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WATER USE IN INDIA'S POWER GENERATION: IMPACT OF RENEWABLES AND IMPROVED COOLING TECHNOLOGIES TO 2030

This paper examines the impact of changes in cooling technologies mandated for thermal power plants and an increased share of renewable energy, on freshwater use (excluding hydropower) and on carbon emissions to year 2030. The analysis builds on previous work undertaken by the World Resources Institute (WRI) and the International Renewable Energy Agency (IRENA), and draws on the commitment made by India at the 2015 Conference of Parties (COP 21) of the United Nations Framework Convention on Climate Change (UNFCCC). The analysis contributes to the growing discourse on integrating water considerations into power sector planning for thermal and renewable energy development.[1]

SUMMARY

» **The power sector contributes to and is affected by water stress.** Rapid growth in freshwater-intensive thermal power generation can contribute to water stress in the areas where plants are located. Power generation is expected to account for nearly 9% of national water consumption by 2050 (in a business-as-usual scenario) – growing from 1.4% in 2025 (Central Water Commission, 2015) and this figure is likely to vary quite significantly from region to region. There is a mismatch between water demand and supply when usable surface water capacity and replenishable groundwater levels are considered. Water stress is particularly acute in naturally arid regions and areas where water is also needed for other uses such as irrigation. Confronted with growing risks to water and energy security, the power sector needs long-term approaches to reduce its dependence on freshwater while also meeting other environmental objectives such as reducing atmospheric, water and soil pollution.

» **The combination of improved power plant cooling technologies and renewable energy technologies, especially solar PV and wind, could lessen the intensity of freshwater use and carbon intensity of the power sector.** In its Nationally Determined Contribution (NDC), India committed to increasing the share of non-fossil sources in its installed power capacity to 40% by 2030. India has a related target of 175 gigawatts (GW) of renewables capacity by 2022, including 100 GW of solar PV and 60 GW of wind. As solar PV and wind power require significantly less water than conventional and other renewable sources during the operational phase, their substantial uptake could contribute to a reduction in freshwater use as well as carbon intensity of power generation. Simultaneously, phasing out once-through cooling technologies at existing power plants and restricting their installation at new thermal plants, through enforcement of the announced regulatory water use standards, will substantially reduce water withdrawal.

» **By 2030, the water withdrawal intensity of the electricity generation (excluding hydropower) could be reduced by up to 84%, consumption intensity by up to 25%, and CO_2 intensity by up to 43% in comparison to the 2014 baseline.** Under all scenarios analysed, the Indian power sector's freshwater and CO_2 intensity (excluding hydropower) would substantially fall compared to the 2014 baseline. Even as intensities reduce, changes to absolute water withdrawal and consumption in 2030 vary. The transition from once-through to recirculating cooling systems will drastically reduce withdrawal but will increase total water consumption in most scenarios. Coupled with continuing thermal and renewable capacity development, total water consumption in 2030 is estimated to increase by up to 4 billion cubic metres (m^3). Measures discussed in this brief to reduce freshwater and carbon intensity complement demand-side measures, such as energy efficiency improvements, thus warranting an integrated approach to power sector planning.

[1] This paper and the related methodology can be found online at http://irena.org/publications and at www.wri.org/publication.

ENERGY AND WATER INTERLINKAGES

Accelerated economic growth in the past two decades in India is correlated with rapid increase in energy demand. Annual national electricity consumption has grown by more than 25% within five years (2011-2016) to 1 002 terawatt-hours (TWh). A significant portion of this is industrial consumption (42%), followed by domestic (24%) and agriculture (17%) (Ministry of Statistics and Programme Implementation, 2017).

A major share of India's electricity (85%) is generated from fossil fuel (coal and natural gas) and nuclear plants, which rely significantly on freshwater for cooling purposes[2]. Water use in the power sector is measured using two distinct metrics. Withdrawal is defined as the "*freshwater taken from ground or surface water sources, either permanently or temporarily, and conveyed to a place of use*" (Organisation for Economic Co-operation and Development, n.d.). Consumption refers to withdrawals that are not returned to the original source.

Natural water supply sources are subject to increased overuse leading to resource depletion. WRI's India Water Tool[3] shows that 54% of India's groundwater wells face high to extremely high water stress. This is caused by erratic rainfall, irrigation pumps that run on subsidised electricity and unsustainable management of groundwater (India Water Tool and World Resources Institute, 2015).

Against this background, the energy sector is expected to consume a steadily increasing share of the available water resources. The sector's relative water consumption is projected to grow from 1.4% to 9% between 2025 and 2050 (from 15 billion m^3 to 130 billion m^3 annually) (Central Water Commission, 2015). All sectors, including irrigation, energy and drinking water, see a growing demand for water. In 2050, total water demand is forecast to reach 1 400 billion m^3. The comparable annual figure for usable surface water capacity is around 690 billion m^3 and potentially replaceable annual ground water capacity amounts to 433 billion m^3 (Central Water Commission, 2015).

