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Hydro-climatic conditions and thermoelectric electricity generation – Part II: Model application to 17 nuclear power plants in Germany

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ABSTRACT

In highly developed countries electricity generation is one of the largest water users. Water is mainly used in the cooling processes of thermal power plants. In as yet less developed countries, electricity requirements are also increasing in step with increasing production and standard of living. Renewable electricity generation is gaining more attention in both highly and less developed economies. However, many types of renewable electricity generation, e.g. wind or solar, are still unreliable due to their dependence on weather conditions. This is why electricity generation by thermal power plants will remain a substantial component of the overall energy system for the next decades.

An approach is applied here for analysing links between water availability and water temperature, air temperature and electricity generation by power plants. A highly disaggregated level is used combining a power plant model and hydrological models. It is applied to analyse effects of climate change on 17 nuclear power plants in Germany. Although even under baseline conditions reduced electricity generation can be observed, any further increase in air temperatures reduces electricity output of almost all nuclear power plants. The different technological and environmental conditions of each plant site mean that specific models are necessary for the simulations.

1. Introduction

In recent years, there have been several heat waves affecting the use of power plants in Europe and the U.S.A. due to high water temperatures and low flows of water (van Vliet et al. [1], Martin [2] or Badr et al. [3]). The IPCC (Intergovernmental Panel on Climate Change, [4]) and other experts expect that air and water temperature will rise in future. In many regions there will also be a reduction in river runoff in summer. Heat waves and droughts as observed in Europe in summer 2003 and 2006 will very likely occur more frequently (Schär et al. [5]). As a result, the number of interruptions in the use of power plants because of lack of water for cooling or high water temperatures could increase, too.

The impacts of climate change on the power plants and the electricity system have been analysed in several studies (cf. Koch and Vögele [6]). In Ref. [6] a new approach is presented for analysing the impacts of climate change on power plant electricity generation, combining a power plant model and hydrological models for river runoff and water temperature. The Krümmel nuclear power plant was selected to demonstrate the methodology. In this paper, we extend the analysis of possible impacts of climate change on electricity generation in Germany by applying the methodology to 17 nuclear power plants located in different river basins in Germany. The uncertainties are analysed with regard to power generation under different climate developments and corresponding increases in air temperatures.

After the Fukushima nuclear disaster in Japan in 2011, half of the nuclear power plants in Germany were shut down and it is planned to close the remaining plants in the near future. Despite of this, the nuclear power plants in Germany are used in this analysis because of the very good database. The concept presented can be used to analyse such effects for other types of power plants with comparable water cooling systems.

Section 2 gives an overview of nuclear power plants in Germany. In Section 3 the hydrological data (water temperature, runoff) used in this study are described, and in Section 4 the results for the nuclear power plants are presented. The article concludes with a discussion of the results in Section 5.

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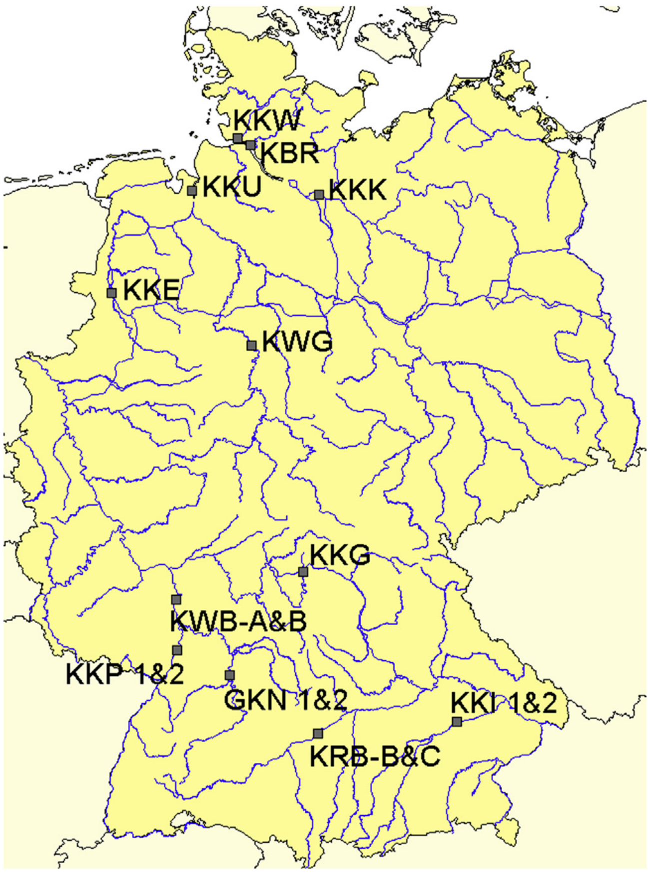

