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Secure and Sustainable Energy in a Water-Constrained World

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The global water needs of the energy sector are large. Without policy changes, they will increase greatly in the future. Already today, water constraints are a risk to a secure electricity supply. In many parts of the world, droughts and heatwaves have led to forced reductions in power generation. Not surprisingly, hydropower has been the most affected energy source. However, generation from nuclear and coal power plants has also been curbed due to constraints on the water needed for cooling. With climate change and a globally rising water demand, competition for water resources will become more intense. Decision-makers will increasingly be forced to make tough choices on water allocation.

So far, energy decision-makers tend to mistakenly consider water an abundant resource that they do not need to worry about in planning. However, the choice of energy sources greatly affects the volumes of water needed for power generation. While technological solutions are available to increase the energy sector's resilience to water constraints, their potential is insufficiently exploited. Alliances between the water sector and water-friendly renewable energy sources can pave the way to meeting global water and energy needs, reconciling socio-economic development with planetary boundaries.

Against this background, the IASS came together with key partners to identify options for enhancing water and energy security at international water and energy conferences: the World Water Weeks 2014[1] and 2015,[2] and the South Africa International Renewable Energy Conference (SAIREC) in 2015.[3] The insights gained in these sessions have informed this Policy Brief. To promote water-resilient electricity generation around the world, the IASS recommends taking the following three steps:

■ **Message 1:** Increase the share of wind power and solar PV in water-scarce regions. Wind power and solar PV are the least water-intensive electricity technologies. In addition, they contribute to mitigating climate-induced water risks due to their very low greenhouse gas emissions.

■ **Message 2:** Incorporate water scarcity into energy decision-making. Charging the energy sector for its water use in a way that better reflects actual water costs and scarcities can be a very effective way to improve water management in the sector. Integrating water scarcity into energy system models for public policy planning is a low-hanging fruit that can have major positive effects.

■ **Message 3:** Enhance transparency on water use in the energy sector. The limited data on actual water requirements in the energy sector in different parts of the world is a fundamental deficiency for informed decision-making. Both private companies and the public sector should therefore significantly improve their monitoring and reporting on water use.

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[1] "Producing electricity with less water", co-organised by the IASS, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Germany), the International Renewable Energy Agency (IRENA), the International Water Management Institute (IWMI), the Turkish Water Institute (TWI) and the World Bank's Thirsty Energy Initiative, Stockholm, 1 September 2014.

[2] "Governing the water-energy nexus: new integrated management practices", co-organised by the IASS, the International Renewable Energy Agency (IRENA) and the World Bank's Thirsty Energy Initiative, Stockholm, 24 August 2015.

[3] "Towards sustainable energy security in a water-constrained world", co-organised by the IASS, Greenpeace Africa, IRENA and the World Bank's Thirsty Energy Initiative, Cape Town, 5 October 2015.

1. Water constraints: a risk for a secure electricity supply

In many parts of the world, water constraints have already compromised electricity supply (see Figure 1 on page 4). Although a global phenomenon, it is the localised reliance and impacts on water resources that makes large hydro- and thermoelectric power plants vulnerable to water constraints. In most cases, droughts and heatwaves have forced power plants to reduce power generation. At the same time, heatwaves often result in increased electricity demand, further compromising the ability to balance supply and demand.

Not surprisingly, it is primarily hydropower generation that has been affected by water constraints. During several long-lasting droughts, hydropower generation decreased significantly due to a lack of water (Table 1). In regions with high shares of hydropower, blackouts and restrictions in electricity demand were experienced during droughts. In 2012, for example, a delayed monsoon reduced hydropower generation in India while raising electricity demand at the same time. This resulted in blackouts that lasted two days and affected over 600 million people.[4] In Brazil in January 2015, more than four million people were affected by electricity rationing and rolling power cuts during the worst drought in Brazilian history. This was mainly due to weak hydropower generation and high demand for air conditioning.[5]

