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Water saving potentials and possible trade-offs for future food and energy supply

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ABSTRACT

The sufficient supply of food and energy requires large amounts of fresh water. Mainly required for irrigation, but also processing and cooling purposes, water is one of the essential resources in both sectors. Rising global population numbers and economic development could likely cause an increase in natural resource demand over the coming decades, while at the same time climate change might lead to lower overall water availability. The result could be an increased competition for water resources mainly in water-stressed regions of the world in the future. In this study we explore a set of possible changes in consumption patterns in the agricultural and energy sector that could be primarily motivated by other goals than water conservation measures—for example personal health and climate change mitigation targets, and estimate the indirect effect such trends would have on global water requirements until 2050. Looking at five world regions, we investigated three possible changes regarding future food preferences, and two possible changes in future resource preferences for electricity and transport fuels. We find that while an increase in food supply as a result of higher protein demand would lead to an increase in water demand as well, this trend could be counteracted by other potential dietary shifts such as a reduction in grains and sugars. In the energy sector we find that an increasing water demand can be limited through specific resource and technology choices, while a significant growth of first-generation biofuels would lead to a drastic rise in water demand, potentially exceeding the water requirements for food supply. Looking at the two sectors together, we conclude that an overall increase in water demand for both food and energy is not inevitable and that changes in food and energy preferences could indeed lead to an alleviation of water resource use despite rising population numbers.

1. Introduction

The types of foods and energy we consume have considerable direct and indirect effects on global freshwater use. By far most water resources get used for irrigation purposes in the agricultural sector, mainly for food production. In another sector, energy, electricity and fuel production requires increasing amounts of water, mainly for resource extraction and cooling (Macknick et al., 2012; Mielke and Anadon, 2010). In some regions this trend has already led to a competition between different water users (The World Bank, 2014). Rising global population numbers and socio-economic development could lead to a further increase in water demand in both sectors over the coming three to four decades. At the same time environmental changes like climate change might decrease the water availability and quality in many parts of the world (Jiménez Cisneros et al., 2014). Hence, the source and type of food, electricity, and transport fuel we choose in the future can either accelerate a rising water demand or offset increasing resource needs, depending on the effects of consumer preferences and policy initiatives on consumption patterns in both sectors. Water is one of the most important natural resources and the interactions between water use, energy demand and food production are complex, as changes in the demand of one resource in one sector can change its availability and that of another resource in another sector and vice versa. Water is used and re-used for food, electricity, and fuel production, while energy is required for agriculture and water supply, creating positive feedback loops that can aggravate already existing water shortages or generate new ones.

Over the last decade a number of scientific papers and policy reports have examined the interactions between the agriculture and energy sector from a natural resource perspective. Resources

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that received highest attention with regard to their regionally interrelated availability are water, energy, and to some extent land. A term that is often used to describe this interconnection is the so-called water-energy-(land)-food (WE(L)F) nexus, i.e. the interaction regarding water that is required for food and energy, energy required for water and food, and land required for food and energy supply. There are qualitative and quantitative approaches, as well as global and regional studies covering either specific parts of the WE(L)F nexus or trying to integrate several resource interdependencies at the same time, searching for trade-offs and potential conflicts. Existing studies on this topic discuss a growing scarcity of natural resources due to rising population numbers and economic development, and their potential social implications, while most of them focus on the water-food or water-energy nexus.

Within this context, an important issue that has not yet been examined in the scientific literature are the effects that potential changes in consumer preferences could have on natural resource use. The amounts of water that get consumed for supplying food, electricity, and transport fuel can vary vastly depending on type of food and energy source chosen. In this study, we address this very question: how an increasing global per capita and overall demand for food and energy would potentially be influenced through a set of different consumption trends regarding changes in dietary and energy source preferences. In the form of a global high-level quantification for water consumption in the agricultural and energy sector, we model the water use for irrigation, cooling and processing purposes in five world regions as defined for the shared socio-economic pathways (SSPs) used for the latest IPCC assessment report (Field et al., 2014). Our aim is to compare and evaluate the water consumption shares for food, electricity, and transport fuels until 2050 and detect global and regional patterns in water demand across these two sectors. Through this integrated analysis we will be able to identify a set of relative and combined effects of resource preference changes on the presumably steadily rising water demand in both sectors.

