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Abstract

India's current per capita electricity consumption is less than a quarter of the world average but is expected to grow significantly in the future. Shared socio-economic pathways (SSPs) are narratives visualising alternative futures of the world. Using five SSP narratives, we develop alternative futures for India's electricity generation sector for up to the end of the century. We then present an India-specific dataset on water withdrawal intensities across different electricity generation technologies as well as on the distribution of thermal power plants (TPPs) by cooling technology and dependence on freshwater/seawater. The withdrawal intensities are based on power plant-specific documents and other data sources, and we use these to estimate India's current and future electricity sector water withdrawals and consumption under the five SSPs. Our analysis suggests that India's electricity generation growth will be significantly different across SSPs, with the average annual growth rate varying from 4% to 7% per annum between 2015 and 2050, and from 0.7% to 1.4% per annum between 2050 and 2095, across scenarios. This growth, along with a varying electricity generation mix, will have significant implications for energy access and emissions from India's electricity generation sector. Further, in the absence of dry cooling technology, water consumption by India's electricity generation sector will grow by 4%–5.6% annually between 2015 and 2050, and will continue to increase across scenarios, putting additional pressure on the country's water resources. Our research shows that the Indian government's draft notification on the power sector will lead to a significant decline in water withdrawals from TPPs in India, and dry cooling technology is likely to become essential in addressing acute water scarcity in some parts of India.

Contents

1. Introduction

Ensuring access to electricity is one of the foremost challenges faced by policy makers in developing economies (Rao & Pachauri, 2017; Ahmed et al., 2014). India's per capita electricity consumption is less than 1200 kWh currently, while that of developed European nations is more than 7000–8000 kWh/capita on an average (World Bank, 2017). Millions of households in India face shortage of reliable electricity supply (Balachandra, 2011; Aklin et al., 2016). As the economy grows, increase in electricity demand and rise in end-use services are bound to happen.

Along with the many positive impacts on human well-being and livelihoods, there are two critical negative implications of increasing electricity generation. The first implication is increasing emissions of local pollutants like soot and sulphur dioxide. Local pollutants are mainly emitted from the use of coal in thermal power plants, as well as the use of bioenergy for meeting the cooking needs of urban and rural households, and have severe implications for the health of local residents (Bell et al., 2013; Smith et al., 2013; Dholakia et al., 2013; Gunatilake et al., 2014). The second implication is increasing emissions of carbon dioxide. Researchers have shown that the electricity sector will be a significant contributor to global and regional carbon dioxide emissions, and any effective emission mitigation strategy must include steps for major transformations in the electricity production sector (Doi et al., 2012; Edmonds et al., 2012; Chaturvedi et al., 2014a).

A third negative implication, arguably of similar importance, that is increasingly being recognised as a critical issue requiring the immediate attention of global policy makers and other stakeholders is the issue of water demand for thermal cooling and other processes in power plants (Hamiche et al., 2016). India has on numerous occasions been identified as a water-scarce country, and growth in the agricultural sector could itself put tremendous pressure on India's water resources (Chaturvedi et al., 2015). India's utilisable water resource was estimated to be only 1123 billion cubic metres (bcm), 28% of the total water resources available in the country (CWC, 2007). Of this, a total of 680 bcm was estimated as consumption across sectors in 2000, with the irrigation sector accounting for 88% of this consumption. Although the bulk of the water is consumed for irrigation (Amarsinghe et al., 2008), the demand for industrial water use and for thermal cooling for electricity generation is increasing year on year.

Researchers have tried to estimate levels of water consumption and withdrawals from electricity generation, and have highlighted the implications for the world as well as for different countries, including India (IEA, 2012; Davies et al., 2013; Hejazi et al., 2013; Byers et al., 2014; Konadu et al., 2015; Liu et al., 2015; Liao et al., 2016). However, in any global study, only average global water consumption and withdrawal coefficients have been used for India. Bhattacharya & Mitra (2013) have collected and used India-specific water coefficients for coal-, gas-, and oil-based power plants, which is very useful, but it is still a fairly limited dataset. Also, Bhattacharya & Mitra (2013) present results only for one scenario. In a recent inter-model comparison study focused on India as well, the authors have used global median values for water withdrawals and consumption (Srinivasan et al., 2017).

It is important to understand the evolution of India's electricity generation in the long run across various socio-economic pathways. It is equally important to know the magnitude of water demand for meeting the thermal cooling and other needs of India's electricity generation in the long run, and the additional pressure that such water demand could potentially exert on India's water resources across different future scenarios, to be better prepared with a policy response. The rate at which India's electricity and related water demands could evolve will be defined mainly by how India's population, income, lifestyle, policies, institutions, and technology evolve in the future. Even the rate of greenhouse gas emissions and the resultant climate change could take different trajectories depending on how global social, economic, and technological parameters change. This means that under these different visions of the future world, socio-economic variables and climate change parameters will interact in myriad, complex and uncertain ways that need to be understood for informing long-term policy decisions. Shared Socio-economic Pathways (SSPs) provide a framework for undertaking this kind of analysis (Kriegler et al., 2017a; KC & Lutz, 2017; Dellink et al., 2017; Riahi et al., 2017). SSPs describe different visions of the future world based on an insightful description and analysis of underlying social, economic, and technological drivers, and provide a range of five scenarios that span the spectrum of underlying uncertainties that are likely to shape the future world (Calvin et al., 2017; Fricko et al., 2017; Fujimori et al., 2017; Kriegler et al., 2017b; van Vuuren et al., 2017). SSP-based scenario analysis is being increasingly adopted as a framework for climate policy scenario analysis.

Our study seeks to contribute to the literature and address the research gaps by (i) modelling the long-term evolution of India's electricity generation sector under five different SSPs; (ii) constructing a unique dataset on thermal cooling technology distribution and associated water consumption/withdrawal coefficients based on India-specific literature; and (iii) estimating the water requirements based on country-specific coefficients for India's electricity generation sector across five different SSPs.

The next section details the modelling approach, the scenario framework, and the data- collation approach used in the study. This is followed by the section on results where we present the key learnings from the India-specific data on water-use coefficients, and from the long-term electricity generation and associated water consumption and withdrawals across the five SSPs. Then we present a discussion based on our results and follow this with a section on conclusions.

2. Methodology

2.1 Integrated Assessment Modelling and Shared Socio-Economic Pathways

We model electricity demand for different scenarios within the integrated assessment modelling framework of Global Change Assessment Model (GCAM). GCAM is an energy sector-focused partial equilibrium model with detailed modelling of the energy supply, transformation, and demand sectors. In version 3.2, which is being used in this study, GCAM tracks energy and emissions of carbon dioxide, other greenhouse gases, and local pollutant gases across 14 regions that collectively constitute the world. India is modelled as a separate region. This GCAM version runs from 2005 to 2095 in five-year time steps. Energy demand is modelled for three end-use sectors–buildings, industry, and transportation. Energy service demand for each of these sectors responds to per capita income, urbanisation, and population. Electricity is modelled in detail within GCAM, with different technologies competing with each other on the basis of capital and operation costs as well as fuel prices. The technologies included within GCAM's electricity sector are coal, gas, oil, biomass, nuclear, solar photovoltaic, solar thermal, wind, and geothermal. Details about the various applications of GCAM can be found in Hejazi et al. (2013); Chaturvedi et al. (2014); McJeon et al. (2014); Iyer et al. (2015); Kyle & Kim (2015); and Chaturvedi & Sharma (2016).

