Disentangling water usage in the European Union: A decomposition analysis

Valeria, Di Cosmo and Marie, Hyland and Maria, LLop

Economic and Social Research Institute and Trinity College, Dublin,
Economic and Social Research Institute and Trinity College, Dublin,
Universitat Rovira i Virgili and CREIP, Reus

15 November 2012

Disentangling water usage in the European Union: A decomposition analysis

Valeria Di Cosmo,[ab] Marie Hyland,[ab] Maria Llop[c*]

[a] Economic and Social Research Institute, Dublin

[b] Trinity College Dublin

[c] Universitat Rovira i Virgili and CREIP, Reus, Barcelona

* Corresponding author: Whitaker Square, Sir John Rogerson's Quay, Dublin 2. Email: valeria.dicosmo@esri.ie. Tel: +353 1 863 2033.

Maria Llop acknowledges funding by the Spanish Ministry of Education and Culture (grant ECO2010-17728) and the Catalan Government (grants SGR2009-322 and "RDI Reference Network in Economics and Public Policies").

The usual disclaimer applies.

Abstract

The Water Framework Directive defines common objectives for water resources throughout the European Union (EU). Given this general approach to water preservation and water policy, the objective of this paper is to analyse whether common patterns of water consumption exist within Europe. In particular, our study uses two methods to reveal the reasons behind sectoral water use in all EU countries. The first method is based on an accounting indicator that calculates the water intensity of an economy as the sum of sectoral water intensities. The second method is a subsystem input-output model that divides total water use into different income channels within the production system. The application uses data from the year 2005 on water consumption in the production system of the 27 countries of the EU.

From our analysis it emerges that EU countries are characterized by very different patterns of water consumption. Mediterranean and central/eastern European countries use water mainly for agriculture whereas northern European countries use it mainly for electricity, gas and water supply.

In most countries, the water used by the fuel, power and water sector is consumed to satisfy domestic final demand. However, our analysis shows that for some countries exports from this sector are an important driver of water consumption. Focusing on the agricultural sector, the decomposition analysis suggests that water usage in Mediterranean countries is mainly driven by final demand for, and exports of, agricultural products, whereas domestic final demand is the main driver of water consumption in central/eastern European countries.

Given these heterogeneous water consumption patterns, our analysis suggests that Mediterranean and central/eastern European countries should adopt specific water policies if water consumption in the European Union is to be efficient.

JEL codes: N5; C67

Keywords: Water use, Subsystem input–output model; Water intensity, European Union.

1. Introduction

The European Water Framework Directive (WFD) (2000/60EC) prescribes that "*Member States shall take account of the principle of recovery of the costs of water services, including environmental and resource costs, having regard to the economic analysis and in accordance in particular with the polluter pays principle*".[1] The idea behind this Directive is that water is a scarce commodity in Europe and it is attributed with social, ecological and cultural values. If these values are to be taken into account, the price of water should reflect not only the scarcity and cost of use but also the externalities generated. Since these objectives are common to all European Union (EU) members, it is crucial to determine whether patterns of water usage are also common to the 27 EU countries and what the main drivers of water usage are in each state. Only in this way can the policies that encourage water saving schemes be successful at the European level.

The main aim of this paper is to identify the patterns of water usage in all the countries of the European Union. Specifically, we investigate the channels through which water is used within the production system of the 27 EU countries. Our analysis is based on two different methods for investigating water consumption. The first one adopts an accounting perspective and uses macro-indicators of both sectoral water use and sectoral production. This method allows us to identify the most water-intensive sectors in European countries, and the relative contribution of these sectors to each country's GDP. The second method is based on a subsystem input-output methodology, which reflects the different income channels that explain water consumption within the production system.

To date only a few multi-country analyses of water usage have been made. Moreover, to our knowledge, the literature does not contain a single complete analysis of sectoral water use for all EU countries. By examining water consumption patterns for all countries in the EU and across 35 production sectors, our study makes an important contribution to the international literature on virtual water consumption. Our analysis provides new and valuable information which could be useful in the process of defining and implementing a new common water policy in line with the EU's Water Framework Directive.

