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Analysis

Assessing regional and global water footprints for the UK

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ABSTRACT

The concept of the water footprint has been recently introduced as an important indicator for human-induced water consumption. The water footprint is defined as the total volume of water used during production and consumption of goods and services as well as direct water consumption by humans. Water is not only consumed directly but also indirectly in production processes. Therefore, calculating the water footprint enables us to quantify total water consumed along the whole global supply chain. In this paper, we develop a regional input–output (IO) model extended by water consumption coefficients to quantify the respective domestic water footprint for different consumption categories for the South-East and North-East of England and the UK, i.e. the water consumed directly and indirectly along the regional supply chain. In addition, we calculate the total water footprints which include both domestic water consumption and the water required in other countries to produce goods and services imported and consumed in the region under investigation through applying a multi-regional input–output (MRIO) model. Both footprints also include households' direct consumption of water.

With regards to the two regions, we can observe a very pronounced regional disparity of regional (domestic and total) water footprints between the relatively water-scarce South-East and the water-rich North-East of England. We find that the domestic water footprint per capita in the South-East is 22% higher than the domestic water footprint per capita in the North-East. The key water consumers include Agriculture, Food Products, Electricity and Gas Production, and Hotel and Catering. The total water footprints per capita in the South-East (1257 m^3/year) are more than twice the ones in the North-East (597 m^3/year).

The domestic water footprint focuses only on the supply chain effects and associated water consumption within the regional boundaries, which are usually of higher interest to policy makers and water companies concerned with the balance of supply and demand of water resources within their respective administrative boundaries or watersheds. The total water footprint allows assessing global effects and supports global supply chain management and is also introducing notions of fairness and equity in terms of resource consumption.

1. Introduction

Worldwide, the demand for freshwater has increased more than fourfold over the last half century (Uitto and Schneider, 1997). In addition to the big consumers such as agriculture and certain industries, household consumption has also been increasing due to population growth and lifestyle changes. This has far-reaching effects on hydro-ecological systems and livelihoods. The World Resources Institute projected that the total number of people who live in water-scarce regions (less that 1000 m^3/capita/year) will be approximately 13–20% of the total world population by 2050 (OECD, 1998). The potential threat of climate change on hydrological systems and food production is likely to exacerbate the problems (Every and Foley, 2005; IPPR, 2005).

Unexceptionally, and similar to many other developed countries, water consumption in the UK has been experiencing a remarkable growth over the last few decades; the UK has been categorized as mildly water stressed by the Worldwide Fund for Nature (WWF) (Optimum Population Trust, 2007). However, there are significant regional disparities of water consumption and, availability and thus stress patterns across the UK. South-East England[1] is one of the most flourishing regions in the UK and in Europe. Over the period 1997–2003, the South-East achieved a fastest growth in Gross Value Added (GVA) per head at 35.3% (South-East England Development Agency,

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[1] South-East England is one of the nine official regions of England. Its boundaries include Berkshire, Buckinghamshire, East Sussex, Hampshire, Isle of Wight, Kent, Oxfordshire, Surrey and West Sussex.

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2006). However, the region is also one of the driest and most densely populated regions in the UK. The rainfall in the South-East is about 710 mm per annum, 11% lower than the UK average (Met Office, 2006), and rainfall per capita is lower than that, for example, in Oman (although with much lower evaporation) (South-East England Development Agency, 2006). The water stress in the region is likely to be exacerbated due to climate change. In comparison, the North-East of England[2] is the smallest of UK's regions in terms of area and population; economic growth has been lagging behind showing a growing ‘productivity gap’ to the rest of the UK. In 2000, the North-East had the lowest GDP per capita in England, which was only at about 77% of the level in the European Union (North-East Development Agency, 2006). In terms of water resources, the North-East is regarded as relatively water-rich with 825 mm annual rainfall; and after evaporation and take-up by vegetation there are still about 2940 L a day per capita for the region's residents (Environment Agency, 2001). The abundant and relatively inexpensive fresh water supply of the North-East is an important environmental and industrial asset to the region, especially also for rural mountain areas where most of the drinking water originates.

In addition to water supply, it is necessary to measure water demand to better understand the water situation in both regions. The water footprint has recently been promoted as an important indicator for human water consumption (Chapagain and Hoekstra, 2004; Hoekstra and Chapagain, 2007, 2008; WFN, 2008). The water footprint was initially developed by Hoekstra and Hung (2002) as analogy to the ‘ecological footprint’ as “the volume of water needed for the production of goods and services consumed by the inhabitants of the country”. This concept provides a consumption-based indicator of water use compared to the traditional production sector based water use indicator. The water footprint is the total virtual water content of products consumed by an individual, business, town, city or country or whatever the unit of analysis (Chapagain and Orr, 2008). Virtual water is described as the total volume of water needed to produce a good or service (Allan, 1994). Since all the goods consume water not only directly, but also indirectly as inputs to production of goods and services, the water footprint can help us to identify the ‘hidden’ water consumers along the whole supply chain. This information helps to balance supply and demand of water resources especially in water scarce regions (Hubacek et al., 2009). In this paper, we distinguish between the domestic water footprint[3] and the total water footprint[4]: domestic water footprint is the water used from domestic water resources; whereas the total water footprint is the domestic water consumption and the water required in other countries or regions to produce goods and services imported and consumed in the region under investigation minus the water used in the production of exports. Both concepts also include household's direct consumption of water. The domestic water footprint focuses only on the supply chain effects and associated water consumption within the regional boundaries, which are usually of higher interest to policy makers and water companies concerned with the balance of supply and demand of water resources within their respective administrative boundaries or watersheds.

