Requirements on a Service Tool to Foster Demand-Side-Management Under Changing Climate Conditions

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Abstract

Several countries in Europe, e.g., Spain, Turkey or Poland and worldwide, are already struggling with the existing impacts of climate change, such as long lasting droughts leading to a higher water demand for agricultural as well as industrial cooling processes (IPCC, 2014). As a result of higher insolation and rising temperatures (as predicted for the future), a higher demand for cooling systems for private as well as public buildings arises. If there is not enough water available for cooling conventional power plants during droughts, power plants have to restrict their amount of electricity generation in order to prevent an overheating of the river water. Additionally, droughts affect hydroelectric power plants as well, as they need certain minimum water levels to run the turbines. In countries with a large share of electricity generation from conventional and nuclear power plants, electricity generation from renewable energies such as wind turbines and photovoltaics can ease this problem. Nevertheless, renewable energy can lead to high fluctuations within the electricity grid as it is not available at all times. In that case, energy supply can neither be secured by the conventional and nuclear power plants nor by renewable energies. Besides alternative cooling technologies, demand-side-management (DSM) is an option, as it can adjust the demand to the actual market situation of water and energy. DSM can help to secure electricity supply by stabilising the operation of the electricity grid: electricity demand can be decreased and/or shifted to times of, e.g., high electricity feed in from renewable energy sources.

Aim of this paper is to define and establish the requirements on a service tool for the distribution of water and electricity, in order to secure energy supply by fostering DSM under changing climate conditions.

1 Dependency of the Security of Electricity Supply on Water Availability

1.1 The Energy-Water-Nexus

The USAID Global Environment Center in Washington D.C. already recognised in 2001, that energy and water have much in common and that energy is necessary to be able to use water and vice versa (Hurdus, 2001). However, the World Economic Forum states, that the International Food Policy research Institute (IFRI) expects a 30 % increase in water demand by 2030 (World Economic Forum, 2011), while the International Energy Agency (IEA) forecasts an increasing energy demand of 25 % by 2040 (IEA, 2015).

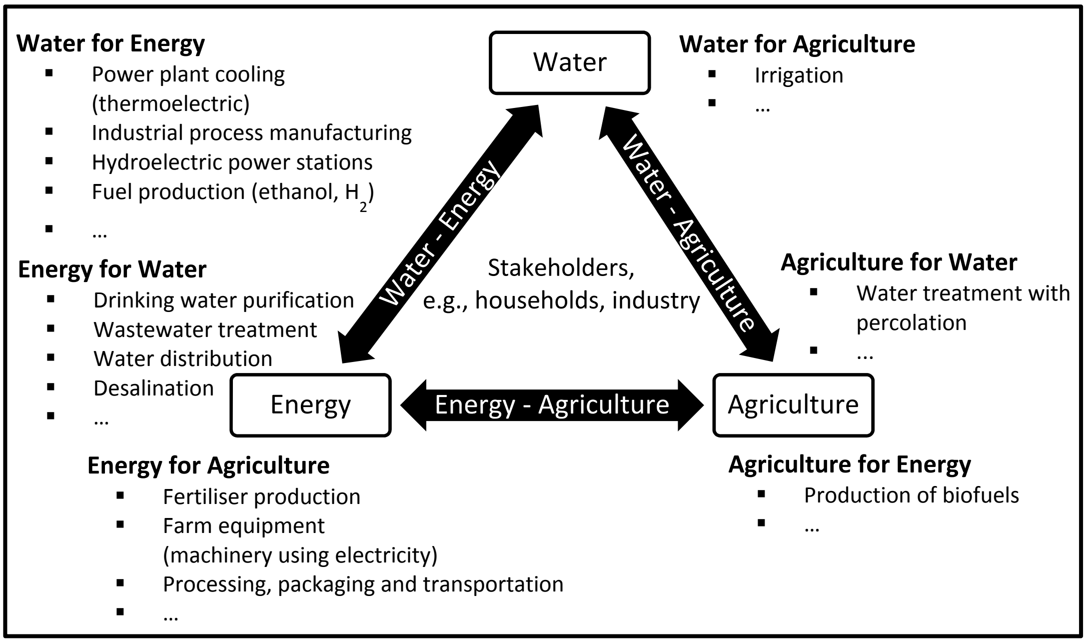

Figure 1.1

Supply triangle water, energy and agriculture (Newiadomsky & Tietze, 2015)

