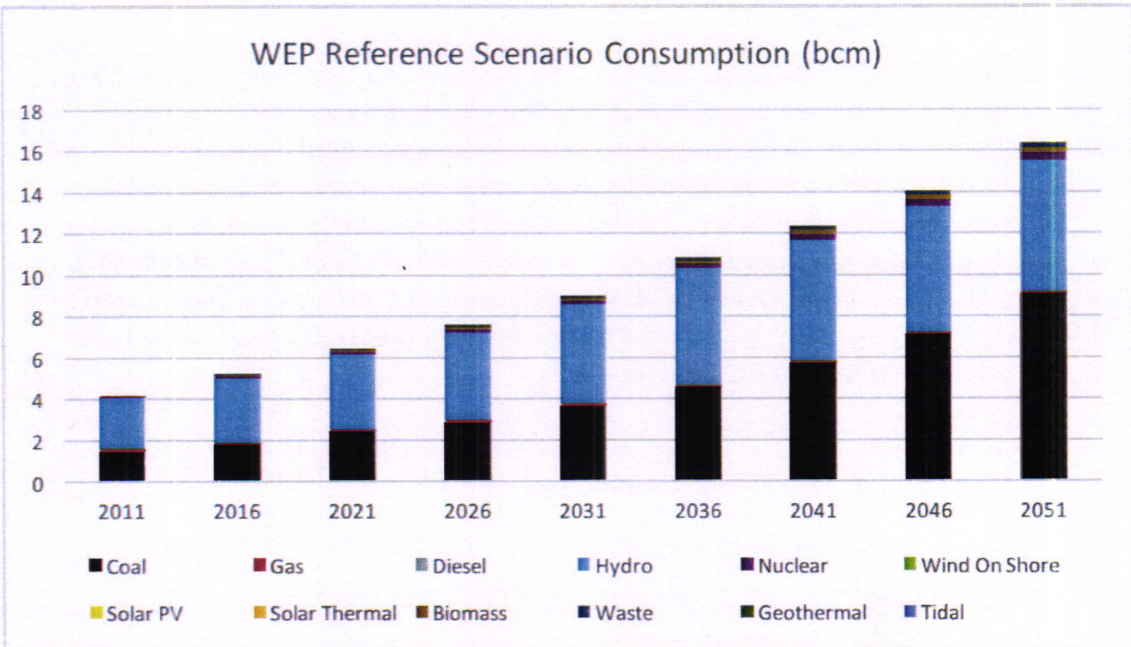

Figure 26: Reference Scenario Water Efficiency Policy Water Consumption

3.2.2.2 Mitigation scenario

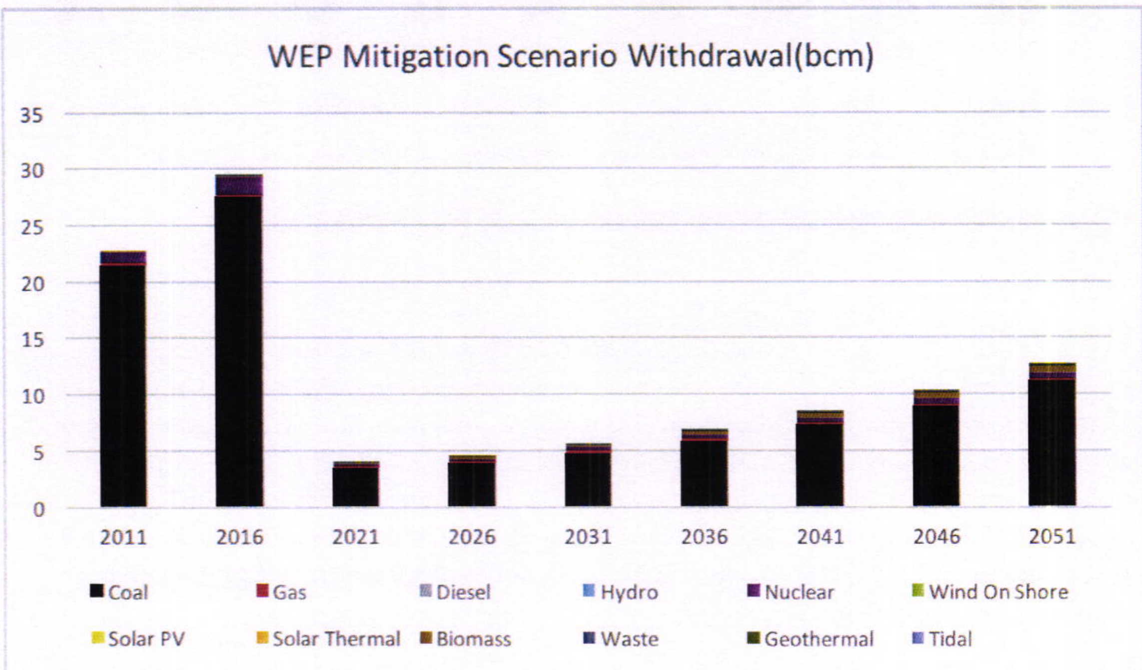

Figure 27: Mitigation Scenario Water Efficiency Policy Water Withdrawal

As may be seen from Figure 27 and 28, the impact of the Water Efficiency Policy is qualitatively similar on the Mitigation Scenario as it was on the Reference Scenario described above, but with the water usage values being significantly lower (This point is discussed further in the comparative analysis section which follows). From Figure 28, one can point out one major difference in case of water consumption, which is that the share of hydropower's water consumption in the total consumption is higher in the Mitigation Scenario case, given its higher penetration in the energy mix.