The aims of this paper are to assess and compare domestic and total water footprints of the South-East and North-East of England and the UK through applying a multi-region input–output model (MRIO) extended by water consumption coefficients. We proceed as follows. Firstly, we construct the regional input–output table for the South-East and North-East and merge each IO table for the South-East, North-East and UK into a MRIO table. Secondly, we extend them to water MRIO tables to evaluate water footprints in the two regions and the UK and identity the key or leading sectors which have dominant influence in terms of water footprints using backward and forward linkage analysis.

2. Methodology

2.1. Construction of regional input–output (IO) tables

The mathematical structure of an input–output system consists of n linear equations as shown in Eq. (1). The equation depicts how the production of an economy depends on intersectoral relations and final demand.

$$\begin{aligned} x_1 &= x_{11} + \cdots + x_{1j}\cdots + x_{1n} + y_1 \\ &\vdots \\ x_i &= x_{i1} + \cdots + x_{ij}\cdots + x_{in} + y_i \\ &\vdots \\ x_n &= x_{n1} + x_{n2} + \cdots + x_{nn} + y_n \end{aligned} \quad (1)$$

where n is the number of economic sectors of an economy; the x_i represents the total economic output of ith sector; y_i is the final demand of sector i. x_{ij} represents the monetary flows from ith sector to jth sector.

The Eq. (1) can be rewritten as:

$$x_i = \sum_{j=i}^{n} x_{ij} + y_i. \quad (2)$$

Technical coefficient, a_{ij}, is calculated by dividing the intersectoral flows from i to j (x_{ij}) with total output of j (x_j),

$$a_{ij} = {}^{x_{ij}}\big/_{x_j}. \quad (3)$$

Therefore, Eq. (2) can be rewritten so as to include the technical coefficient (a_{ij}):

$$x_i = \sum_{j=i}^{n} a_{ij}x_j + y_i. \quad (4)$$

In matrix notation and for the economy as a whole, the Eq. (4) can be shown as:

$$X = \mathbf{A}X + Y \quad (5)$$

where $\mathbf{A}$ is the coefficient matrix.

To solve for x, we get

$$X = (I - \mathbf{A})^{-1}Y \quad (6)$$

where $(I-\mathbf{A})^{-1}$ is known as the Leontief inverse matrix, which shows the total production of each sector required to satisfy the final demand in the economy (Miller and Blair, 1985).

There are various methods to construct regional input–output tables: survey-based, semi-survey and non-survey techniques. The survey-based method has high accuracy with high cost and is time-consuming through a careful compilation of the survey results (McMenamin and Haring, 1974; Miller and Blair, 1985). In contrast, semi-survey and non-survey based techniques have less accuracy and less costs, thus they are widely applied approaches that adapt national table together with limited regional data to reflect regional economic conditions (e.g. Czamanski and Malizia, 1969; Jensen et al., 1979; Schaffer, 1976; Schaffer and Chu, 1969; Shen, 1960; Stilwell and Boatwright, 1971). Because of its relative low cost and time requirement, in this paper, we employ the non-survey based approach through using the Simple Location Quotient (SLQ) and Cross-Industry

[2] North-East England is one of the nine official regions of England and comprises the combined area of Northumberland, County Durham, Tyne and Wear, part of North Yorkshire and Tees Valley.

[3] The domestic water in this study is defined as the total water volume used from domestic water resources in the national or regional economy, whereas the internal water Hoekstra and Chapagain (2008) exclude the volume of virtual water exported.

[4] The total water footprint has the same definition as in Hoekstra and Chapagain (2008).

Location Quotient (CILQ) to generate two regional IO tables for the South-East and North-East of England based on the national IO table of the UK.

2.1.1. Simple Location Quotients (SLQ)

The rationale for using LQ is examined in Richardson (1972), Mayer and Pleeter (1975), Round (1983) and Miller and Blair (1985). This method is used for adjusting the national technical coefficients from the **A**-matrix to consider the potential for local demands to be satisfied locally. Many studies have been done to adjust the national technical coefficients to generate local multipliers (Brand, 1997; Flegg et al., 1995; Flegg and Webber, 1997, 2000; Hubacek and Sun, 2005; McCann and Dewhurst, 1997).

For region R, a regional IO coefficient can be defined as

$$a_{ij}^{RR} = LQ_i^R(a_{ij}^N) \quad (7)$$

where a_{ij}^{RR} is the regional input–output technical coefficient, LQ_i^R is the location quotient for demonstrating the importance of sector i in the local economy relative to the national economy, a_{ij}^N is the national technical coefficient (Miller and Blair, 1985).