2.2 Scenario Framing: Shared Socio-Economic Pathways

Shared Socio-Economic Pathways (SSPs) are a group of scenarios that have been developed recently to better understand the challenges related to climate change mitigation, impacts, and adaptation. This is an evolution from the scenario framework used initially by the Intergovernmental Panel on Climate Change (IPCC), also known as Special Report on Emissions Scenarios (SRES) scenarios (Nakicenovic & Swart, 2000). SRES scenarios mainly focused on the mitigation challenges and the role of technologies and policies in climate change mitigation in different future worlds. SSP scenarios have been developed with this explicit understanding that along with mitigation, adaptation to climate change impacts is becoming a real concern, and hence a deeper understanding of socio-economic systems is required to prepare the world to devise mitigation strategies as well as to adapt to climate change impacts. Various expert teams have developed five SSPs based on different dimensions for individual countries and for the world as a whole. The middle-of-the-road pathway, SSP2, defines a future world that is not different from the dynamics of the current world. Under SSP2, worldwide development and growth proceed unevenly. Societies are aware of the threat of climate change, and challenges to mitigation and adaptation are moderate. As against this, SSP3 is a deeply divided world, with marked regional differences and strong nationalistic tendencies, grappling with high population and low GDP growth rates. Institutions are weak, and challenges to both mitigation and adaptation are high. SSP1 describes a sustainable world with inclusive development and better management of global commons. Mitigation and adaptation challenges are low in this scenario. SSP4 is also a deeply unequal world with low-income growth, but where a combination of low-carbon supply options and expertise, and a decisive international political and business class, ensures that mitigation challenges are low, although adaptation challenges are high. Finally, the SSP5 world is a highly industrialised world with low population and high GDP growth. This is a highly resource- and fossil-intensive economy, and hence challenges for mitigation are high. Challenges for adaptation are, however, low due to high incomes and less vulnerability. Table 1 presents our assumptions for India under the five SSPs narratives. We use the OECD SSP database for GDP growth rates (Dellink et al., 2017). The GDP growth rates are for GDP in terms of purchasing power parity (PPP), while GCAM works in terms of market exchange rates (MER). We conserve the growth rates in PPP as between 2015 and 2100 as reported in the OECD SSP database while translating from PPP to MER.

For our analysis, we focus not only on the population, GDP, and urbanisation rates of different socio-economic scenarios, but also translate the SSP narratives into varied narratives of the evolution of the Indian electricity generation sector, in addition to the government's water policy for thermal cooling. For SSP1, the sustainable scenario, we assume that renewable energy will produce 40% and 65% of total electricity in 2050 and 2095 respectively. Our numerical assumption for this scenario is inspired by India's goal of increasing the share of renewable energy in its electricity generation capacity, 175 GW by 2022 as per India's domestic renewable energy targets, as well as being based on the existing literature on India's potential decarbonisation pathways (Shukla et al., 2015). For SSP3, we have assumed three times the share of nuclear energy in electricity generation in 2050 and 2095 as compared to SSP2, our reference scenario, to reflect the impetus of this technology in a world fraught with regional rivalries. For SSP4 also, we model a higher share of low-carbon technologies (as against renewable technologies only in SSP1), reflecting a stronger international political will and increased business initiatives along with some development of low-carbon options as per the SSP4 narrative. Under the fossil-dominant SSP5, we assume that the share of fossil in generated electricity will increase to 90% in 2095 compared to 75% in the reference scenario, a 58% increase in absolute terms due to higher overall generation of electricity under SSP5. Our choice of numerical targets across scenarios has been made with the intention of reflecting the respective scenario narratives, and hence should be taken only as a stylised representation of the core scenario elements. Our numerical assumptions should not be considered as the 'best' or 'most appropriate' numerical assumptions. We are not aware of any SSP research focused on India's electricity generation sector, although we are aware that SSP-based papers also model India along with other regions of the world. There could be multiple ways in which different researchers can visualise the evolution of India's electricity generation under various SSPs. We believe that our visualisation represents the core elements of the five SSP narratives, and would be a useful reference point for future research on India's electricity sector under SSPs.

Table 1: Demographic and technological assumptions for India under five SSP narratives

	Population, Billion (Urbanisation rate)		GDP-MER, Trillion, 2015 prices		Electricity generation sector	Thermal cooling water technology
	2050	2095	2050	2095		
SSP1 Sustainability– Taking the green road	1.55 (67%)	1.20 (89%)	32.67	81.64	A higher share of renewable* energy-based electricity generation, 40% in 2050 and 65% in 2095	Focus on water- efficient technologies. All inland thermal power plants (TPPs) shift away from OTC** technology. Higher share of dry cooling technology, 20% in 2050 and 30% in 2095
SSP2 (reference scenario)–Middle of the road	1.73 (53%)	1.64 (73%)	19.39	70.90	Reference scenario mix (model endogenously determines the electricity sector mix)	All inland TPPs from 2017 onwards based on CT** technology
SSP3 Regional rivalry–A rocky road	1.97 (37%)	2.55 (45%)	9.95	22.9	Authoritarian national governments, along with increasing conflicts. A higher share of nuclear- based electricity generation, 20% in 2050 and 30% in 2095	All inland TPPs from 2017 onwards based on CT technology
SSP4 Inequality–A road divided	1.60 (67%)	1.24 (89%)	17.15	45.47	A higher share of low-carbon**-based electricity generation, 41% in 2050 and 60% in 2095	Water policy failure: Failure to implement shift to CT technology, share of OTC and CT in inland TPPs remains the same in the future as in 2015
SSP5 Fossil fuel development– Taking the highway	1.54 (67%)	1.20 (89%)	43.21	123.19	Increasing focus on fossil energy, high share of fossil- based electricity generation, 90% in 2095	Focus on water- efficient technologies. All inland TPPs shift away from OTC technology. Higher share of dry cooling technology, 20% in 2050 and 30% in 2095

**Renewable energy according to our definition includes solar, wind, biomass, and geothermal; ** Low carbon according to our definition includes nuclear and hydro along with renewable energy.*

***OTC=once through cooling technology; CT=cooling tower-based technology.*

2.3 India-specific water data

Water-related data for Indian power plants are scarce, be it information on the distribution of cooling technologies across thermal power plants (TPPs), share of seawater-based plants versus freshwater-based plants, or consumption and withdrawal intensities. Two types of cooling technologies are used predominantly in Indian thermal power plants—once through cooling (OTC) and cooling tower-based cooling (CT). OTC has high water withdrawal, while CT decreases the withdrawal need significantly, although it increases water consumption. Water withdrawals should be differentiated from consumption. Withdrawals are the total water intake from the water source, while consumption is the evaporative losses in the thermal cooling process. A third technology, dry cooling, eliminates almost entirely the need for water withdrawals, but it is costly and decreases power plant efficiency. The Ministry for Environment, Forest and Climate Change (MoEFCC), Government of India (MoEFCC, 2015) has released a draft notification for water consumption in TPPs that mandates that all new power plants will have to be based on CT technology and that older power plants will also have to convert to CT technology, which will be assumed to have been implemented by 2020. One scenario (SSP4) also tests the impact of the failure of this policy.

For data on the distribution of cooling technologies and the share of freshwater-based capacity, we create an inventory of 198 power plant units (146 coal based, 31 gas based, and 21 nuclear based) using different environmental impact assessment (EIA) studies, compliance reports, water tariff petitions, characteristics of the respective plants taken from their official websites, and reports published by different environmental organisations.