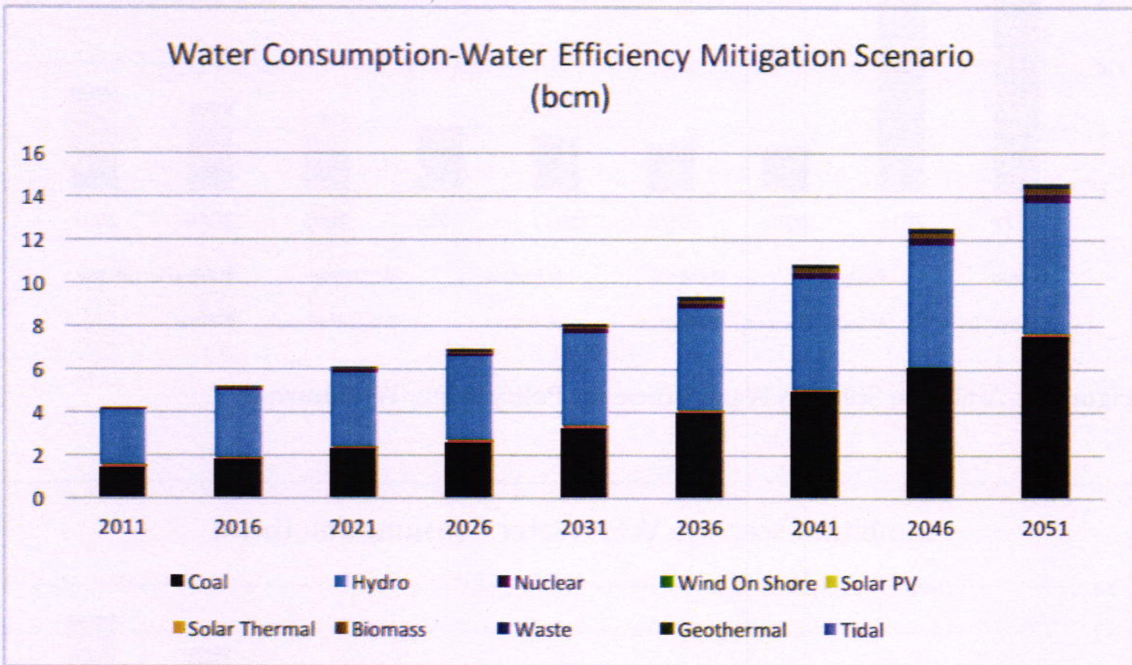

Figure 28: Mitigation Scenario Water Efficiency Policy Water Consumption

3.2.2.3 Ambition Scenario

The water efficiency policy effectuates a significant fall in water withdrawals of the Ambition scenario (Figure 29) as well as consumption (Figure 30). Indeed, the combination of heavy renewable penetration as well as shift to water saving technologies is cumulative and the water withdrawal in 2051 is only ~28% that in 2016. Also, from the graph it may be seen that the overall values are all lower than the mitigation scenario for each respective year. Looking at both the withdrawal and consumption numbers, solar thermal forms the highest fraction, followed by coal in the former case and hydropower in the latter. The comparative analysis section which follows discusses some of the inter-scenario differences in more detail.

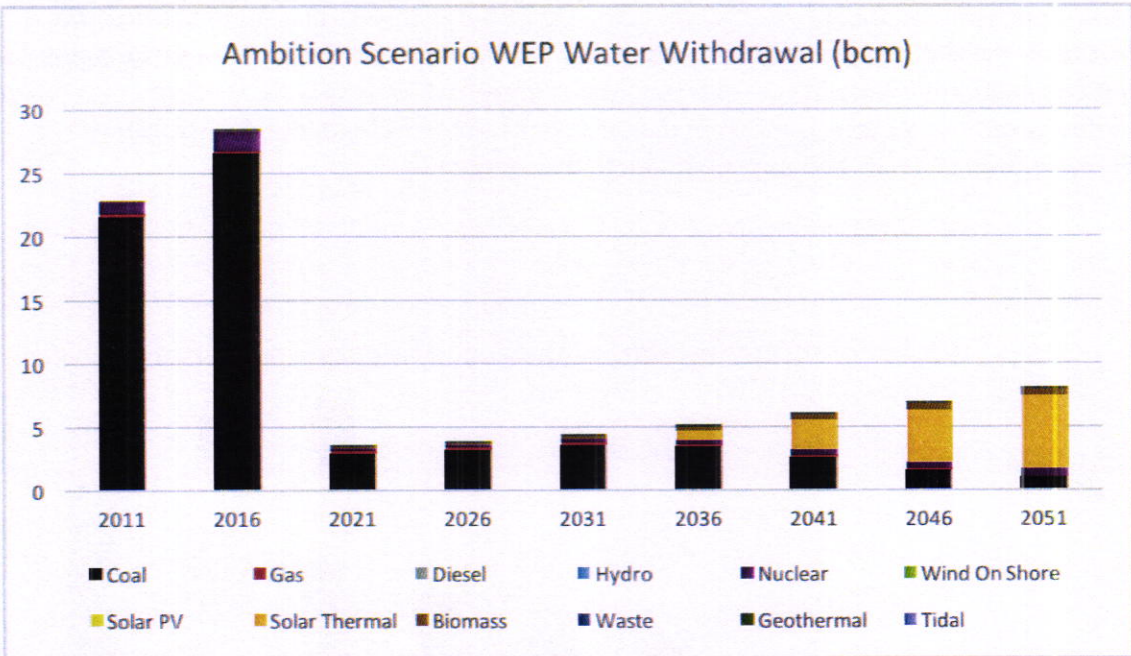

Figure 29: Ambition Scenario Water Efficiency Policy Water Withdrawals

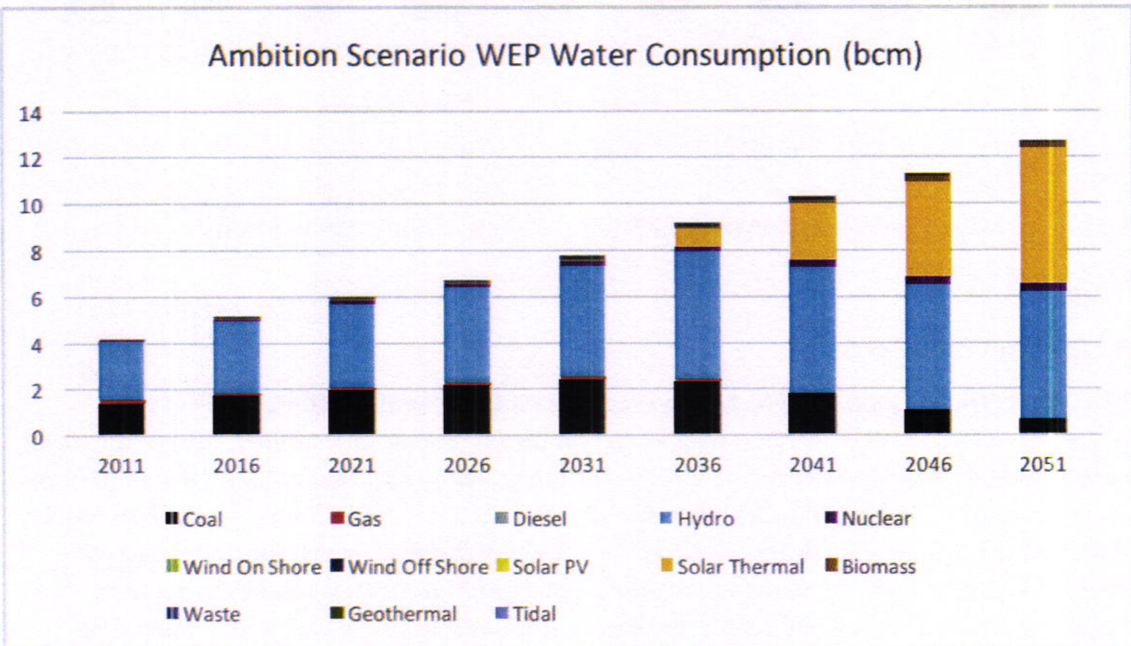

Figure 30: Ambition Scenario Water Efficiency Policy Water Consumption

3.2.3 Comparative Analysis- Reference and WEP Scenarios

A comparative analysis is provided to give a clear picture on the reduction in water requirements due to the application of the water efficiency policy on the scenarios. Figures

31 and 32 below showcase the comparative analysis. Figure 31 shows the impact of the Water Efficiency Policy on water withdrawals, and Figure 32, that on water consumption.