In this paper, we use Gross Value Added (GVA) to measure the *Simple Location Quotient*. Let V_i^R and V^R denote GVA of sector i and total GVA, respectively, in region R; V_i^R/V^R is the share of sector i in regional GVA. Similarly, V_i^N and V^N are GVA of sector i and total GVA at the national level; V_i^N/V^N indicates the share of sector i in national GVA. Then the SLQ for sector i in region R is defined as:

$$SLQ_i = \left[\frac{V_i^R / V^R}{V_i^N / V^N}\right]. \quad (8)$$

As Miller and Blair noted, the LQ is “a measure of the ability of regional industry i to supply the demands placed upon it by other industries in the region and by regional final demand”. If the SLQ_i is greater than one ($SLQ_i>1$), this implies that sector i is more concentrated in region R than in the nation as a whole, and the regional coefficient is the same as the national. If the SLQ_i is less than one ($SLQ_i<1$), it is assumed that the region is being less able to satisfy regional demand for its output, and the national coefficients are needed to be adjusted by multiplying them by the SLQ_i for sector i in region R. Therefore, for row i of the regional table, the formulas are shown below (Miller and Blair, 1985):

$$a_{ij}^{RR} = \begin{cases} a_{ij}^N(SLQ_i^R) & \text{if} \quad SLQ_i^R < 1 \\ a_{ij}^N & \text{if} \quad SLQ_i^R \geq 1 \end{cases} \quad (9)$$

2.1.2. Cross-Industry Location Quotient (CILQ)

Another variant of the LQ technique is the *Cross-Industry Location Quotient* (*CILQ*), which is superior to the LQ technique (Flegg et al., 1995). Flegg et al. (1995) argued that the use of SLQ to adjust national coefficients may have serious distortions due to uniform adjustments along each row. Comparing to SLQ, CILQ allows for differing cell-by-cell adjustments within national coefficients matrix (Miller and Blair, 1985).

In the formula below, V_i^R/V_i^N denotes the share of region R in sector i national GVA; V_j^R/V_j^N is the share of region R in sector j national GVA. Thus a value added based $CILQ$ for sectors i and j can be defined:

$$CILQ = \frac{SLQ_i}{SLQ_j} = \frac{V_i^R / V_i^N}{V_j^R / V_j^N}. \quad (10)$$

Flegg et al. (1995) noted that if the supplying sector is relatively small compared to the purchasing sector at the regional level, ($CILQ_{ij}^R<1$), some of the required inputs will have to be imported. It means that the national coefficients need to be adjusted by multiplying them by the CILQ. If the $CILQ_{ij}^R \geq 1$, there is no need to adjust the national coefficient, as all the needs for inputs can be met from within the region.

$$a_{ij}^{RR} = \begin{cases} a_{ij}^N(CILQ_{ij}^R) & \text{if} \quad CILQ_{ij}^R < 1 \\ a_{ij}^N & \text{if} \quad CILQ_{ij}^R \geq 1 \end{cases} \quad (11)$$

Flegg et al. (1995) suggested that it is more appropriate to use the SLQ to adjust the coefficients along the principal diagonal and CILQ elsewhere, because CILQ ignores the size of the local industry. We adopted their suggestions in this paper.[5]

2.2. The water footprint input–output model

A large number of input–output studies have focused on water consumption. An early study has been done by Hartman (1965) examining aspects of the input–output model regarding its usefulness as a research technique for analyzing regional water consumption and allocation. Examples of more recent studies of water related input–output models include Lenzen's analysis of water usage in Australia (Lenzen and Foran, 2001); Leistrtz et al. (2002) examined the regional economic impacts of water management for Devils Lake; Vela'zquez (2006) explored intersectoral water relationships in Andalusia; Hubacek and Sun (2005) compared water supply and demand for all major watersheds in China. These studies are instrumental in using input–output techniques to investigate the impacts of economic structures on water use and related issues.

More recently, the notions of water footprint and virtual water flows have been combined with input–output analysis to improve the analysis of water issues. In order to measure the water footprint of a nation or region, it is necessary to quantify the virtual water flows associated with imports and exports. The notion of virtual water flows was first introduced in the early 1990s by Allan (1994), as the volume of water required to produce a commodity, that is virtually embedded in the commodity. By applying this concept, Allan (1994) found that water-scarce countries can secure their food supply and release the water resources pressure by importing water-intensive food products. Most studies on virtual water trade have been carried out mainly for the water embedded in agricultural products associated with food security (e.g. Allan, 1998, 2002; Fishelson, 1994; Hoekstra and Hung, 2005). Recently, Guan and Hubacek (2007) extended the concept of virtual water flows to all goods and services when evaluating the regional trade structure and its influences on water consumption and pollution via virtual water flows in China.

In this study, we distinguish between domestic and total water footprints for different study areas with very different water availability and consumption patterns. After constructing two regional input–output tables, we link each regional and the national table with a multi-region input–output (MRIO) framework. The multi-region input–output framework is based on the MRIO system constructed by SEI-York for measuring the embedded carbon emission in the UK (Wiedmann et al., 2008). This framework includes UK trade with three world regions, EU OECD countries (Region e), Non-EU OECD countries (Region o) and Non-OECD countries (Region w). In this framework, the UK is represented with its symmetric input–output table, whereas the three world regions are represented by their domestic and imports

[5] However, Boomsma and Oosterhaven (1992) pointed out this LQ technique may result in a systematic overestimation as it maximizes intra-regional transactions. But due to data limitations we decided to stick with the LQ technique.

transaction matrices. The imports to UK include the intermediate (z^{ku}) and final demand (y^{ku}). This framework only contains the trade between the UK and the three world regions, but not between the regions themselves (Wiedmann et al., 2008).