Several papers have used an input-output framework to analyse patterns of water consumption from a single-country perspective. For example, Lenzen and Foran (2001) constructed an input-output model based on multipliers for Australia. They found that the production of food to satisfy domestic demand accounted for 30% of water consumption and, similarly, exported goods accounted for 30% of water consumption. Their analysis also showed that Australia exported substantially more virtual water than it imported.

Dietzenbacher and Velázquez (2007) used an input-output framework to analyse the consumption of water in the Andalusian production process. They also analysed how much virtual water – i.e. the amount of water used to produce goods and services, including the water used to satisfy intermediate demand – was embodied in trade. The Andalusian agricultural sector was responsible for 90% of direct water consumption, but contributed only 8% to the Gross Regional Product. Additionally, more than half of the final output of the agricultural sector was exported to the rest of Spain, the EU and the rest of the world. The authors highlighted that as Andalusia is a relatively arid

[1] The Directive is available here: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:327:0001:0072:EN:PDF

region, their results contradicted the Hecksher-Ohlin theory which states that countries (or regions) should specialise in the production of goods that use inputs which are relatively abundant in that country/region.

Guan and Hubacek (2007) used a regional input-output model for eight regions in China to analyse patterns of regional trade and the flow of virtual water. They noted that while the northern part of China had only one-fifth of the water resources, it was supporting more than half of the population. The authors constructed two regional input-output tables for North and South China, and supplemented these with data on interregional trade flows. They noted that while northern China had fewer water resources, it was a net exporter of virtual water; they also noted that southern China was a net importer. These results are yet another contradiction of the Hecksher-Ohlin theory. The authors also stated that water scarcity in northern China is becoming a barrier to further economic development. To conclude, the authors remarked that direct and indirect water usage was not sufficiently taken into account in consumption and production decisions, which can lead to the unsustainable use of water resources.

Zhao et al. (2009) used an input-output framework to calculate the national water footprint for China, which illustrated the water used directly and indirectly to satisfy final demand, including demand for exports. The authors highlighted the advantage of using this national water footprint indicator as it matches the use of water, an import resource, to consumption, which may be a better tool for altering water consumption patterns. They also highlighted the importance of virtual water and noted that it should be imported from relatively water-abundant countries if water security is to be achieved.

International studies include Hoeskstra and Hung (2002), who calculated the flows of virtual water (although not within an input-output framework) in relation to crop trade between nations in the period 1995–1999 and found that the main virtual water exporters are the US, Canada, Thailand, Argentina and India, while Sri Lanka, Japan, the Netherlands and China are the main water importers. One shortcoming of this study is that it only takes crop production into account, and not the entire production system.

Within the input-output framework, an individual sector, or group of sectors, can be regarded as a subsystem which interacts with the other sectors. This approach isolates the relations of a limited number of activities from the whole system, and shows the particular patterns of individual units as part of the entire production sphere. The subsystems (economic) model was originally proposed by Sraffa (1960), Pasinetti (1973, 1988), Deprez (1990) and Scazzieri (1990) among others. Subsequently, this method was extended to the analysis of pollutant emissions.[2] However, as far as we are aware, the subsystem model has not been applied to water usage in the production system.

Our analysis shows that European countries are characterized by very different water usage patterns. In particular, agriculture is the most water-intensive sector in both central/eastern and

[2] See Alcántara (1995), Sánchez-Choliz and Duarte (2003), Alcántara and Padilla (2009), Cardenete and Fuentes (2011) and Butnar and Llop (2011) for applications to Spanish emissions; and Llop and Tol (2012) for an application to Irish emissions.

Mediterranean European countries; whereas the electricity, gas and water supply sector is the most water-intensive sector in Northern European countries.

Focusing on the agricultural sector, our results also show that in central/eastern European countries the contribution of agriculture to each country's output is relatively high (5% of the GDP on average). The water intensity in these countries is also above the EU mean. However, by applying the input-output methodology we find that the water used in the agricultural sector of the central/eastern European countries is mainly destined for domestic consumption. Therefore, specific policies, oriented to water demand, should be applied in order to influence final consumption and thus encourage water savings in these countries.