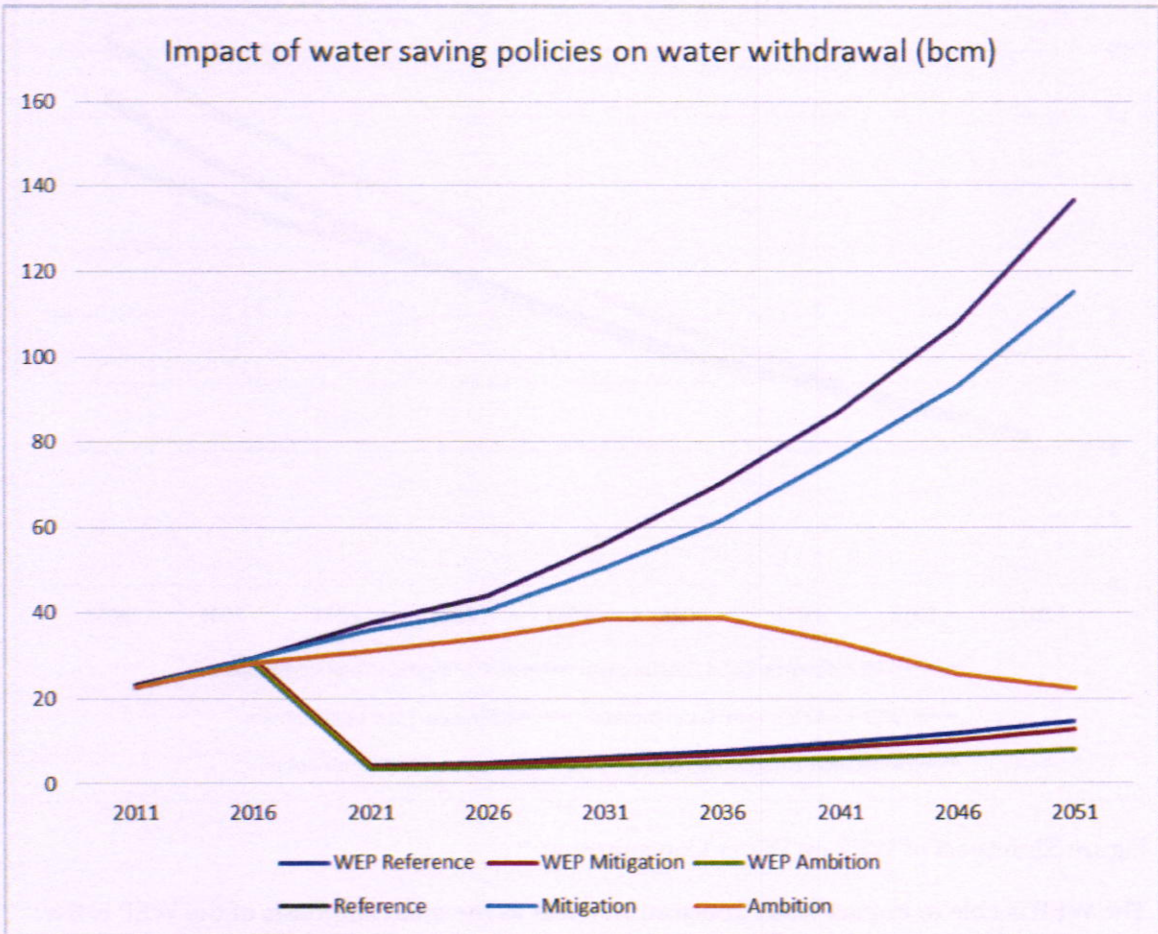

Figure 31: Impact of WEP on Water Withdrawals

It is interesting to note, from Figure 31, that although through mitigation action, the water withdrawals come down significantly between the Reference Scenario and the Ambition scenario (as described earlier), the value being 84% in 2051, the application of the Water Efficiency Policy(WEP) brings this down further, to the lowest water withdrawal scenario, which is the Ambition Scenario with the WEP active. The difference between this and the Reference comes to be ~94%. In a sense thus, mitigation and the low water policy work in tandem to bring down the water withdrawals.

The reason for this additional reduction is that as a high fraction of withdrawal is due to thermal open cycle cooling, switching to closed cycle substantially reduces water withdrawal. Thus, the Reference scenario without a low water use policy demonstrates the highest water footprint while Ambition Scenario with WEP has the lowest water footprint.

