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Sustainable solutions require the integration of water into energy and climate policies

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Abstract

Water, energy and climate are inextricably linked. Energy is needed to provide freshwater; and water is needed to produce most forms of energy. Climate change will hit through water. Power production is the largest single source of climate changing greenhouse gas emissions.

Rising demand for energy and water will intensify the competition for increasingly scarce water resources – in many places of the world water has already become a business risk for the power sector. Sustainable energy production requires the integration of water in energy and climate policies. Failing to address the water consumption of power generation and focusing solely on lowering carbon emissions will make it more difficult to secure a reliable supply of both – energy and water.

Keywords

Energy, Integrated policies, Renewable energy, Water, Water/Energy/Climate Nexus

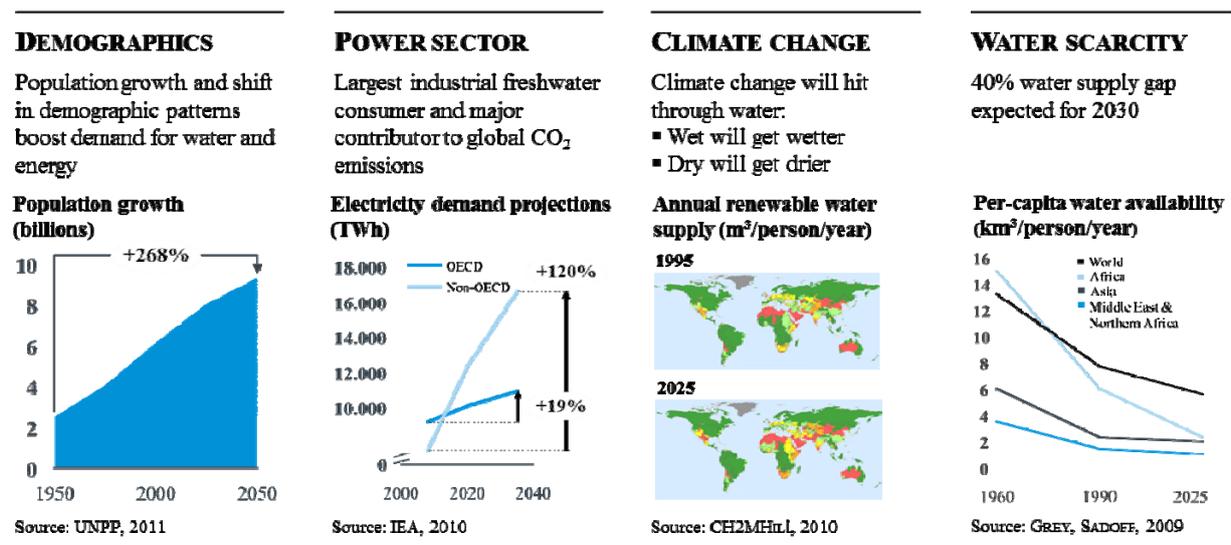
1. Sustainable solutions must address interlinkages of water, energy and climate change

“Take one world already being exhausted by 6 billion people. Find the ingredients to feed another 2 billion people. Add demand for more food, more animal feed and more fuel. Use only the same amount of water the planet has had since creation. And don’t forget to restore the environment that sustains us. Stir very carefully.”

Margaret Catley-Carlson, Patron Global Water Partnership, 2008-2009 Chair of World Economic Forum (WEF) Global Agenda Council on Water Security (WEF, 2009)

Human livelihood depends on both water and energy. As for any vital resource that is difficult to substitute, a reduction in supply leads to over-proportional price increases. The energy crisis of the 1970s is only one example illustrating how economies are vulnerable to these price inelasticities (Voinov, Cardwell, 2009). Though water is still relatively cheap in developed countries the World Energy Council (WEC) forecasts that “water will almost certainly be more costly and valuable every year” (WEC, 2010).

Figure 1: Key factors driving today’s tomorrow



Today more than 40% of the global population is already confronted to some form of water scarcity (UN, 2008). The projected impacts of climate change and demographic changes will further decrease per-capita water availability (IPCC, 2007; Voinov, Cardwell, 2009) – the decrease in supply being confronted to an increase in demand. The 2030 Water Resources Group forecasts that under a business-as-usual approach 40% of the global water demand will be unmet by 2030. For about one-third of the global population, the water supply gap will exceed more than 50% – not taking into account the expected impacts of climate change, pollution or saltwater intrusion in aquifers in coastal regions (Addams et al., 2009).