For data on India-specific water-withdrawal coefficients, we collated data from official sources and available secondary research studies. This India-specific database includes information from, and pertaining to, 21 coal-based, nine gas-based, three nuclear-based, three biomass-based, and three types of CSP-based power plant units. No such data are available for oil- or diesel-based plants; hence we have taken estimates from Bhattacharya & Mitra (2013). We have excluded the Bhattacharya & Mitra (2013) coefficients for other technologies as specific details of power plants (e.g., capacity, location, etc.) are not given in the report. During our detailed search, we were unable to find data on India-specific water 'consumption' coefficients for coal and gas TPPs. This is because for these TPPs, only withdrawals are measured at the point of water intake. We have hence taken the ratio of median values of consumption versus withdrawals as reported in Macknick et al. (2011) and applied that to our India-specific withdrawal values to arrive at the consumption values for Indian wet cooled plants. For nuclear power plants, however, we have the required evaporative losses along with withdrawal coefficients. Detailed information is presented in the results section and in Appendix 1. Water-withdrawal intensities for coal and gas are based on actual usage data as reported in various sources, while those for nuclear TPPs are based on estimates as submitted in EIA reports prior to the commissioning of these power plants.

For modelling consumption and withdrawals across SSPs in the post-2020 period, we assume that under the sustainable scenario SSP1 as well as the fossil-intensive scenario SSP5, the share of dry cooling increases in India as a response to growing water scarcity. Both these scenarios are high-income scenarios, and the challenges for adaptation are low. Under SSP2 and SSP3, all inland TPPs use CT technology from 2020 to 2095, which basically means that the draft power rules proposed by the Government of India come into force from 2017 onwards, as envisaged. The draft rules mandate that all old and new inland TPPs are to be based on CT technology from 2017 onwards, and also propose a limit of 3.5 m3/MWh for all inland thermal power plants. However, as of now there is no clarity whether this limit will be accepted or not, so we have used the median number from our calculations (e.g., 3.79 m3/MWh in case of coal TPPs) for calculating our future estimates. We assume water policy failure for SSP4 under the growing inequality narrative. This implies that not all new inland TPPs will be based on CT technology, and that the share of OTC will remain constant even in the future, thereby intensifying water-related inequalities. For our future estimates, we focus only on inland power plants and assume that the share of inland versus seawater-based power plants will remain constant in the future. Generally speaking, the data are for sub-critical coal power plants as most of the power plants in India are sub-critical. The Institute for Global Environmental Strategies (IGES) survey specifically includes a super-critical coal power plant. The water consumption coefficient of this power plant is, in fact, in the mid-range of values for the sub-critical plants (see Appendix 1).

3. Results

3.1 Learning from India-specific data for water consumption and withdrawals coefficients

Distribution of seawater (SW)/freshwater (FW) based power plants and cooling technologies

Our sample represents 100% of India's nuclear-based capacity, 50% of India's gas-based capacity, and 88% of India's coal-based capacity as of 31 December 2015. Assuming that our sample data on the distribution of TPPs are representative of all TPPs in India, it is clear that the bulk of coal-based power plant capacity is based on freshwater (84%). The share for nuclear power plants is much lower at 51%. Given that most of India's thermal generation capacity is coal based, as reflected in our sample as well, about 83% of India's thermal power plant capacity is inland.

Table 2: Source and cooling technology-wise distribution of Indian TPPs in sample dataset

Fuel type	Number of units (%)					Capacity in GW (%)				
	FW		SW			FW		SW		
	CT	OTC	CT	OTC	Total	CT	OTC	CT	OTC	Total
Coal	110 (75%)	18 (12%)	14 (10%)	4 (3%)	146	104.36 (71%)	19.8 (13%)	16.21 (11%)	6.57 (5%)	146.95
Gas	26 (84%)	0 (0%)	5 (16%)	0 (0%)	31	11.4 (83%)	0 (0%)	2.4 (17%)	0 (0%)	13.81
Nuclear	10 (48%)	4 (19%)	0 (0%)	7 (33%)	21	2.2 (38%)	0.74 (13%)	0 (0%)	2.84 (49 %)	5.78

Source: CEEW Analysis

Whether inland power plants use CT technology or are based on OTC technology has important implications for estimating the pressure on water resources in India. In terms of the distribution of cooling towers in inland power plants, 84% of coal-based capacity and 100% of gas-based capacity is based on CT technology. Even 75% of inland nuclear-based capacity uses cooling towers.

What is interesting to note is that many seawater-based power plants also use cooling tower based systems. Our analysis shows that 75% of seawater-based coal power plant capacity and all of gas power-based capacity uses cooling tower systems. In contrast, all seawater-based nuclear power plants are based on OTC. These data are noteworthy because OTC systems have significant implications for the marine ecosystem as they could lead to thermal pollution and consequent impacts if the temperature of the discharge water is high. These technology-wise estimates also help us to better estimate India's electricity sector water withdrawals in 2010 and beyond.

India-specific water consumption and withdrawal coefficients

We present our estimates of cooling water consumption and withdrawals and compare these with data presented by Macknick et al. (2011). The comparison is presented in Table 3. Our coefficients for coal and gas TPPs have been estimated based on water tariff petitions as well as coefficients as given in reports by other civil society organisations. Water coefficients for nuclear power plants are based entirely on EIA reports. The detailed dataset with information on each power plant with references is given in Appendix 1. As mentioned earlier, the data available in India for coal and gas TPPs are related to withdrawal intensities only. For estimating India specific water consumption coefficients, we take the ratio of median values of withdrawal and consumption coefficients as reported by Macknick et al. (2011) for different technologies, and apply these on India specific withdrawal coefficients collected by us. Also, our India-specific water intensities are not only related to thermal cooling, but also include water use for other purposes like coal ash handling. However, in the newer TPPs, the bulk of the water is used for thermal cooling purposes. Two particularly interesting observations emerge here. First, the median CT withdrawal intensities of gas-based TPPs in India are much lower than the global median values. Second, the corresponding CT withdrawal intensity for nuclear plants is high in India compared to the global averages. For coal, the Indian and global numbers seem to converge. For OTC-based coal and nuclear power plants, however, the median withdrawal numbers are much higher than the global median numbers as presented by Macknick et al. (2011). Variations in power plant technologies, thermal cooling technologies, as well as local factors like temperatures could be the reasons for these differences, although the exact reasons are unclear from the available information.

Another interesting observation is that there is significant variation in water-withdrawal intensities across power plants for the same fuel. This is the same as in the case of global values as presented by Macknick et al. (2011). Power plants work in different operating conditions and hence there will necessarily be some variation in their water demands.

Generally speaking, the data collected by us are for sub-critical coal power plants as most of the coal power plants in India are sub-critical. Bhattacharya & Mitra (2013) specifically include a super-critical coal power plant in their study. The water consumption coefficient of this power plant is, in fact, in the mid-range of the values for the sub-critical plants. It is expected that all new coal TPPs in India will be based on super-critical technology. Looking at the data, and comparing them to the data in the draft notification by the MoEFCC, and considering the additional water requirement for the desulphurisation process that is expected to be mandated soon for coal TPPs, it does appear that the limits on water withdrawal per unit of electricity production as proposed by the MoEFCC under the draft notification are relatively stringent.