According to the MRIO framework, the technical coefficients matrices are obtained from the absolute transaction matrices. The coefficient matrices $\mathbf{A}^*$ can be calculated by $a_{ij}^{ks} = z_{ij}^{ks}/x_j^s$. A compound $\mathbf{A}$ matrix can be displayed by:

$$\mathbf{A}^* = \begin{pmatrix} \mathbf{A}^{uu} & 0 & 0 & 0 \\ \mathbf{A}^{eu} & \mathbf{A}^{ee} & 0 & 0 \\ \mathbf{A}^{ou} & 0 & \mathbf{A}^{oo} & 0 \\ \mathbf{A}^{wu} & 0 & 0 & \mathbf{A}^{ww} \end{pmatrix}$$

and a compound final demands and a compound total input can be displayed by:

$$y^* = \begin{pmatrix} y^{uu} \\ y^{eu} \\ y^{ou} \\ y^{wu} \end{pmatrix}, \quad x^* = \begin{pmatrix} x^u \\ x^e \\ x^o \\ x^w \end{pmatrix}$$

Therefore, the basic input–output relationship can be represented by:

$$\mathbf{A}^* x^* + y^* = x^*. \tag{12}$$

Then

$$x^* = (I - A^*)^{-1} y^*. \tag{13}$$

We extend the MRIO tables by adding water input in physical units. The extended MRIO tables are used to quantify the total volume of water consumed (Guan and Hubacek, 2007). Thus we calculate the direct water consumption coefficients e_j by dividing the total amount of water directly consumed in the jth sector by total input to that sector x_j, which represents the share of water consumption per unit of output in sector j. Thus, a row vector of compound water coefficient is shown by:

$$e^* = (e^u \ e^e \ e^o \ e^w).$$

Therefore, the UK domestic water footprints can be calculated using Eq. (12).

$$w_{\text{dom}} = e^u (I - \mathbf{A}^{uu})^{-1} \hat{y}^u + w_{hh}^u \tag{14}$$

where w_{dom} is the domestic water footprint in the UK; e^u is the direct water intensity for the UK domestic production sectors, $\hat{y}^u$ indicates a diagonal y^u which include both the UK domestic final demand and the export. w_{hh} is the direct water consumption by household in the UK.

However, the water required for the production of goods and services is not only from domestic supply, but also from external sources through import of goods and services from other countries. Hence, it is also necessary to measure the imported and exported virtual water in order to measure the total water footprint. The total water footprints for the UK can be calculated based on the water extended MRIO framework by:

$$w_{\text{tot}} = e^* (I - \mathbf{A}^*)^{-1} \hat{y}^* + w_{hh}^u. \tag{15}$$

Here, the total water footprint is defined as the domestic water footprint plus the imported virtual water from three world regions minus exported virtual water.

The above framework is also applied to the South-East and North-East of England for calculating their water footprints.

2.3. Backward and forward linkages

We use the water inter-industry linkage approach to explore which key or leading sectors have greater influence on the whole water consumption process, through both purchases and/or sales, in the economy. The notion of backward and forward inter-industry linkages to identify the key sector was initially introduced by Hirschman (1958). According to Hirschman, backward linkages are related to the stimuli going to sectors that supplied the inputs for a given activity, whereas forward linkages are related to the inducement to set up new activities using the output of the given activity (Hirschman, 1958). This method has been applied in numerous studies (e.g. Aroca, 2001; Duarte et al., 2002; Han et al., 2004; Karkacier and Gokalp Goktolga, 2005; Kwak et al., 2005; Lenzen, 2003; Rimmler et al., 2000). In this section we present the backward and forward linkages approach for the South-East, North-East and UK.

Backward linkages, in terms of water consumption, are expressed as the capacity of sector j to influence water consumption in sectors providing direct or indirect inputs to sector j (Miller and Blair, 1985). The larger the value for a sector, the greater the sector's influence on water consumption within the economy. For region R, the backward linkage (B_j^R) of sector j is described as the column sum of the elements in the jth column of the direct and indirect water coefficients matrix, $\hat{e}(I-A)^{-1}$ where the hat symbol ^ denotes diagonalization. Hence, in our water IO model,

$$B_j^R = \hat{e} \sum_{i=1}^{n} \alpha_{ij}^R \tag{16}$$

where a_{ij}^R represents each of the elements in the Leontief inverse matrix $(I-A)^{-1}$.

Forward linkage, in terms of water consumption, indicates the capacity of sector i to stimulate the production of other sectors, and therefore the consumption of water (Miller and Blair, 1985). The forward linkage (Fi^R) of sector i is calculated as the row sum of $\hat{e}(I-\mathbf{A})^{-1}$ in the supply-side IO model,[6] where the elements are denoted as $\vec{\alpha}_{ij}^R$, the expression is the following:

$$F_i^R = \hat{e} \sum_{j=1}^{n} \vec{\alpha}_{ij}^R. \tag{17}$$

The backward and forward linkages can be measured mathematically as an index:

$$U_{BL} = \frac{\frac{1}{N} B_j^R}{\frac{1}{N^2} \sum_{j=1}^{n} B_j^R} = \frac{B_j^R}{\frac{1}{N} \sum_{j=1}^{n} B_j^R}. \tag{18}$$

