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Meta-Study on Energy Scenarios

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4 Global Scenario Analysis

4.1 Meta-Study on Energy Scenarios

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Water and energy are of central importance for sustainable development globally and in Germany. At the same time, there are many links between water and energy supply, so that developments and decisions in one sector can have a direct or indirect impact on the other. Especially in view of the restructuring of the global energy supply, possible trade-offs and synergies between water resources and energy production should be investigated on a global and regional level.

The energy sector today accounts for about 10% to 15% of global freshwater withdrawal, and for about 3% of total water consumption (OECD/IEA, 2016; IRENA, 2015). Most water in the energy sector is used for generating electricity (about 88%), especially for cooling processes in thermal power plants (thermal power plants account for about 70% of today's global installed power plant capacity (OECD/IEA, 2016)). At the same time the demand for electricity is expected to increase significantly due to population growth and economic development in emerging and developing economies, growing demand is also driven by electrification strategies pursued by industrialized countries to decarbonize their economies (Bauer et al., 2017). With the global demand for electricity expected to increase significantly in the coming decades also the water demand in the power sector is expected to rise. However, due to the on-going global energy transition, the future structure of the power supply – and hence future water demand for power generation – is subject to high levels of uncertainty because the volume of water required for electricity generation varies significantly depending on both the generation technology and cooling system. And even assuming rapid decarbonization of the energy sector, the development of future water demand for electricity generation remains unclear because different renewable energy and climate protection technologies also have very different water use intensities (Jin et al., 2019).

In light of these challenges the objective of this analysis is to provide more systematic and robust answers in terms of the impacts of different decarbonization strategies in the electricity sector on water demand at global and regional level. The focus is on operational water use for electricity generation. The first step was to determine in which countries or regions the technologies in question are already widespread or where they are to be expanded in the future. To this end, a meta-analysis of existing long-term energy scenarios was conducted.

The time horizon was set to 2040 based on the data availability in the analyzed energy scenarios. In a second step, demand-side water scenarios are created by coupling the determined installed capacity of the technologies under consideration with their water consumption, so that the water consumption per year and region can be represented. To do so a set of future scenarios was designed by combining decision options in two technological fields: a) types of electricity generation technologies; and b) types of cooling technologies. In the third step, the water withdrawal and consumption levels of the different technological pathways are calculated for each region up to 2040, resulting in water demand scenarios for different electricity futures and making it possible to identify the most water-efficient transition pathways for the electricity sector.

4.1.1 Research approach

The water demand for electricity generation depends mainly on three key parameters: (a) the mix of energy sources and type of generation technologies applied; (b) the type of cooling technology deployed at thermal power plants; and (c) the water use intensity in form of specific water withdrawal and consumption levels for each combination of electricity generation technology and cooling technology. To determine the future water requirements of the power sector, these three parameters are first assessed individually and then combined to estimate the water demand of the electricity sector according to different given future energy scenarios. The approach is summarized in Figure 4-1.