As it can be seen in Figure 1.1, water is needed for several industrial processes (production, cooling etc.) as well as for irrigation for agriculture (Halstead, Kober, & van der Zwaan, 2014). Moreover, energy is necessary for water supply (treatment, purification, distribution etc.) while it is also crucial for the production of fertilizers, biofuels or transport for the agricultural industry (Thirlwell, Madramootoo, & Heathcote, 2007). Products of the agricultural industry are in turn indirectly important for water treatment, e.g., purification via percolation (OECD, 2014). Households as well as industry are located in the middle of the described supply triangle, as they are depending on all three sectors in order to secure their demand. Industry depends additionally on these sectors in order to secure their supply (Newiadomsky & Tietze, 2015). A vicious circle can be observed, when countries depending on hydroelectricity have to turn to other energy sources leading to higher emissions and thus, influence the climate change (Thirlwell, Madramootoo, & Heathcote, 2007; Halstead, Kober, & van der Zwaan, 2014).

Depending on the plant size and the power plant type, different amounts of water are needed for cooling purposes, e.g., a nuclear power plant with once-through cooling withdraws between 95 to 227 m^3 of water per MWh electricity, while cooling with a wet tower would lead to only 3.0 – 4.2 m^3/MWh and with a pond to 1.9 – 4.2 m^3/MWh. Water is necessary for every conventional plant type producing electricity, which shows the dependency on this resource (Davies, Kyle, & Edmonds, 2013). Regarding the amounts of water needed, it is crucial to find a solution to maintain energy security.

Apparently, there are conflicting interests between the sectors agriculture, water and energy as well as between the stakeholders, e.g., electricity versus water suppliers. Each stakeholder has its own focus, not necessarily considering the focus of the other stakeholders.

1.2 Climate change and energy security

Several studies on the impact of climate change on the environment predict an increase of air temperature (IPCC, 2013; Christidis, Jones, & Stott, 2015). This leads to increased evaporation from the water surfaces and an augmented need for water for, e.g., cooling in power plants (Colman, 2013) or for irrigation of agricultural areas. Simultaneously, water temperatures increase and industrial cooling is impeded (Zammit, 2012). Although rising temperatures lead to melting glaciers, which could increase the regional water supply again, the glaciers are melting faster than they can build up again during the winter months. Due to rising air temperatures, the clouds would rather start raining than snowing during the winter months. In the foreseeable future, the additional inflow from glacial waters would no longer be available and the regional water supply can be significantly reduced in the summer months (IPCC, 2013). An overview about possible climate change impacts on energy supply gives Schaeffer et al. (2012). Reports from summer 2003 deliver an example of the impeded industrial cooling, in which 15 coal-fired power plants in Germany (Strauch, 2011) and 30 nuclear power plants in Europe (IAEA, 2004) were affected by the unusually high temperatures. In Germany, seven of the 30 European nuclear power plants as well as the aforementioned 15 coal-fired power plants had to reduce their electricity generating capacity by up to 78 % in the months of May to October due to the high water temperatures and the legal maximum temperatures for returning cooling water (Strauch, 2011).

Higher global temperatures will increase the possibility of droughts or floods: Due to rising temperatures, polar caps and glaciers melt and in turn result in rising sea levels. Furthermore, the temperature increase reduces the quality, quantity and accessibility of water resources: They lead to higher evaporation in lakes as well as rivers, which could lead to drying and thus, restriction on aquatic habitat and lowered water quality due to increased pollutant concentrations and oxygen deficits (IPCC, 2013). Accordingly, higher temperatures will lead to higher energy use to treat low quality water or to pump water from greater depth (U.S. Department of Energy, 2007). In turn, increased energy use will cause an increase in greenhouse gas emissions, while lower water availability leads to trade-offs between water users, such as agricultural industry and electricity suppliers, e.g., conventional and nuclear power plants (cf. Figure 1.1).

1.3 Rising generation costs due to lack of water

Evidently, increasing temperatures followed by more evaporation and less water availability, will force conventional power plant operators to decrease the amount of electricity generation (van Vliet, Yearsley, Ludwig, Vögele, Lettenmaier, & Kabat, 2012; Hoffmann, Häfele, & Karl, 2013) until the power plant has to be shut down. According to Flörke et al. (2012), the average water availability during summer is decreasing until 2050, so the competition for water resources increases for conventional power plants. Consecutively, the generation costs of the conventional power plants are likely to increase, as it will get more and more difficult to run the power plants with enough water, while water treatment will exacerbate because of the lack of electricity for treatment and distribution (van Vliet, Yearsley, Ludwig, Vögele, Lettenmaier, & Kabat, 2012).

