WATER USE IN INDIA'S POWER GENERATION:

IMPACT OF RENEWABLES AND IMPROVED COOLING TECHNOLOGIES TO 2030

Methodology and data sources

This document details the methodology and data sources for the paper published by the World Resources Institute (WRI) and the International Renewable Energy Agency (IRENA) on 16 January 2018, *Water use in India's Power Generation: Impact of Renewables and Improved Cooling Technologies to 2030*. The paper examines the impact of higher shares of renewable energy deployment, combined with improved power plant cooling technologies, on freshwater use in the Indian power sector (excluding hydropower). WRI and IRENA conducted the analysis using data compiled from various sources on water withdrawal and consumption, considered in the context of power sector scenarios from IRENA and India's Central Electricity Authority (CEA).

Objective

This study analyses the prospective impact of renewable energy deployment and recently mandated changes to cooling systems on the freshwater intensity of non-hydro power generation under different scenarios. The analysis aims to quantify the impact of the energy transition underway in India on freshwater use. These findings highlight the need to incorporate water considerations into energy planning.

Scope

This paper examines India's power generation at the national level. The terms "water consumption" and "withdrawal" refer to the amount of freshwater withdrawn and consumed by thermal power plants (coal, oil and natural gas), nuclear power plants, geothermal and solar photovoltaic (PV) plants. Wind farms are assumed to require no water. Water use relating to the manufacturing of equipment (*e.g.* power plant components, wind turbines, solar panels), as well as fuel extraction and processing, is not considered in this study.

Analytical approach

Input scenarios

The baseline year for the analysis is 2014. Future scenarios include IRENA's REmap 2030 and the associated Reference 2030 case, as well as two CEA scenarios for 2027: Scenario 1 (high coal/low hydropower) and Scenario 2 (low coal/high hydropower).[1] The input scenarios (both baseline and projected) include data on the power capacity and generation mix by fuel. A brief description of the scenarios considered is given below.

Power sector scenarios

This study concentrates on the national power sector. Expected developments in the generation mix are captured by the different scenarios (IRENA's REmap 2030, the associated Reference 2030 case, and CEA 2027 – Scenario 1 and Scenario 2).

Baseline year – 2014

National power generation data for 2014 are retrieved from the International Energy Agency (IEA, 2014) while national installed capacity data are sourced from CEA (CEA, 2014). This study takes 2014 as baseline year for two reasons. Firstly, limited disaggregated data are available on fossil fuel capacity and generation (coal, oil, gas). Secondly, major policy changes driving accelerated renewable energy deployment and improved cooling technologies were announced in 2015.

Reference 2030 and REmap 2030

Power generation scenarios to 2030 are sourced from IRENA's REMap report *Renewable Energy Prospects for India* (IRENA, 2017). IRENA's Reference 2030 case represents a pathway to 2030 in which business-as-usual conditions prevail and there is no change to current energy and environmental policies. This means fossil fuels dominate India's total energy mix in 2030 and beyond. REmap 2030 is an analytical approach for assessing the gap between current national renewable energy plans and potential additional renewable technology options available in 2030. The accelerated deployment under REmap 2030 is consistent with India's Nationally Determined Contribution (NDC) commitments, as noted in IRENA (2017).

CEA 2027

The CEA released the *Draft National Electricity Plan* (NEP) in December 2016 (CEA, 2016). The installed capacity considered in the present analysis is taken from this plan.

The power generation numbers in Scenario 1 were not part of the NEP but were shared by CEA on request. They are based on the NEP's low hydropower scenario.

Scenario 2 has been developed by IRENA and WRI and is based on the high hydropower and low plant load factor (47.9%) scenario for thermal plants outlined by CEA in the draft NEP.

Both scenarios assume that India achieves its target of 175 gigawatts (GW) of installed renewable energy capacity by 2022.

The NEP's most ambitious scenario assumes hydro-electric potential is maximised. This classifies hydropower as a form of renewable energy irrespective of its size and is further supported by the measures proposed by the Ministry of Power through the *Draft Hydro Policy 2017*. This classification of hydropower as a form of renewable energy helped conceptualise an aggressive scenario in which renewables and hydropower dominate and coal plant load factors fall to 40%. However, this scenario relies heavily on snowmelt, monsoons and the perennial flow of peninsular rivers. Table 1 details the power generation mix indicated in this report.