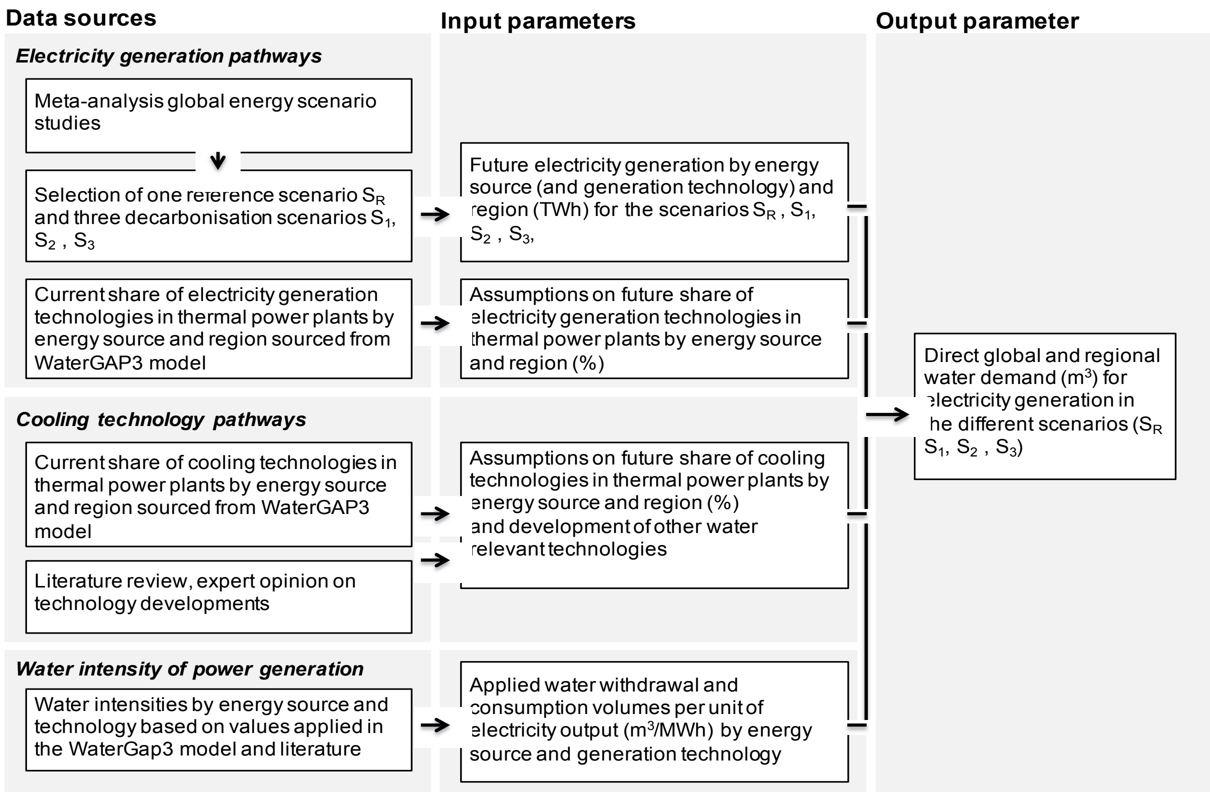

Figure 4-1: Overview of methodology applied to estimate water demand for different electricity generation pathways (Terrapon-Pfaff et al., 2020).

4.1.2 Meta-analysis global energy scenario studies

As a result of the comparative literature review, one reference scenario (IEA CP) and three decarbonization scenarios were chosen based on their heterogeneity in terms of energy transition strategies and their ambition levels in terms of greenhouse gas emission reductions, i.e. in line with, or at least close to, the target of limiting the global temperature increase to "below 2°C" (Table 4-1). This allows for comparisons to be made concerning the impact on water demand arising from major shifts in the electricity sector required to achieve these climate objectives.

Table 4-1: Overview of selected energy scenarios (Terrapon-Pfaff et al. 2020)

Study	**Time horizon**	**Scenario**	**GHG-changes 2040** (compared to 1990)	**Summary strategies**
World Energy Outlook (IEA/OECD 2017)	2040	**Reference scenario:** IEA | Current Policies (CP)	+104%	• Assessment of energy sector development in the absence of any additional measures
		IEA | Sustainable Development (SD)	-13%	• Back-casting approach • Stronger role of renewable energies • Broad exploitation of efficiency potentials in the industrial sector • Transport sector: increasing electrification and increasing use of ("advanced") biofuels and natural gas assumed • Carbon capture and storage (CCS)
The advanced energy [r]evolution (Greenpeace 2015)	2050	GP | Advanced Energy Revolution (Ad.[R])	-61%	• Renewable electricity as the most important primary energy resource • Limited use of biomass (100 EJ/a) • Broad electrification of the transport sector • Hydrogen and other synthetic fuels in sub-sectors difficult to electrify (e.g. freight transport) • No carbon capture and storage (CCS) • Phase-out of nuclear energy
Global Energy and Climate Outlook (JRC 2017)	2050	GECO | B2°C	+1%	• Combination of carbon capture and storage (CCS) , renewables and nuclear power in the electricity sector • In the transport sector: combination of electricity, biofuels, natural gas and hydrogen

The comparison of transition pathways for the electricity sector show that all the scenarios anticipate an increase in electricity generation by 2040 compared to 2015 (Figure 4-2). However, the extent of the increase and the overall mix of energy sources vary considerably depending on the scenario. The different underlying decarbonization strategies and the level of ambition in respect to GHG emissions reductions explain these differences. For example, scenarios assuming a higher degree of electrification in sectors such as transport or industry require higher amounts of electricity. Moreover, assumptions about economic development and population growth underlying the energy scenarios can influence the anticipated total future electricity demand. Unsurprisingly, all the scenarios expect an increase in electricity generation from renewable energy sources, with wind and photovoltaic anticipated to increase the most.