And, the forward linkages index can be expressed as follows:

$$U_{FL} = \frac{\frac{1}{N} F_i^R}{\frac{1}{N^2} \sum_{i=1}^{n} F_i^R} = \frac{F_i^R}{\frac{1}{N} \sum_{i=1}^{n} F_i^R}. \tag{19}$$

If U_{BL} is greater than 1, it means that one unit change in a final demand in sector j, will result in an above-average increase in the

[6] More details can be seen from Miller and Blair (1985).

water consumption of all sectors in the entire economy. In contrast, if U_{FL} is greater than 1, a unit change in all sectors' final demand will lead to an above-average increase in the water consumption of sector *i*. When the backward and/or forward linkage indexes are greater than 1, we can say that these sectors are key sectors in terms of water consumption (Drejer, 2002).

2.4. Data

In this study, we used the 2001 UK national IO table from the UK office for National Statistics (ONS) and EUROSTAT, trade data from HM Revenue and Customs, foreign input–output data from the Global Trade Analysis Project (GTAP) provided by the Stockholm Environment Institute (SEI). We then aggregated to 28 sectors[7] corresponding to the available water consumption data. We used Gross Value Added (GVA) to calculate the LQs. GVA data in the two regions obtained from the Office for National Statistics (ONS). Household expenditure data was also obtained from ONS.

The direct water consumption in industry and service sectors for 1999 was derived from REWARD (Regional and Welsh Appraisal of Resource Productivity and development) and the ONS. The direct water consumption for Agriculture is based on Hoekstra and Chapagain (2008). Household water use data was obtained from the Environment Agency (Environment Agency, 2001).

3. Water footprints for the UK: results and discussion

UK's water consumption has received much attention, especially in the South-East of England, which is considered as the driest region in the UK. In order to compare and analyze the water footprint patterns in the two study regions and the UK, we calculate a number of indicators. *The direct water coefficients* allow us to see which sectors have higher water intensity and thus consume relatively more water in order to produce goods and services. *The domestic water footprint* shows the amount of water consumed directly and indirectly within the study region *whereas the total water footprint* shows the water consumption along the global supply chain. By measuring the *backward and forward linkages*, we are able to identify the key sectors with the greatest influence on overall water consumption within a region.

3.1. Direct water coefficients

After constructing the South-East regional IO table and employing water multiplier we are able to quantify both direct water coefficients for each industrial sector and indirect water consumption which includes inputs from other sectors. We can show how much internal or external water is required to produce certain goods and services to satisfy people's needs in the region.

Table 1 represents direct water coefficients of 28 sectors in the South-East, North-East and the UK. From Table 1 we can see that Agriculture is the highest water-intensive sector with more than 2000 m^3 of water consumption per thousand pounds of sectoral output. Water intensity in Fishery and Forestry sectors are also very high, while the absolute amount of water consumption are relatively low because of low sectoral output. The secondary sectors, Electricity and Gas Production require the highest water input per unit of output followed by Leather Products, Textile, Chemicals and Metal Products. The direct water intensities in the tertiary sectors are relatively low.

Table 1
Direct water coefficients in the South-East, North-East, and the UK.
(Source: Environment Agency, Scottish Executive, ONS and REWARD).

	Industrial sectors	South-East (m^3/£1000)	North-East (m^3/£1000)	UK (m^3/£1000)
1	Agriculture	2131.24	2116.43	2103.73
2	Livestock	7.01	15.29	10.03
3	Forestry	141.05	168.06	147.03
4	Fishery	2080.13	2050.26	2066.65
5	Mining	2.52	2.65	2.61
6	Food Products	2.83	5.37	4.93
7	Textile	4.20	8.61	8.94
8	Leather Products	15.83	8.96	8.97
9	Wood and Wood Products	4.62	5.10	4.83
10	Paper, Paperboard and Publishing	9.52	7.04	4.83
11	Chemicals	10.17	23.40	8.72
12	Non-metal Mineral Products	5.23	5.62	6.60
13	Metal Products	4.65	6.03	8.47
14	Manufacture Machinery	3.97	3.97	3.97
15	Electric Machinery	1.58	2.67	0.73
16	Transport Equipment	1.90	2.27	0.57
17	Furniture and Other Manufacturing	9.54	11.26	10.76
18	Electricity and Gas Production	126.81	126.81	126.81
19	Water Supply	353.89	382.89	360.89
20	Construction	0.08	0.11	0.12
21	Retail and Trade	0.81	0.90	0.33
22	Hotels, Accommodation and Catering	1.71	1.80	0.71
23	Transportation	0.32	0.42	0.38
24	Business and Finance	0.33	0.39	0.36
25	Public Administration	0.12	0.19	0.37
26	Education	2.26	1.89	1.77
27	Health and Social Activities	0.31	0.40	0.25
28	Recreational and Cultural Activities	0.10	0.09	0.11
	Household (liter/cap/day)	165.20	141.20	151.20

For instance, Retail and Trade sector only needs less than 1 m^3 of direct water inputs per thousand pounds of sectoral output, and Hotel, Accommodation and Catering, usually considered a water-intensive sector only requires 1.80 m^3 and 1.71 m^3 per thousand pounds of output in the North-East and South-East, respectively. There are also some regional differences in terms of water intensity. Particularly, in the South-East the water intensity in Leather Products sector is almost twice as the water intensity in the North-East, whereas the water intensity in Chemicals sector in the North-East is approximate 2.5 times than the one in the South-East.