The energy sector, with a share of 25.9% the largest single source of carbon emissions, is a major contributor to climate change (IPCC, 2007) and the second largest water user after agriculture

(WBCSD, 2009). Satisfying increased demand for electricity might stumble in many regions upon the power sector's water dependency – if the water requirements continue being neglected in the decision making process for new power plants.

Attempts to alleviate some of these serious challenges on a stand-alone approach will create or aggravate other serious problems arising of the water/energy/climate nexus.

2. Water consumption in power production

The water use in the power sector varies significantly based on the power generating technology. Water is required for the extraction, refining and processing of fossil fuels, the production of biomass as well as for the electricity generation itself (Glennie, Lloyd, 2010). The power plant technology, the type of fuel and the need for cooling determine the amount of water withdrawn and consumed.

The term “water withdrawal” refers to the amount of water removed from any source, whether it is consumed or totally or partially returned to the source.

“Water consumption/use” refers to the difference between the water withdrawn and the water returned to the source. Water consumed is no longer available for use – due to evaporation, pollution, inclusion in products and crops or because it is otherwise removed from the freshwater sources.

Source: Mielke et al., 2010; Glennie, Lloyd, 2010

2.1. Extraction, production and processing of fuels

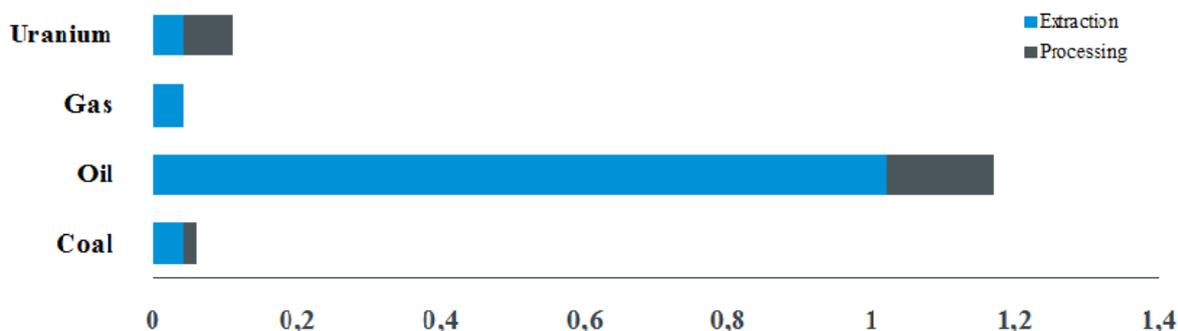
The water requirements for extracting, producing and processing fossil and renewable fuel sources vary from negligible to significant but are generally less important than the amount of water needed for producing the electricity (Glennie, Lloyd, 2010). But the used water is often altered in its quality and requires intensive cleaning in order to avoid non acceptable environmental impacts (Glennie, Lloyd, 2010; WEF, 2009b).

The extraction of oil and gas out of **conventional reserves** frequently produces more water than it consumes. But the water that is recovered along with oil and gas is usually contaminated or saline and its disposal, if not reinjected into the reservoirs to enhance oil and gas recovery, requires significant treatment prior to surface discharge (WEF, 2009b).

As easily accessible oil and gas reserves are becoming increasingly scarce, **new recovery technologies** as well as also **unconventional fuel resources** are more and more common. Enhanced oil recovery (EOR) technologies for example involve the injection of water in liquid or steam form into the reservoirs to increase the underground pressure, which increases the fuel output (WEF, 2009b). Applying these technologies generally requires large, but varying amounts of water – from 0.17 m³/MWh up to 30 m³/MWh using the micellar polymer technology (Glennie, Lloyd, 2010; U.S. DoE, 2006). Steam production for oil sand mining can require from 0.02 m³/MWh to 0.5 m³/MWh. Less water is required to fracture underground formations of shale or tight sandstone to extract unconventional natural gas resources – from 0.01 m³/MWh to

0.02 m³/MWh (WEF, 2009b). Water consumption for mining of coal and uranium depend on the mining technology.

Figure 2: Water requirements of fuel production and processing (m³/MWh)



Note: Data based on weighted U.S. averages reflecting current mix of extraction and processing technologies. The average water consumption is expected to increase with the growing share of water-intensive fuel sources and recovery technologies.