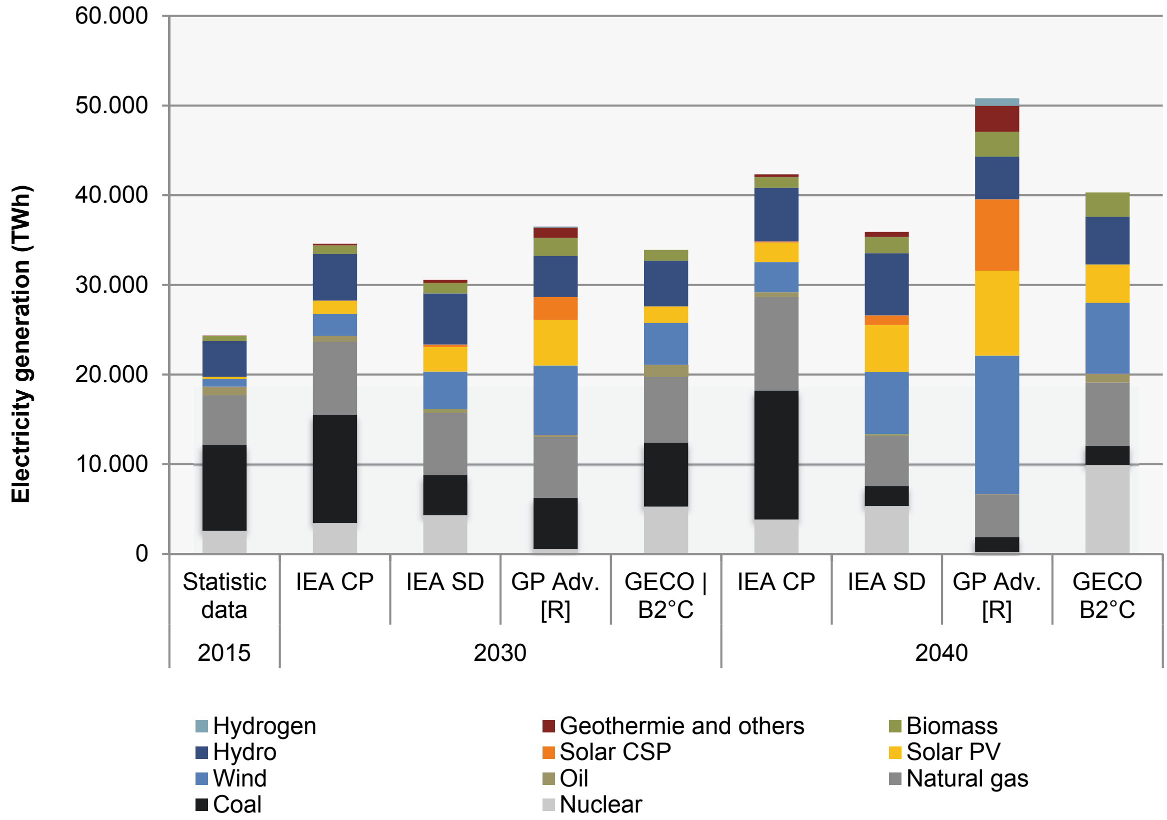

Figure 4-2: Electricity generation by energy source (in TWh) for the year 2015 and the four selected energy scenarios in 2030 and 2040 (Terrapon-Pfaff et al., 2020. Based on data from IEA/OECD, 2017; Greenpeace, 2015; JRC, 2017).