From Table 1, we also can see that the household direct water use per capita in the more affluent South-East is notably larger than in the North-East region. The household direct water use per capita in the South-East is about 17% higher than the one in the North-East, and about 9% higher than the UK average.

3.2. Water footprints for the South-East, North-East and UK

The water footprint shows both direct and indirect water needed to produce goods and services, which includes water required in the production of goods and as inputs from other sectors. The domestic and total water footprints in the UK are about 32 Giga-m^3 per year (Gm^3/yr) and 66 Giga-m^3 per year (Gm^3/yr), respectively. The total water footprint is more than twice the UK domestic water footprint; which is fairly similar to the earlier calculations of 73 Gm^3/yr by Hoekstra and Chapagain (2008). The main difference to the study by Hoekstra and Chapagain (2008) is that they give a very detailed measurement of water consumption from agricultural products, but the measurements for industry and service sectors are rather limited, while in this study we measure the detailed sectoral water footprints over the whole supply chain. The interesting and policy relevant information is contained in the sectoral details.

[7] Due to lack of detailed sectoral water consumption data, we aggregated the available 76 sectors to 28 sectors, therefore, introducing a bias by aggregating a greater number of distinct products into one sector. This bias is kept to a minimum through including the largest water consuming as well as most important economic sectors.

Table 2
Water footprints for the South-East, North-East, and the UK (million m^3/year).

	Sector	South-East		North-East		UK	
		Domestic	Total	Domestic	Total	Domestic	Total
1	Agriculture	1197.9	1654.9	330.0	346.5	9206.7	11,464.9
2	Livestock	45.2	240.1	14.2	35.4	397.3	2226.1
3	Forestry	11.9	11.1	3.5	3.4	33.9	29.4
4	Fishery	147.1	8.2	42.2	4.2	879.8	83.8
5	Mining	17.2	37.3	4.5	2.8	94.4	28.4
6	Food Products	652.9	2910.0	107.2	251.2	3964.9	18,316.4
7	Textile	40.6	144.3	8.0	42.3	61.6	403.5
8	Leather Products	9.2	7.4	1.7	1.6	73.9	3906.4
9	Wood and Wood Products	4.5	15.2	0.8	2.0	16.3	50.7
10	Paper, Paperboard and Publishing	31.5	38.3	6.2	6.3	153.1	306.4
11	Chemicals	115.9	120.1	54.1	17.1	792.5	1152.2
12	Non-metal Mineral Products	8.5	9.7	2.6	2.1	47.4	64.9
13	Metal Products	34.2	49.3	9.9	9.4	287.6	77.2
14	Manufacture Machinery	50.3	177.6	8.2	19.7	243.2	43.2
15	Electric Machinery	55.2	151.8	22.4	25.7	179.6	379.2
16	Transport Equipment	71.9	131.0	18.7	16.5	365.9	657.3
17	Furniture and Other Manufacturing	37.5	88.7	4.2	21.4	169.2	781.2
18	Electricity and Gas Production	379.8	411.5	105.9	108.1	2706.9	2882.4
19	Water Supply	74.4	76.1	20.5	20.7	1111.4	1121.9
20	Construction	32.7	342.5	9.5	51.8	468.3	106.8
21	Retail and Trade	130.5	768.9	38.0	126.8	1277.8	3786.8
22	Hotels, Accommodation and Catering	261.1	319.6	72.8	52.0	3112.7	5535.8
23	Transportation	28.2	183.7	9.0	30.7	165.6	576.7
24	Business and Finance	62.3	462.3	4.9	12.7	777.9	1207.1
25	Public Administration	50.1	67.6	13.5	14.2	583.4	1943.8
26	Education	50.4	978.7	11.5	112.1	456.0	1266.3
27	Health and Social Activities	52.1	207.0	14.5	37.4	683.4	2998.8
28	Recreational and Cultural Activities	21.8	47.1	6.0	5.5	214.1	1162.5
	Household	487.2	487.2	133.4	133.4	3250.0	3250.0
	Total	4162.2	10,147.1	1078.0	1512.9	31,754.9	65,810.3

Table 2 describes water footprints for the South-East, North-East and the UK. From Table 2 we can see that Agriculture, Food Products, Electricity and Gas Production, Retail and Trade and Hotels, Accommodation and Catering sectors have relatively high domestic water footprints in the UK. In fact, Agriculture, Electricity and Gas Production consume a large amount of water from the UK domestic water resources through their high direct water input; whereas Food Products, Retail and Trade and Hotels, Accommodation and Catering sectors receive a huge amount of water indirectly through purchasing the goods and services from other water-intensive sectors, such as Agriculture and Fishery sectors. However, in terms of total water footprint in the UK, Food Products (about 18 Gm^3/year) exceeds Agriculture (about 11.5 Gm^3/year) and becomes the largest water consumer, as it imports a large amount of virtual water from abroad. Similarly, Livestock, Leather Products and Chemicals also become key water consumers with much higher total water footprints than domestic water footprints through importing a considerable amount of water from other world regions. In summary, we can see that more than 55% of the total water footprint in the UK, and that is about 35 Gm^3 depends on water resources in other world regions.