Source: Glennie, Lloyd, 2010; U.S. DoE, 2006

Though often referred to in the context of alternative transportation fuels, **biomass** can also be used for electricity generation. The water requirements for biomass production depend on the type of biomass and eventual irrigation needs. The irrigation requirements for corn or soy crops can amount to up to 27.8 m³/MWh respectively 75 m³/MWh or even more in some areas whereas sugar cane usually does not require irrigation. Subsequent water intensities in the biomass production would be negligible – also for using other non-irrigated crops or crop or wood waste (WEF, 2009b; U.S. DoE, 2006).

But like fossil fuel recovery the biomass production can have negative impacts on the water quality, considering for example the contamination of surface water by extensive fertilizer usage (WEF, 2009b). Other potential environmental impacts of bioenergy due to land use change or deforestation as well as eventual food market linkages also need to be considered (Cushion et al., 2010).

Fuel processing, whether from conventional or renewable sources, requires less water than fuel extraction – from negligible in case of burning solid biomass to 0.15 m³/MWh for oil refining (Glennie, Lloyd, 2010; U.S. DoE, 2006).

Full water footprint or focus on the water intensity of the electricity generation?

The water consumption of electricity generation is the commonly used criteria to compare different power generating technologies – essentially because the majority of power plants consume most of the water during the power generation (Macknick et al., 2011). And as life cycle assessments (LCA) are a relatively recent development, there is not enough reliable data available to allow for global comparisons based on full water footprints that include e.g. the water needed to build the power plant, to produce and process the fuels, to generate the electricity and to decommission the power plant.

Furthermore it has to be taken into account that water, unlike carbon, is a local issue. The decision on a new power plant must consider the impact of the power generation on the local water resources. The decision criteria should therefore include the impact of the water consumption / withdrawal on the local water resources that are related to the electricity production. If the fuel is produced and/or processed in watershed of the power plant, the related water consumption should be added to the water intensity of the electricity generation.

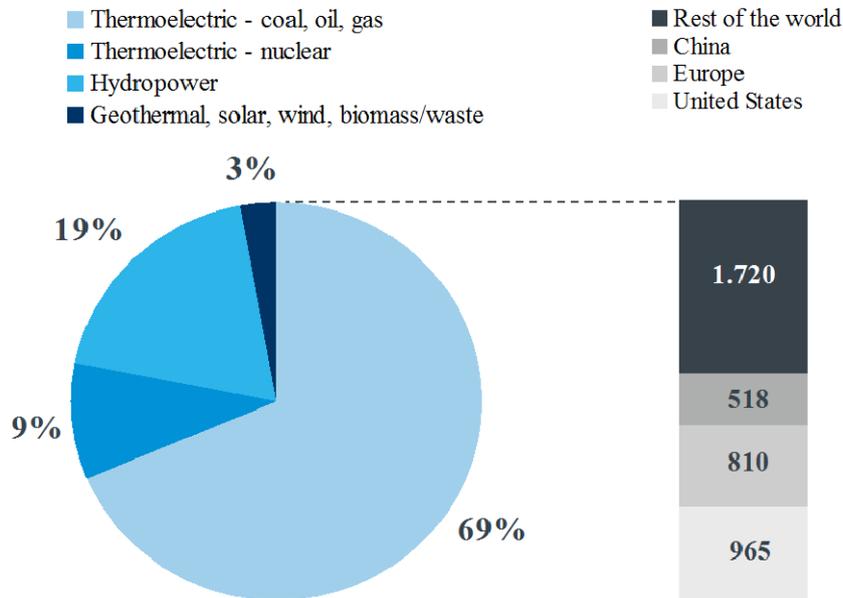
The assessment of the full water footprints is equally important as it provides information regarding the global sustainability of power generating technologies. But full water footprints are less suitable when analyzing power generation's impacts on local water resources.

2.2. Electricity generation

Power plant and fuel type, cooling requirements as well as other operations are key factors driving the water consumption in power generation.

Thermoelectric power plants constitute the major share of the global power generation capacity. Whether the heat producing the steam is generated from coal, oil, gas, nuclear, biomass, solar or geothermal energy, the water needed to cool and condense the steam that drives the turbines represents 80 to 90% of the water consumption in thermoelectric power plants (U.S. DoE, 2006; WEF, 2009b).