[1] *The IRENA scenarios are all national and do not break down capacity/generation deployment by state.*

Table 1. Power generation mix scenarios, 2014 to 2030 (TWh)

Source of energy (TWh)	2014	IRENA Reference 2030	IRENA REmap 2030	CEA Scenario 1 2027	CEA Scenario 2 2027
Coal	964	2 692	2 171	1 151	872
Natural gas	60	95	95	92	56
Oil	23	17	6	1	0
Nuclear	36	32	32	95	57
Hydro	134	131	230	285	652
Biomass (incl. biogas)	18	35	105	32	64
Solar PV	5	82	346	283	243
CSP	0	0	28	0	0
Wind onshore	33	342	450	188	188
Wind offshore	0	3	8		
Geothermal	0	0	16	0	0
Ocean / tide / wave	0	0	0	0	0
Other				15	
Total	**1 273**	**3 428**	**3 487**	**2 142**	**2 132**

CSP = concentrating solar power; TWh = terawatt-hours

A question arises as to the low values of CEA power generation numbers vis-à-vis the IRENA scenarios. In its NDC, India discusses a 33% to 35% reduction in emissions intensity by 2030. Energy efficiency is one way to achieve this. The reduced overall generation figure might result from that lower demand – a function of changes in economic growth rates. The NEP produced by CEA shows an electricity savings target of 336.36 terwatt-hours (TWh) by 2027, which is reflected in the scenarios. In addition, the CEA analysis takes the view that both older coal-fired units with a lifetime of more than 40 years and smaller units with up to 100 megawatt (MW) capacity are retired.

By contrast, the REmap options for India originate from a range of studies that include the National Institution for Transforming India (NITI Aayog, formerly the Planning Commission), the Global Change Assessment Model and the NDC for the power sector. Additionally, expert opinion from the Ministry of New and Renewable Energy (MNRE), IRENA and other academic/quasi-academic experts was incorporated into the analysis. IRENA's Reference 2030 case represents policies in place or under consideration, including any energy efficiency improvements contained in these projections. See IRENA (2016) for further details.

Parameters

Three key parameters are used in this analysis:

i) freshwater consumption and withdrawal intensity (by fuel and cooling technology);

ii) share of different cooling technologies in the mix (by fuel, 2014 and 2030[2]); and

iii) carbon dioxide intensity of power generation (by fuel).

A short description for each of these parameters follows.

Freshwater withdrawal and consumption intensity

When available, country-specific data is used for both water withdrawal and consumption intensity of different types of power plants, all of which use different fuels and cooling technologies. When country-level data were not available for specific power or cooling technologies, these metrics were drawn from similar contexts. For example, they were based on data used by IRENA and China Water Risk (IRENA and CWR, 2016b) relating to plants in China or on global averages from the literature (summarised in Table 2).

In the paper, water consumption and withdrawal includes uses in thermal power generation (coal, oil or natural gas), nuclear power, biomass power, solar PV and concentrated solar power (CSP). Water use for hydropower is not considered, as this paper focuses only on water withdrawal and consumption for cooling thermal power plants and washing solar PV arrays.

Assumptions on future water withdrawal and consumption factors in this paper are outlined below.

- According to the NEP 2016, all existing once-through thermal plants, whose cooling systems only once use the water's cooling capacity, typically withdrawing a large volume of water and discharging it after a single use (GE Power & Water, 2018) must be retrofitted to recirculating systems and achieve a withdrawal intensity of 3.5 m^3 per megawatt-hour (MWh). All existing recirculating plants must also achieve 3.5 m^3/MWh intensity.
- The NEP plan also states that all new thermal plants installed after January 2017 have to meet a water withdrawal intensity of 2.5 m^3/MWh or less and achieve zero discharge.
- The share of other cooling and source water types stays the same.
- For nuclear power, the proportions of generation with cooling by either seawater or freshwater are assumed to stay the same as in the base year, 2014.