The subsystem input-output analysis shows that in some of the Mediterranean countries most of the water used in agriculture is exported through agricultural goods (i.e., embodied water). Therefore, in order to achieve a more sustainable production structure and enhance water savings, an appropriate tariff for water should be set in these countries.

The rest of the paper is organised as follows. Section 2 describes the database used in the analysis and Section 3 presents the two methods used to decompose sectoral water usage. Section 4 contains the results of the empirical application to the 27 European countries. At the end of the paper we provide some concluding remarks.

2. Data

The water use data and the input-output tables used in our analysis are from the World Input-Output Database (WIOD: www.wiod.org). This database contains Input-Output tables and environmental accounts (which includes water usage) for 27 EU countries and 13 other countries in the world between 1995 and 2009. The Input-Output tables and the water use data are presented at a 35-sector level of aggregation.[3] While data are available for all years up until 2009, we have chosen to focus on 2005 in our analysis so that we could analyse patterns of water use and economic activity that were not being affected by the current period of economic recession, which may mask the structural features of water use. Our analysis focuses on the 27 countries within the EU.

The water use data presented in the WIOD divides water use, in thousands of m^3, into blue, green and grey water. Blue water is water drawn from surface and ground water; green water is rainwater absorbed in soil; and grey water is water which is used to dilute pollutants. In our analysis we focus on the use of blue and green water (note however that green water is consumed only by the agricultural sector). In many countries a large portion of total grey water is consumed by private households. As we focus on the productive sectors of the economy in our analysis we ignore the use of grey water.

There are a number of data caveats in the WIOD. Water use data for certain sectors is reported as zero even though it is unlikely that no water was used (for example, in the electricity, gas and water supply sector in both Malta and Cyprus). Details of the methodologies and data sources used to construct the economic tables and the environmental accounts can be found in Genty et al (2012) and Timmer et al (2012); in particular further data caveats are discussed by Timmer et al (2012).

[3] See Timmer et al (2012) for a list of the sectors and countries presented in this database.

The WIOD gives input-output and water use tables for 35 productive sectors although the vast majority of water used in an economy is in fact concentrated in a small number of sectors. Thus, in our analysis we have chosen to focus on the sectors above the EU median in terms of water consumption; these are the Agriculture, Hunting, Forestry and Fishing sector; the Food, Beverages and Tobacco sector; the Chemicals and Chemical Products sector; and the Electricity, Gas and Water Supply sector (see table 1). Together these sectors account for, on average, 99% of water used in production in the EU.

Table 1: Sectors by water intensity (1000m^3 per million USD): EU, 2005*

Sector	**Deciles**
All other sectors	0.1
Basic Metals and Fabricated Metal	0.2
Food, Beverages and Tobacco	0.3
Other Non-Metallic Minerals	0.4
Pulp, Paper, Paper, Printing and Publishing	**0.5**
Textiles and Textile Products	0.6
Chemicals and Chemical Products	0.7
Electricity, Gas and Water Supply	0.8
Agriculture, Hunting, Forestry and Fishing	0.9

* Median in bold.

3. Methods

Our analysis can be divided into two parts: first we use statistical indicators to quantify the importance of the sectoral water intensity for the economies of the EU-27 countries; second, we use an input-output decomposition analysis to find the main drivers of water usage for the sectors which have been identified as the most water intensive.

3.1. Water Intensity Indicator

Various methods can be used to calculate the water intensity of an economy. In what follows, we distinguish between those sectors that are above the median level of EU water intensity (j = 1, ..., 4) and the other sectors (r = 5, .., 35). We also distinguish between the 27 EU countries (C = 1, ..., 27). So, we use the following calculation:[4]

$$\frac{W_C}{Y_C} = \sum_{j=1}^{4} \frac{W_{j,C}}{Y_{j,C}} \frac{Y_{j,C}}{Y_C} + \frac{W_{r,C}}{Y_C} \qquad (1)$$

The first term in Equation (1) shows the water intensity in the C-th country considered: water consumption (W_C) per GDP (Y_C) as a function of water intensity per sector $\frac{W_{j,C}}{Y_{j,C}}$, where index j corresponds to the economic sectors identified previously; agriculture, food and beverages, chemicals and electricity, gas and water supply.

