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Reduction and reallocation of water use of products in Beijing

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ABSTRACT

The virtual water concept has received significant attention through manifesting the role of human activities such as consumption and international trade on water resources. However, few studies have focused on how the interactions of local supply chain exert impact on local water resources associated with virtual water flows. In this study, we introduce an indicator which is attached to the virtual water concept, termed the "internal water use of products" (IWUP), to examine the direct and indirect water use from local water supply for goods and services in Beijing for the years 1997, 2000, 2002, 2007, and 2010. This indicator links the pressure on local water resources to the final products with sectoral details, highlighting the importance of economic analysis in local water resource management. A structural decomposition analysis revealed that the increase in economic water productivity would have caused Beijing's IWUP to decrease by 196% from 1997 to 2010, if other determining factors remained constant. Such great efficiency improvements have allowed Beijing to fulfill its objectives of economic growth, whilst in the meantime reducing the water used in production. However, we also found that production structure adjustment would increase the IWUP, mainly due to a shift from agricultural and industrial sectors to service sectors.

1. Introduction

The imbalance of water supply and increasing water demand has become a serious problem for many local authorities (Llop, 2013; Zhao et al., 2015). It is widely known that most local water supply is used for the production of goods and services. However, less attention is given to the fact that this water is then embodied in goods and services to their places of consumption, which may be across local, regional and international boundaries. Such water flows along the economic supply chain from on-site (direct) water use to final products are not real water flows but virtual water flows. Introduced by Allan (1992), the virtual water concept has since developed into two research areas, i.e. virtual water trade and water footprint. Virtual water trade studies focus on how water demand in one location can lead to freshwater depletion in other locations through trade (Yang et al., 2013a). Whilst, as a consumption-based indicator, water footprint is used to quantify the water use derived from consumption of final products (Feng et al., 2011; Hoekstra and Chapagain, 2006). Both indicators appreciate the importance of extending the water study to global dimensions (Hoekstra and Mekonnen, 2012). However, few studies have focused on how the interactions of the local supply chain exert impact on local water resources associated with virtual water flows.

The effects of the supply chain can indirectly determine changes in water use. For example, it is a direct effect that expanded production in upstream sectors increases on-site water use, and such expansion might be driven by increasing need for raw materials from local downstream industries. The above driving force can be attributed to indirect effects arising from supply chain interactions (Zhang, 2010). Policy makers usually acquire the information of direct effects. For example, in China water statistics provide the direct water use in each productive sector (defined hereafter as direct water use of products, DWUP). However, quantifying the changes in indirect effects, which are often ignored, can answer a series of questions relating to local economic and water management, such as how production structure adjustment can affect local water use, or what are the key sectors that drive the direct and indirect water use through the supply chain.

This paper aims to propose a framework to study the drivers of local water use changes derived from the interactions of the local economic system. First, we introduce a virtual water related

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indicator called the internal water use of products (IWUP). IWUP is defined as the water required to support local production of final products. 'Internal' means that no imported products are considered in the process. Both water footprint and IWUP underline the supply chain effects, but they have different scopes. The starting point of the water footprint is to highlight the consumption impact of a region to water resources wherever the production happens. Such impact is usually beyond a region's territorial boundary through importing products. Whereas IWUP in turn traces how the water resources of a region are influenced by final consumption and local supply chain effects, thus providing information of interrelationships between water use and local economy.

Second, we carry out a decomposition analysis to study the driving forces of changes in IWUP. There are two commonly used decomposition techniques: index decomposition analysis (IDA) and structural decomposition analysis (SDA) (Su and Ang, 2012). Detailed comparison of the two methods can be found in Hoekstra and van den Bergh (2003), and Su and Ang (2012). In short, IDA decomposes the resource use or emission without sector information, while SDA is associated with the input-output methodology incorporating the supply chain effects with detailed sector information. In this study, we use SDA with a single-region input–output (SRIO) analysis to quantify the drivers of IWUP changes. The SDA model has been widely employed to study the key drivers of energy use and carbon dioxide (CO_2) emissions (Guan et al., 2008; O'Mahony et al., 2012; Wood, 2009), but has rarely been used for water, with a few notable exceptions for studies of water footprints (Guan et al., 2014; Zhang et al., 2012). The rationale of selecting the SRIO methodology and the comparison with other input–output techniques are presented in Section 2.