Table 3: Water-withdrawal and consumption intensities for Indian TPPs

Water-withdrawal intensities (m^3/MWh)								
Power generating technology	Cooling technology	CEEW				Macknick et al. (2011)		
		Sample size	Min.	Median	Max.	Min.	Median	Max.
Coal	CT	19	2.31	3.79	5.16	1.90	3.80	4.54
	OTC	2	171	216	261	76	138	189
Gas	CT	9	1.24	1.62	2	3.60	4.60	5.50
	OTC	-	-	-	-	38	132	227
Nuclear	CT	1		6.42		3	4.20	9.80
	OTC	2	196.2	242.71	289.22	95	168	227
Refined liquids	CT	1	-	-	-	3.60	4.60	5.50
	OTC	1	-	-	-	38	132	227
CSP trough*	N/A	3	2.90	3.20	3.50	2.70	3.30	4
CSP tower*	N/A	3	2.24	2.30	2.80	2.80	3	3.30
CSP Fresnel*	N/A	3	2.80	3.20	4.50	3.80	3.80	3.80
CSP**	N/A	-	2.45	2.68	3.10	-	-	-
PV	N/A	-	-	-	-	-	0.10	0.10
Biomass	N/A	3	3.94	4.35	4.37	-	-	-

Water-consumption intensities (m^3/MWh)								
Power generating technology	Cooling technology	CEEW				Macknick et al. (2011)		
		Sample size	Min.	Median	Max.	Min.	Median	Max.
Coal	CT	19	2.19	2.59	4.80	1.80	2.60	4.20
	OTC	2	0.86	1.56	1.64	0.40	1	1.20
Gas	CT	9	0.86	1.17	1.60	2.50	3.10	4.40
	OTC	-	-	-	-	0.40	0.90	1.10
Nuclear	CT	1	-	3.82	-	2.20	2.50	3.20
	OTC	2	0.78	1.45	1.91	0.40	1	1.50
Refined liquids	CT	1	-		-	2.5	3.10	4.40
	OTC	1	-	0.21-0.82	-	0.40	0.90	1.10
CSP trough*	N/A	3	2.90	3.2	3.50	2.70	3.30	4
CSP tower*	N/A	3	2.24	2.30	2.80	2.80	3	3.30
CSP Fresnel*	N/A	3	2.80	3.20	4.50	3.80	3.80	3.80
CSP**	N/A	-	2.45	2.67	3.10	-	-	-
PV	N/A	-	-	-	-	-	0.10	0.10
Biomass	N/A	-	-	-	-	-	-	-

**Indicates data collected from Sharma et al. (2015). ** The value for CSP is the weighted average value for the three CSP technologies on the basis of their respective shares in India as per Bhushan et. al. (2015).*

***Note:** For three CT-based coal power plants, withdrawals ranged from 8.40 to 10.36 m^3/MWh. These were found to be for old technologies and also were outliers in the data and hence were excluded from our dataset. Comparisons with current intensities show a significant decline in the water-use intensities of Indian TPPs in the last few decades. Also, India-specific water intensities are not only related to thermal cooling, but they also include water use for other purposes like coal ash handling as well.*

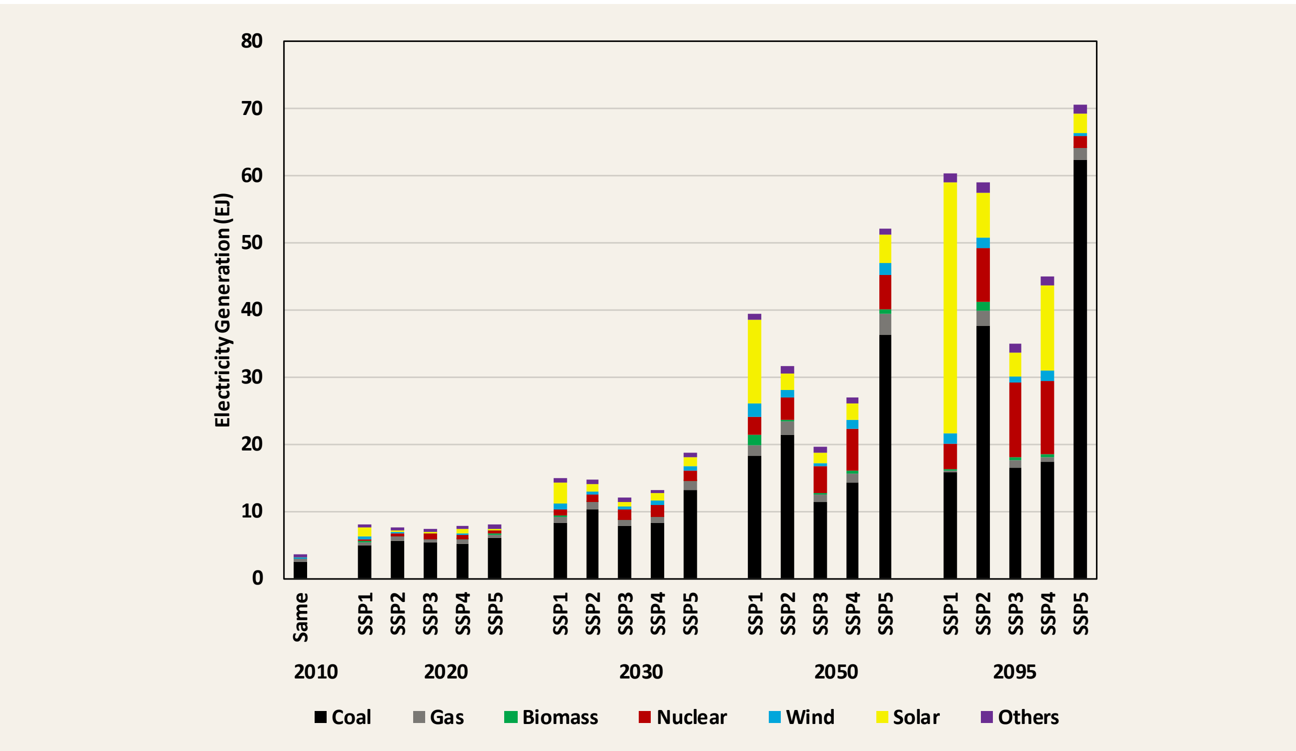
3.2 India's electricity generation across SSPs

The evolution of India's electricity generation is determined by two key elements of the SSPs. First, the rate of growth of electricity generation is determined mainly by GDP and urbanisation, which is different across different SSPs. Second, the generation mix is determined by the key elements of the SSP narratives as explained in the methodology section. So SSP1 is focused on sustainable (renewable) energy, SSP3 on nuclear energy, SSP4 on low carbon (renewable, hydro, and nuclear), and SSP5 on coal-based electricity. Given the focus of our paper on water withdrawals, we have defined sustainable energy only in terms of renewable energy, excluding nuclear energy from our definition. In terms of the growth rate, generation growth is the slowest under SSP3 and is the highest under SSP5. Electricity generation under SSP5 is three times relative to SSP3 in 2050 and beyond.

The extent of penetration of electricity in India varies significantly under the different SSPs, largely driven by the differences in urbanisation and per capita incomes. Under SSP2, or our reference scenario, electricity generation increases to four times between 2010 and 2030 (Figure 1). The lowest growth is in the SSP3 scenario that represents the unequal world scenario. Electricity generation grows annually at an average of only 5.8% between 2015 and 2030 as compared to 9.2% under the high-income SSP5. Between 2030 and 2050, the average annual growth rates for the two scenarios are 2.6% and 5.4% respectively.