However, nuclear and coal power plants have also been switched off temporarily or have had to be operated at reduced load due to water constraints. Especially in the United States, Europe and Australia there are numerous examples of water-related incidents that compromised power generation from coal and nuclear (Table 1). These regions have large numbers of coal and nuclear power plants and relatively strict environmental regulation. In Poland, for example, a heatwave resulted in reduced power generation from coal power plants due to cooling water constraints in August 2015. As a consequence, the government enforced restrictions on industrial electricity demand.[6] During a heatwave in the summer of 2003, the dominant power utility in France, Electricité de France (EdF), had to temporarily curtail nuclear power generation equivalent to the load of four to five reactors because of high river temperatures.[7] With climate change, the combined impacts of lower river flows and higher river water temperatures may significantly increase the risk of forced reductions in coal and nuclear power generation in Europe and the United States.[8]

Together with climate change, the globally rising demand for water resources will further aggravate water-related risks. By 2050, more than 40 per cent of the global population is expected to live in areas of severe water stress.[9] As a consequence, decision-makers will increasingly be forced to make tough allocation choices in the light of competing water demands, which will impact users across the economy.[10] Moreover, climate change is likely to increase variations in rainfall and the frequency and severity of droughts; rising temperatures are leading to greater evaporation and transpiration by vegetation; and sea-level rise is threatening groundwater in coastal areas.[11]

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[4] International Energy Agency (IEA) (2012): World Energy Outlook 2012.

[5] The Guardian (2015): Brazil's worst drought in history prompts protests and blackouts. 23 January 2015.

[6] PSE S.A. (2015): Information on the situation in the Polish power system. pse.pl/index.php?dzid=32&did=2516.

[7] The Guardian (2003): Heatwave hits French power production. 12 August 2003.

[8] van Vliet,, Michelle T. H. et al. (2012): Vulnerability of US and European electricity supply to climate change. In: Nature Climate Change 2 (9), pp. 676 – 681. DOI: 10.1038/NCLIMATE1546.

[9] UNESCO (2014): Water and Energy. The United Nations World Water Development Report 2014.

[10] World Economic Forum (2015): Global Risks 2015. Geneva.

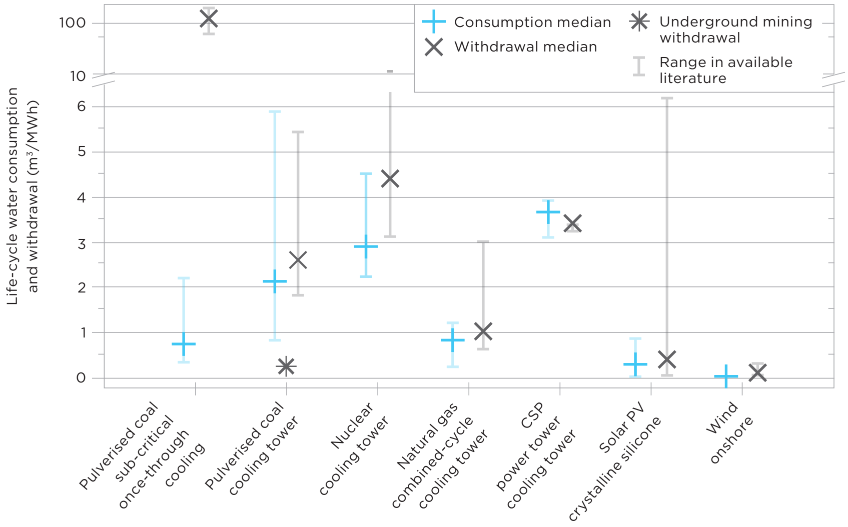
[11] UNESCO (2015): Water for a Sustainable World. The UN World Water Development Report 2015.

Figure 1: Worldwide water stress (Source: WRI Aqueduct 2014).
For indicated locations refer to Table 1.

Table 1: Selected examples for water-induced cuts in hydro (✪ in Figure 1), coal and nuclear (both ✪ in Figure 1) power generation.

