WANDEL: Water resources as important factor in the energy transition at local and global scale

Requirements for a water footprint approach to compare different energy generation systems

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ABSTRACT

Water and energy are crucial for sustainable development globally. As water needs energy and energy needs water, the on-going energy transition in industrialized countries but also the evolving transition in emerging and developing economies has to be scrutinized in terms of water usage. At the heart of WANDEL is the question of whether restrictions in water availability limit the use of conventional energy systems, thus accelerating or even slowing down the energy transition. Herewith WANDEL considers both, the on-site impacts of electricity generation on water resources locally and regionally by analysing four case studies in Germany, Brazil and Morocco, and the remote impacts worldwide by taking into account the entire supply chain in an integrated and interdisciplinary way. Central to this approach is an enhanced water footprint methodology that is able to assess the impacts on water resources from human activities, including water scarcity and water quality, in a comparable way and hence allows to answer the target question. WANDEL combines data- and model-based analysis of different water and energy scenarios, case-study-specific regulatory and technical solutions for the reduction of negative effects and qualified consulting services to present results in an innovative manner. So far, the conceptual framework of the water footprint approach has been outlined and data from the case studies are currently acquired to assess the water footprint of four energy generation systems.

INTRODUCTION

Both, water and energy, are part of the Sustainable Development Goals (SDGs) of the United Nations (UN, 2015) calling for "clean water and sanitation" and "affordable and clean energy". Recent research has provided insights into the interactions between the SDGs showing that the 17 goals are strongly intertwined and cannot be achieved without considering the interlinkages among them. These linkages give rise to possible synergies, but also trade-offs. In terms of energy supply, it becomes clear, that a transition towards renewable and low carbon technologies has to take place in order to mitigate climate change and reach the goals of the Paris Agreement. Renewable energy technologies can help achieving SDG 7 and SDG 13, but could counteract the targets of SDG 6 if they negatively affect water resources on-site or remotely along the supply chain. Vice versa, reduced water availability may limit the use of water demanding energy technologies. However, while also renewable energy technologies, like solar thermal energy, require water, it has been shown that especially the enormous cooling water demand of conventional thermal power plants based on fossil resources will result in cooling water gaps in several regions of the world in 2050 (Flörke et al., 2013). WANDEL focuses on this water-energy nexus and aims to answer the question whether restricting water availability limits the use of conventional energy systems, thus accelerating or even slowing down the energy transition. To answer this question WANDEL develops an enhanced water footprint methodology taking existing water footprint concepts into account.

METHODS

Water footprint assessment framework for electricity generation

In recent years, the initial water footprint concept developed by Hoekstra & Hung (2002) where green, blue and grey water footprints are calculated, has been intensively discussed, further developed and modified for many purposes. An assessment of water footprints with respect to regional water scarcity (e. g. Alcamo, Flörke, & Märker, 2007) has been adopted, and most recently, the water footprint has been introduced to Life Cycle Assessment (LCA, Kounina et al., 2013). However, there is no general approach and discussions are ongoing. Either way, simple green, blue and grey water calculations (see e.g. Water Footprint Network) fail to relate water usage to regional water scarcity, whereas highly aggregated LCA impact assessment indicators are complex and contain many uncertainties. To address WANDEL's objectives, concepts have to be enhanced: It is crucial to combine spatially explicit information on grid cell level, as provided by the applied hydrological modelling framework WaterGAP3, with a LCA systems perspective that covers the entire supply chain. Every process and related components along this chain contributing to the water footprint of the final product (i.e., generated electricity) have to be identified and quantified to determine the total water footprint. In terms of blue water (i.e., freshwater stored in surface and groundwater bodies, snow and glaciers) a clear differentiation must be made between impacts on surface and groundwater bodies which have to be assessed separately. Facilities to store blue water, like reservoirs and sewers, may have a direct impact on water availability for downstream users, but so far, water footprint approaches have only focused on the evaporation losses (Mekonnen & Hoekstra, 2012). Indicators quantifying the volume of retention and the associated evaporation losses with respect to river discharge volume (Grill et al., 2015) should be added to the water footprint in order to improve the concept for hydropower. Presenting green water (i.e., soil moisture from precipitation, used by plants via transpiration) as own water footprint category still has to be discussed with respect to the different case studies. Either way, it is calculated by the modelling framework WaterGAP3 that simulates also sectoral human water use, water availability and regional water scarcity. Impacts on water quality have to be included, as poor water quality can result in water scarcity if it is below agreed water quality standards and cannot be used without any treatment, by means of the virtual dilution volume (grey water footprint). The spatially explicit water footprint developed in WANDEL should be able to answer the question whether water use in a specific watershed is within the 'safe operating space', given by the SDGs (UN, 2015), or not. A sustainability assessment with respect to regional water availability is required respectively. Finally, a transparent reporting of each single indicator is required while the aggregation of the single indicators into one common water footprint can be helpful to disseminate results easily to specific audiences. A web-based data and information portal, called WANDEL-Share, that is developed based on using Free and Open Source Software (FOSS) and international standards of the Open Geospatial Consortium (OGC) and thus adaptable, will be used to do so. It enables the storage, management and processing of Earth Observation data and geo-data in order to give a geo-related comprehension not only on the water footprint.

Case studies

To develop and test the water footprint methodology, meeting the demands as described above, four case studies were selected as practical examples. For the water footprint approach different sets of data are required to address direct and remote impacts on water resources in terms of quantity and quality. In collaboration with local praxis partners, the required datasets are gathered and evaluated.