The mismatch between demand and supply could affect the availability of water for different end uses, increasing risk of competition, particularly in water-constrained areas. Furthermore, as demand increases, water will need to be pumped from sources further away or from deeper underground, thus increasing energy demand (IRENA, 2015).

For the power sector, water availability directly impacts all plants to varying degrees. WRI analysis shows that shutdowns related to water shortages in 2016 resulted in the loss of roughly 14 TWh of thermal electricity generation – equivalent to the annual power use in India's North-Eastern region (WRI, 2017; Central Electricity Authority, 2017a). The present paper covers thermal and non-hydropower renewable electricity, whose operational water risks[4] differ from those of large hydropower plants. Differences arise from the extent to which water considerations are integrated into planning and plant design; water quality requirements (*e.g.* impact of input water temperature increase on thermal generation efficiency); resilience to variability in water supply; and the complexity of competition with other end uses (*e.g.* upstream and downstream impacts for large hydropower).

THE ROLE OF HYDROPOWER

Hydropower plays a key role in India's power sector. The development of large hydropower requires a careful consideration of the water-energy-food nexus. Water use in hydropower generation is normally associated with evaporative losses (consumption) from the reservoirs. Given the multi-purpose nature of hydropower infrastructure (*e.g.* irrigation, water supply, flood control), evaporative losses from reservoirs cannot always be attributed entirely to power generation. For this reason, water use in hydropower generation has been excluded from this analysis, which concentrates specifically on the freshwater intensity of thermal and solar PV, wind power and select other renewable power options.

[2] *A number of power plants, especially nuclear, use seawater for cooling. However, these have been excluded from this analysis, which is devoted to freshwater use in the power sector. The methodology provides details on the related assumptions (e.g. proportion of nuclear generation based on seawater cooling). The use of treated sewage water for cooling was recently mandated for thermal power plants within 50 kilometres of treatment plants (Ministry of Power, 2016). However, this is marginal at present, and insufficient data are available to assess its use to 2030.*

[3] *The India Water Tool is an online tool for companies and other users to understand their water risks and prioritise actions toward sustainable water management. The tool can be accessed at www.wri.org/resources/maps/india-water-tool.*

[4] *The analysis does not account for water use in fuel processing or equipment manufacturing.*

In response to growing concern over water shortage and its economic impact on plants, the Ministry of Environment, Forest and Climate Change (MoEF & CC) published the rules listed below on 7 December 2015 (MoEF & CC, 2015):

- All thermal power plants with once-through cooling[5] are expected to install cooling towers and to achieve specific water consumption[6] of 3.5 m^3 per megawatt-hour (MWh) by December 2017 (within two years of notification).
- All existing plants using cooling towers shall reduce specific water consumption down to a maximum of 3.5 m^3/MWh by December 2017 (within a period of two years of notification).
- New plants installed after 1 January 2017 must meet specific water consumption of 2.5 m^3/MWh and achieve zero water discharge.[7]

To comply with changes in national regulations and to mitigate operational risks, operators of existing and new thermal power plants are expected to move towards improved cooling technologies. Coupled with the growing share of solar PV and wind energy in the power generation mix, this will have a strong influence over the future water and CO_2 intensity of the non-hydroelectric power sector. The analysis presented in this paper aims to quantify these impacts.

Thar desert - wind power plants and a local man leading camel caravan. India (c) Matyas Rehak | Shutterstock.com

[5] Once-through systems take water from nearby sources (e.g. rivers, lakes, aquifers or the ocean), circulate it through pipes to absorb heat from the steam in systems called condensers, and discharge the warmer water to the local source.

[6] Amount of freshwater consumed while producing 1 MWh of electricity.