Fig. 1. Location of nuclear power plants in Germany (abbreviations see Table 1).

2. Nuclear power plants in Germany

Three main types of wet cooling systems can be distinguished for nuclear power plants in Germany [6]:

i) once-through cooling, in which the water withdrawn from a body of water is used for cooling in the condenser and subsequently returned in its entirety into the body of water; the amount of water required for this type of cooling is considerable;
ii) once-through cooling with cooling tower, in which the water is cooled in a tower before it is returned, so that the potential stress on the body of water is reduced; and
iii) closed-circuit cooling, in which the water heated in the condenser is cooled in a tower and fed back into the condenser; the amount of water required for this type of cooling is small.

In some power plants combinations of the cooling systems mentioned above are used. For instance some power plants equipped with closed-circuit cooling systems can also run in once-through cooling mode. In this way, additional operation costs associated with the more complex closed-circuit cooling system can be avoided. For a more general overview of power plant cooling systems, including dry cooling systems, the reader is referred to Martin [2] and Badr et al. [3].

For power plants using water as cooling medium the reduction in electricity generation can be due to restrictions regarding the discharge water temperature. For most of the nuclear power plants in Germany the maximum discharge water temperature is between 33 and 35 °C while the permissible temperature rise of the cooling water is usually 10 K. Therefore, this restriction is relevant if the water temperature at the point of intake reaches approximately 23 and 25 °C, respectively. The maximum mixing water temperature allowed downstream of the discharge point is 28 °C for most locations. If the water temperature at the point of intake is already high or if insufficient water remains in the river after the withdrawal to take up the discharged heat, the restriction for maximum mixing water temperature comes into operation. If the water temperature at the point of intake even reaches the maximum mixing water temperature of 28 °C the withdrawal water temperature may be a further restriction. In the latter case, no further increase in water temperature is allowed and the electricity generation must be completely shut down.

In 2010, 17 nuclear power plants were in operation in Germany (see Fig. 1). In some cases, two plants are located more or less at the same spot (e.g. Biblis A and B in Fig. 1). Table 1 gives basic information about the separate nuclear power plants according to [7] and [8]. All the plants use water as the cooling medium and are simulated using the approach presented in Ref. [6].

Table 1
Overview of nuclear power plants in Germany (status year 2010).

Name of nuclear power plant	Abbreviation	Capacity (gross) (MW)	Capacity (net) (MW)	Cooling system	Start of commercial production (year)
Biblis A	KWB-A	1225	1167	ccs*	1975
Biblis B	KWB-B	1300	1240	ccs*	1977
Brokdorf	KBR	1440	1410	ots	1986
Brunsbüttel	KKW	806	771	ots	1977
Emsland	KKE	1400	1329	ccs	1988
Grafenrheinfeld	KKG	1345	1275	ccs	1982
Grohnde	KWG	1430	1360	ccs	1985
Gundremmingen B	KRB-B	1344	1284	ccs	1984
Gundremmingen C	KRB-C	1344	1288	ccs	1985
Isar 1	KKI 1	912	878	ccs*	1977
Isar 2	KKI 2	1475	1400	ccs	1988
Krümmel	KKK	1402	1346	ots	1984
Neckarwestheim 1	GKN 1	840	785	ccs*	1976
Neckarwestheim 2	GKN 2	1400	1310	ccs*	1989
Philippsburg 1	KKP 1	926	890	ccs*	1980
Philippsburg 2	KKP 2	1458	1392	ccs*	1985
Unterweser	KKU	1410	1345	ots	1979

ccs: closed-circuit cooling.
ots: once-through cooling.
ccs*: once-through available.

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