[4] Mendiluce et al (2010) proposed a similar method to measure energy intensity in the Spanish economy.

Also in Equation (1), the term $\frac{Y_{j,C}}{Y_C}$ measures how much the *j-th* sector contributes to the *C-th* country's GDP. Thus the indicator allows water intensity to be decomposed into sectoral water intensity and output intensity.

3.2. Input-Output Subsystem Decomposition

Having examined the water intensity of the EU countries, we then use the details of the production structure of each economy, as given in the national input-output tables, to decompose sectoral water use into different channels within the production system. Specifically, we use a subsystem input-output model to analyse the patterns of sectoral water consumption.

The subsystems approach considers an individual sector (or a group of sectors) as a particular unit that does not modify the main characteristics of the system of which it is a part. Taking into account that a subsystem responds to the notion of an individual sector or group of sectors that produce a specific commodity, an input-output table enables sectors of production to be considered as subsystems. In this paper we separately take into account four sectors of production and, for each one, we apply a subsystem division of its water use.[5] This analysis, which decomposes the water use of each sector into different sources, extends our knowledge about the water consumption within the production system.

The starting point of the subsystem representation consists of decomposing the *N* accounts of an input-output system into two categories (*M* and *S*), with 1, 2, .., *m* sectors belonging to *M* subsystem, and *m* + 1, .., *n*, belonging to the *S* subsystem. If these accounts are separated, the input-output representation can be written as follows:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix}\begin{pmatrix} x^M \\ x^S \end{pmatrix}+\begin{pmatrix} y^M \\ y^S \end{pmatrix}=\begin{pmatrix} x^M \\ x^S \end{pmatrix}, \qquad (2)$$

where the subscripts and superscripts denote the group of accounts *M* and *S*, respectively. In Equation (2), matrices *A* contain the technical input-output coefficients, the column vector $x=\begin{pmatrix} x^M \\ x^S \end{pmatrix}$ contains the sectoral production and the column vector $y=\begin{pmatrix} y^M \\ y^S \end{pmatrix}$ contains the final demand. From Equation (2), we can calculate sectoral production as $x=(I-A)^{-1}y=By$, where *B* is the Leontief inverse matrix. Using this definition, the model can be written as:

$$\left[\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix}\right]\begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix}\begin{pmatrix} y^M \\ y^S \end{pmatrix}+\begin{pmatrix} y^M \\ y^S \end{pmatrix}=\begin{pmatrix} x^M \\ x^S \end{pmatrix} \qquad (3)$$

Expression (3) contains the following two equations:[6]

---

[5] Specifically, we will consider the four activities that show a level of water intensity above the EU median (see Table 1).

[6] The literature on input-output subsystems usually assumes that the final demand in one subsystem is zero and, accordingly, this subsystem is thought to only produce for the intermediate demand (see Alcántara and Padilla (2009)). Unlike other similar studies, expression (4) captures all the income relations within the production system.

$$A_{MM}B_{MM}\ y^M + A_{MM}B_{MS}\ y^S + A_{MS}B_{SM}\ y^M + A_{MS}B_{SS}\ y^S + y^M = x^M\ , \qquad (4)$$

$$A_{SS}B_{SM}\ y^M + A_{SS}B_{SS}\ y^S + A_{SM}B_{MM}\ y^M + A_{SM}B_{MS}\ y^S + y^S = x^S$$

The two equations in (4) show the production of the *M* and *S* subsystems, respectively. Let us assume that we are interested in analysing the *S* subsystem. Then, the interpretation of Equation (4) is as follows: The first equation, which defines the total production of *M*, can be divided into two parts. The first, $A_{MM}B_{MS}\ y^S + A_{MS}B_{SS}\ y^S$, shows the effects of the final demand of the *S* subsystem on the production of *M* and we can regard it as an *external component*. The remaining elements in the first equation of (4), $A_{MM}B_{MM}\ y^M + A_{MS}B_{SM}\ y^M + y^M$ show the production of *M* needed to cover its final demand.[7]