Figure 3: Global installed electricity generation capacity in 2006 (GW)



Source: adapted from U.S. EIA, 2008

Power plants based on open-loop or once-through cooling systems withdraw 40 to 80 times more water than more recent power plants relying on closed-loop or recirculating cooling systems and are hence more vulnerable to water shortages. But power plants that reuse cooling water about 80% higher evaporative water losses (U.S. DoE, 2006; Stillwell et al., 2009; Voinov, Cardwell, 2009).

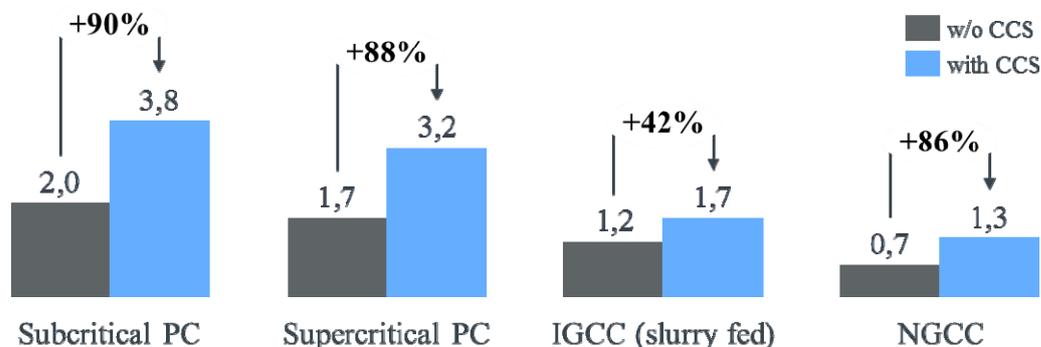
Air- or dry-cooling systems can significantly lower the water requirements of thermoelectric power plants, but these technologies are less efficient and have three to four times higher capital costs (U.S. DoE, 2006; Stillwell et al., 2009; Glennie, Lloyd, 2010). Power plants with hybrid wet-dry cooling technologies are more efficient than air-cooled plants and consume less water than plants with recirculating cooling systems, and are increasingly employed in arid areas (U.S. DoE, 2006).

The water consumption of thermoelectric power generations is also influenced by the power plant technology. Sub- and supercritical pulverized coal (PC) plants that constitute about 90% of the global coal based electricity production are the least efficient fossil fuel fired power plants in terms of water consumption. These plants consume approximately 50% more water than Integrated Gasification Combined Cycle (IGCC) plants that produce electricity by converting coal into a synthetic gas that is burned in a gas turbine. Natural Gas Combined Cycle (NGCC) plants have the lowest water consumption of all fossil fuel based generation platforms (WEC, 2010; Glennie, Lloyd, 2010).

Other water requirements in thermoelectric power plants are determined for example by the Flue Gas Desulfurization (FDG) process, which reduces sulphur dioxide emissions. FDG is essentially relevant for sub-and supercritical fossil fuel plants and can contribute to up to 10% of the power plant’s water consumption (Glennie, Lloyd, 2010).

The carbon emissions of thermoelectric power plants that rely for example of gas or coal can be reduced by employing *carbon capture and storage (CCS)* technologies. Capturing, processing and storing of carbon emissions is energy intensive, reducing reduces the plant’s net power production, as well as water intensive. The water consumption of power plants equipped with CCS technologies increases by up to 90% (U.S. DoE, 2009; Glennie, Lloyd, 2010)

Figure 4: Increase in water consumption with CCS (m3/MWh)



Source: US DoE 2009; Glennie, Lloyd, 2010

Similar to coal fired thermoelectric power plants, **nuclear power plants** use the heat generated by nuclear fission reactions to drive steam turbines. As nuclear reactors do not emit flue gases more energy is released as waste heat via the cooling water. Consequently cooling water requirements are 20 to 30% higher than for coal plants, ranging from 1.6 m³/MWh (once-through cooling) to 2.7 m³/MWh (recirculating cooling system with cooling tower) (U.S. DoE, 2006; U.S. DoE, 2009; Stillwell et al., 2009; Glennie, Lloyd, 2010).