India's emission mitigation strategy has been framed by policy makers in the context of sustainable development. Energy access is a high priority for Indian policy makers, and the challenge is to ensure higher energy access to Indians while addressing climate change mitigation goals. Discussing the implications of SSPs for energy access becomes important from the Indian perspective. Different SSPs reflect varying levels of energy poverty and energy access. Per capita electricity generation in 2050 will be 2,657 kWh under SSP3 as compared to 9,209 kWh under SSP5. Under SSP1 and SSP2, India's per capita electricity generation in 2050 will be 6,908 kWh and 4,921 kWh respectively. The current average per capita electricity consumption for many developed countries is around 7,000–8,000 kWh/capita/year. Thus, under SSP5 and SSP1, India would have resolved its energy access challenge by 2050, and under SSP2 as well, India will be quite close to addressing these challenges by 2050. In other scenarios, however, energy access would still be a challenge in 2050.

Figure 1: Electricity generation by source



Source: CEEW Analysis

The mix of electricity generation is also determined by the SSP narratives. We see that under SSP1, solar energy forms a large part of India's electricity generation portfolio by 2050 and beyond. Sixty-two per cent of electricity generated in 2095 is based on solar energy. There are two main reasons for this high share of solar energy. First, the cost of PV-based solar electricity is already lower than that of wind-based electricity, and is expected to remain so in the long-run future. Second, India has limited wind potential, while the solar potential is huge, because of which any renewable push policy for India will end up being a solar-based policy. On the other hand, the resource-intensive lifestyle of SSP5 is mainly based on coal energy. Generally speaking, all scenarios apart from SSP1 are fossil dependent. Even under SSP3, which has a higher share of nuclear energy relative to the reference scenario, coal is an equally important part of India's electricity generation mix. Under SSP2, our reference scenario, coal-based electricity accounts for a dominant 63% share in 2095, although the share of renewable energy increases in the long-term future.

The variations in electricity generation growth and mix lead to very different emission trajectories from the electricity generation sector. Carbon dioxide emissions from India's electricity generation under our reference scenario, SSP2, reach 5.72 GtCO2 in 2050, and then rise to 9.41 GtCO2 in 2095. The emissions growth of the Indian electricity sector between 2020 and 2050 varies from 2.19%/annum in SSP3 to 5.73%/annum in SSP5. Further, between 2050 and 2095, electricity sector emissions grow by 0.21%/annum in SSP3 to 1.11%/annum in SSP2. Only under the sustainable scenario, SSP1, do emissions from the electricity generation sector decline by 0.60%/annum between 2050 and 2095 due to the high share of renewable energy. In 2095, there is a large variation in electricity sector emissions, ranging from 3.9 GtCO2 in SSP1 to 14.5 GtCO2 in SSP5.

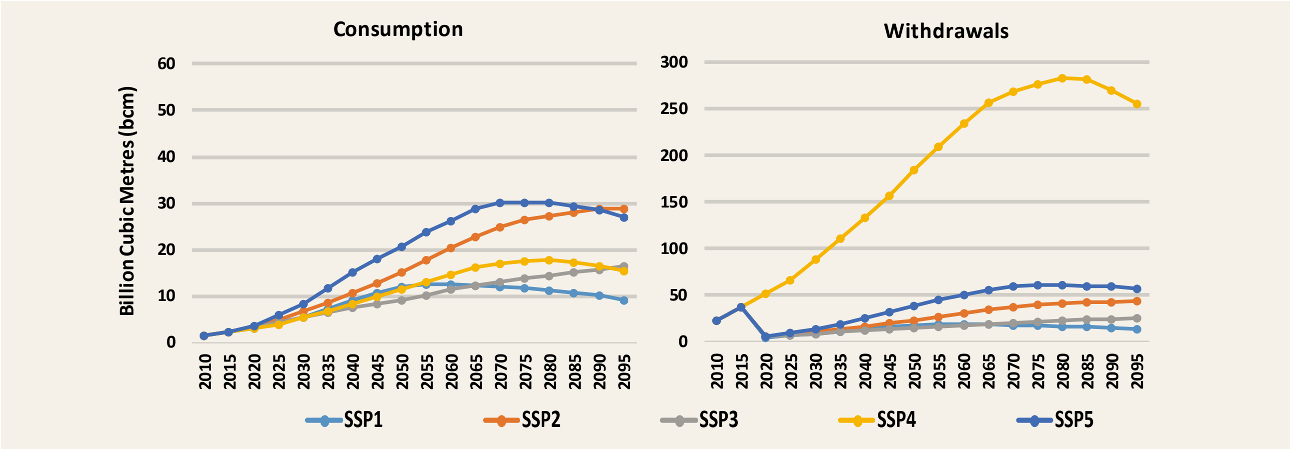
The peaking year for India's electricity sector emissions varies across scenarios. Under SSP2 and SSP3, emissions peak only after 2090; under SSP4 and SSP5, emissions peak in 2090/2095; under the sustainable scenario SSP1, emissions peak much earlier, that is, in 2060. Even a significant push for renewable-based electricity is not able to shift the peak in India's electricity sector emissions to before 2050, which is an important observation from the climate policy perspective. We see a significant increase in solar only between 2030 and 2050. To shift the peak to before 2040, investments in long-gestation coal-based generation will have to be minimised.

3.3 Water consumption and withdrawals

Based on India-specific withdrawal intensities and derived consumption intensities, we first estimate the historical freshwater withdrawals and consumption for India's electricity generation. As per our estimates, India's electricity generation-related water withdrawals stood at 22 billion cubic metres (bcm) in 2010 and at 33.6 bcm in 2015. The estimates from the Centre for Science and Environment based on wastewater numbers for the period from 1990 to 2001 by the Central Pollution Control Board place the water requirements by TPPs at 35 bcm (CSE, 2004). According to the World Energy Outlook 2012 (IEA, 2012), water withdrawals for TPPs was approximately 102 bcm in 2010. It appears that the estimates by CSE and IEA are very high compared to our estimates based on the detailed India-specific dataset. It is, however, possible that the penetration of OTC technology was much higher in 1999/2000 as compared to 2010 and 2015. A report by IGES (Bhattacharya & Mitra, 2013) estimates the water demand for coal-based TPPs at approximately 10 bcm in 2010. The most recent analysis by Srinivasan et al. (2017) estimates freshwater withdrawal for electricity generation in India in 2010 at 34 bcm, which is also significantly higher compared to our estimates. It should be noted here that our estimates are not specific or exclusive to thermal cooling only, and instead reflect water withdrawal for all other requirements as well. The corresponding estimates for consumption are 1.59 bcm and 2.28 bcm respectively for 2010 and 2015.

Across scenarios excluding SSP4, there is a sharp drop in water withdrawals between 2015 and 2020 (Figure 2). This is because, as per government policy, all OTC-based power plants will have to shift to CT-based technology, and any new inland power plant has to be based on CT technology. The key results specific to each SSP are discussed below.

Figure 2: Water consumption and withdrawals across SSPs



Source: CEEW Analysis

SSP1: A Sustainable World

SSP1 is a world where society consciously invests in sustainable behaviour. In the SSP1 world, Indian policy makers recognise the stress caused by additional water demands for meeting the requirements of power plants, and consequently dry cooling is introduced in regions that face extreme and frequent water scarcity. We assume that 20% of India's inland TPPs in 2050 and 30% in 2095 will be based on dry cooling technology. This coupled with an increasing share of solar energy in India's electricity generation mix implies that water withdrawals will never cross the 2015 levels across the century. Water consumption will, however, still increase up to the mid-century by seven and a half times between 2015 and 2050, and thereafter will decrease owing to a greater share of solar energy and an increased share of dry cooling. In essence, this scenario is the greenest scenario from the perspective of the electricity generation system as well as water usage in TPPs in India. As future withdrawals will always be lower than current levels, and as dry cooling will be used in the water-scarce regions of India, this scenario can be expected to present low challenges for adaptation.