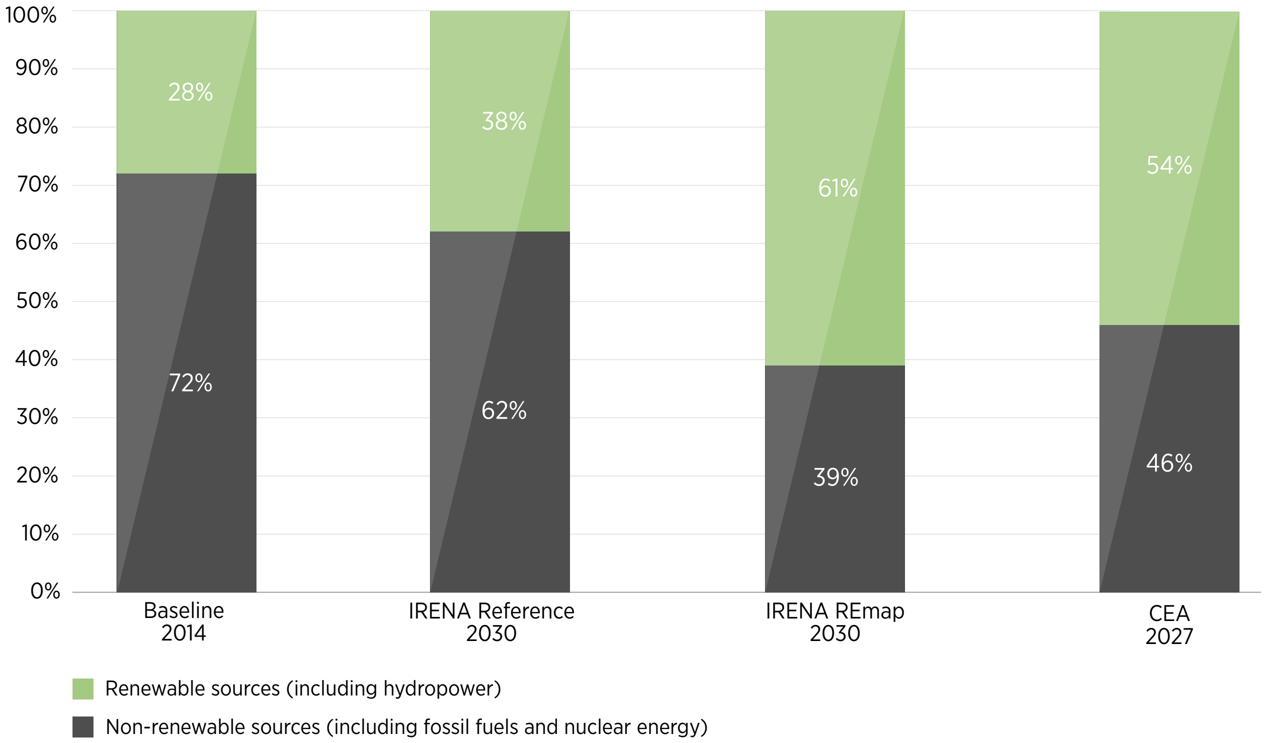
[7] This requirement has been relaxed to 3 m^3/MWh through a draft Ministry of Environment, Forest and Climate Change notification from October 2017 (MoEF & CC, 2017 - draft).

PATHWAYS TO POWER SECTOR GROWTH

Renewable energy is a key pillar of India's strategy to meet growing electricity demand while addressing environmental and energy security objectives. Recent cost reductions in solar PV and wind technologies have made these technologies increasingly cost-competitive for capacity additions compared to conventional technologies. Renewable energy deployment in India has grown at an average rate of 9% between 2006 and 2016 (IRENA, 2017a). Total capacity reached 61 GW in 2017 with contributions from wind, solar, small hydropower, and bioenergy (Ministry of New and Renewable Energy, 2017). In its NDC, the government committed to increasing the share of non-fossil sources – including hydropower – in installed capacity from 30% in 2015 to 40% in 2030 (Government of India Press Information Bureau, 2015). This incorporates a target for deploying 175 GW of renewables by 2022, including 100 GW solar, 60 GW wind and 10 GW biomass (Climate Action Tracker, 2017).

In its REmap study[8] for India, IRENA formulated two scenarios for the power sector's development to 2030: the Reference[9] and REmap cases. In the former, 38% of the installed capacity would be based on renewable sources (including hydropower), while the latter envisages a share of 61% (IRENA, 2017b). The CEA in India also puts forth a generation capacity mix scenario projected to year 2027, as illustrated in Figure 1 (CEA, 2016)[10].

Figure 1. India's installed power capacity under different scenarios



Based on IRENA (2017b) and CEA (2017b).

[8] IRENA's REmap programme determines the realisable potential for countries, regions and the world to scale up renewables. It provides a roadmap towards 2030 for countries to ensure an affordable and sustainable energy future. One of the recent REmap publications is "Renewable Energy Prospects for India" (IRENA, 2017b). The data on the Reference Case and REmap 2030 options are based on IRENA (2017b). The roadmap is subject to updates as new policies and regulations are introduced.