2 Methodology

A solution to the problems of a secure electricity supply is a service tool considering Demand Side Management (DSM), amongst others. The consideration of DSM assists in fulfilling electricity and water demand to the possible extend: efficient appliances reduce water and electricity demand in times of low electricity availability and intelligent appliances shift demand to times with high water and electricity availability. A service tool considering DSM will be assembled as computer model, which is fed with information on water and electricity demands by the stakeholders as well as the availability of central and decentral electricity-generating systems. External web services and data sources, clouds or sensor data can additionally be included. Basis for the service tool is a matrix showing in detail the information needed. These data are rule-based processed to a decision support matrix for each stakeholder, highly depending on the prevailing or predicted weather. It provides detailed information for the distribution of water and electricity under different circumstances. Aim of the service tool is, to provide decision support for the water distribution and to secure electricity supply: The individual water demands are differentiated into initial demand and minimal demand accompanied by a priority scheme for the individual demands. In order to ensure energy security, the service tool has to find the point of electricity balance by weighing the demands and possible supply as well as by weighing between smart grid systems and electricity from renewable energy power plants.

3 Requirements and Specifications on a Service Tool

3.1 Approaches for a service tool for the distribution of water and electricity

Hoffmann, Häfele & Karl (2013) conducted a first model approach with projections up to the year 2070, considering several climate data projections, selected thermal power plants as well as their respective cooling systems and the legal threshold values for returning cooling water into waterbodies. Main aim of Hoffmann, Häfele & Karl is to analyse the impact of climate change on the efficiency of electricity generation with thermal power plants under consideration of different cooling technologies. The efficient distribution of water and electricity were not included in the study.

Several approaches exist with regard to energy management in industry, e.g., DIN EN ISO 50.001. Schieferdecker, Fünfgeld & Bonneschky (2006) describe for example the necessary parametrisation of industrial appliances for efficient energy controlling and load management. In order to cover the part for water distribution, similar information should be provided for water management. Additionally, information about the interdepending relation between electricity and water management has to be analysed.

A universal service tool to connect models for water resources management, energy management and energy system analysis is missing.

3.2 Establishment of a service tool

In order for a service tool to be used as decision support for the stakeholders, it has to provide information concerning energy and water management. Depending on the current and forecasted weather as well as the stakeholders' demand, river basin managers get decision support concerning a beneficial distribution scheme for water. The same information is of interest for electricity and water suppliers: Water suppliers can plan when to treat water and how to distribute the available water to the subsequent stakeholders (e.g. households). Whereas electricity suppliers (e.g. conventional power plants) can plan their amount of electricity generation according to available cooling water amounts and receive information for a beneficial electricity mix for feed-in into the grid. Households, industry and the agricultural sector receive decision support in terms of how to shift energy and/or water intensive processes (e.g. use of washing machines) into times of high water / electricity availability. Additionally, these three groups receive decision support concerning, e.g., the use of energy efficient equipment. Transmission system operators and distribution grid operators receive decision support in terms of a beneficial mix of electricity from conventional, renewable and smart-grid sources to secure electricity supply. Apparently, the service tool is a solution to increase the service level of each stakeholder by offering a decent distribution solution for all stakeholders concerning the conflicting interests. For this, the service tool is developed as computer model, containing near-realtime data of and from the stakeholders, climate predictions as well as recommendations for DSM and water distribution. At first, a stakeholder analysis is conducted in order to consider all affected parties. On the one hand, an input matrix is build, including each stakeholder and, e.g., its necessary amount of water and electricity to operate. On the other hand, the required information from the service tool for each stakeholder has to be determined, in order to offer the stakeholders an incentive to use the service tool for decision support. An obvious incentive may be driven by economic behaviour, but in case of negative effects, political or legal incentives become necessary.

Table 1 shows an exemplary requirements matrix for the service tool from the stakeholder's point of view. It shows the expected information from the service tool. In the example matrix are eight stakeholder groups, who are affected by electricity and/or water supply: Industry, households, the agricultural sector, river basin management, the distribution grid operator, the transmission system operator as well as water and electricity suppliers (e.g. power plants, public services). Obviously, there are stakeholders from different organisational levels (national, regional, local etc.). The number of stakeholder groups can increase when dividing into smaller subgroups. As an example, the "electricity supplier" can be aggregated firstly by power plant type, e.g., nuclear, and secondly by cooling technology. Each stakeholder group focusses on different requirements for decision-making.