In the North-East and South-East, Agriculture, Food Products and Electricity and Gas Production are key consumers of domestic water resources. At the same time, Chemicals, Retail and Trade and Hotels, Accommodation and Catering also play a significant role in terms of the regional domestic water footprints due to their large outputs and thus water consumption in both regions. The domestic water footprint in the South-East is about 4 times the domestic water footprint of the North-East. From Table 2 we also see a big regional difference between North-East and South-East in terms of total water footprints. The total water footprint in the South-East is 6 times the total water footprint of the North-East. In the South-East, the largest water consumer is the Food Products, whereas Agriculture is still the largest water consumer in the North-East. Retail and Trade, Hotels, Accommodation and Catering and Education are also key water consuming sectors in both regions, in terms of total water footprints. Interestingly, in the North-East, the total water footprint for Chemicals is much smaller than its domestic water footprint, as about 60% of its sectoral output is used for exporting goods to other regions or countries. The difference between total and domestic water footprints in the South-East is bigger than the difference in the North-East, 2.5 times (SE) and 1.5 times (NE) respectively. It means that the South-East is much more relying on the water resources outside its region than the North-East.

In addition, there are large regional disparities on water footprints per capita in the North-East and South-East. From Fig. 1 we can observe that the domestic water footprints per capita in the South-East are about 22% higher than the domestic footprints in the North-East, 520 m^3/year and 427 m^3/year respectively. However, total water footprints in the South-East are more than double of those in the North-East. The domestic water footprints in the South-East and the UK are almost the same, while the S-E has slightly higher ones than all of the UK. The domestic and total water footprints per capita are

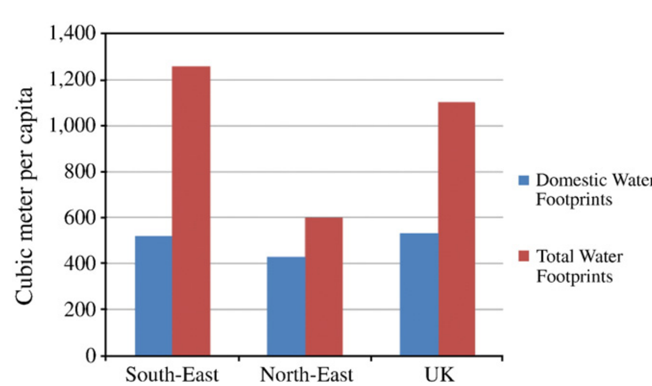

Fig. 1. Water footprints per capita (m^3/year).

531 m^3/year and 1101 m^3/year in the UK, where the total water footprint per capita is almost double the domestic water footprint, which means that people in the UK consume half their water from regions outside the UK.

3.3. Inter-industrial linkage analysis

Inter-industry linkage analysis is frequently applied to identify ‘key sectors’ (Drejer, 2002). Backward linkages illustrate how a one unit rise in final demand influences a sector's suppliers, therefore backward linkages quantify the relative extent to which sectors depend upon other sectors for their inputs. Forward linkages quantify the extent to which sectors supply inputs to other sectors throughout the whole economy (Drejer, 2002; Hirschman, 1958). Sectors that have a backward and forward linkage index greater than 1 are considered as key sectors in the economy (Lesher and Nordas, 2006). In this study, we use the inter-industry linkage analysis to explore which key or leading sectors have greater influence on the whole water consumption process.

Tables 3 and 4 represent the key water consumption sectors based on the detailed results of backward linkages and forward linkages in the South-East and North-East. In Table 3, for both regions, we note that Agriculture, Fishery, and Water Supply have the largest backward linkages (column sum of water footprint multipliers) with respect to total water consumption, followed by Electricity and Gas Production sector. None of the service sector exhibits large backward linkages. With respect to forward linkages (row sum of water footprint multipliers), in both regions, the highest values are found in the Agriculture and Fishery sectors, followed by Food and Water Supply sectors. With respect to the service sectors, Hotels, Accommodation and Catering and Retail and Trade sectors show large forward linkages. This measure can be interpreted as a measure of sensitivity of the respective sector to consume water given the other sectors' demands on its products as inputs (Duarte and Sánchez-Chóliz, 1998). These sectors push water consumption up, more so than other sectors, when selling their products to other sectors.

Table 3
Backward Linkages (BL), Forward Linkages (FL) in the South-East and North-East.