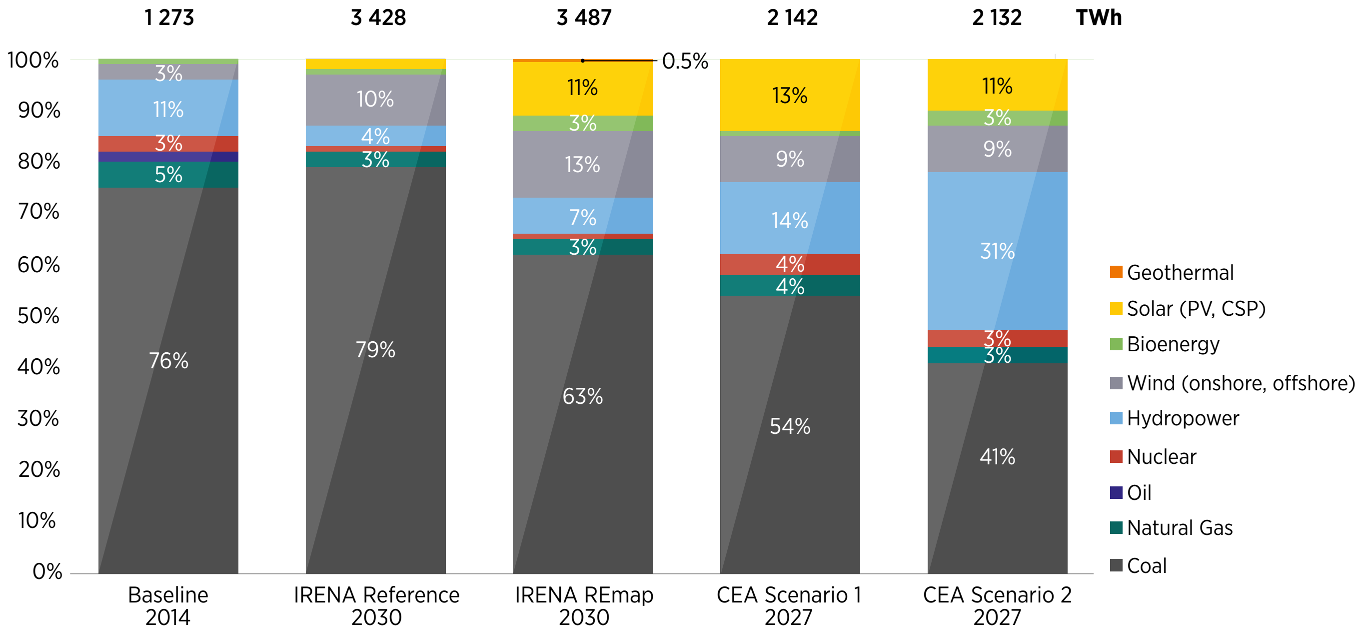
[9] The Reference Case for 2030 is a pathway under business-as-usual conditions, while REmap 2030 reflects an accelerated deployment scenario more in line with NDC objectives. More details on the scenarios are available in the methodology.

[10] 2014 is the baseline year in this analysis because it is the latest year for which complete and disaggregated generation and capacity data (by source) are available in both the International Energy Agency and the CEA datasets. Furthermore, given that policies driving renewable energy and changes to cooling technologies were introduced in 2015, the 2014 baseline is considered appropriate for this analysis.

Renewable generation (including hydropower) would reach a 17% share in the Reference Case and a 34% share in the REmap case, compared to 15% in 2014 (Figure 2). Keeping the CEA capacity mix the same, two scenarios have been derived that vary mostly according to hydropower and coal in the generation mix (see methodology). CEA Scenarios 1 and 2 see the share of renewables grow to 38% and 54% respectively, as shown in Figure 2. Most scenarios show substantial growth in renewable generation from solar PV and wind. Solar power represents 2% in IRENA's Reference Case, rising to more than 10% under REmap 2030 and both CEA 2027 scenarios. While absolute hydropower generation is projected to rise in each scenario, its share will contract under the Reference and REmap cases, and grow to 14% (CEA Scenario 1) or even 31% (CEA Scenario 2) in 2027.

The four scenarios examined here represent a wide range of growth pathways for the power sector in India. A critical difference between the IRENA and CEA scenarios is the total estimated generation in 2030 and 2027, respectively. As detailed in the methodology, the difference is largely due to the varying approach to energy efficiency in each scenario (a likely result of differing assumptions for economic growth, energy intensity of growth, etc). The CEA scenarios reflect electricity saving targets of 336 TWh by 2027, as well as the retirement of older thermal generation capacity – plants that would have been in operation for 40 years or more (CEA, 2016). Despite the differences in the total generation, it is assumed that the cooling technology mix would not significantly change between scenarios. The remainder of the paper analyses the water and carbon implications of the four scenarios.

Figure 2. India's power generation under different scenarios by source



Note: Concentrating Solar Power (CSP) accounts for a negligible share of solar generation (less than 1% in the REmap 2030 scenario).

Based on data from IRENA (2016), IRENA (2017a), International Energy Agency (2014), CEA (2016), CEA (2014).