[2] *The cooling technology mix is considered the same in both the CEA 2027 and IRENA 2030 scenarios.*

Table 2. Intensity of water consumption and withdrawal by source of energy

Source of energy and cooling type	Fresh water withdrawal (m^3/MWh)			Fresh water consumption (m^3/MWh)			Reference
	Baseline in 2014	Existing plants after 2030 upgrade	New plants in 2030	Baseline in 2014	Existing plants after 2030 upgrade	New plants in 2030	
Biomass - dry	0.13	0.13	0.13	0.13	0.13	0.13	NREL, 2012
Biomass - recirculating	3.32	3.32	2.50	2.09	2.09	2.50	NREL, 2012
Coal - dry	0.31	0.31	0.31	0.31	0.31	0.31	IRENA, 2016
Coal - once-through	216	216	216	1.56	1.56	1.56	CEEW, 2017
Coal - recirculating	3.79	3.50	2.50	2.59	2.57	2.50	CEEW, 2017
Gas - dry	0.06	0.06	0.06	0.06	0.06	0.06	IGES, 2013
Gas - recirculating	1.62	1.62	1.62	1.17	1.17	1.17	CEEW, 2017
Nuclear - once-through	242.71	242.71	242.71	1.45	1.45	1.45	CEEW, 2017
Nuclear - recirculating	6.42	6.42	6.42	3.82	3.82	3.82	CEEW, 2017
Oil - dry	0.06	0.06	0.06	0.06	0.06	0.06	IGES, 2013
Oil - recirculating	1.62	1.62	1.62	1.17	1.17	1.17	CEEW, 2017
CSP - recirculating	2.68	2.68	2.68	2.67	2.67	2.67	CEEW, 2017
CSP - dry	0.20	0.20	0.20	0.20	0.20	0.20	CSE, 2015
Solar PV - none	0.08	0.08	0.08	0.08	0.08	0.08	Solar PV developers: Cleanmax Solar, CLP India
Geothermal - Recirculating	6.80	6.80	6.80	3.42	3.42	3.42	NREL, 2012

CEEW = Council on Energy, Environment and Water (India);
CSE = Centre for Science and Environment (India);
IGES= Institute for Global Environmental Strategies (Japan);
NREL = National Renewable Energy Laboratory (U.S.).

Cooling technologies

We also assessed the current proportion and estimated evolution of cooling technologies to 2030 in power plants using once-through, recirculating or dry cooling. The model also differentiates between plants either cooled by seawater or by freshwater. Table 3 summarises the proportion and estimated evolution of cooling technologies to 2030.

The 2014 baseline sources for water, cooling and fuel type distributions in Table 3 have been built using the Platts database as inventory for plants and their capacity, and CEA's daily reports for generation data, along with WRI analysis on cooling and source water identification. The detailed, step-by-step methodology can be found in WRI (2018). The projected 2030 distributions arise from the 2014 baseline with adjustments assuming that the proposed regulations from the Ministry of Environment, Forest and Climate Change are successfully implemented, as described in the analysis.

Table 3. Proportion and estimated adoption of cooling technologies to 2030

Water source	Source of energy	Cooling type	% share in generation	
			2014 baseline	2030 projection
Fresh water	Biomass	Dry	4.9%	4.9%
Fresh water	Biomass	Recirculating	95.1%	95.1%
Fresh water	Coal	Dry	0.9%	0.9%
Fresh water	Coal	Once-through	6.2%	0.0%
Fresh water	Coal	Recirculating	83.9%	90.1%
Seawater	Coal	Once-through	4.5%	0.0%
Seawater	Coal	Recirculating	4.4%	8.9%
Fresh water	Gas	Dry	17.0%	17.0%
Fresh water	Gas	Recirculating	82.8%	82.8%
Seawater	Gas	Recirculating	0.1%	0.1%
Fresh water	Nuclear	Once-through	20.9%	20.9%
Fresh water	Nuclear	Recirculating	39.1%	39.1%
Seawater	Nuclear	Once-through	39.9%	39.9%
Fresh water	Oil	Dry	1.2%	1.2%
Fresh water	Oil	Recirculating	96.9%	96.9%
Seawater	Oil	Recirculating	1.9%	1.9%
Fresh water	CSP	Recirculating	100.0%	100.0%
Fresh water	Geothermal	Recirculating	100.0%	100.0%

Carbon emissions

In addition, the emissions impact of the generation mix was analysed, as outlined in the four scenarios described earlier.