The left-hand side of the second equation in expression (4) can be divided into different components that convey different economic meaning. The term $A_{SS}B_{SM}\ y^M + A_{SM}B_{MM}\ y^M$ shows the production of *S* required to cover the final demand of *M* or the *induced component*. The term $A_{SS}B_{SS}\ y^S + A_{SM}B_{MS}\ y^S$ is interpreted as an *internal component* that shows effects that both end in *S* and start from *S*. Finally, the last component, y^S, is the final demand for the *S* subsystem and can be divided into exports final demand (y_X^S) and domestic final demand (y_D^S):[8] $y^S = y_X^S + y_D^S$.

To transform Equation (4) into a water-use model, we use the diagonal matrices W^M and W^S that contain in the main diagonal the water-use coefficients, calculated as the water used (in physical units) per unit of total production in the *M* and *S* subsystems, respectively. The water-use associated with the components of the *S* subsystem is equal to:

$$EC_S = W^M(A_{MM}B_{MS} + A_{MS}B_{SS})y^S$$

$$INC_S = W^S(A_{SS}B_{SM} + A_{SM}B_{MM})y^M$$

$$ITC_S = W^S(A_{SS}B_{SS} + A_{SM}B_{MS})y^S$$

$$EXC_S = W^S y_X^S$$

$$DC_S = W^S y_D^S$$

These expressions show the water use explained by the external component (*EC_S*) – the water used in subsystem *M* due to demand for *S*; the induced component (*INC_S*) – the water used in subsystem *S* due to demand for *M*; the internal component (*ITC_S*) – the water used in subsystem *S* due to demand for *S*; the export level component (*EXC_S*) – the direct water use due to foreign demand for *S*; and the domestic final demand component (*DC_S*). The total (direct and indirect) water use (*TW_S*) of the *S* subsystem can then be calculated as:

 EMBED Equation.DSMT4 (5)

[7] Note that if we are interested in the *S* subsystem, this part of the *M* production can be avoided.
[8] The domestic final demand includes sectoral private consumption, public consumption and investment.

4. Results

The main aim of our study is to investigate whether a common pattern emerges in the water usage of the EU 27 countries. As the WFD defines common criteria to evaluate the water consumption in different countries and suggests the implementation of economic analysis to quantify the prices and the costs associated with water usage, an analysis of water intensity in different sectors and the drivers of water usage in the water-intensive sectors for all the member countries would be an important step in helping policy-makers to understand whether common incentives will have parallel effects in all EU countries.

Figure 1: Water intensity by country and by sector (2005)