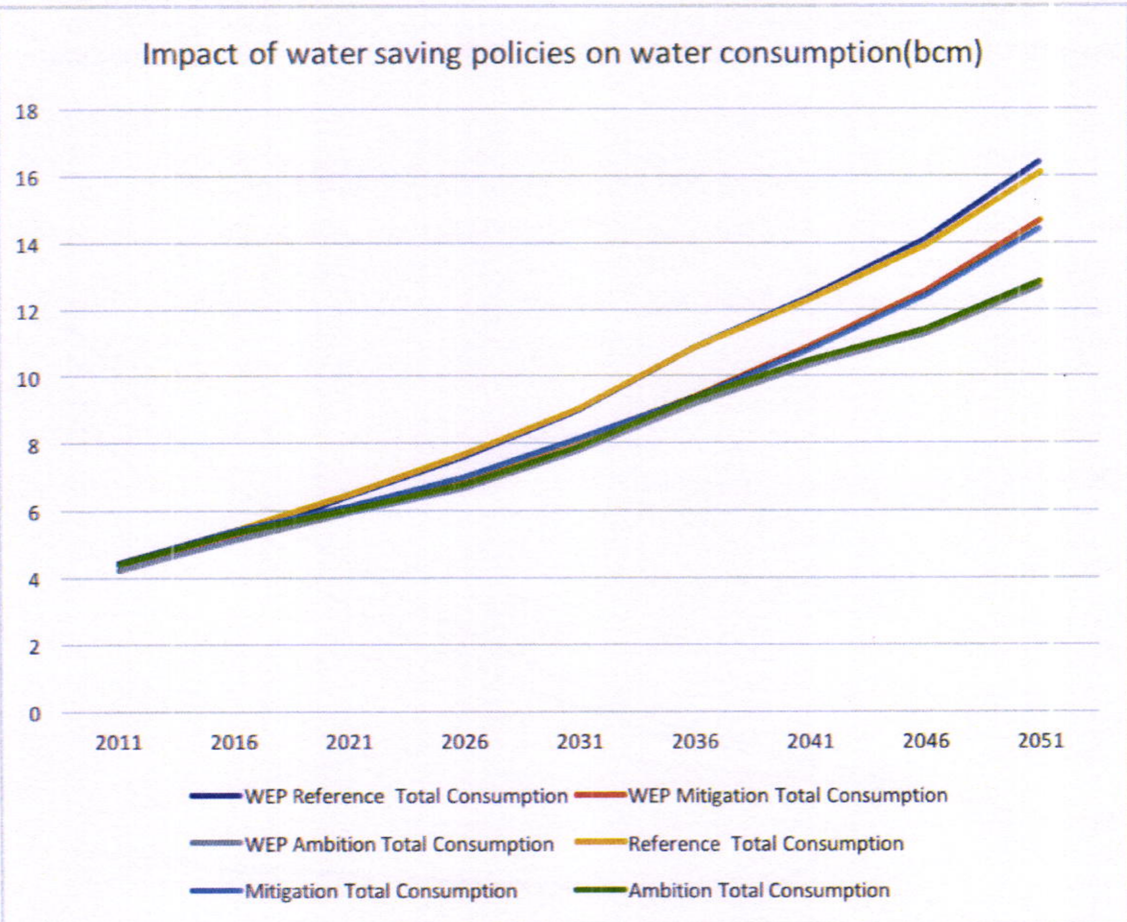

Figure 32: Impact of WEP on Water Consumption

The WEP is able to impact water consumption less as the main emphasis of the WEP is the shift from once through cooling to recirculating cooling, the latter of which has a higher water use intensity than once-through cooling (Table 2). The significant reductions one sees in Figure 32 are due to mitigation, rather than the WEP.

Further, as pointed out in (Srinivasan et al., 2017); these results are consistent with assessments of water implications of power generation in the US, China and the UK (Byers et al., 2014; Konadu et al., 2015; Liao et al., 2016; Macknick et al., 2012; Wan et al., 2016). Further, Macknick et al. (2012) goes on to highlight that retirement of once-through cooling systems over time can significantly reduce water withdrawals, while consumptive uses are seen to increase in several low-carbon scenarios, due to the effect explained above.

The following section looks at the impact of High and Low growth sensitivities on these results.

3.3 High& Low Growth Sensitivity

As described earlier on, in addition to the 3 main scenarios, a high and a low GDP growth sensitivity were also constructed, to study the impact of higher and lower GDP growth on the parameters of interest.

The high growth scenario assumes a growth rate of around 7.8% between 2011 and 2051 whereas the low growth scenario takes up a growth rate of 5.9% between 2011 and 2051.

The two are replication of the Reference scenario in the sense that no additional effort is assumed regarding mitigation. However, the uptake of efficient technologies between the three will differ on account of the high/ low growth. In the high growth scenario, efficient technologies penetrate faster owing to improved spending abilities of the people stemming from higher levels of economic activity while in the low growth scenario, the uptake is restricted on account of the overall sluggish economy. For instance, the high growth scenario faces higher energy demand owing to high GDP growth, the technologies improve their efficiency faster, whereas in the low growth scenario the energy demand is low while technologies less efficient.

3.3.1 High Growth Sensitivity

Figures 33 and 34 describe the capacity and generation in the high growth scenario. The overall capacity reaches 681 GW in 2031 and 1422 GW in 2051, and the generation 3520 TWh and 7836 TWh in the same years. These values are all higher than the respective values in the reference scenario, due to increased demand. The comparison with the Reference scenario is provided in the following section. Natural gas and coal continue to dominate the energy mix in this scenario, owing to no additional emphasis on mitigation(as it is a sensitivity analysis to the Reference scenario)

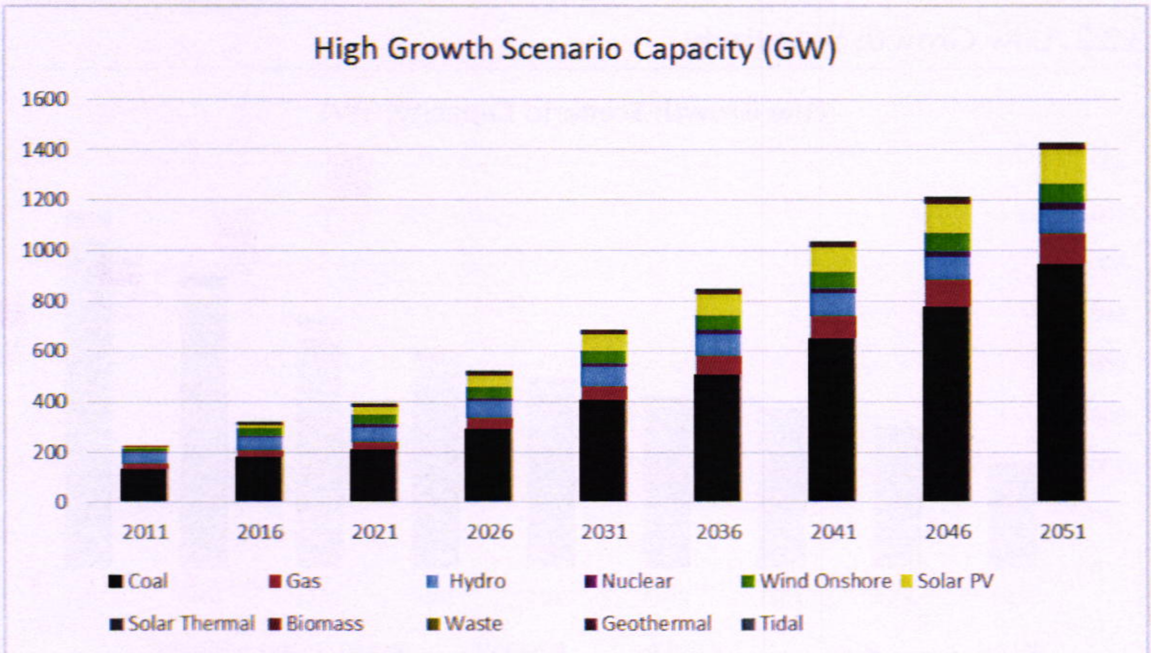

Figure 33: High Growth Scenario Capacity (GW)