The carbon dioxide (CO_2) emissions for different power types are based on the CO_2 Baseline Database for the Indian Power Sector issued by CEA as part of its CO_2 Baseline for the appropriate year. However, the values for biomass are taken from the Intergovernmental Panel on Climate Change Technology-specific Cost and Performance Parameters, 2014 (Schlömer, *et al.*, 2014).

Carbon dioxide emissions per kilowatt-hour (kWh) for biomass are considered constant through to 2030. The trend in the variation of specific emissions from the other sources is documented from FY 2011-2012 to FY 2015-2016. (Table 4).

Table 4. Carbon dioxide emissions intensity of power generation in India, 2012-2016

gCO_2/kWh	2012	2013	2014	2015	2016
Coal	1 043	1 033	1 015	995	990
Diesel	590	613	590	573	570
Natural gas	465	485	490	468	460
Lignite	141	139	136	136	136
Oil	625	628	638	895	980

The trend for 2012-2016 is assumed to continue until 2030. However, for oil only the trend from 2012-2014 is considered because of abnormal variations in 2015 and 2016. This is mainly because of improving technology and stricter standards. The 2030 specific emissions are thus documented in Table 5.

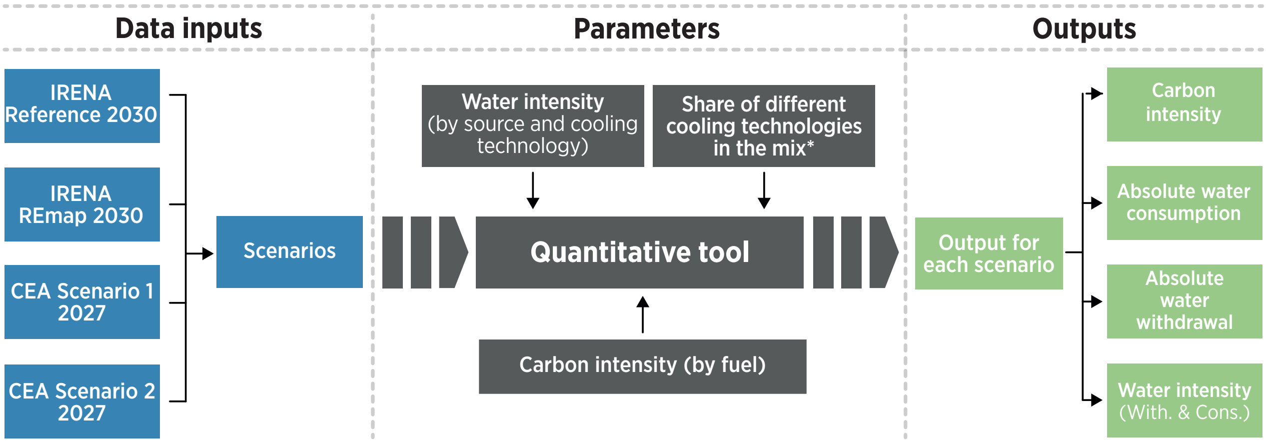
Table 5. Carbon dioxide emission of power generation in India, 2030

Source of energy	Carbon emissions (g/kWh)
Coal	810
Natural gas	500
Biomass (incl. Biogas)	230
Diesel	510
Lignite	1170
Oil	980

Methodology

The methodology followed in the present analysis is illustrated in the figure below.

Figure 1. Analytical approach



* A sensitivity analysis may be needed when strong assumptions are made regarding the evolution of the cooling technology mix in the power sector.

The generation mix for each scenario outlined in Table 1 has been further split into generation from upgraded old plants and new plants, as shown in Table 5.