Hydroelectric power generation constitutes the largest renewable energy source. Instead of steam, hydropower turbines are driven by water. While all the water withdrawn by run-of-the-river plants with no water storage is returned to the water body, plants with large reservoirs can result in important evaporative water losses (WEF, 2009b, Torcellini et al., 2003). The evaporative water consumption depends on the reservoir surface, the water depth and on local climate conditions. Its calculation should take into account the amounts of water evaporated prior to the construction of the reservoir (Glennie, Lloyd, 2010). Based on the significant impact of local factors it makes less sense to create global average water intensities – published case by case assessments provide values ranging from none in case of run-of-the-river plants with no water storage to on average 585 m³/MWh for large dam hydro plants in the U.S. state Kentucky (Torcellini et al., 2003; Glennie, Lloyd, 2010). Reservoirs fulfil furthermore other purposes than just electricity generation, like for example the storage of freshwater, flood control and recreation. These other functions are generally not reflected in global water consumption average values (Glennie, Lloyd, 2010).

Geothermal power plants produce electricity by utilizing the natural heat of the earth. As for other thermoelectric power plants the heat is used to produce steam that drives the turbine, but geothermal water requirements are generally covered by deep-underground aquifers to which the water is returned after use (WEF, 2009b; Glennie, Lloyd, 2010). Evaporative losses depend on the employed cooling technologies as well as on the temperature of the geothermal resource and range from 0.02 m³/MWh for dry-cooled binary cycle plants (Glennie, Lloyd, 2010) to up to 5.3 m³/MWh for plants with cooling towers (U.S. DoE, 2006).

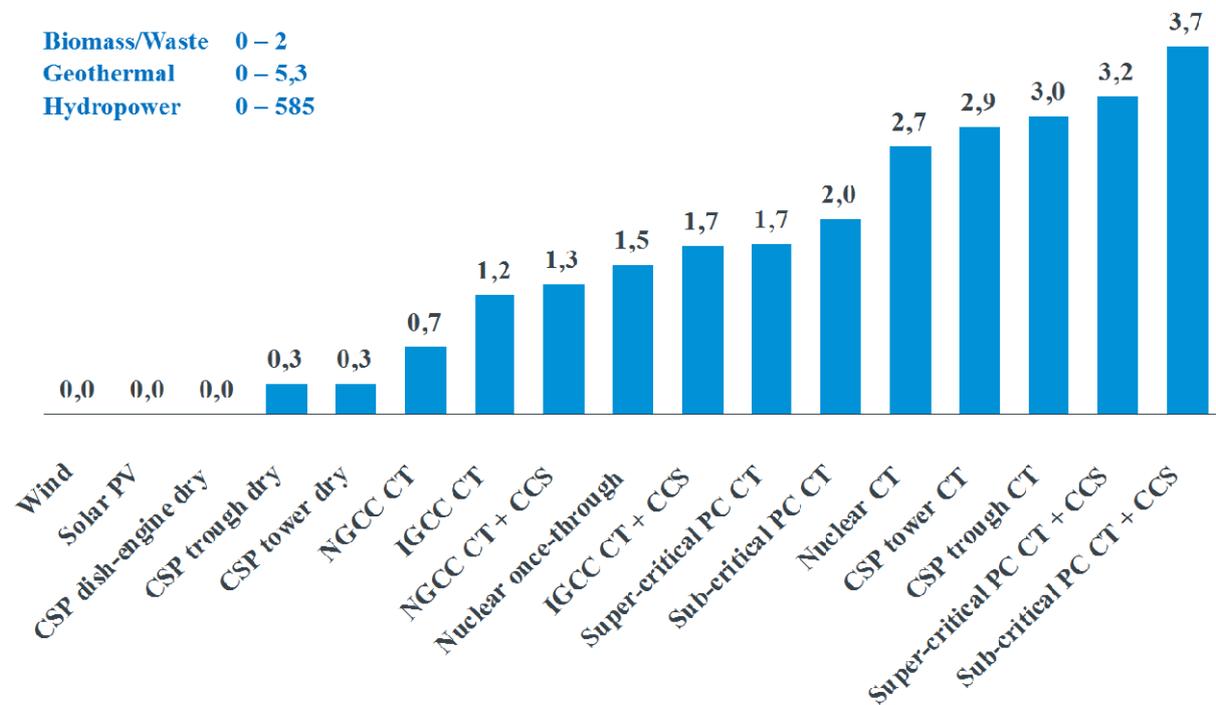
The water requirements of **biomass** or **waste** based electricity production depend as for other thermoelectric power plants essentially on the employed cooling system. Water intensities range from 0.04 m³/MWh for firing dry-cooled NGCC plants with biogas from e.g. landfill or wastewater treatment (Tellinghuisen, 2008) to up to 2.0 m³/MWh for burning biomass or waste in traditional steam plants with cooling towers (Glennie, Lloyd, 2010; U.S. DoE, 2006; WEC, 2010).