2. Background

A number of recent qualitative and quantitative papers have discussed the WE(L)F nexus in general and particular resource interactions, often focusing on specific parts of the world which are characterized by significant natural resource scarcity and competition. A first set of studies has looked at (aspects of) the WE(L)F nexus on a qualitative basis. Ringler et al. (2013) discussed the linkages of water and food, energy and water, energy-food, land-energy, and energy-land, and underlined the importance of an integrated management approach. Halstead et al. (2014) reviewed the current literature on the WEF nexus, though did not relate water use shares of both sectors to each other. FAO (2014) examined the WEF nexus as a new approach to support food security and sustainable agriculture. Bogardi et al. (2012) analyzed the interconnected challenges for water security for a planet facing increasing regional water stress due to rising population, climate change, urbanization and development, calling for an integrated management framework in order to address all of these challenges simultaneously. De Fraiture et al. (2010) discussed comprehensive assessment methods for water management in agriculture. Also Rosegrant et al. (2009) focused on the water use intensity of the agricultural sector and how to maintain food security while water stress increases with an emphasis on improving efficiencies. Hellegers et al. (2008) presented a debate on the interactions between water, energy, food and environment with a focus on water-related policy issues. Allouche (2011) looked at water and food security predominantly from a social and political perspective, doing so on a global, regional and national scale. Harvey and Pilgrim (2011) explored the "new competition for land", integrating food, energy and climate change into their discussion. All of these studies have envisioned a drastic rise in natural resource demand based on an extrapolation of current requirements to future population numbers and ongoing socio-economic development trends, and hence have called for an integrated policy and management framework.

Another set of studies has tried to quantify natural resource interconnections on a global level. Hanjra and Qureshi (2010) analyzed expected reduced global water availability and future food security, reviewing quantitative results from previous studies to underline the severity of limited water resources for agriculture over the coming decades. Chartres and Sood (2013) undertook a global quantitative analysis for the water demand for food production until 2050. Using the WATERSIM model they developed three scenarios with differing assumptions on population and GDP growth rates where they extrapolated current dietary patterns, but did not integrate a discussion on potential changes in future consumer preferences. All scenarios show an increase in global water demand for agriculture from 2400 km^3/yr in 2010 to between 3820 and 7230 km^3/yr in 2050. Sulser et al. (2010) used IFPRI's IMPACT model for their analysis of the Nile and Ganges river basins, including a set of global scenarios that illustrate the potential growth rates of consumptive water use in the agricultural sector until the mid-century depending on global per capita income growth. They projected an increase from 1425 km^3/yr irrigation (blue) water demand for crop production in 2000 to 1785 km^3/yr in 2050 in their baseline scenario.

A third set of studies followed a regional approach to the WE(L)F nexus. Lele et al. (2013) debated governance issues when integrating food, water and energy security, including a case study for water management in China and India. Gulati et al. (2013) presented a national WEF study for South Africa, exploring the interdependencies of these three resources, including an economic analysis. Hardy et al. (2012) undertook a quantitative analysis of the water-energy nexus for Spain, calculating a potentially increasing water demand for energy supply. Scott et al. (2011) looked at the policy and institutional dimension of the water-energy nexus including cases studies from the United States, highlighting the role of integrated local water management. Khan et al. (2009) presented ways to reduce water and energy demand for grain production in Australia. Larson (2013) analyzed the water demand for alternative food security policies in the Middle East and North Africa, focusing on wheat production and trade. Rasul (2014) studied food, water and energy security in South Asia. Lawford et al. (2013) gave a basin perspective on the WEF security nexus, using results from case studies from different large river basins. Perrone et al. (2011) presented an integrated qualitative analysis framework for the water-energy nexus on the community level. In all of these regional analyses natural resource availability is expected to decline due to rising demands and simultaneous adverse ecological changes.

There have also been several regional and global studies looking particularly at the water (and land) demand of energy in the form of biofuels, and their potentially negative impacts on food security and water availability when scaling up biofuel production in the future. Dominquez-Faus et al. (2009) analyzed the water requirements for maize as energy crop in the US, concluding that a major shift to such an energy source would have large detrimental effects regarding water availability and environmental health. Fingerman et al. (2010) examined the water impacts of producing bioethanol in a comprehensive environmental assessment with a case study for California, finding that the production of ethanol from maize or sugar beets would require enormous amounts of water with up to 5100 L/L ethanol. Yang et al. (2009) calculated the land and water requirements for biofuel production in China and its potentially adverse consequences for food supply and the environment. Using