Index	Country	Year	Fuel	Impact
1	**Brazil**	2015	Hydro	Electricity rationing and rolling power cuts
2	**USA, California**	2015, 2014	Hydro	Hydro generation in 2014 at 50% of its value in 2013
3	**India**	2012	Hydro	Blackouts lasting two days and affecting over 600 million people
4	**China**	2011	Hydro	Strict energy efficiency measures, electricity rationing
5	**Vietnam, Philippines**	2010	Hydro	Reduced generation, electricity shortages
6	**Ecuador**	2009	Hydro	Electricity crises, blackouts across Ecuador
7	**Uganda**	2006, 2004	Hydro	Reduced generation, supply stress, price increases
8	**Kenya**	2002, 1999	Hydro	Reduced generation by 25%
I	**Poland**	2015	Coal	Restrictions on industrial demand due to reduced coal power generation
II	**Germany**	2015	Coal	Reduced generation from two coal power plants
III	**USA, Connecticut**	2012	Nuclear	One of two reactors shut down due to high sea-water temperatures
IV	**USA, Illinois**	2012	Nuclear	Operation beyond cooling pond temperature limits
V	**USA, Alabama**	2011, 2010, 2007	Nuclear	Reduced generation
VI	**Australia**	2009, 2007	Coal	Reduced generation and electricity price peaks
VII	**France, Germany, Spain**	2006	Nuclear	Reduced generation due to high river water temperatures
VIII	**France**	2003	Nuclear	Reduced generation equivalent to the load of 4 to 5 reactors; operation beyond temperature limits

Figure 2: Life-cycle water consumption and withdrawal for different energy sources and cooling technologies (Source: IASS based on data from Meldrum et al., 2013)



2. Water is often overlooked in energy decision-making

Energy decision-makers tend to mistakenly believe that water is an abundant resource that they do not need to worry about.[12] It is only in the most water-scarce areas of the world that there is a consciousness of the finite nature of water. Water users – in the energy sector and beyond – often treat water as an abundant resource because its value and scarcity are seldom adequately reflected in the prices that consumers pay. In many parts of the world, water consumption is free of charge or prices do not cover costs of supply.[13] In comparison to other sectors, the energy sector's corporate water disclosure is poorly developed.[14] The public sector even lags behind the private sector when it comes to dealing with water risks.[15]

One major reason for the insufficient attention paid to water constraints is a lack of data. In many parts of the world, there is no reliable information on water resources. And even when it is available, it is often not compatible with energy data. A lack of water data is a feature of the energy sector as a whole. However, water requirements are even less understood in energy sectors beyond electricity. And the data gaps become even larger if whole life cycles are considered.[16]

Power imbalances are another major reason for the energy sector's limited consideration of water. As the sector is politically and economically powerful, its water demands tend to prevail over those of other users. In some countries, energy utilities are classified as strategic water users: if the water supply is not able to satisfy competing demands, they are the last to be cut off. The negative impacts of the energy sector's water use – be it reduced availability of water for other users or water pollution – often do not get the political attention they deserve. This is especially the case if the people who are adversely affected are underprivileged groups with little political influence, such as slum dwellers or small farmers.

In addition, water is often overlooked because it falls outside the institutional responsibilities of energy decision-makers. Energy and water are often managed as separate issues. While division of labour and specialisation often bring benefits, they can also lead to blind spots, since decision-makers are less likely to consider issues that lie beyond their responsibilities. Energy and water management are also dealt with at different scales: while energy is often managed at national level, water is typically managed at local level or on a watershed basis. The higher the policy scale, the more difficult policy integration becomes: integrated planning is most likely to be found at local level, while 'silo thinking' increases at national and international scales. Often, there is little incentive to coordinate energy and water policies across sectoral institutions.[17]

The public sector in particular tends to neglect water-related risks in favour of short-term interests. This applies primarily to areas where water is not yet a major risk, but will become one in future. Investment decisions in the energy sector are often driven by short-sighted concerns, even though they cover long time spans and are therefore severely affected by future risks.

[12] See, for example, UNESCO (2015); UNESCO (2014); IRENA (2015): Renewable Energy in the Water, Energy and Food Nexus; World Bank (2013): Thirsty Energy, Water Papers.

[13] UNESCO (2015).