IMPACTS ON WATER WITHDRAWAL, CONSUMPTION AND CARBON EMISSIONS

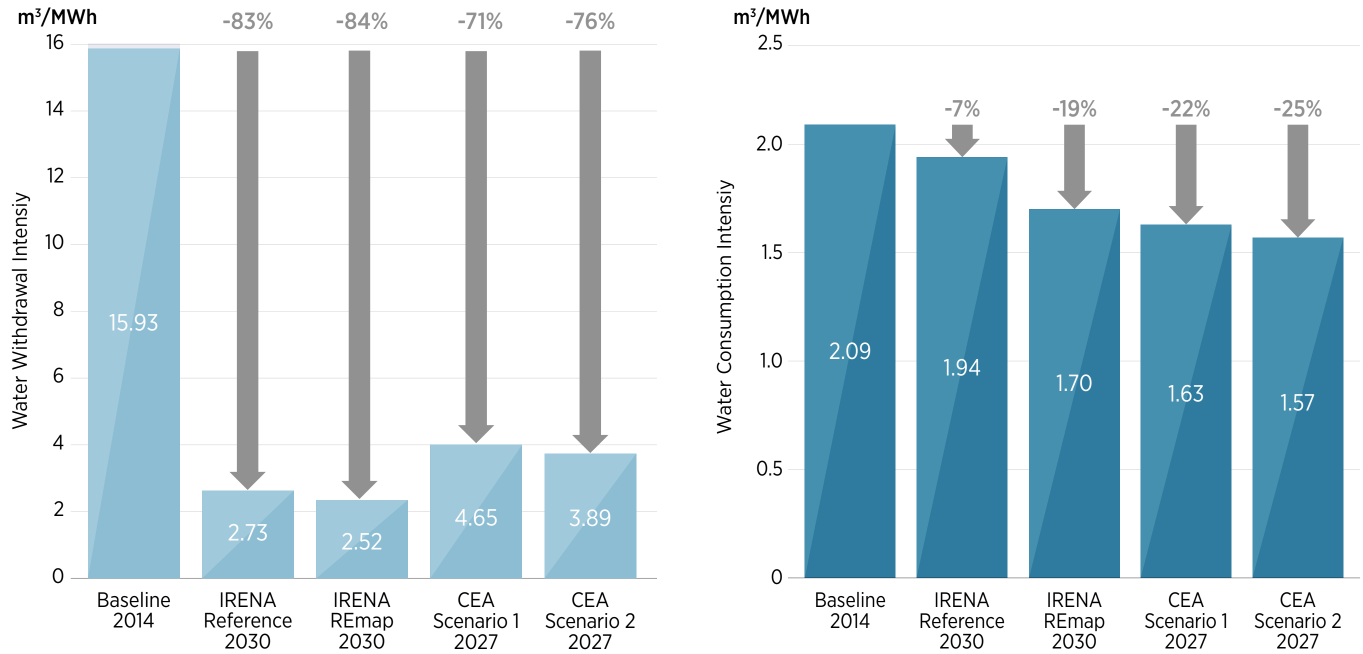
Water withdrawal and consumption

The current water withdrawal intensity of India's power sector (excluding hydroelectricity) is largely driven by thermal power plants using once-through cooling systems. Withdrawal intensity could be reduced by upgrading plant cooling technology (Council on Energy, Environment and Water, 2017) and by supporting the development of less water-intensive generation technologies (European Wind Energy Association, 2014; National Renewable Energy Laboratory, 2015). For instance, the operational withdrawal intensity of solar PV in India is around 0.08 m^3/MWh (primarily related to panel cleaning), which is only 0.5% of the thermal average, while for wind, the water withdrawal is zero.

The quantitative analysis presented in this brief examines changes in the freshwater intensity of thermal and renewable power generation for the four scenarios presented earlier. It also estimates the total water withdrawal and consumption for different power generation options across the scenarios, based on trends in cooling technology and power plant efficiency[11]. The results, referenced to a 2014 baseline, are listed below (Figure 3).

- **IRENA Reference 2030:** water withdrawal intensity would decrease by about 83%, and water consumption intensity would decrease by 7%.
- **IRENA REmap 2030:** water withdrawal intensity would decrease by about 84%, and water consumption intensity would decrease by 19%.
- **CEA Scenario 1 2027:** water withdrawal intensity would decrease by about 71%, and water consumption intensity would decrease by 22%.
- **CEA Scenario 2 2027:** water withdrawal intensity would decrease by about 76%, and water consumption intensity would decrease by 25%.

FIGURE 3. CHANGE IN WATER WITHDRAWAL (LEFT) AND CONSUMPTION (RIGHT) INTENSITY OF THERMAL AND NON-HYDROPOWER RENEWABLE GENERATION, BY SCENARIO (RELATIVE TO 2014)