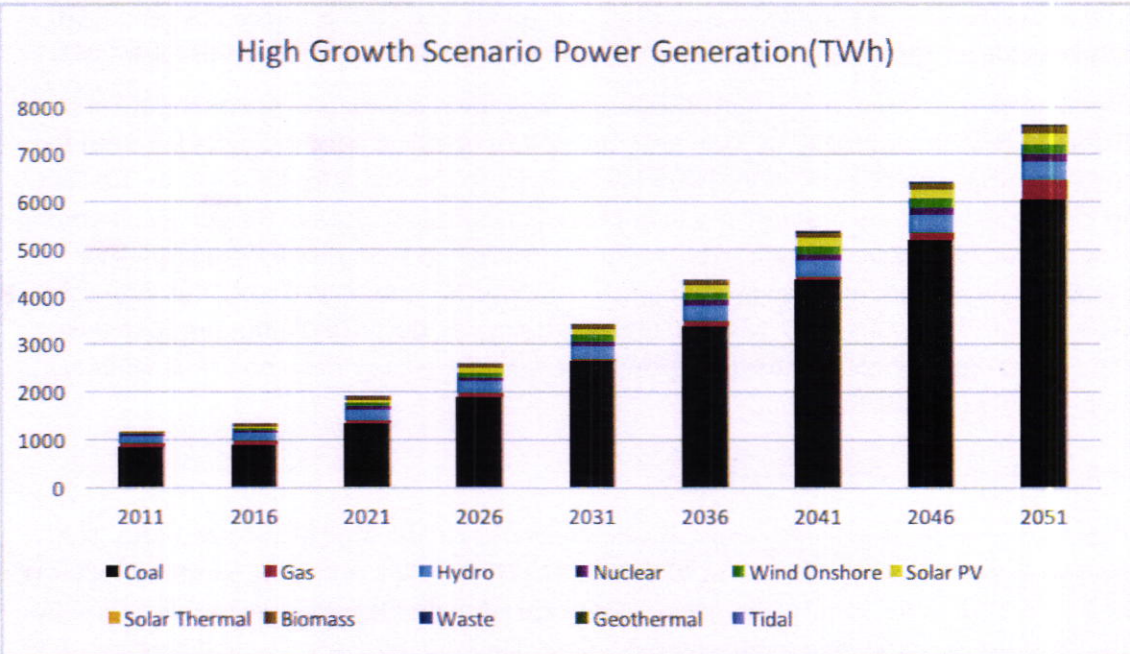

Figure 34: High Growth Scenario Power Generation(TWh)

3.3.2 Low Growth Sensitivity

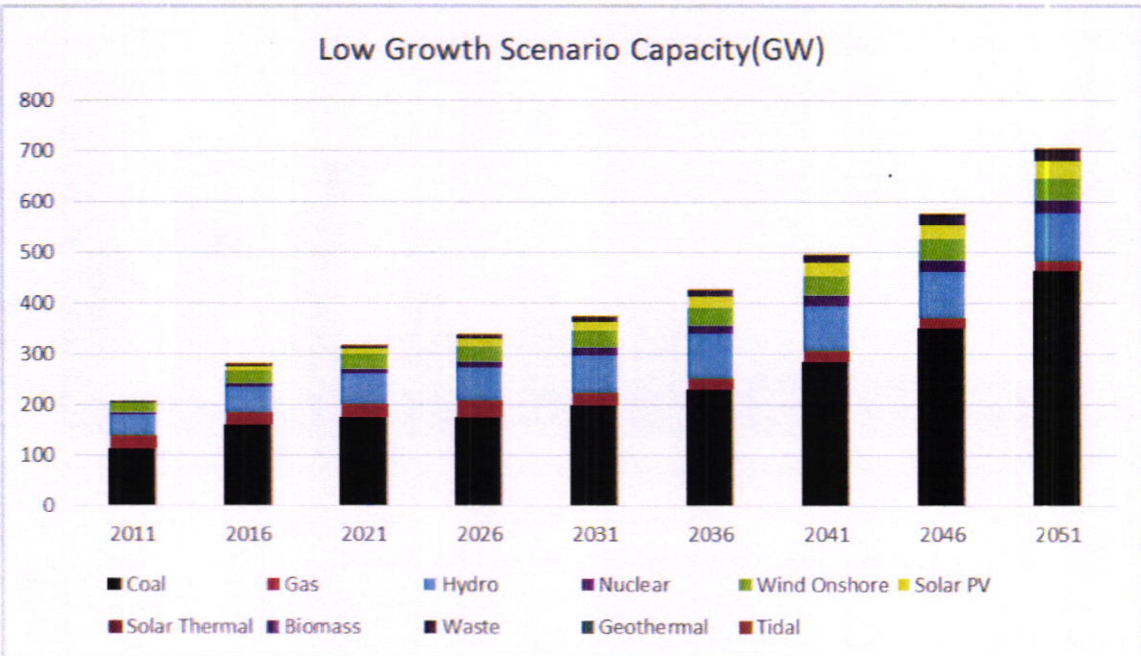

Figure 35: Low Growth Scenario Capacity(GW)

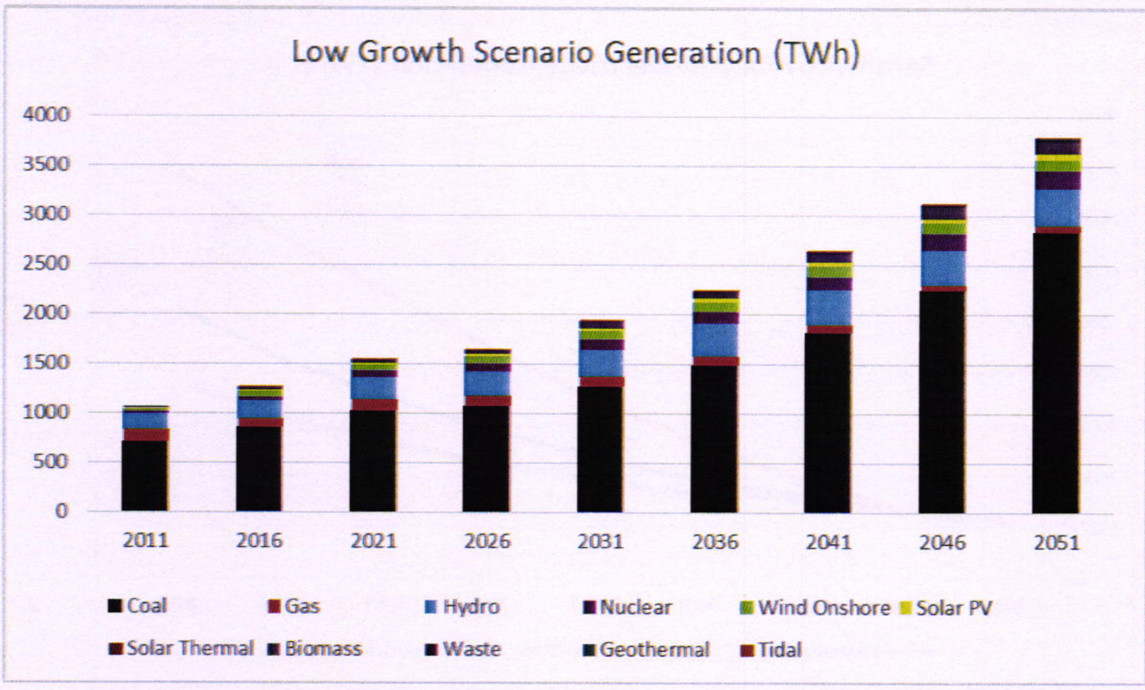

Figure 36: Low Growth Scenario Generation (TWh)

Figures 35 and 36 describe the capacity and generation in the low growth scenario. The overall capacity reaches 372 GW in 2031 and 702 GW in 2051, and the generation 1927 TWh and 3791 TWh in the same years. These values are all lower than the respective values in the reference scenario, due to reduced demand. A comparison with the Reference scenario is provided in the following section.