[14] CDP (2014): From water risk to value creation. CDP Global Water Report 2014.

[15] Westphal, K./Roehrkasten,S. (2013): Energieversorgung: Vom Umgang mit internationalen und vernetzen Versorgungsrisiken, in Beisheim, M. (ed.): Der „Nexus" Wasser-Energie-Nahrung, Berlin: SWP.

[16] IRENA (2015); World Bank (2013); UNESCO (2015).

[17] IRENA (2015); UNESCO (2014); World Water Week (2014): Overarching Conclusions.

3. Water is crucial for current power generation

The global water needs of the energy sector are large and will greatly increase in the future if there are no policy changes. In 2010, an estimated 583 billion cubic metres (15 per cent of total global withdrawals) were attributable to the energy sector.[18] Water consumption[19] accounted for about 66 billion cubic metres (equivalent to the volume of a cube with an edge length of 4 km). According to the IEA's New Policies Scenario in the *World Energy Outlook 2012*, global water withdrawals from the energy sector will increase by about 20 per cent and consumption will rise by about 85 per cent by 2035.

Power generation accounts for the bulk of water use in the energy sector and a large share of total water use in industrialised countries. Conventional power generation uses water mainly for two purposes: water is the working medium in hydropower plants and the standard cooling medium in thermal power plants such as coal or nuclear power plants. In the United States, freshwater withdrawals for thermal power generation account for about 40 per cent of total freshwater withdrawals and 4 per cent of total freshwater consumption.[20] In developing and emerging countries, the amount of water used in the energy sector may increase significantly with economic development if conventional forms of power generation (hydro, steam turbines) are established on a large scale.

Water availability for power plants is constrained by both physical and regulatory limitations. The volumes of water withdrawn for power plant cooling need to be physically available. Furthermore, power plant water consumption may be limited by water allocation rights. Thermal pollution due to cooling water discharge from power plants may be regulated by temperature thresholds to protect local ecosystems. Limits may also be imposed on the extent of chemical water resource contamination due to power plant discharge (e.g. zinc compounds for cooling water conditioning). In the past, water availability and thresholds for water temperature have been the factors that have compromised power supply the most.

The choice of energy sources greatly affects the volumes of water needed for power generation. Looking at the whole life cycle, thermal power plants require most water for operation, i.e. for cooling during power generation (see Figure 2 on page 4).[21] Among the different energy sources, nuclear, coal and concentrated solar power plants have the highest requirements for cooling water. Combined-cycle power plants that are fuelled with natural gas need less water due to their higher efficiency. Wind turbines and solar PV systems have very low water needs, which are mainly attributable to production (see Figure 2 on page 4). The water use of hydro, geothermal and biomass power generation varies widely, depending on local circumstances like climatic conditions (evaporation, precipitation).

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[18] See footnote 4.

[19] Water consumption: the water volume removed from a water resource for a very long time, typically by evaporation. Water withdrawal: total water volume removed from a water resource even if only temporarily.

[20] EPA (2014): The Impact of Traditional and Alternative Energy Production on Water Resources: Assessment and Adaptation Studies. USA.

[21] Meldrum, J. et al. (2013): Life cycle water use for electricity generation. A review and harmonization of literature estimates. In: Environmental Research Letters 8 (1), p. 15031. DOI: 10.1088/1748–9326/8/1/015031.

Cooling technology significantly influences the water demand of thermal power plants. The most common cooling technologies in thermal power plants are once-through cooling and recirculating cooling. Power plants with once-through cooling have very high water withdrawal, while their water consumption is relatively low. Power plants with recirculating cooling systems have much lower withdrawal, but the bulk of the withdrawn water is consumed (see Figure 2).