Weser: Coal-fired power plants in Germany in times of progressing energy transition fulfil the role of stabilizing the power grid, but no new investments are arranged. Hence, the conventional coal-fired power plant, a classical in-stream cooling water user located at the Weser River, Germany, serves as a reference for the other case studies representing renewable energy systems as part of the energy transition. On-site impacts on water resources are mainly due to the use of cooling water from the river and heated return flows discharged back to the river, while remote impacts are related to the origin of construction materials and, probably most important, the origin of coal. Trading mix data of coal have to be traced back to the countries of origin, i. e. to single mines, to make the water footprint spatially explicit. Uniper as the local praxis partner supports the project with data on cooling water use and return flows, construction materials and origin of coal.

Danube: The case study at the Danube River, Germany, is a cascade of barrages that generate electricity in run-of-river hydropower stations. This kind of power stations does not cause significant retention effects in terms of water availability. Likewise, the evaporation losses due to backwater effects (e. g. increased water surface area) are rarely quantifiable. Rather of importance here is the water footprint of the construction materials of the barrage facilities. Also, in the course of the supply chain analysis of construction materials (for all case studies) retention volume and evaporation losses from damming in areas, where it matters, may play a role again. The local project partners are the Bayerische Elektrizitätswerke GmbH (BEW) and the Bayerisches Landesamt für Umwelt (LfU Bayern) providing essential information on hydropower generation, construction materials and impacts of cascades on ecosystems.

Brazil: In the Cerrados biome in Brazil sugar cane is cultivated to produce sugar and ethanol. Originally, mills burnt bagasse, the fibrous raw material, to remove waste and to generate electricity for self-supply. Currently, as the energy market opened the possibility for them to sell electricity surplus, mills invest in improving their facilities to increase the electricity generation. To calculate and assess the water footprint of the bagasse-based electricity, it is necessary to determine both the water footprint of the sugarcane production and that of the sugar mill separately: (i) sugarcane production demands blue and green water for irrigation. For the grey water footprint the application of fertilizer and pesticides have to be considered. (ii) To calculate the water footprint of the sugar mill, its water balance is analysed. To determine remote impacts, the water use at the places of origin for construction materials and fertilizer/pesticides is assessed and included in the footprint. In this case study, the attribution of the water use to the different output products (sugar, ethanol, electricity and yeast) is a challenge, since in the past, bagasse was considered as a waste with zero water footprint, while today the produced electricity is sold and has therefore an economic value. Thus, the footprint allocation has to be adjusted. The WANDEL consortium collaborates with EMBRAPA as local praxis partner with expertise in water use efficiency and water balance in sugarcane production as well as long-year of trust based relationship with the sugar mills in the study area.

Morocco: The Moroccan case study focuses on the utility-scale concentrated solar power (CSP) plant NOORO I in Ouarzazate, Morocco. CSP plants need high direct solar radiation, a condition usually found in arid and semi-arid areas where water resources are often scarce. This is also the case for the province Ouarzazate, which is characterized by a semi-arid to arid climate. Accordingly, the operational water demand is a critical aspect in the case study NOORO I. The main operational water demand of CSP plants include water for cooling processes and mirror cleaning. The water demand for cooling varies significantly depending on the cooling technology applied. NOORO I was designed as a wet-cooling plant, requiring high amounts of water. Next to this direct operational water use, this study will also analyse the indirect water demand for the construction materials along the entire value chain. The focus of the analysis lies on the water footprint of different mineral resources needed for the solar mirrors and energy storage facilities. The case study itself is conducted together with the local partner MENARES.

Scenarios and global modelling

In the second step, the methodology developed at case study level will be used to determine the water footprint under different energy scenarios up to 2030 and 2050 on a global level. In order to evaluate the key question on how water availability will influence the energy transition, land use and climate changes as well as socio-economic developments will be taken into consideration. The water footprint will be used to identify hot spots of water scarcity along the energy supply chains outlined by the selected energy scenarios and provide information about potential problem shifts due to remote impacts. This is an important step to support the achievement of SDG 6 and SDG 7.

INTERIM RESULTS AND DISCUSSION

The water footprint concept was discussed with local and international praxis partners in regional stakeholder meetings (March-June 2018) and at the first International Workshop in November 2018. Currently the team incorporates the stakeholder's feedback into concepts, methodologies and data needs to address practitioner's needs. Figure 1 shows how the water footprint approach will bring together spatially explicit on-site and remote impacts on water resources in order to assess sustainable usage (as indicated by different colours in the figure) at different scales (local case studies, global energy supply chains) for the analysed case studies.

Figure 1: *On-site and remote water footprints that contribute to one energy production system along its supply chain. Coloured dots indicate the assessment of sustainable water use (green = no impact, yellow = medium, red = severe).*

SUMMARY & OUTLOOK

- WANDEL developed the first water footprint approach for comprehensive and spatially explicit assessment of different energy systems.
- Uses a data- and model-driven methodology that combines local knowledge and information with global pathways in a systems approach.
- Collaborates with local partners as a key element of successful evaluation and implementation.
- Implements four case studies on different energy systems in different regions to allow for a differentiated and comprehensive assessment of the water footprint.
- Will integrate the local level case studies and the global energy scenarios to draw a holistic picture that allows the key research question to be answered in a science-based way.
- Will carry out a global analysis to allow linking results to freshwater biodiversity effects, to analyse SDG achievement related to conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems, and their services (Target 15.1).

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