3.3.3 Comparative Analysis- Growth Rate Sensitivity

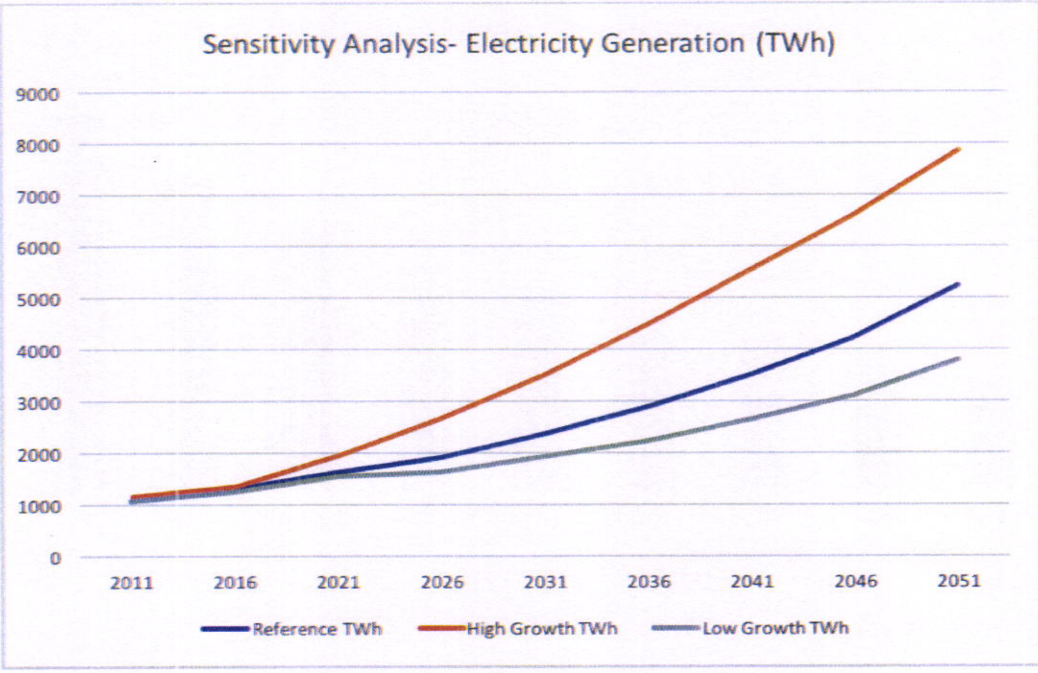

Figure 37: Electricity Generation Growth Rate Sensitivity

Figure 37 depicts the sensitivity of electricity generation to growth rate. While the reference scenario reaches a value of 5235 TWh in 2051, under the high growth case, 7836 TWh of electricity is generated, while in the low growth case, 3790 TWh is generated. There is thus a difference of 2601 TWh and 1445 TWh above and below the Reference scenario in 2051, respectively.

With this difference in generation, it may be expected that the water consumption and withdrawal requirements will also show a substantial variation. This Figures 39 and 40 below quantify this, for the reference water and the WEP case.

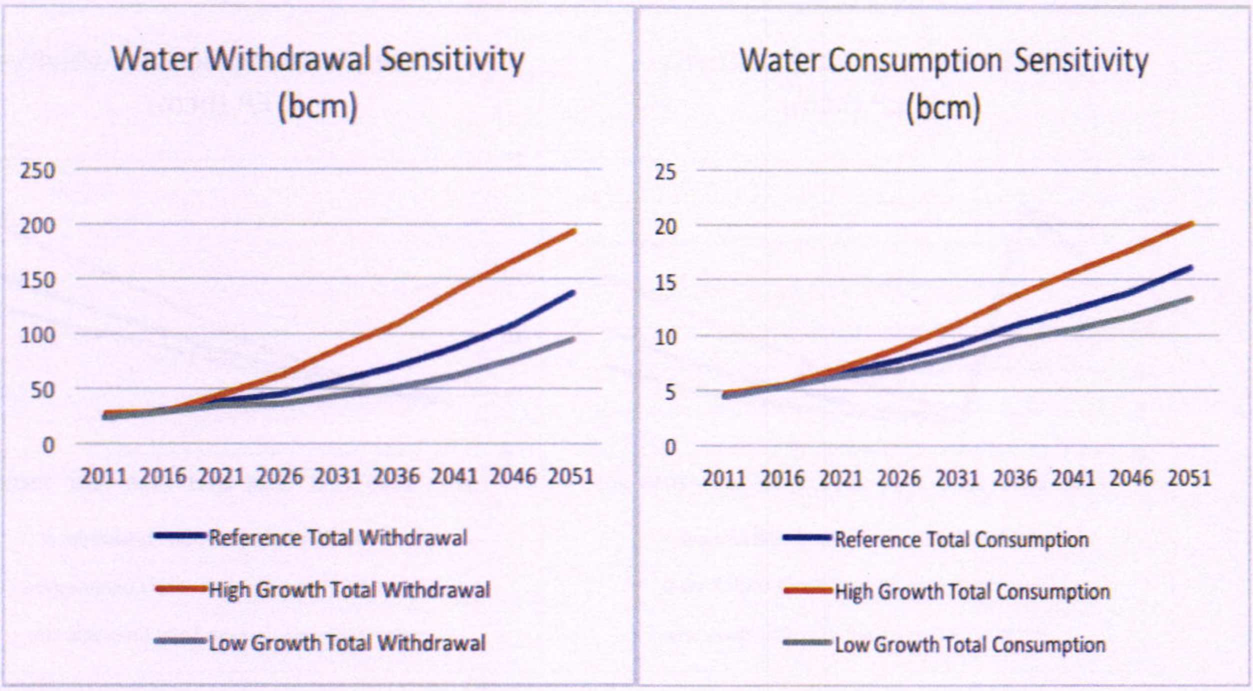

Figure 38: Water Withdrawal and Consumption Growth Rate Sensitivity under Reference Water Scenario

From Figure 38, which depicts results in the Reference water policy case, it can be seen that both water withdrawal and consumption are higher in the high growth scenario vis-a-vis the Reference scenario; and lower in the low growth scenario. Concretely, the high growth scenario has a water withdrawal higher than the reference scenario by 41% and water consumption higher by 24%. On the other hand, the low growth scenario has a lower water withdrawal of 31% and consumption by 18%.

On the other hand, Figure 39 shows the results in the WEP case. Here, the high growth scenario has a water withdrawal higher than the reference scenario by 42%, and a higher consumption by 26%. On the other hand, the low growth scenario has a lower water withdrawal by 29% and consumption by 18%.