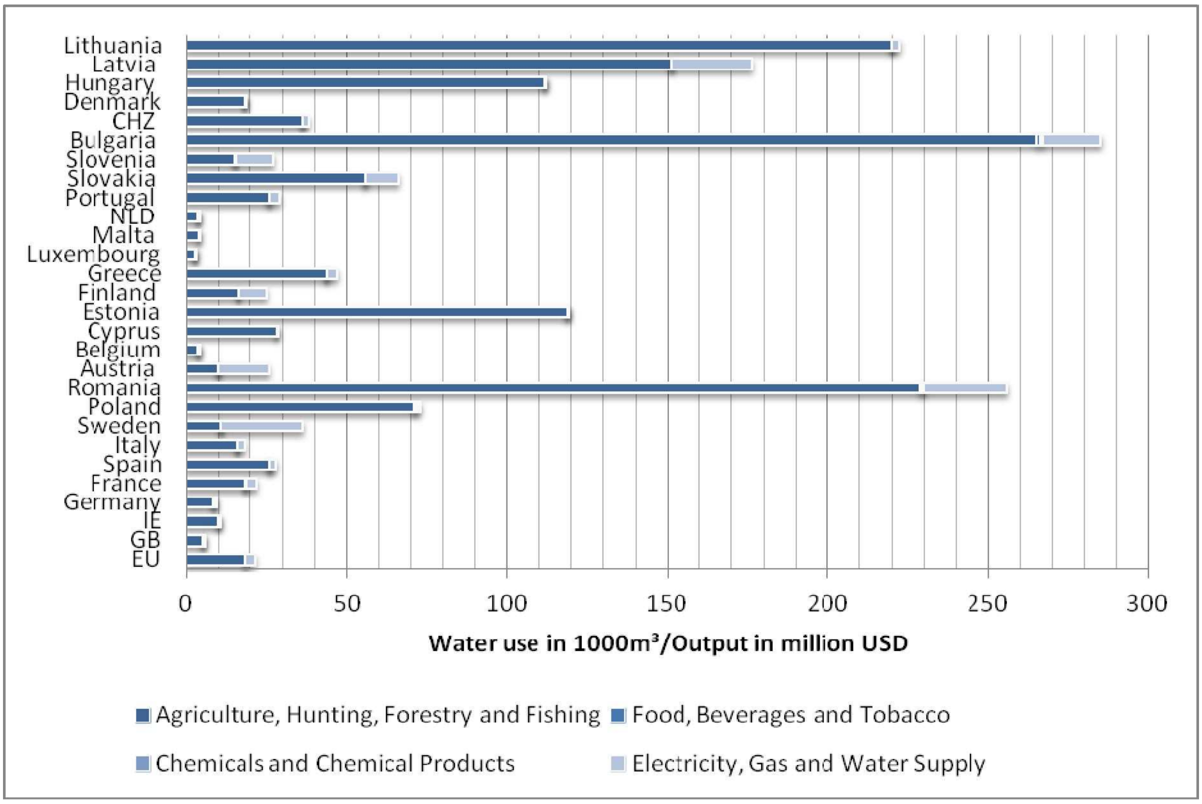


Figure 1 shows the total water intensity calculated by Equation (1) in all the EU 27 countries. From this figure we can see that water intensity is quite heterogeneous at a national level. It can be seen, however, that common patterns emerge across different groups of countries. In particular, the water used in agriculture is particularly high for central/eastern European countries, such as Romania, Lithuania, Bulgaria and Hungary. Moreover, the water used in the electricity, gas and water supply sector in countries with nuclear power plants (Sweden, France, Romania) is higher than in other countries.

To analyse more homogeneous trends in water usage between countries and reduce the asymmetric behaviours observed in Figure 1, below we divide our sample into different sub-regions to identify common patterns of water use within them. Looking at the common characteristics between countries, we then divide our sample into three main regions: the area which we refer to as "Northern Europe" is comprised of Great Britain, Ireland, Germany, France, Sweden, Austria, Belgium, Finland, Luxembourg, the Netherlands and Denmark; the "Mediterranean" region is comprised of Spain, Italy, Cyprus, Greece, Malta and Portugal; finally "central/eastern Europe" refers to Estonia, Slovakia, Slovenia, Poland, Romania, Bulgaria, the Czech Republic, Hungary, Latvia and Lithuania. Water consumption within each group exhibits broadly similar patterns; however, our results show a general heterogeneity of water consumption within the EU.

4.1 Water Intensity

Our aggregate water intensity indicator is comprised of two separate indicators; sectoral water intensity and sectoral output intensity. We find that in the northern European countries, most sectors are below the EU average for water usage relative to the total output of the economy. However, there are some exceptions: in France the water usage relative to output is above average in all sectors, and in Sweden, Austria and Finland water intensity is above average in the Electricity, Gas and Water supply sectors. In some of these countries (for example, Sweden, Finland and France), the high levels of water intensity in this sector may be due to the use of nuclear power in electricity generation (European Union, 2012), which requires the use of significant amounts of water to cool the nuclear reactors and produce steam (EPA, 2012).