Dry cooling is a proven technological option to reduce the water demand of thermal power plants, but it is expensive and land-consuming. If dry-cooling systems are used, the water demand of thermal power plants can be reduced to about 2 per cent[22] of the water demand that would otherwise apply in the case of wet cooling. However, there are significant trade-offs. Dry cooling is not as efficient as wet cooling. This means a higher fuel demand and higher greenhouse gas emissions per megawatt hour (MWh) generated. Furthermore, dry-cooling systems have higher investment costs (2 to 4 times) and land area requirements than equivalent wet-tower cooling systems, since air requires a much larger surface area for heat dissipation than water.[23]

Freshwater for cooling may be partly replaced by non-freshwater sources, but this is associated with increased costs and reduced efficiency. By using wastewater (municipal wastewater, shale gas discharge, coal mining discharge, etc.) or saline water from the sea or saline aquifers, demand for freshwater can be reduced. However, wastewater usually needs to be treated before it can be used as cooling water to avoid corrosion in the cooling system, inducing additional costs and reduced overall efficiency of the power plant. Similar to freshwater cooling from surface sources, seawater cooling can have adverse impacts on local aquatic ecosystems, especially due to thermal pollution. Moreover, seawater cooling is only feasible at or near the coast.

[22] Combined-cycle natural gas power plant: dry cooling compared to cooling tower (see footnote 21).

[23] World Bank (2013): Thirsty Energy (Water Papers).

4. Increase the share of wind power and solar PV in water-scarce regions

Solar PV systems and wind turbines need very little water. Over their whole life cycle they consume about 0.1–14 per cent and withdraw about 2–15 per cent of the water typical conventional power plants (coal or nuclear) use to generate 1 MWh of electricity (see Figure 2 on page 4). Apart from their reduced water demand, another huge co-benefit of solar PV and wind is their very low greenhouse gas emissions. Further benefits are well known, such as fuel import independence, local value creation, improved system resilience, and opportunities to improve electricity access for off-grid regions.

With the rapid expansion of the solar PV system and wind power plant markets,[24] the costs of these technologies have dropped dramatically.[25] Still, creating a stable political environment is the key to promoting investment in renewables. A whole range of flexibility options can help to balance intermittent supply by solar PV and wind power and electricity demand. In regions that are already experiencing water stress or will be under stress in the future, investments in solar PV and wind can be a promising option to meet rising electricity demand without increasing stress on the climate and on scarce water resources. The same is true of regions where alternatives to hydro generation need to be found due to decreasing water availability (e.g. in Brazil and California).

Technological solutions are important but will not suffice. In order to decrease the energy sector's vulnerability to water constraints and lessen its water impacts, policy changes are needed as well.

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[24] The global installed capacity in 2014 was 177 GW of solar PV and 370 GW of wind power (REN21 2015).

[25] The levelised costs of electricity (LCOE) differ from country to country due to different framework conditions. In Germany, the levelised costs of electricity at the end of 2013 were 10–14 ct/kWh for roof-top solar PV, 7.8–12 ct/kWh for utility-scale solar PV, and 4.5–11 ct/kWh for onshore wind. This compares to 6.3–8.0 ct/kWh for hard coal power plants and 7.5–9.8 ct/kWh for combined-cycle gas power plants (Kost et al. 2013).

5. Enhance transparency on water use in the energy sector

In order to improve the knowledge base on the energy sector's water use, various actors need to collaborate. Each of them can make an important contribution to increasing the available data on the water intensity of the energy sector and the water pollution it causes. As the water intensity of energy technologies may vary significantly from one location to another,[26] context-specific data is required. Collecting such data is particularly pressing in areas that are already affected by water stress or will be so in the foreseeable future.

Energy companies can improve how they assess their water requirements, both in ex-ante planning and in the course of implementation. This serves the enlightened self-interest of corporations, as this information is a central precondition for effective risk prevention. These efforts might build on voluntary action. Here, a positive example is the Water for Energy Framework Action Group, which helps energy companies to assess their water use and water impacts.[27] If necessary, regulatory instruments can be employed. For example, the State of California approved a bill that requires oil companies to report how much and what sources of water they use in their drilling operations.[28]

Likewise, energy decision-makers in the public sector can also improve their water assessment. A comprehensive assessment covers the different stages of the policy cycle: planning, implementation and evaluation. It should apply to both domestic energy investments and energy projects in international development cooperation. It is important that the results are easily accessible to the public and also outline the distributional implications of the energy sector's water use.