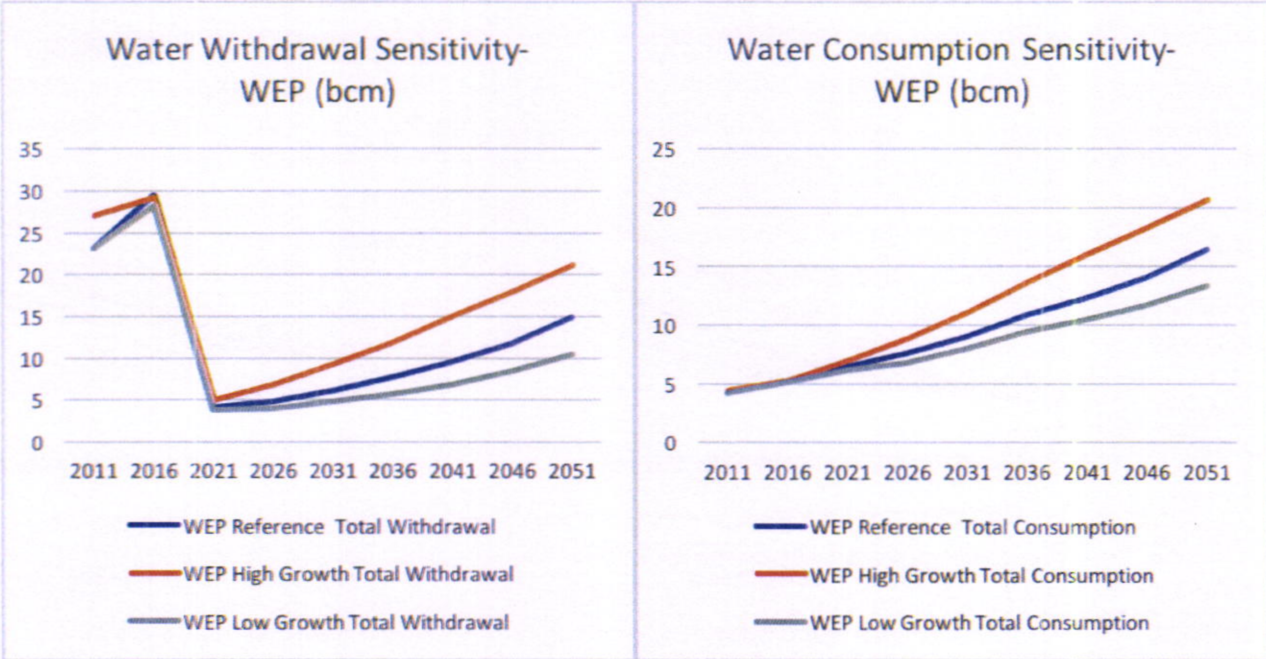

Figure 39: Water Withdrawal and Consumption Growth Rate Sensitivity under WEP Scenario

The sensitivity analysis thus shows that under both high and low growth paradigms, the water withdrawals and consumptions follow the patterns of the reference scenario albeit at higher and lower values, and gives us a band-width in which the water withdrawal and water consumption of the electricity sector would likely vary given these different growth rates. For the horizon year 2051, the band-widths are found to be about 100 bcm and 7 bcm for withdrawal and consumption in the no-WEP case; and about 10 bcm and 7 bcm for withdrawals and consumption in the WEP case.

A further observation that may be made from figures 38 and 39 is that the high growth scenario with WEP is more water efficient than the Reference case; a point highlighting that water efficiency has the potential to offset increased resource requirements. In 2051, the high growth scenario with WEP sees withdrawals lower than the Reference case by 84% and consumption lower by 28%.

4 Conclusion

This study on the energy-water nexus, with its scenario based analysis of the implications of alternative energy futures during 2011-2051 on the country's water resources, indicates the following key findings:

1. Both mitigation action and water efficiency policies have substantial impact on reduction in water withdrawal as well as consumption.
2. As compared to the Reference Scenario, the Mitigation and Ambition scenarios indicate a fall in water withdrawal of 16% and 84% and a fall in water consumption of 10% and 20% in 2051. This shows the significant water co-benefit of mitigation action. Further, it also shows that the variation in water consumption is not so much, but the variation in water withdrawal increases significantly with higher levels of mitigation across the scenarios.
3. The results across the scenarios indicated that a 10% cumulative (2011-2051) reduction in carbon dioxide emissions would result in a ~11% cumulative reduction in water withdrawal and a 10% cumulative reduction in water consumption; while a 28% cumulative reduction in emissions in ~51% cumulative saving of water withdrawal and ~14% cumulative reduction in water consumption, respectively.
4. Additional implications of Water Efficiency Policy (WEP) were examined via scenarios reflecting strong enforcement of government regulations. The WEP scenario indicated reduction in water withdrawal of the Reference scenario by 89% in 2051, although the water consumption increased marginally (~2%), due the effects explained earlier. The largest water savings, particularly in water withdrawals, were seen in the case where the WEP acted on a scenario which had a high level of mitigation. Accordingly, mitigation and WEP seemed to work in tandem in bringing down water withdrawals. The Ambition scenario with an active WEP indicated water savings of around 94% in 2051, with respect to the Reference Scenario, due to the result of cumulative effects.
5. An important point that emerged particularly in the deep decarbonization scenario, or Ambition scenario, was that to meet the base load demand, increasing PV or wind, would perhaps be supplemented by increased solar thermal as well. Solar thermal emerged as a technology which could meet the deep decarbonization ambition while also meeting base load requirements, due to the efficiency and viability of thermal storage. However, solar thermal is a renewable energy with a substantial water footprint, particularly in terms of water consumption. Increased penetration of solar thermal technology in the Ambition scenario was seen to be the reason behind water consumption not falling as low as may have been the case if the mitigation had been achieved by solar PV or wind energy (nearly 0 water consumers), despite the substantial mark-up of mitigation and reduction in coal capacity. This directional finding is important since it raises the point that certain technologies that are important for mitigation may have a much higher water footprint than others, and the choice of technologies must be made keeping in mind the local context of water.
6. The sensitivity analysis with higher and lower GDP growth rates showed that the water withdrawals and consumptions broadly followed the patterns of the reference scenario itself, with only the levels of magnitude varying. This indicates that growth

rate per se may only result in a variation of levels within a certain band-width in which the water withdrawal and water consumption would likely vary. The bandwidth was found to be about 100 bcm and 7 bcm in withdrawal and consumption terms without the WEP in place, and about 10 bcm and 7 bcm with the WEP in place. Further, it was noted that the high growth scenario with the WEP in place used less water than the reference scenario.

Accordingly, going ahead, it is evident from this study that mitigation action has significant water saving potential, and is most certainly a co-benefit of climate change mitigation action. Further, strict adherence to MoEFCC guidelines on water saving in thermal plants has the capacity to substantially reduce water withdrawals, as the water savings it brings, with respect to the scenario without its implementation are very significant, must be adhered to.