SSP2: The Reference World

In SSP2, withdrawals will first decline significantly between 2015 and 2020, increase to the current level by 2070, and then keep on rising. Interestingly, although overall GDP and electricity production are low as compared to SSP1, we still see that withdrawals and consumption in SSP2 are higher. This is because the energy mix in the reference world is determined endogenously in the model and we see India's electricity generation being dominated by coal even in the long run. Low water-intensity technologies like solar and wind increase their share, but account for only 12% in 2050 and for 14% in 2095, as against the high share of solar under SSP1. Electricity generation under SSP2 is hence more water intensive as against SSP1 because of the high reliance on water-intensive generation technologies, as well as the absence of penetration of dry cooling technology.

One of the oldest estimates on industrial water requirements, the National Commission on Integrated Water Resources Development (NCIWRD) in 1999, projected that water requirements for electricity generation from TPPs will be 2.8 bcm (low-demand scenario, LDS) and 3.4 bcm (high-demand scenario, HDS) in 2012; 7.8 bcm (LDS) and 9.5 bcm (HDS) in 2025; and 28.7 (LDS) and 35 bcm (HDS) in 2050 (NCIWRD, 1999). Our estimate for consumption in our reference scenario is 11.23 bcm and is much lower than the NCIWRD estimates. This could be because the NCIRD study is old and outdated, and water demand for new power plants is much lower as a result of technological improvements as well as the result of new mandates by the Indian government. The recent inter-model comparison study by Srinivasan et al. (2017) estimates that water withdrawals in 2050 will be in the range of 12–18 bcm under the successful water policy scenario. Our estimate is 22.5 bcm under SSP2.

SSP3: The Regional Rivalry Scenario

The SSP3 scenario has many interesting implications, as it is fraught with regional tensions and rivalries and countries can be expected to be driven by nationalistic concerns. In terms of electricity generation, this implies that countries will push for increasing the share of nuclear-based electricity in their generation portfolio in order to enhance their defence and deterrent capabilities. In terms of water consumption, electricity generation will be more water intensive as nuclear-based TPPs have much higher withdrawal and consumption intensities as reflected in our India-specific data. Overall water consumption and withdrawals will be lowest across all scenarios till 2060 largely due to low GDP and consequently limited electricity production. Still, we see a secular growth in water consumption across the century in the SSP3 scenario.

We can expect disputes over water with India's neighbouring countries. Currently, India is locked in conflicts with three of its neighbours—with Bangladesh over the sharing of Teesta river water, with China over the sharing of Brahmaputra river water, and with Pakistan over the sharing of Indus river water. We can expect such conflicts to intensify under the SSP3 world. TPPs dependent on the Brahmaputra for meeting their water needs can expect water stress in a regional-rivalry scenario because China is located upstream in the river basin. Low GDP also implies that adaptation challenges will be high, and that apart from nuclear energy, the cheapest source of energy will be used. Expensive technologies like dry cooling will not be used because of their high cost, thereby exacerbating the pressure on India's water resources.

SSP 4: An Unequal India

The SSP4 world is characterised by inequalities. It is better in terms of average incomes as compared to the SSP3 world, but the gap between the haves and the have-nots is ever increasing. This implies that even though in terms of average per capita electricity generation, this scenario is similar to SSP2, the distribution across income groups as well as across states will be very different within India or in any other country. We also assume that in this increasingly unequal India, it will be difficult to implement the policy to convert all existing TPPs and new TPPs to cooling tower technology. Inequality between states will compel the poorer states to not invest in the costlier CT technology, and a number of TPPs in the country will continue to be based on OTC technology. This will lead to significant increase in water withdrawals. Hence, this scenario is characterised by the failure of the water policy regarding TPPs in India. Consequently, we will see a jump in water-withdrawal demands from India's power sector from 22 bcm in 2015 to 179 bcm in 2050, and further to 249 bcm in 2095. The increasing pressure on water resources and the rising competition from alternative sectors, especially agriculture, will be manifested in heightened unrest and conflict between farmers and power plant operators, and between farmers and the state governments.

It should be noted here that as the SSP4 world is fraught with conflict and lack of cooperation, there will be increasing inter-state trans-boundary conflicts in India over the sharing of river water which is the main or exclusive source for water for inland power plants. Conflicts between Indian states, particularly states in south India that do not have perennial rivers, as well as between local populations and industries/power plants occur regularly every year. The states of Karnataka and Tamil Nadu witness mass demonstrations and violent outbreaks every year, especially during summer, over the sharing of water from the Cauvery river. Power plants in some states in western and southern India are forced to shut down during heat waves and during low-monsoon years due to water shortages. Such inter-state political and social conflicts can be expected to increase under the SSP4 scenario in India. Challenges for adaptation will be high.

SSP5: A High-Growth Fossil-Intensive Scenario

The SSP5 scenario is characterised by high income growth and increased electricity production. The resource-intensive lifestyle will mean the construction of many new power plants. Electricity generation is largely based on coal as India has significant domestic reserves of coal. This is, however, a high-income scenario in which the government will invest in dry cooling technology and consequently the withdrawal of cooling water will be low. The challenge for adaptation for the electricity generation sector will be low.

Even though all TPPs shift to CT technology by 2020, water withdrawals under the SSP5 scenario are higher than the water withdrawals in 2015 (33.6 bcm) by 2055 and further increase to 45 bcm by 2075. Consumption of water in TPPs is highest under this scenario and increases by 6% per annum between 2020 and 2050, although after 2050 this growth is much subdued. However, challenges for adaptation are expected to be low as GDP in this scenario is high, making it possible for the government to spend resources on increasing water-use efficiency across sectors, particularly in the agricultural sector, as well as on increasing dry cooling in the electricity generation sector.

4. Discussion

Implications of electricity generation: Access, affordability, security

An important goal of the SSP narratives is to better understand the socio-economic challenges and the adaptive capacities of societies in different future scenarios. Our analysis is one of the first such analysis that focuses on India's electricity generation sector. Although this study focuses on the supply side, some interesting observations can nevertheless be made about three important aspects of India's energy policy—access, affordability, and security.

From the perspective of energy access, SSP1 and SSP5 will be most favourable due to high per capita electricity consumption under both these scenarios. Electricity access-related challenges will be most pronounced under SSP4, which is the unequal scenario. Interestingly, average per capita electricity consumption under SSP4 will be similar to that under SSP2, the reference scenario. Understanding how different levels of energy access and consumption across different income groups and regions lead to the same average national number for India is a highly relevant area of future research. Although SSP3 is a regional-rivalry scenario where countries focus on addressing their own internal challenges, the energy-access challenge under this scenario will be huge because of low per capita income.

Affordability of electricity will be the biggest challenge under SSP3 due to very low per capita incomes even in the long run. To ensure consumption of electricity, policy makers will need to continue with electricity subsidy policies, which will add to the budgetary burden. As in the case of access, Indian consumers in the SSP1 and SSP5 worlds will not face the affordability challenge beyond 2035.