Table 1: Exemplary requirements matrix for a service tool (to be extended)

Stakeholders	**Weather forecast (short-term)**	**DSM options electricity**	**Distribution options water**	**Allotted amount of electricity in kW**	**Allotted amount of water in m^3/h**
Transmission system operator	To prevent power failure of the grid	To secure electricity grid	NR[1]	NR[1]	NR[1]
Distribution Grid Operator	To prevent power failure of the grid	To secure electricity grid	NR[1]	NR[1]	NR[1]
Electricity Supplier	To estimate electricity feed-in to the grid	Increase efficiency on the user-side of the electricity meter	NR[1]	NR[1]	To plan amount of electricity generation
River basin manager (water)	To distribute water according to contracts	NR[1]	To distribute water by demand	NR[1]	NR[1]
Water Supplier	To estimate water supply to stakeholders	NR[1]	NR[1]	To plan water treatment	NR[1]
Agricultural Sector	NR[1]	NR[1]	NR[1]	e.g., for use of farm equipment	e.g., to plan irrigation
Households	NR[1]	e.g. use of energy efficient equipment	NR[1]	e.g., for cooking	e.g., for washing
Industry	NR[1]	e.g. demand shift	NR[1]	e.g., for manufacturing	e.g., for boiling processes

[1] Not Relevant

In the example matrix, several requirements of the stakeholders on the service tool are included: short-term weather forecasts, DSM options for electricity, distribution options for water as well as the allotted amounts of electricity and water. The matrix states, how each stakeholder group can use the given information. Not yet included are targets of each stakeholder to reduce their specific demand of electricity and water as well as the future climatic projections, which also have to be taken into account in order to let the service tool help the stakeholders in decision making for the distribution of water and electricity. To date, distribution decisions are mainly business-driven. Water distribution is depending on current contracts with stakeholders and the available water amounts. Electricity distribution is depending on the standard load profile of households or the individual load profiles of each company as well as on the current contracts with the stakeholders. Grid and system operators provide energy security with the merit order curve, implicitly taking into account the current feed-in from renewable energy sources and conventional power plants; they decide under consideration of the current energy acts, which power plants have to uncouple from the grid or have to couple to it, in order to secure electricity supply.

Depending on the prevailing or predicted weather, the results from the service tool change and it is defined, how the water distribution should look like. As soon as it is, e.g., not possible to distribute enough water to the power plants and they have to reduce their electricity outputs, the service tool has to determine, how much electricity is needed to stabilise the grid.

4 Conclusion & Outlook

In order to set up a functioning and reliable service tool for the distribution of water and electricity, every stakeholder and all influencing conditions have to be taken into account, e.g, future water and electricity demands and supplies, future climate projections, future political decisions as well as service tools already in use. Besides alternative cooling technologies for power plants and distribution systems already in use, DSM can additionally be taken into account for securing water and electricity supply, particularly when considering upcoming climate change impacts, i.e., droughts or increasing ambient air temperatures.

The presented approach of a reliable service tool tries to include all before mentioned information concerning supply and demand as well as the nexus approach, in order to be used as decision support for the distribution of water and electricity. With the aim of gathering all necessary data to establish the matrices for the service tool, it is crucial to work closely with the stakeholders. Based on this infor-

mation, decision support with the service tool cannot yet be given to the stakeholders based on political, ecological, economical as well as social evidence.
Further research has to be done about the future technical improvements for energy saving measures, future political decisions, targets of each stakeholder to reduce their specific demand of electricity and water, possible incentives for the stakeholders to participate in the DSM service tool as well as the future climatic projections. Additionally, necessary correlations between water and electricity demand have to be deduced and reasonable distribution patterns developed. Furthermore, a literature review concerning available service tools, an analysis about the existing gaps, possible extensions or meaningful combination of several applications should be made, in order to include this information into the service tool in addition to the matrices.
The more detailed data can be fed in into the service tool, the better will be the results for decision support concerning water distribution and securing the electricity supply for all stakeholders. Additionally, the service tool should be easily operating, to assure the use by the stakeholders. Finally, one has to bear in mind that the integration of the service tool should not be underestimated: On the one hand, a solution based state of the art has to be developed as well as emerging technologies for the technical and semantical integration of the very heterogeneous data sources. On the other hand, it has to be investigated, how current solutions for sufficient water supply to the stakeholders, while securing electricity supply, look like, e.g., how energy markets are organized and how a potential DSM could be integrated.

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