Table 2: Water Intensity (WI) (1000m^3 per million USD) and Output Intensity (YI) (sectoral output as a percentage of total output) in northern Europe[*]

	Agriculture, Hunting, Forestry and Fishing		**Food, Beverages and Tobacco**		**Chemicals and Chemical Products**		**Electricity, Gas and Water Supply**		**Total WI**		**Total YI**	
	WI	YI	WI	YI	WI	YI	WI	YI	Intensive sectors	Others	Intensive sectors	Others
EU avg.	18.599	1.9%	0.064	3.9%	0.116	2.9%	2.899	2.7%	21.677	0.125	11.3%	88.7%
GB	5.337	0.9%	0.027	2.8%	0.021	2.1%	0.288	**3.1%**	5.672	0.035	8.9%	91.1%
Ireland	10.047	1.7%	0.032	**5.1%**	0.079	**8.6%**	0.370	1.3%	10.528	0.026	16.6%	83.4%
Germany	8.490	1.1%	0.025	3.5%	**0.206**	**3.3%**	0.952	2.4%	9.673	0.105	10.3%	89.7%
France	**18.607**	**2.5%**	**0.114**	3.8%	**0.135**	**3.0%**	**3.271**	2.3%	22.128	0.190	11.6%	88.4%
Sweden	10.712	1.3%	0.004	2.5%	0.057	2.6%	**25.674**	2.2%	36.448	0.069	8.6%	91.4%
Austria	9.953	1.7%	0.002	3.1%	0.074	1.8%	**15.938**	**4.1%**	25.966	0.067	10.7%	89.3%
Belgium	3.757	1.0%	**0.119**	**4.3%**	**0.121**	**5.2%**	0.090	1.7%	4.087	0.145	12.2%	87.8%
Finland	16.211	**2.6%**	0.009	2.8%	0.072	2.1%	**8.945**	1.8%	25.238	0.203	9.4%	90.6%
Lux.	2.822	0.4%	0.002	1.0%	0.002	0.6%	0.245	1.3%	3.071	0.012	3.2%	96.8%
NL	3.720	**2.5%**	**0.084**	**5.0%**	0.102	**4.7%**	0.018	**3.0%**	3.925	0.029	15.2%	84.8%
Denmark	18.581	**2.4%**	0.017	**5.1%**	0.006	2.5%	0.013	1.9%	18.617	0.014	11.9%	88.1%

[*] Figures in bold are those which are above the EU average.

A very different pattern of water intensity can be seen in the Mediterranean and eastern/central European countries. Countries in these regions have much higher levels of water intensity in the agriculture, hunting, forestry and fishing sector than in the Northern European countries. This result might be seen as surprising because, as mentioned above, the measure of water use in our analysis includes rain water absorbed from soil. However, it should be noted that Mediterranean countries generally use a vast amount of blue water in agriculture, given their arid climate.

Table 3: Water intensity (WI) and Output Intensity (YI) in Mediterranean Europe*

	Agriculture, Hunting, Forestry and Fishing		Food, Beverages and Tobacco		Chemicals and Chemical Products		Electricity, Gas and Water Supply		Total WI		Total YI	
	WI	YI	WI	YI	WI	YI	WI	YI	Intensive sectors	Others	Intensive sectors	Others
EU avg.	18.599	1.9%	0.064	3.9%	0.116	2.9%	2.899	2.7%	21.677	0.125	11.3%	88.7%
Spain	**26.088**	**2.5%**	0.023	**5.0%**	0.077	2.3%	1.988	2.6%	28.176	0.066	12.3%	87.7%
Italy	15.841	1.7%	0.052	3.8%	0.046	2.5%	2.542	2.6%	18.481	0.142	10.6%	89.4%
Cyprus[9]	**28.420**	**3.3%**	0.004	**5.9%**	0.000	0.8%	0.000	**2.7%**	28.424	0.003	12.7%	87.3%
Greece	**43.759**	**4.5%**	0.012	**5.2%**	0.004	1.2%	**3.277**	2.5%	47.051	0.022	13.3%	86.7%
Malta	3.910	**2.4%**	0.001	3.5%	0.001	1.4%	0.000	**4.8%**	3.912	0.001	12.1%	87.9%
Portugal	**25.966**	**2.7%**	0.032	**4.6%**	0.024	1.6%	**3.365**	**3.8%**	29.387	0.153	12.7%	87.3%

* Figures in bold are those which are above the EU average.