Industrial sectors		South-East		North-East	
		BL	FL	BL	FL
1	Agriculture	2.17	2.14	2.15	2.15
2	Livestock	0.05	0.08	0.06	0.09
3	Forestry	0.21	0.20	0.06	0.06
4	Fishery	2.15	2.13	2.22	2.20
5	Mining	0.01	0.01	0.01	0.01
6	Food Products	0.11	1.31	0.07	1.15
7	Textile	0.01	0.02	0.01	0.02
8	Leather Products	0.02	0.02	0.01	0.01
9	Wood and Wood Products	0.01	0.03	0.01	0.01
10	Paper, Paperboard and Publishing	0.02	0.03	0.01	0.02
11	Chemicals	0.02	0.06	0.03	0.06
12	Non-metal Mineral Products	0.02	0.01	0.02	0.01
13	Metal Products	0.02	0.03	0.02	0.04
14	Manufacture Machinery	0.01	0.02	0.01	0.02
15	Electric Machinery	0.01	0.03	0.01	0.04
16	Transport Equipment	0.01	0.03	0.01	0.03
17	Furniture and Other Manufacturing	0.02	0.02	0.01	0.01
18	Electricity and Gas Production	0.19	0.21	0.19	0.21
19	Water Supply	0.40	0.40	0.40	0.40
20	Construction	0.00	0.06	0.01	0.04
21	Retail and Trade	0.01	0.13	0.01	0.16
22	Hotels, Accommodation and Catering	0.03	0.51	0.03	0.69
23	Transportation	0.00	0.05	0.01	0.07
24	Business and Finance	0.00	0.09	0.01	0.05
25	Public Administration	0.00	0.04	0.01	0.04
26	Education	0.01	0.03	0.01	0.03
27	Health and Social Activities	0.00	0.05	0.01	0.05
28	Recreational and Cultural Activities	0.00	0.02	0.01	0.03

Table 4
Backward Linkage Index (BLI), Forward Linkage Index (FLI) in the South-East and North-East.

Industrial sectors		South-East		North-East	
		BLI	FLI	BLI	FLI
1	Agriculture	11.05	7.72	11.23	7.82
2	Livestock	0.27	0.30	0.31	0.31
3	Forestry	1.05	0.71	0.33	0.2
4	Fishery	10.93	7.66	11.59	8.01
5	Mining	0.04	0.03	0.03	0.04
6	Food Products	0.57	4.70	0.35	4.19
7	Textile	0.06	0.08	0.05	0.08
8	Leather Products	0.11	0.07	0.08	0.04
9	Wood and Wood Products	0.07	0.09	0.07	0.05
10	Paper, Paperboard and Publishing	0.09	0.12	0.08	0.08
11	Chemicals	0.09	0.22	0.16	0.22
12	Non-metal Mineral Products	0.09	0.04	0.10	0.05
13	Metal Products	0.08	0.12	0.08	0.14
14	Manufacture Machinery	0.05	0.09	0.03	0.07
15	Electric Machinery	0.03	0.10	0.04	0.14
16	Transport Equipment	0.04	0.12	0.04	0.11
17	Furniture and Other Manufacturing	0.09	0.08	0.03	0.04
18	Electricity and Gas Production	0.96	0.74	0.99	0.76
19	Water Supply	2.05	1.43	2.10	1.44
20	Construction	0.02	0.21	0.02	0.14
21	Retail and Trade	0.03	0.48	0.03	0.58
22	Hotels, Accommodation and Catering	0.13	1.83	0.13	2.52
23	Transportation	0.02	0.18	0.02	0.24
24	Business and Finance	0.01	0.33	0.01	0.17
25	Public Administration	0.02	0.15	0.02	0.16
26	Education	0.03	0.13	0.03	0.11
27	Health and Social Activities	0.02	0.18	0.02	0.19
28	Recreational and Cultural Activities	0.01	0.09	0.01	0.10

The results for inter-industry linkage index are shown in Table 4. From Table 4 we can see that in both regions (South-East and North-East), Agriculture, Fishery and Water Supply sectors have largest backward and forward linkages; and both backward and forward linkage indices of these sectors are larger than 1. It means that Agriculture, Fishery and Water Supply are key sectors, in terms of water consumption in both regions. In the South-East region, however, Forestry sector has a backward linkage index above 1, which means that when Forestry purchases products from other sectors, it pushes water consumption up to a larger extent than other sectors; and a unit change of its final demand will cause an above-average increase in water consumption throughout the economy. The forward linkage indices in Food Products and Hotels, Accommodation and Catering are larger than 1, which it means that one-unit increase in all sectors' final demand would lead to an above-average increase of water consumption in these sectors.

4. Conclusions

In this paper, we have applied a multi-region input–output framework extended by water consumption to assess and compare both the domestic and total water footprints for the UK and the South-East and North-East of England. This framework allows us to examine the relationships between production structure and water consumption in the study regions. By means of comparing various water related indicators and analyzing forward and backward linkages we were able to identify the key water consumers in the two regions.

We found that Agriculture is the largest water consumer in the UK and also in the South-East and North-East in terms of domestic water footprints, with high direct water consumption. Food Products and service sectors such as Retail and Trade and Hotels, Accommodation and Catering have high indirect water consumption, which means the production of these sectors requires large amounts of water through purchasing the goods and services from other water-intensive sectors.

This is also reiterated from their larger forward linkages showing that these sectors will induce an extensive increase of water consumption within the region. Some sectors such as Leather Products, Electric Machinery, and Furniture and Other Manufacturing sectors have larger total water footprints than domestic water footprints due to large virtual water shares from other world regions.

We also observed considerable regional disparities between the South-East and North-East. A distinctive feature in the South-East is that Food Products rather than Agriculture has the largest total water footprint. In the South-East, Chemicals, Retail and Trade and Hotels, Accommodation and Catering sectors contribute a significant share of regional domestic water footprints in contrast to the North-East. Both direct and indirect water consumption for each economic sector must be taken into account in planning water provision and promoting sustainable water consumption. The total water footprint also allows assessing global effects and supports global supply chain management with regards to water consumption introducing also notions of fairness and equity in terms of resource use.

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