Concentrating solar power (CSP) plants rely as other thermoelectric technologies on steam to drive the electricity generating turbines. In function of the cooling technology, the water consumption ranges from from 0.3 m³/MWh (dry-cooled CSP parabolic-through) to 3.8 m³/MWh (wet-cooled CSP fresnel). The water requirements of CSP dish-engine technologies are however insignificant as these plants are generally dry-cooled. **Solar photovoltaic (PV)** requires water only for occasional washing of the solar panels and has as such negligible water consumption (Tellinghuisen, 2008; Glennie, Lloyd, 2010).

Wind turbines do not require any cooling water and the only potential water requirements are related to occasional blade washing. For most modern wind farms, natural rainfall is sufficient to

clean the blades from dust and insects. No additional water is needed for cleaning purposes (Tellinghuisen, 2008; Glennie, Lloyd, 2010; U.S. DoE, 2006; WEF 2009b).

Figure 5: Water intensities of power generation (m³/MWh)



Abbreviation: CT (Cooling Tower)

Source: Glennie, Lloyd, 2010, 2010; Mielke, et al., 2010; Torcellini et al., 2003; Stillwell, et al., 2009; Tellinghuisen, 2008; U.S. DoE, 2006; U.S. DoE, 2009; WEF, 2009b

3. Integrated policies as response to the water/energy/climate nexus

The International Energy Agency (IEA) forecasts that global electricity consumption will grow by 64.3% from 2008 to 2035 (based on IEA's 450 ppm scenario that includes amongst carbon emission reductions reduced demand due to energy efficiency measures). More than 100% of the forecasted power demand increase will occur in non-OECD countries, China and India being important demand drivers (IEA, 2010). Securing reliable electricity supply is hence becoming a major concern in industrialized and emerging economies. The growth in electricity demand will require capacity additions more than doubling installed capacity by 2030, also because many power plants in OECD countries will come to the end of their lifetime (IEA, 2010).

Rising demand for energy and water will intensify the competition for increasingly scarce water resources – in many places of the world water has already become a business risk for the power sector. Sustainable energy production requires the integration of water in energy and climate

policies: To mitigate climate change power generation must become low carbon – globally – as well as low water – wherever water is or is expected to become scarce.

Failing to address the water consumption of power generation and focusing solely on lowering carbon emissions will make it more difficult to secure a reliable supply of both – energy and water.

Key actions that policy makers can take to contribute to ensuring a sustainable energy supply include:

- Pursue awareness raising and promote collaboration among different stakeholders and sectors – also in a trans-boundary context
- Ensure availability of reliable meteorological and hydrological data allowing stakeholders to take factual decisions
- Evaluate impacts of possible energy mix scenarios on local water resources including the an assessment of risks related to water scarcity projection (Macknick et al., 2011) and impacts on other water reliant sectors
- Pursue the promotion of energy efficiency – as a lower energy use implies lower water consumption as well as reduced carbon emissions
- Provide incentives for low carbon technologies that are sustainable in regard to the local water availability in addition to prioritizing technologies solely on a national portfolio level or on carbon emissions criteria.
- Encourage financial institutions, public and private, to incorporate water sustainability together with carbon emissions into the investment criteria (Emtairah et al., 2004).
- Require that decisions for new power plants integrate carbon emissions as well as water and plant efficiency implications of various possible cooling and carbon capture technologies – including factors such as local and regional climate conditions, air quality as well as current and projected water availability (Stillwell et al., 2009).
- Provide regulatory incentives for implementing technologies with lower fresh water requirements than conventional techniques, like no water/no carbon technologies and promote wastewater reuse.
- Provide regulatory incentives for deploying cooling technologies with lower water requirements than conventional cooling methods, like air-cooling or hybrid wet-dry cooling (Stillwell et al., 2009).

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