The mega-city of Beijing was chosen for a case study with the years 1997, 2000, 2002, 2007, and 2010. The provision of sufficient water is becoming a great challenge for the world's large cities (Darrel Jenerette and Larsen, 2006). By 2050, 1 out of 3 billion of the world's urban dwellers are expected to live in cities with perennial water shortage (McDonald et al., 2011). Beijing, a mega-city of about 20 million inhabitants, is facing severe water shortage due to its rising population and poor freshwater availability. The data for 2010 shows that water availability for Beijing was only 140 m^3/capita (Beijing Water Resources Bureau, 1988–2012), much lower than the acknowledged water scarcity threshold of 1700 m^3/capita (Falkenmark and Widstrand, 1992). Since the late 1990s the city has suffered from ongoing drought, whilst during the period from 1997 to 2010, the population of Beijing has increased by 61% and the real gross domestic product (GDP) has increased more than fourfold (Beijing Municipal Bureau of Statistics, 1989–2013).

Several studies have shown water use increases in mega-cities, mainly due to population growth and industrial development (Darrel Jenerette and Larsen, 2006; Jury and Vaux, 2005). However, on-site water use for producing goods and services in Beijing has seen a declining trend. Between 1988 and 2010 the water use for agricultural and industrial production in Beijing decreased by 48% and 64% respectively (Beijing Water Resources Bureau, 1988–2012), and the declining trend has continued since then. Hence, it is interesting to examine the economic explanations for such a large decrease in water use against substantial economic growth.

2. Methodology and data

2.1. Conceptual framework of water reallocation in the supply chain of products

In examining the factors contributing to changes in IWUP, we examined the total volume of freshwater used in all steps of the production supply chain. In particular, such accounting highlights the role of downstream industries on water demand. Such a role is also part of the extended producer responsibility, which refers to: "Producers of products should bear a significant degree of responsibility not only for the environmental impacts of their products downstream from the treatment and disposal of their products, but also for their upstream activities inherent in the selection of materials and in the design of products" (Lenzen et al., 2007).

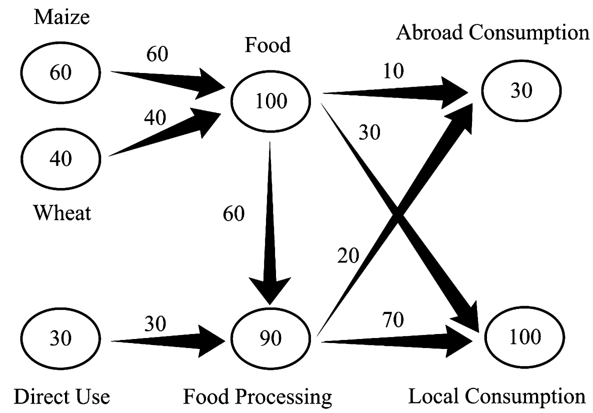

Fig. 1. A simple framework of virtual water flow in the supply chain of products.

In order to illustrate the above process we use a simple flow diagram of water reallocation in the supply chain of products (Fig. 1). Here, we assume there are only two sectors (food and food processing) in a hypothetical region, and the food sector produces wheat and maize for onward sale or further processing. The food processing sector produces the processed products using wheat and maize as raw materials. Here the water embodied in the imported products, which is also referred to as virtual water import (Hoekstra et al., 2011), is not considered in the process. Since we want to trace the virtual water flow from local water supply in the supply chain.

Fig. 1 shows that the total DWUP is 130 m^3, and the DWUP for the food sector is 100 m^3 (60 m^3 for wheat and 40 m^3 for maize). However, as 60 m^3 of water (embodied in the food products as raw materials) flows into food processing, the water use in producing the food products for final demand, i.e. the IWUP is actually only 40 m^3 and the IWUP of food processing is 90 m^3 (its DWUP is 30 m^3). Hence, IWUP represents a real pressure on local water resources caused by local production activities. Meanwhile, it shows how the local water supply was reallocated among the supply chain to different sectors. Such a reallocation extends the producer responsibility for both direct and indirect water use.

2.2. Top-down approaches in quantifying IWUP

Top-down and bottom-up are two quantification approaches used in virtual water related studies (Yang et al., 2013a). The detailed comparison of the two approaches has been given by Yang et al. (2013a) and Feng et al. (2011). In a nutshell, a bottom-up method accounts for the water use for a single product with detailed descriptions of individual production processes. The top-down method usually refers to input–output analysis (IOA), which shows the interdependency among different economic sectors (Feng et al., 2011). An IOA has long been recognized as an appropriate tool to attribute resource use or pollution to final products in a consistent framework (Wiedmann, 2009).

In recent years, many studies have adopted SRIO to quantify water footprint and virtual water trade (Guan and Hubacek, 2007; Guan et al., 2014; Zhao et al., 2009). A major limitation of SRIO is the