Policy actors involved in international energy cooperation can further raise global awareness of the energy sector's water impacts and advise decision-makers on how to conduct water assessments. *The World Energy Outlook 2012* of the IEA, which comprised a chapter on water for energy, made an important contribution here. In future, the IEA could provide regular updates in its World Energy Outlooks and online databases. IRENA's *Nexus Report 2015* was another step in the right direction. It presents a conceptual framework for assessing the water and land requirements of different energy-mix scenarios. In addition to international organisations such as the IEA and IRENA, the United Nation's Sustainable Energy for All Initiative (SE4All) and its Nexus High Impact Opportunity are suitable platforms for increasing transparency on the energy sector's water use.

Non-governmental organisations, academic institutions and journalists around the world can provide additional and independent analysis on the water impacts of energy decisions. While this supports energy decision-makers who are willing to consider water constraints, it can also exert the public pressure necessary to induce behaviour changes in those energy actors who have so far been reluctant to act – for example, in cases where energy sector actors use water at the expense of others. As such, assessing the distributional impacts of the energy sector's water use would help to make transparent who loses from the energy sector's water use.

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[26] IRENA (2015).

[27] The partnership is led by Electricité de France and supported by the European Innovation Partnership on Water. See EIP Water, W4EF, http://www.eip-water.eu/W4EF; see also World Water Week (2014) and World Bank (2014): Thirsty Energy Update.

[28] IRENA (2015).

6. Incorporate water scarcity into energy decision-making

Charging the energy sector for its water use in a way that better reflects actual water costs and scarcities can be a very effective way to improve water management in this sector. While the centrality of freshwater for human survival might be a major rationale for zero or low water prices, this pricing leads to adverse effects: it signals that water is something consumers do not need to worry about, leading to overuse and aggravating water scarcity. Moreover, the low pricing does not only apply to private households, but also to water users in industry, the energy sector and agriculture – which together account for 90 per cent of global water withdrawals.[29] Thus, most of the benefits of cost savings due to subsidised water prices are enjoyed by these end-use sectors rather than private households.

In order to ensure that water pricing does not undermine the human right to water by creating an access barrier for low-income households, price increases would need to apply to non-household water use only or to household water use above a certain threshold.

Integrating water scarcity into the energy models of public policy planning is a low-hanging fruit that can have major positive effects. In this context, the launch of the World Bank's Thirsty Energy Initiative in 2014 was an important step. The initiative – currently active in South Africa, Morocco and China – helps countries to identify synergies and trade-offs between energy development plans and water use, and to pilot cross-sectoral planning.

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[29] World Water Week (2014).

7. Widening the perspective: advancing the global sustainability agenda

The newly adopted SDGs further reveal the potential – and need – for conscious and conserving water management in the energy sector. They set a clear course: by 2030, the international community shall ensure the availability and sustainable management of water and sanitation for all (SDG 6) and provide access to affordable, reliable, sustainable and modern energy for all (SDG 7). In the realm of energy, the SDGs are a remarkable step: until recently, the UN had remained almost silent on energy issues since it could not achieve consensus among its member states.[30]

Conscious and conserving water management practices in the energy sector are crucial to pursuing the SDG on energy without undermining the SDG on water. Founded on the vision of sustainable development formulated by the international community in 1992, the catalogue of 17 SDGs comes with the requirement and the opportunity to create synergies among different goals. Integrated water and energy management and the promotion of water-saving energy technologies such as wind and photovoltaics are a good case in point. Expanding energy access at the cost of water scarcity and climate change, by contrast, forgoes these opportunities and perverts the idea of sustainability by reducing the agenda to individually selected goals.

The SDGs provide a strong case for strengthening alliances between the water sector and water-friendly renewable energy sources. The power of the new sustainable development agenda lies in the way it raises awareness of and sets the agenda for sustainability policies and international cooperation around the globe. This is an exceptional window of opportunity for reconciling water and energy security. ▮

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[30] Roehrkasten, S. (2015): Global Governance on Renewable Energy, Springer VS Research.

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