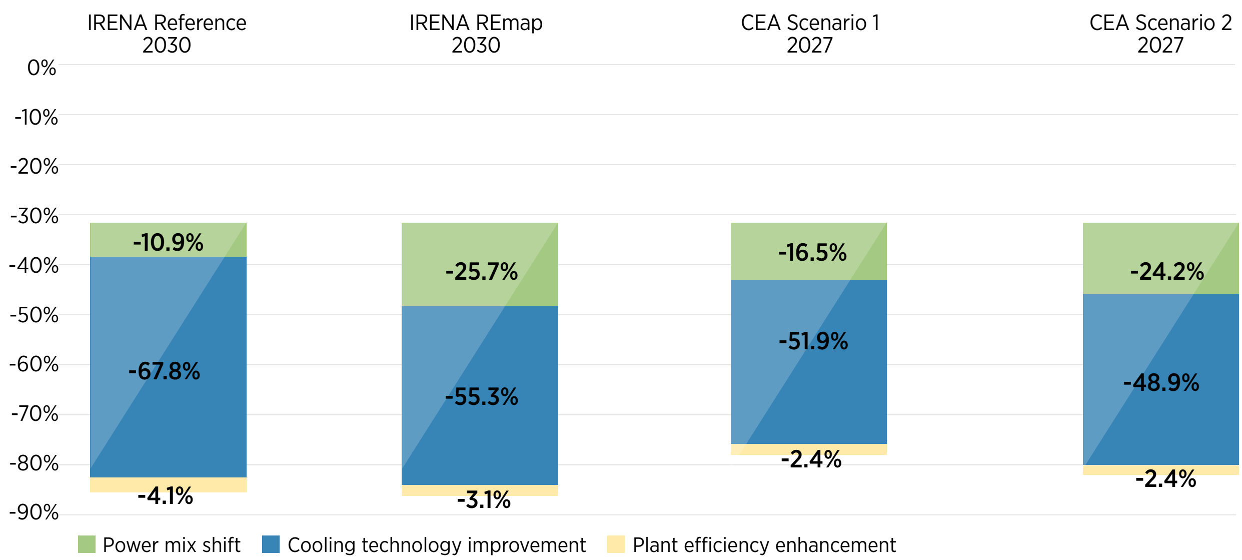
IRENA/WRI analysis

[11] *Details on the methodology, including data inputs (e.g. water and carbon intensity factors by technology), sources and assumptions, can be found in the supplementary document.*

Compared to 2014, all scenarios see a decrease in **withdrawal intensity**, which is predominantly due to the shift towards improved cooling technology at thermal power plants (*i.e.* from once-through cooling to recirculating cooling) driven by regulations and mandates discussed earlier. Figure 4 illustrates the key drivers contributing to the change in water withdrawal intensity for each scenario. The contribution from the power mix shift rises in scenarios with a higher share of less water-intensive renewables, such as solar PV and wind (as seen in the IRENA scenarios) and lower share of coal generation (as in the CEA scenarios). Power plant efficiency improvements, based on India's new draft National Electricity Plan (CEA, 2016), also contribute, although less significantly than other factors.

The difference between IRENA Reference 2030 and REmap 2030 is relatively low (2.73 and 2.52 m^3/MWh respectively). This is because REmap 2030 considers a higher share of biomass, CSP and geothermal, all of which have high operational water needs (not considering the adoption of dry cooling technologies) that partly offset the savings achieved from a reduced share of coal within the fuel mix. Neither of the CEA cases consider CSP or geothermal, but each includes more nuclear generation, which implies high water withdrawal when plants are freshwater-cooled.

Figure 4. Key drivers of change in water withdrawal intensity by scenario

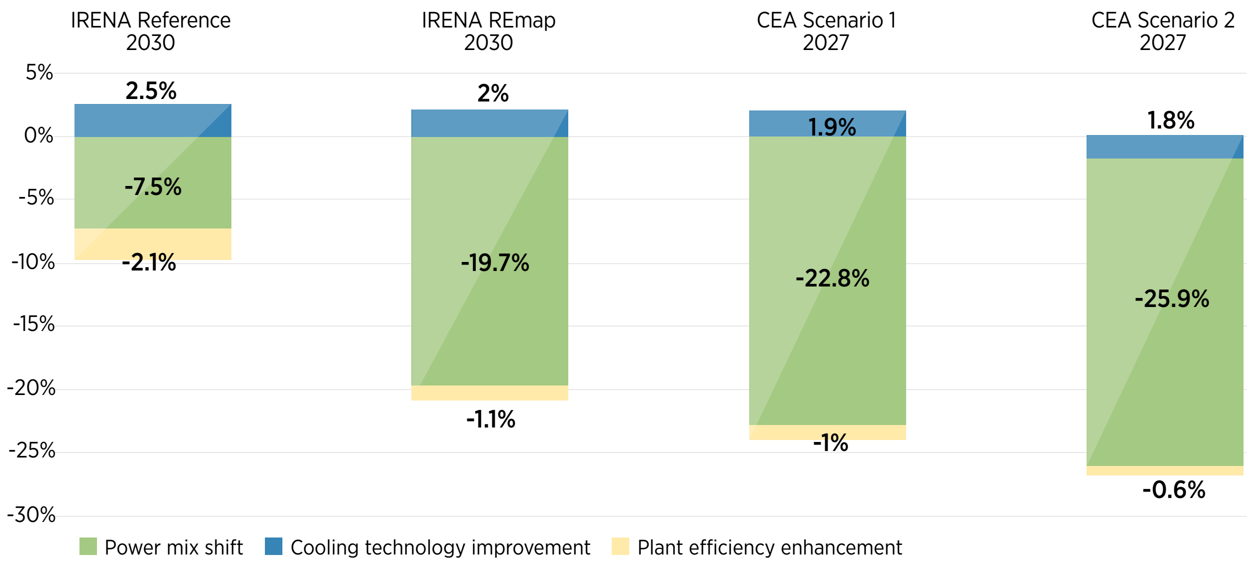


IRENA/WRI analysis.
Note: excludes large hydropower .

Compared to the 2014 baseline, the overall **consumption intensity** decreases across all scenarios. The contributing factors are shown in Figure 5. The IRENA Reference 2030 scenario shows a minor reduction compared to 2014 due to the growth of wind and solar PV which reduce consumption. This is in part offset by the rise in consumption from existing thermal plants switching cooling technology, and from new thermal capacity commissioned by 2030.