The main challenge under SSP5 will be energy security. Given the high resource-intensive growth, demand for energy commodities will pose a major challenge for energy-security planners. In the electricity sector, India will be forced to go in for fossil-intensive growth owing to its large domestic coal reserves, which will also be depleted at a faster pace. If diversification becomes an important objective, India will either need to explore other options like shale gas or will need to import competing fuels. SSP1 will also throw up another interesting energy-security challenge. This scenario is based on solar electricity. As of now, India has a small manufacturing base for solar panels and largely imports these panels. The manufacturing of panels requires some critical minerals like tellurium, and India has not explored the availability and supply of these critical minerals as yet. Thus, under SSP5, India will either need to import panels, or to import critical minerals, or to start exploring and mining these minerals within its own boundaries.

Implications of India's draft notification in the short and long runs

It is clear from our analysis that the rules as proposed in the draft notification by the MoEFCC, Government of India will be critical in reducing water withdrawals from Indian TPPs. Across scenarios, we see a significant decline in the requirement for water withdrawals in the short run. In one scenario, SSP4, we also test the failure of this policy, and it is quite evident that a failure to implement this policy will result in a continuous increase in withdrawals and will put more pressure on India's water resources. In the long run, however, withdrawals will increase across scenarios due to the growth in electricity generation, but will still be comparable to current withdrawals if the policy is successfully implemented.

Spatial distribution of power plants

Water is a local issue, and what ultimately matters is how future power plants are distributed across regions in India. Generally speaking, northern and eastern India are relatively water- abundant areas, and western and southern India are relatively water-scarce regions. Even in water-abundant regions, TPPs can create challenges as they withdraw surface water from rivers. Building and operating multiple power plants on rivers, as is the current practice, ends up drawing large amounts of water and creates an artificial scarcity of surface water. The most acute problems, however, are faced in arid and drought-prone regions. As India seeks to expand its power generation capacity, it has to avoid constructing and operating power plants in such water-deficient regions, or it has to move towards the adoption of dry cooling technology. This is possible only if the government has financial resources to subsidise these power plants, or if this more expensive electricity is affordable for consumers. Ultimately, researchers and planners need to understand the future distribution of power plants and the associated water demands for a more insightful comprehension of the challenges before them and the most effective responses.

Interaction with climate policy and cooling technology

Our analysis is focused on the five SSPs. SSP1 is the scenario with the lowest emissions and the least mitigation challenges. But all the other scenarios see a high share of fossil-based electricity systems. To achieve deep decarbonisation, India can move towards renewables with low water intensities, nuclear energy with high water intensity, or fossil fuel energy with carbon capture and storage which is also expected to be water intensive. Decarbonisation, if based on inland nuclear power plants, will have to face the water-scarcity challenge, which can potentially be addressed by dry cooling technology, adding to the cost of decarbonisation. The issue of linkages between climate policy and water will become increasingly important in the future, and hence needs to be better understood at present.

Renewable water availability

As compared to estimates by India's Central Water Commission (CWC, 2007; see introduction), FAO-AQUASTAT estimates India's total renewable freshwater resource at 1,911 bcm (including both surface water and groundwater resources), and only 1,089 bcm is considered exploitable (690 bcm from surface water and 399 bcm from groundwater sources) because of constraints related to topography and to the uneven distribution of the resource over space and time (FAO-AQUASTAT, 2017). FAO-AQUASTAT also estimates total water withdrawal for India in 2010 at 761 bcm, which doubled over the past four decades from 380 bcm in 1975. Graham et al. (in review) find that total water withdrawals in India will grow to 1022–1290 bcm in 2050 and to 814–1461 bcm in 2100 across their implementation or visualisation of the five SSPs. These estimates exceed the total exploitable amounts of water resources in India, and are likely to greatly strain India's groundwater resources and hinder its ability to meet future water demands. India is already facing depletion of its groundwater resources beyond its renewable resources [Konikow, 2011: 53 bcm/annum; Tiwari et al., 2009: 54 bcm/annum; Wada et al., 2012: 71 bcm/annum; Shah, 2009: 220–230 bcm/annum]. This suggests that even if India's future electricity water withdrawal is maintained at around the current levels (e.g., through MoEFCC's TPP water policy), growing water demands in other sectors, already strained water resources, and growing depletion rates of groundwater will persist in the coming decades. These challenges will be further complicated by a changing climate, and hence India's efforts to mitigate its emissions will necessarily require a more holistic assessment of the energy–water nexus in the country.

5. Conclusion

SSPs are narratives that have been developed recently to better understand the mitigation and adaptation challenges across different regions of the world. We model five SSPs for India to understand the evolution of electricity generation in the medium and long terms as well as the associated water withdrawals. For this purpose, we use different visualisations of India's GDP, population, urbanisation, and electricity generation sector under the five SSPs. Our two unique contributions are (i) we present a dataset of water-withdrawal intensities, distribution of cooling technologies, and distribution of freshwater/ seawater-based power plants based on India-specific data sources, and estimate India's long-term water demands for TPPs based on India-specific numbers; and (ii) our analysis, to the best of our knowledge, is the first India-focused analysis of long-term electricity generation and associated emissions within the SSP framework. For estimating water demands, we focus only on inland TPPs that are relevant for the water debate and that constitute 83% of India's total thermal power plant capacity as of March 2015.

Owing to these alternative narratives, we see various possible evolutions of India's electricity generation sector across the different SSPs. The growth in India's electricity generation between 2015 and 2050 varies from 4% per annum under SSP3 to 7% per annum under SSP5, leading to a very different state of energy-access scenarios. The electricity generation mix ranges from a 65% share of solar and wind in 2095 in the sustainable world under SSP1 to an 88% share of coal in 2095 under the fossil-intensive SSP5 scenario. Emissions growth is subdued only if economic growth in India is limited or slow, or if India moves towards a greener electricity generation mix. Else, the growth of emissions from electricity generation will be substantial.

The varying electricity mix implies significantly different average water-withdrawal and consumption intensities across scenarios. One thing is clear, that the draft notification from the government mandates that any new inland TPP will have to be based on cooling tower technology and this will have a huge impact on reducing water withdrawals from this sector in the short run. Irrespective of the water intensities and the adoption of CT technology, it is clear that sooner or later water demand from TPPs will put increasing pressure on India's water resources and hence managing the competing demand for alternative uses will become a challenge. Water consumption by India's inland TPPs will increase by 4.0- 5.6% per annum in absence of dry cooling technology between 2015 and 2050, and by 6.5% per annum under SSP5 even with a higher share of dry cooling due to a larger electricity generation sector in this scenario.

The challenge to adaptation will vary and will especially be high in the SSP3 and SSP4 worlds where heightened nationalist sentiments and inequalities will prevail respectively as against mutual cooperation and policies focused on ensuring equal access to resources. The role of dry cooling will be critical, especially with a changing climate that exacerbates the challenges already faced in many arid and drought-prone regions in India. But in a low-income world, like that of SSP3, it will be difficult to invest in the costly dry cooling technology. Climate policy and the share of cooling technology can have significant implications for water withdrawals that need to be examined further.

Our attempt has been to understand the evolution of India's electricity sector and the associated water demands under various SSPs. We hope Indian experts and researchers will build on our work and develop a deeper understanding of India's energy, water, and climate scenarios under these alternative visualisations of the world.