4.1.3 Modeling future water demand for electricity generation

These differences in the electricity mix influence both the water withdrawal and consumption of future electricity systems. The changes in future global water withdrawal vary between +55% and -72% compared to 2015 (Figure 4-3). Overall, higher shares of fossil fuels are likely to lead to greater water withdrawal, while scenarios with high shares of renewable energies perform better in terms of reducing future water withdrawal. This is due to the fact that electricity generated from fossil fuels still comes predominantly from thermoelectric power plants based on technologies with higher water withdrawal intensities.

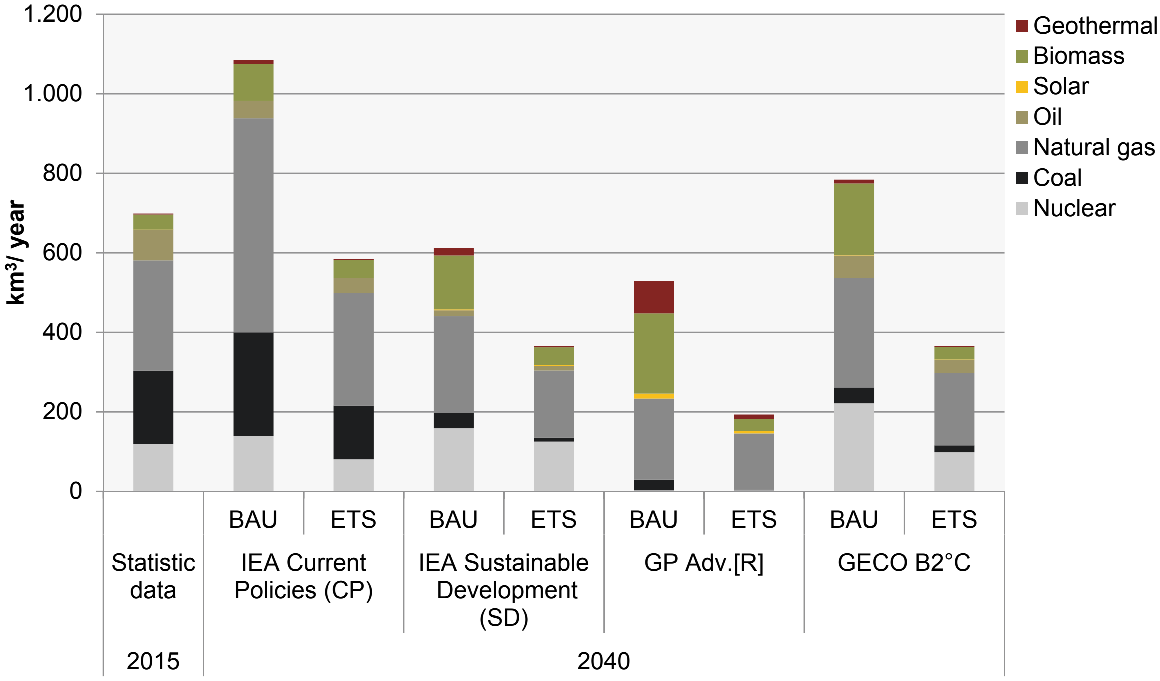

Figure 4-3: Water withdrawal (in km³ per year) for electricity generation by energy source for different scenarios in 2040 (Terrapon-Pfaff et al., 2020. Based on data from IEA/OECD, 2017; Greenpeace, 2015; JRC, 2017).

In term of global water consumption for electricity generation it is shown that water consumption is expected to rise in five out of eight scenarios (by between 9% and 78%) compared to 2015. The increase in global water consumption occurs as a result of an increase in electricity production and a shift towards improved cooling systems, which withdraw less water but consume more (Figure 4-4). Furthermore, the widescale implementation of thermal renewable energy technologies such as geothermal, biomass and concentrated solar power (CSP) compared to solar photovoltaic or wind can lead to an increase in water consumption from the renewable energy side. From a global perspective, it can be concluded that more efficient cooling and electricity generation systems (i.e., ETS scenarios) can significantly reduce the water demand of the power sector in terms of water withdrawal and consumption.

