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Reduction of cooling water consumption due to photovoltaic and wind electricity feed-in

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ABSTRACT

In Germany, in the coming decades, nuclear and some coal power plants shall be substituted mainly by photovoltaic (PV) and wind turbines. In this study the impact of PV+wind electricity feed-in on the operation of thermoelectric power plants and the corresponding water consumption was analyzed for July 2011–June 2013. Using hourly time-series of electricity demand, feed-in by renewables, and net export of power abroad, cycling of all thermoelectric power plants along the River Neckar was simulated and the corresponding cooling water amount was calculated. The study show that the electricity generation by PV+wind results in a 7% reduction of cooling water consumption, that equals 43 l per total MWh. The substitution of coal power plants by PV+wind is highest in spring and autumn due to a coincidence of medium-high electricity demand and high electricity feed-in by PV+wind. Water consumption reduction varies seasonally between 4% and 11%. Over one day a maximum of 28,690 m^3 less water was consumed due to PV+wind feed-in.

By 2050 the targeted share of renewables is about 80% (fourfold feed-in by PV+wind), that corresponds to a roughly estimated 70% reduction of water consumption. This reduction help to alleviate low flow situations and decrease water temperature but might be offset by climate change impacts.

Contents

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1. Introduction

Thermoelectric power plants require large amounts of water to cool their steam cycle. In Germany, in 2010 approximately 63% of total freshwater abstracted was used in the energy sector, 99% of which was for cooling purposes. In the federal state Baden–Württemberg the proportion of abstracted water for power plant cooling was even higher at 76% [4].

The cooling process is generally associated with a specific water consumption, as extensively reviewed by [8]. Furthermore, the elevated temperature of discharged cooling water may have significant impacts on the receiving river ecosystem. These include the destruction of vegetation, increased oxygen depletion, algae growth, the extinction of heat intolerant species, and the expansion of exotic or pest fish or other fauna suited to elevated temperatures [e.g. [6]]. In Germany, nearly all thermoelectric power plants are located adjacent to large rivers. In late summer and autumn, when river flow and/or water temperatures reach certain thresholds, thermoelectric power plant discharges have to be curtailed according to official regulations. This reduction in output, however, may result in power shortages and thus negative economic impacts. During the drought of August 2003 (foreshadowing potential climate change impacts) water use was severely restricted due to low flow and unsustainably high water temperatures, such that nearly all large thermoelectric power plants had their output curtailed.

In the future, one consequence of climate change may be lower river discharges and higher water temperatures in late summer. Thermoelectric power plants are highly vulnerable to these changes not only because of their high water demand but also due to the restricted transport of coal by river during low flow [11]. Furthermore, the future development of the electricity sector, especially power demand and the electricity generation mix, will have important implications for regional water resources [9,2,3]. Since the implementation of the German Renewable Energy Act in 2000 a very large expansion of biomass, photovoltaic (PV), and wind power plants has occurred. In Baden–Württemberg, the share of renewable energy sources (RES) in power generation increased from 9% in 2004 to 20% in 2011, mainly due to on-going new installations of PV and biogas power plants. In December 2012 the installed PV power plants corresponded to a total 4300 MW_{peak} generation capacity, equivalent to 0.4 kW per person, and approximately 7% of total electricity generation. The number of wind turbines did not increase so strongly, this was due to limited acceptance among the population, and currently stands at about 1% of the generation mix in Baden–Württemberg. In the aftermath of the 2011 Fukushima nuclear disaster in Japan, the subsequent political turnaround in Germany has resulted in a goal for 2020 that PV and wind should have a share of 12% and 10% of the energy mix, respectively.

Until now, the relationship between power supply from non-thermal RES and water consumption by conventional power plants has scarcely been analyzed. Kyle et al. [7] and Clemmer et al. [2] provided future scenarios with a higher share of RES in the electricity generation mix. However, only annual water amounts were calculated based on hypothetical situations. We present a model (PVW²) which simulates the output reduction of thermoelectric power plants in relation to PV+wind feed-in, and thereby the reduced cooling water consumption, based on hourly power demand and PV+wind feed-in data. Although this study focuses on energy supply in Baden–Württemberg and water use along the River Neckar, the model presented is applicable to other water bodies and some figures calculated can be transferred to other regions. The results are of particular relevance to policy and decision makers in regions with an expected increase of power demand and a threat of water scarcity.

2. Cooling water consumption

Thermoelectric power plants need large amounts of cooling water to condense steam after its passage through the turbines. Three general types of cooling systems can be distinguished, and are associated with different water consumption and heat input into the receiving water body [5,1]. Once-through systems use the water once before discharging it back into the river or lake. Here, the higher temperature of the discharged water leads to a higher evaporation rate in the water body and therefore to cooling-induced water consumption. Wet recirculating systems reuse cooling water multiple times. In these systems cooling towers are normally used to dissipate heat from cooling water to the atmosphere: warm cooling water sprinkles through the lower part of a natural, or mechanically induced, draft cooling tower and evaporates. This process has a higher evaporation rate than for a once-through cooling system, but the total volume of water withdrawn and the warming of the water body, per unit electricity generated, is lower. The third type of cooling system is the dry recirculating system, which needs and consumes no water and the steam-carrying pipes are cooled by ventilation. Dry, and also some wet, recirculating cooling systems require much more energy than once-through systems.

Most power plants operate a combination of the aforementioned cooling methods depending on site-specific conditions and official approvals. Once-through systems are often equipped with a cooling tower, which reduces the temperature of the water discharged. In so-called hybrid cooling systems both wet and dry cooling components are used either separately or simultaneously.

Mean water consumption rates for German power plants, are relatively low compared to other countries (Table 1). For example, in the USA the water consumption of coal power plants with wet recirculation and cooling towers averages 1.8 m^3/MWh [5]. Dry-cooling systems consume no water and are not used in Germany, and are thus not listed in Table 1. German power plants with combined-cycle gas turbines use a once-through cooling system and are not equipped with cooling towers or hybrid cooling systems.

3. Relationship between power generation by non-thermal renewable energy sources and water consumption

According to the German Act on Granting Priority to Renewable Energy Sources transmission system operators are obliged to take the electricity feed-in by renewable energy sources (RES) in priority to electricity generated from conventional power plants. Thus, if the electricity generation by PV and/or wind is high, the "load-following" power plants and even some base-load power plants curtail their output to a certain extent. This reduction in generation results in a reduction of cooling water consumption. In this study "consumption" refers to the amount of water lost to evaporation, and is, hence, not discharged back to the water body. The lower water consumption due to electricity feed-in by photovoltaic and wind is referred to as "consumption reduction".

Table 1
Mean water consumption for German power plants given in m^3/MWh [[5]].

Cooling system	Coal	Nuclear	Combined-cycle
Once-through	0.90	1.44	0.47
Once-through with cooling tower	1.19	1.87	–
Wet recirculating with cooling tower	1.33	2.12	–
Wet and dry recirculating (hybrid)[a]	0.97	1.58	–

[a] Proportion of dry cooling = 30% is assumed.