By contrast, a greater reduction occurs in the REmap 2030 scenario as the share of solar PV and wind grows further and coal generation reduces. The drivers are similar for CEA scenarios, although reductions are more significant given greater renewable energy penetration in the generation mix as seen earlier in Figure 2. In the long term, the water dependency of power generation will not fall without a major shift in the power mix together with the deployment of more advanced cooling technologies such as dry cooling.

Figure 5. Key drivers of change in water consumption intensity by scenario

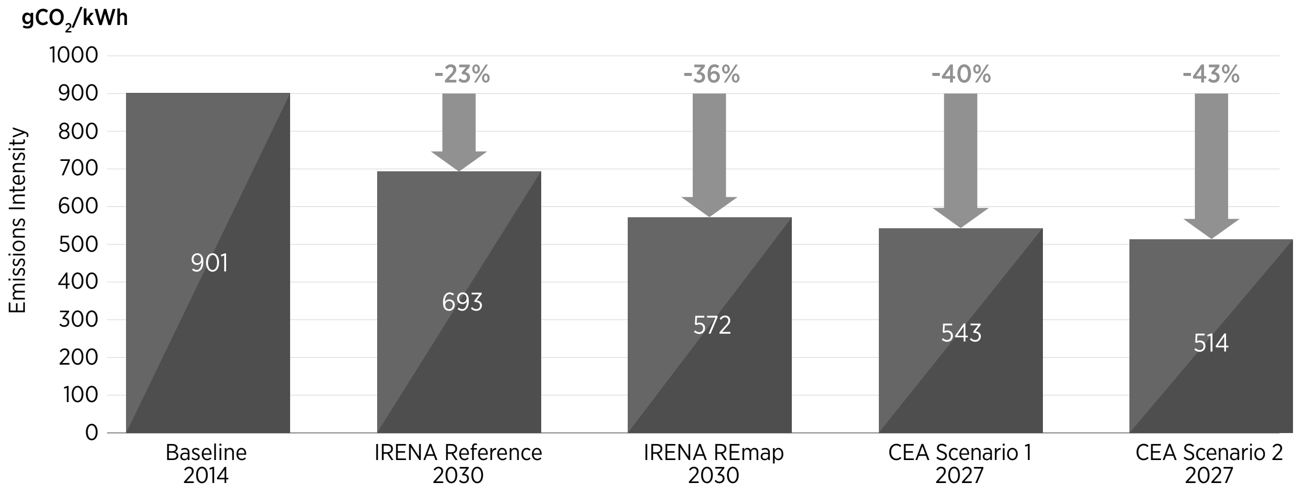


IRENA/WRI analysis.
Note: excludes large hydropower .

Carbon emissions

Increasing the share of non-fossil fuel based electricity is a key component of India's NDC submitted at COP 21. Across all scenarios analysed, a strong decrease in the carbon intensity of power generation can be seen (Figure 6). Compared to the 2014 baseline, adopting IRENA scenarios would reduce emissions intensity by up to 36% in 2030. The CEA scenarios are more aggressive and see a reduction of up to 43%. In India, where the power sector is expected to continue to expand as the demand for electricity increases and universal access is achieved, reduction in the carbon dioxide (and water) intensity help rein in absolute increases.

Figure 6. Change in carbon dioxide intensity of power generation, by scenario



IRENA/WRI analysis; 2014 data based on CEA, 2017c.