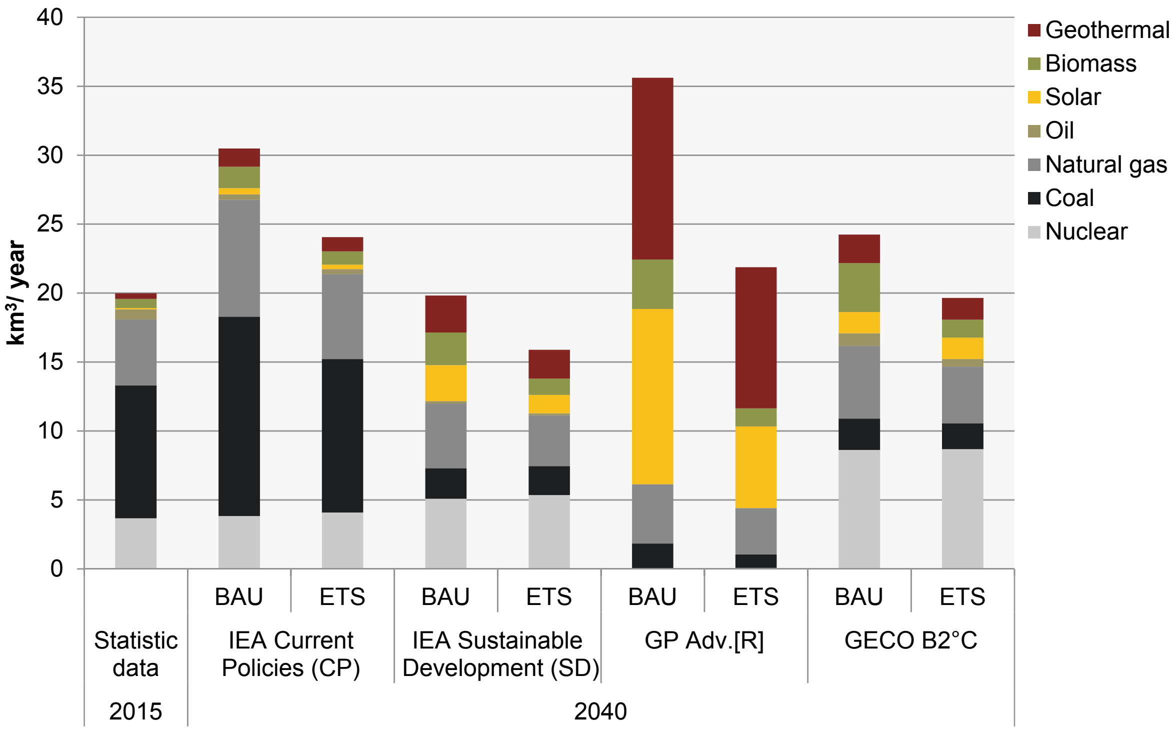

Figure 4-4: Water consumption (in km³ per year) for electricity generation by energy source for different scenarios in 2040 (Terrapon-Pfaff et al., 2020. Based on data from IEA/OECD, 2017; Greenpeace, 2015; JRC, 2017).

At the regional level, the analysis focuses on the development of water demand for power generation in ten regions. The shifts in electricity generation expected in the scenarios lead in part to very different regional developments. North America is the only region that shows a consistent reduction in water withdrawals (5% to 74%) across all scenarios. Despite this decrease, North America remains the region with the highest share of global water withdrawals (20% to 28%) in six of eight scenarios. A decrease in water withdrawal is also observed in most scenarios for Europe, Eastern Europe and Eurasia, and Asia-Oceania-OECD. On the other hand, the developing and emerging regions, namely China, India, Asia (other), the Middle East, Latin America, and Africa, are characterized by an increase in water withdrawals for electricity generation in the scenarios with higher shares of fossil fuels. Overall, the results indicate that it is particularly important for developing and emerging regions to combine the expansion of energy supply with less water-intensive technologies, including in particular renewable energy technologies such as photovoltaics and wind energy, in order to reduce water demand for electricity generation. The results for water consumption also differ markedly across the regions (Figure 4-5) depending on the scenario. In North America, four of the scenarios result in reduced water consumption by 11% to 31%, while four predict an increase of 1% to 11%. In Europe, seven scenarios predict a reduction in water consumption which can mainly be attributed to the decrease of coal and oil in the electricity mix and to the phase-out of nuclear energy. The water consumption for renewable electricity generation increases in Europe in all scenarios but remains lower than the use of water for fossil power generation in 2015 in seven out of the eight scenarios. Scenario results also show large variations in water consumption for future electricity generation in China. In India, Asia (Other), the Middle East, Latin America and Africa, the growth in water consumption is substantial in all scenarios except one. The rise in water consumption in these regions is mainly driven by the rapid growth in electricity demand. In terms of technologies, natural gas, biomass, solar and nuclear energy, are the main drivers for the increase in water consumption in these regions.