Therefore, for a country like India, where year on year, the stress on water resources is becoming more and more apparent, the benefits that mitigation and WEP can provide are crucial, and both should be promoted by the policy environment. At the same time, certain technologies important for mitigation may have a significant water footprint, and therefore policies need to consider both perspectives carefully, promoting technologies that are benign both from an emissions and water use perspective, keeping in mind the local water context. Such an approach is crucial, given that India's absolute energy consumption would continue to increase, which could exacerbate the pressures on water demand (which could also increase across each of the sectors, ranging from households to industries to agriculture). This holds increased relevance in the context of climate variability, which is likely to only exacerbate water scarcity across several regions in the future.

Appendix - Work done under SGWG Published Paper

In the first component of the project, the teams part of the SGWG agreed to study the water footprints of India's electricity scenarios using a Reference and a Low Carbon Scenario, the latter having about a 50% emission intensity reduction of the electricity sector. The results of all teams were collated and published as a journal publication. Some of the figures from the analysis are presented here for completeness of the report. Details can be seen at (Srinivasan et al.,2017).

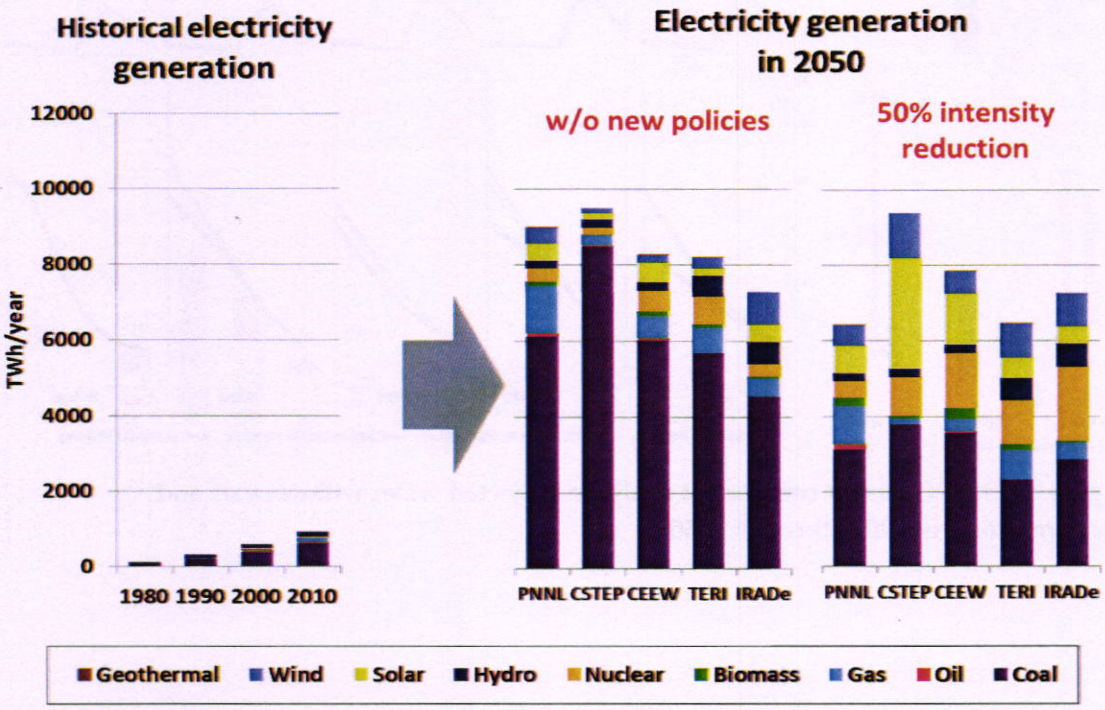

Figure 40: SGWG Earlier Component Analysis: Evolution of energy mix between 2011 and 2050

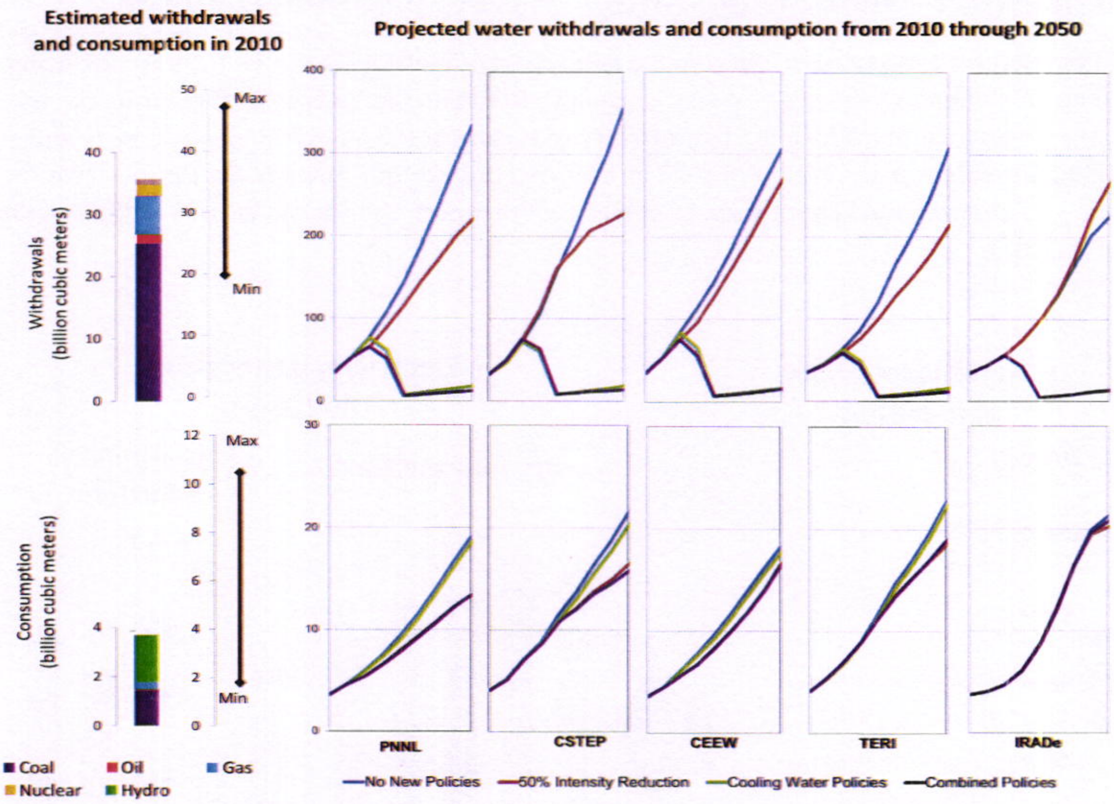

Figure 41: SGWG Earlier component analysis: Projected water withdrawals and consumption from 2010 through 2050

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