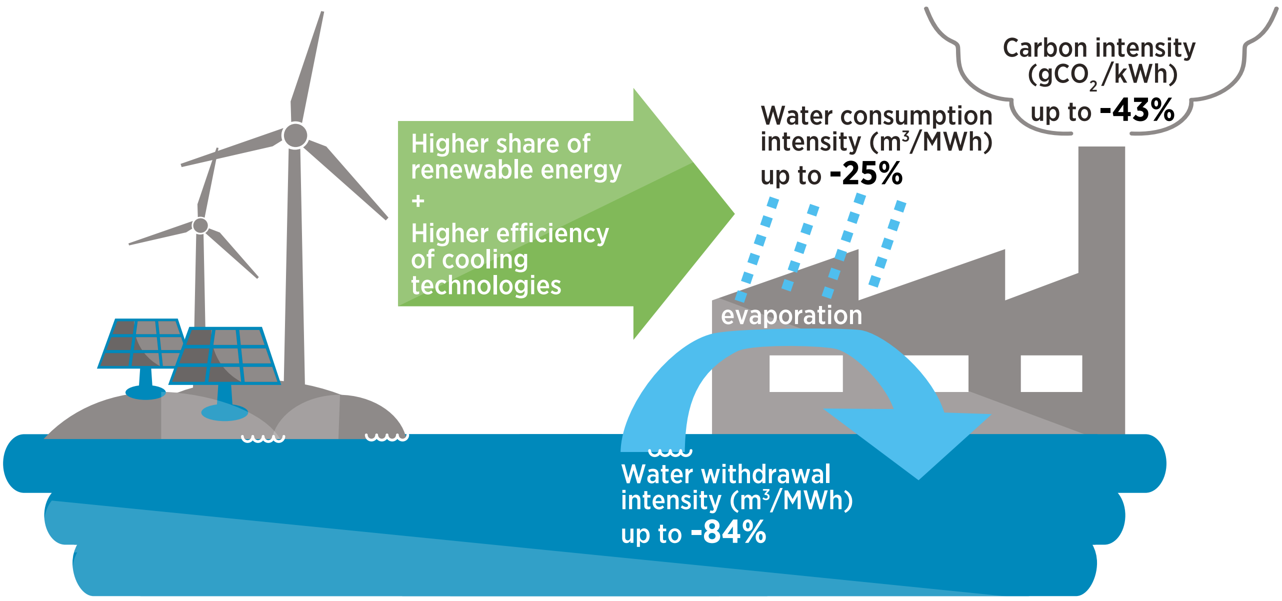
ABSOLUTE WATER AND CARBON SAVINGS

India's energy demand is expected to double, while electricity demand is expected to almost triple by 2030 compared to 2014 (IRENA, 2017c) leading to absolute increases in water consumption and carbon dioxide emissions in some scenarios. However, the lower intensity values achieved through improved cooling technologies and higher shares of solar PV and wind will help realise relative savings in both water and carbon across all scenarios.

Absolute **water withdrawal**, excluding hydropower, is projected to decrease in all scenarios compared to 18 billion m^3 in 2014. Under the IRENA Reference 2030 case, freshwater withdrawal could decrease by half in 2030, largely due to the elimination of once-through systems, representing a reduction of 9 billion m^3 of freshwater withdrawn. Compared to the IRENA Reference Case, water withdrawal is projected to decrease further by 813 million m^3 under the REmap scenario as savings from solar PV and wind increase. Compared to 2014, the absolute withdrawals are projected to reduce by 9.5 billion m^3 under CEA Scenario 1 and over 12 billion m^3 under CEA Scenario 2.

Absolute water consumption is projected to increase in all scenarios compared to 2014, except for CEA Scenario 2, which is projected to see a reduction of 52 million m^3 despite the doubling of the total generation through to year 2030. The primary driver for this reduction is the increase in share of renewable energy and a reduction in electricity generation from coal. In comparison, CEA Scenario 1 is projected to see water consumption rise by over 620 million m^3 in 2027. In the case of the IRENA Reference Case and REmap 2030, an increase of over 4 billion m^3 and 3 billion m^3 is projected respectively in 2030 compared to 2014.

Regarding **carbon dioxide emissions**, in the IRENA Reference Case a rise of more than 1 billion tonnes of CO_2 (tCO_2) is estimated compared to 2014. Adopting REmap options is projected to limit the increase to approximately 82% (840 million tCO_2). CEA scenarios are projected to create an even bigger impact on carbon dioxide emissions, reducing them by between 3% (30 million tCO_2) (Scenario 1) and 26% (around 270 million tCO_2) (Scenario 2).



CONCLUDING REMARKS

This paper has analysed the implications of a changing power mix and improving power plant cooling technologies, both driven by policy action, on water withdrawal, consumption and carbon emissions in the power sector. Four scenarios were considered using previous research conducted by IRENA, WRI and India's CEA. The results of the analysis have shown that:

» The adoption of improved cooling technologies, as well as the deployment of a higher share of wind and solar PV, could substantially decrease water withdrawal and consumption intensity of non-hydropower generation;

» The shift in the power mix towards renewable energy, especially solar PV and wind, is estimated to contribute greatly to a reduction in consumption intensity while cooling technology change is the primary driver of reduction in withdrawal intensity;

» Absolute water withdrawal is lower despite an increase in power generation due to the transition of thermal plants to recirculating cooling. However, in three out of four scenarios analysed, there is an increase in overall water consumption mainly due to increasing aggregate power generation capacity up to the years 2027 and 2030;

» The growth in power sector emissions is projected to decrease across all scenarios analysed, contributing to meeting India's international and national climate commitments.

Continuous policy and regulatory support is required to achieve both water and carbon benefits. On both counts, dedicated policies and mandates have already been introduced - including time-bound targets. However, their effective implementation and enforcement will be crucial to meeting the targets. Furthermore, the magnitude of the impacts presented here demonstrates the importance of integrating water considerations, including associated risks, into power sector planning strategies. Investments in less water-intensive and low carbon technologies offer a pathway to managing the power sector while meeting environmental and energy security objectives.

This paper looks at one part of the water-energy nexus puzzle in the context of India's power sector. Hydropower generation, a key feature of India's generation mix, is itself exposed to water risks associated with resource availability, climate uncertainties and complex interactions between upstream and downstream end uses (WRI, 2018). This paper concentrated on thermal generation and non-hydropower renewables. It acknowledges that an analysis of hydropower is necessary to capture relevant water-energy risks more comprehensively and to integrate into planning processes alongside quantitative analysis such as the one presented in this brief.

The analysis presented here is intended to contribute to a wider discourse on the importance of integrating water considerations. The overall objective is to gain a better understanding of the effectiveness of different measures in reducing freshwater consumption and therefore in reducing the water-dependency of the power sector over the medium term.

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