Table 6. Absolute generation across different energy sources and plant types

Source of energy	2014 generation	Generation (TWh) from upgraded old plants				Generation (TWh) from new plants			
		IRENA Reference 2030	IRENA REMap 2030	CEA Scenario 1 2027	CEA Scenario 2 2027	IRENA Reference 2030	IRENA REMap 2030	CEA Scenario 1 2027	CEA Scenario 2 2027
Biomass	18	16	19	19	10	19	86	45	22
Coal	964	1 078	1 080	540	712	1 614	1 091	332	438
CSP	0	0	1	0	0	0	27	0	0
Gas	60	95	95	43	70	0	0	13	21
Geothermal	0	0	0	0	0	0	16	0	0
Hydropower	134	121	132	361	167	10	98	290	134
Nuclear	36	31	31	18	30	1	1	39	65
Ocean/ tide/ wave	0	0	0	0	0	0	0	0	0
Oil	23	17	6	0	1	0	0	0	0
Solar PV	5	5	5	5	6	77	341	238	277
Wind	33	53	53	42	42	291	405	146	146
Total	**1 273**	**1 417**	**1 422**	**1 029**	**1 038**	**2 012**	**2 065**	**1 103**	**1 103**

The engine for the present analysis is the quantitative tool described below. The tool takes the year 2014 as a baseline for both the power generation mix and installed capacity. The tool forms a baseline using WRI (2018) analysis of India's cooling technology distribution and water withdrawal and consumption factors. It generates projected future distribution and factors for India based on notified regulation from the Ministry of Environment, Forests and Climate Change. The tool differentiates between power generation from existing plants and from plants built just after the baseline year 2014, assuming they operate at the same capacity factor in 2027 or 2030, depending on the scenario. Modelling for changes to future cooling distribution and intensity factors capture cooling technology advancement and plant efficiency enhancement at the national level.

Results and interpretation

Outputs

The quantitative analysis produces the following outputs for different scenarios tested:

i) absolute freshwater consumption in the power sector, excluding hydropower (m^3);

ii) absolute freshwater withdrawal in the power sector, sector, excluding hydropower (m^3);

iii) freshwater consumption and withdrawal intensity, excluding hydropower (m^3/MWh); and

iv) CO_2 emissions intensity of power generation (gCO_2/kWh).

The quantitative impacts calculated account for two factors: a) cooling technologies in both conventional power plants and renewable energy technologies; and b) how each of these contributes to the changing water intensity of power generation (excluding hydropower) under different scenarios.

Total CO_2 emissions across scenarios by source were calculated in tonnes by multiplying the emissions intensity of each source by its corresponding generation. On this basis, the total emissions intensity (gCO_2/kWh) for the sector was calculated by dividing total annual emissions by total generation.

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The following renewable energy developers provided additional data on power-sector-related withdrawal and consumption: Cleanmax Solar, CLP India (solar PV); Megawatt Solutions Pvt (solar thermal) and CLP India (wind).

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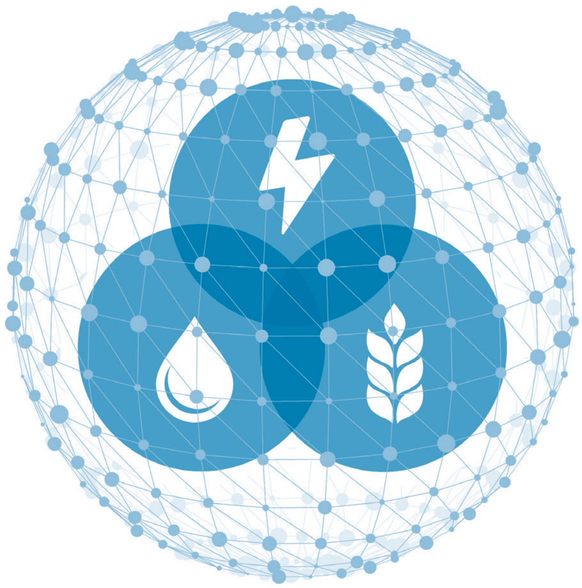

ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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ABOUT WRI

WRI is a global research organisation that turns big ideas into action at the nexus of environment, economic opportunity and human well-being. Its work focuses on six critical issues: climate, energy, food, forests, water, and cities and transport.