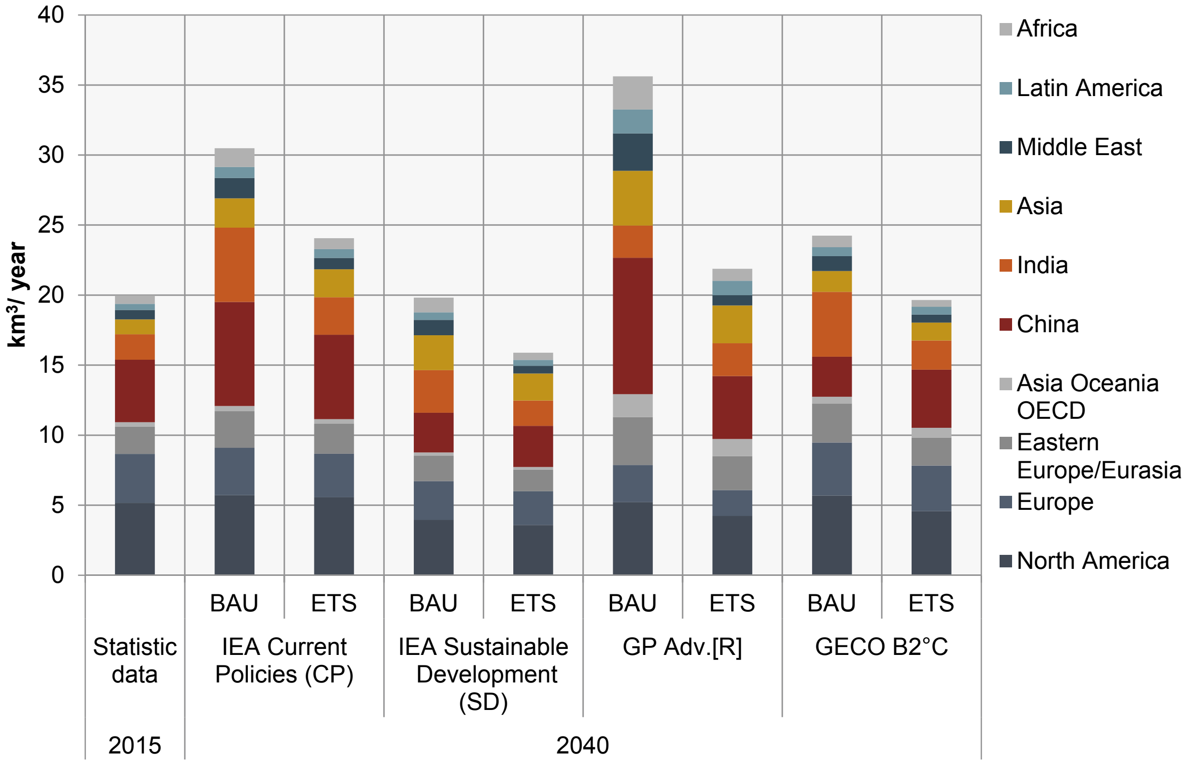

Figure 4-5: Water consumption for electricity generation (in km3 per year) by region for different scenarios in 2040 (Terrapon-Pfaff et al., 2020. Based on data from IEA/OECD, 2017; Greenpeace, 2015; JRC, 2017).

The results show that water demand varies significantly between different electricity mixes. Ambitious decarbonization scenarios with extensive use of renewables and high electrification rates in key energy-intensive sectors have the lowest water intensities, but in absolute terms these systems may result in higher water use than the less ambitious climate change mitigation scenarios. The results underline the importance of considering not only the potential to reduce greenhouse gas emissions but also other environmental aspects - such as water demand - when designing future electricity systems to ensure a holistically sustainable energy transition.

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