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Appendix 1: Detailed power sector coefficients for India

S. No.	Power Plant	Capacity (MW)	Water Source	Total Water (m3/MWH)		Cooling Water (m3/MWH)		CT/OTC	Reference
				Consumption	Withdrawal	Consumption	Withdrawal		
Coal-Based Thermal Power Plants									
1	Adani Electricity Project	3300	Dhapewada stage 2		3.11			CT	(Boyle et al., 2012)
2	M/s Dhariwal Infrastructure Pvt. Ltd.	600	Wardha river, Chandrapur		3.67			CT	
3	M/s Indiabulls Power Ltd.	2640	Upper Wardha reservoir		3.79			CT	
4	M/s Ideal Energy Projects Ltd.	270	Lower Wunna/ Wadgaon reservoir		4.23			CT	
5	M/s Vidarbha Industries Pvt. Ltd.	300	Lower Wunna/ Wadgaon reservoir		4.70			CT	
6	National Thermal Power Corporation Station (NTPC)	2320	Gosikhurd reservoir		4.92			CT	
7	Korba	2600	Hasdeo barrage		4.57			CT	(NTPC Ltd., 2014)
8	Sipat	2980	Hasdeo barrage		4.86			CT	
9	Vindhyachal	3260	Rihand reservoir		3.73			CT	
10	Talcher-Kaniha	3000	Brahmani river		2.96			CT	
11	Unchahar	1050	Sarda Sahayak canal		5.16			CT	
12	Tanda TPS	440	Saryu river		10.36			CT	
13	Kahalgaon	2340	Ganga river		4.10			CT	
14	Simhadri	2000	Sea water		0.83			CT	
15	Adani Power Ltd.	4620	Sea water				7.02		(FICCI-HSBC, n.d.)
16	Jindal Power Ltd., Tamnar	1000	Kurket river	2.21	2.31		2.19	CT	
17	Tata PCL, Jojobera	548	Subarnarekha river	2.12	2.78	2.01		CT	
18	Tata PCL, Mundra Kutch	4000	Sea water		163.75		157.5	OTC	
19	Lanco-Amarkantak	600	Hasdeo river		3.9			CT	(CSE, n.d.)
20	JSEB-Patratu	770	Patratu dam		9.84			CT	
21	DVC-Bokaro 'B'	630	Bokaro barrage		8.7			CT	
22	UPRVUNL-Anpara 'A & B'	1630	Rihand dam		171			OTC	
23	UPRVUNL-Obra	1288	Obra dam		261			OTC	
24	Reliance-Rosa	1200	Garrah river		3			CT	
25	Raj West Power Ltd.	1080	Indira Gandhi Nahar Pariyojna canal		3.84			CT	(Raj WestPower, 2014)
26	Raj West Power Ltd.	660			2.75			CT	

S. No.	Power Plant	Capacity (MW)	Water Source	Total Water (m3/MWH)		Cooling Water (m3/MWH)		CT/OTC	Reference
				Consumption	Withdrawal	Consumption	Withdrawal		
27	KSK Mahanadi Power Ltd.	1200	Freshwater & Groundwater		2.83			CT	(KSK Mahanadi Power Ltd., 2015)
28	CEA – Dry Cooling System	NA	NA		0.55			CT	(CEA, 2012)
29	CEA – Wet Cooling System	NA	NA		3			CT	
30	IGES Survey – Coal Sub-Critical Wet Cooling – Plant 1	NA	NA		2.96			CT	(Institute for Global Environmental Strategies, 2013)
31	IGES Survey – Coal Sub-Critical Wet Cooling – Plant 2	NA	NA		3.01			CT	
32	IGES Survey – Coal Sub-Critical Wet Cooling – Plant 3	NA	NA		3.15			CT	
33	IGES Survey – Coal Sub-Critical Wet Cooling – Plant 4	NA	NA		3.29			CT	
34	IGES Survey – Coal Sub-Critical Wet Cooling – Plant 5	NA	NA		3.57			CT	
35	IGES Survey – Coal Super-critical Wet Cooling	NA	NA		3.2			CT	
36	IGES Survey – Coal Sub-Critical Once	NA	NA		0.16			OTC	
37	IGES Survey – Coal Sub-Critical Once Through – Plant 2	NA	NA		0.18			OTC	
Gas-based Thermal Power Plants									
1	Anta	419	Kota Right Main canal		1.40			CT	(NTPC Ltd., 2014)
2	Auraiya	663.36	Etawah canal		2.00			CT	
3	Faridabad	431.57	Rampur distributaries of Gurgaon canal		1.46			CT	
4	Kawas	656.2	Hazira Branch canal Singanpur weir		1.62			CT	
5	RGCCPP, Kayamkulam	350	Achankovil river		1.71		1.43	CT	
6	Gandhar CCPP	657.39	Narmada river		1.90			CT	
7	ESSAR Power, Hazira	515	NA	1.86	1.24			CT	(FICCI-HSBC, n.d.)
8	IGES Survey – CCGT Wet Cooling 1	NA							
9	IGES Survey – CCGT Wet Cooling 2	NA	NA		1.48			CT	
10	IGES Survey – CCGT Dry Cooling	NA	NA		0.06			CT	
11	IGES Survey – CCGT Once Through	NA	NA		0.1			OTC	

S. No.	Power Plant	Capacity (MW)	Water Source	Total Water (m3/MWH)		Cooling Water (m3/MWH)		CT/OTC	Reference
				Consumption	Withdrawal	Consumption	Withdrawal		
Nuclear-Based Thermal Power Plants									
1	Rajasthan Atomic Power Station (RAPS), Rajasthan	100	Rana Pratap Sagar reservoir, Chambal river		196.20			OTC	(NEERI, 1989) (NEERI, 2005)
2		200						OTC	
3	Rajasthan Atomic Power Station (RAPS), Rajasthan	220	Rana Pratap Sagar reservoir, Chambal river		17.88			CT	
4		220						CT	
5		220						CT	
6		220						CT	
7		700						CT	
8		700						CT	
9	Kaiga Generating Station (KGS), Karnataka	235	Kali river	10.300	289.22	9.78	288.68	OTC	(NEERI, 1989) (NEERI, 1990)
10		235						OTC	
11	Kudankulam Atomic Power Project, Tamil Nadu	1000	Sea water	0.16	291.00	0	290.5	OTC	(NEERI, 2002) (Engineers India Ltd., 2011)
12		1000						OTC	
15	Narora Atomic Power Station (NAPS), Uttar Pradesh	220	Ganga upstream of Narora barrage	4.54	11.34	4.24	8.48	CT	(NEERI, 1992)
16		220						CT	
17	Kakrapar Atomic Power Station (KAPS), Gujarat	220	Kakrapar weir, Moticher pond	4.77	22.73	4.59	22.55	CT	(NEERI & NPCIL, 2006)
18		220						CT	
19	KAPS, Gujarat	1400	Kakrapar weir, Moticher pond	4.53	6.42	4.37	6.27	CT	(NEERI & NPCIL, 2006)
Biomass-Based Power Plants									
1	My Home Power Ltd., Andhra Pradesh	9	Manjeera river/ Godavari's tributary	4.35				CT	(Sri, 2010)
2	Sri Satyakala Power Plant, Andhra Pradesh	4	Bore well/ Groundwater	4.37	4.37			Data unavailable	
3	Sri Rayalaseema Green Energy Limited, Andhra Pradesh	5.5	Bore well/ Groundwater	3.94	3.94			Data unavailable	
Oil-Based Power Plants									
1	IGES Survey – Diesel-based plants		NA	0.82				OTC	(Institute for Global Environmental Strategies, 2013)
2	IGES Survey – Oil-based plants		NA	0.21				OTC	

Note: For our estimates of median values for coal and gas TPPs, we have excluded IGES and CEA values because details of the power plants like capacity and location are not available.

Appendix 1: References

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