Table 4: Water intensity (WI) and Output Intensity (YI) in central/eastern Europe*

	Agriculture, Hunting, Forestry and Fishing		Food, Beverages and Tobacco		Chemicals and Chemical Products		Electricity, Gas and Water Supply		Total WI		Total YI	
	WI	YI	WI	YI	WI	YI	WI	YI	Intensive sectors	Others	Intensive sectors	Others
EU avg.	18.599	1.9%	0.064	3.9%	0.116	2.9%	2.899	2.7%	21.677	0.125	11.3%	88.7%
Estonia	**119.083**	**3.7%**	0.022	**4.3%**	0.001	1.4%	0.179	**2.9%**	119.285	0.119	12.3%	87.7%
Slovakia	**55.612**	**3.4%**	**0.167**	3.3%	0.041	1.6%	**10.545**	**6.8%**	66.365	0.132	15.1%	84.9%
Slovenia	15.135	**2.5%**	**0.068**	3.0%	0.113	**3.8%**	**12.023**	**2.8%**	27.339	0.439	12.0%	88.0%
Poland	**71.196**	**4.5%**	**0.247**	**6.7%**	**0.854**	2.3%	0.892	**3.9%**	73.190	0.301	17.4%	82.6%
Romania	**228.571**	**9.1%**	**1.061**	**8.4%**	0.073	1.7%	**26.278**	**5.9%**	255.983	0.745	25.1%	74.9%
Bulgaria	**265.078**	**8.8%**	**1.137**	**5.6%**	**0.994**	2.0%	**17.789**	**4.6%**	284.997	2.966	21.0%	79.0%
Cz. Rep.	**36.269**	**2.5%**	**0.086**	**4.4%**	0.033	2.1%	1.875	**3.8%**	38.263	0.147	12.8%	87.2%
Hungary	**111.93**	**4.2%**	**0.132**	**4.7%**	0.085	2.6%	0.216	**3.8%**	112.363	0.824	15.2%	84.8%
Latvia	**151.137**	**4.7%**	0.043	**5.2%**	0.065	0.6%	**25.109**	**3.1%**	176.354	0.082	13.7%	86.3%
Lithuania	**220.042**	**5.4%**	0.017	**6.2%**	0.005	1.8%	2.413	**4.7%**	222.477	0.026	18.1%	81.9%

* Figures in bold are those which are above the EU average.

The water intensity of the agricultural sector relative to total output is exceptionally high in many of the central and eastern European countries (particularly in Romania, Bulgaria and Lithuania). The food, beverages and tobacco sector generally has a very low level of water intensity in all countries; however, it is above average in some central/eastern European countries. In all the countries in the central/eastern European block, the contribution of the agricultural sector to total output is above the EU average of 1.91% and in some countries it is well above the EU average (e.g. Bulgaria: 8.8% and Romania: 9.1%). However, our results show that these countries use water at levels that are higher than can be explained by the relative economic importance of these sectors. In both the

[9] As highlighted in Section 2, data on Cyprus and Malta are not reliable in the electricity, gas and water supply sector.

Mediterranean and central/eastern European countries, water use in the chemicals and chemical products sector is below the EU average (with the exception of Bulgaria). On the other hand, in a number of the central/eastern European countries, the electricity, gas and water supply sector consumes water at a level which is above the EU average. Again this may be due the electricity generation mix in these countries, many of which use nuclear and hydro power generation (European Union, 2012).

4.2 Subsystem Decomposition of Water Usage

Having examined the general patterns of sectoral water intensity in the EU countries, we now run an input-output subsystem decomposition analysis in order to get a better understanding of what is driving water use in the different sectors and countries.

As shown in Table 1, we will focus on the four sectors above the median level of water intensity in production: agriculture, hunting, forestry and fishing; food, beverages and tobacco; chemicals and chemical products; and electricity, gas and water supply.

4.2.1 Agriculture, Hunting, Forestry and Fishing

In 2005, the agricultural sector in northern Europe was responsible for 37% of total water use by this sector within the EU, and contributed to 56% of EU output from this sector. In central and eastern Europe the agricultural sector was responsible for 34% of EU agricultural water use, and this region accounted for 16% of EU agricultural output. The figures for Mediterranean EU countries were 29% of water use and 28% of output.

Figure 2: Decomposition of water use in the agricultural sector – northern Europe

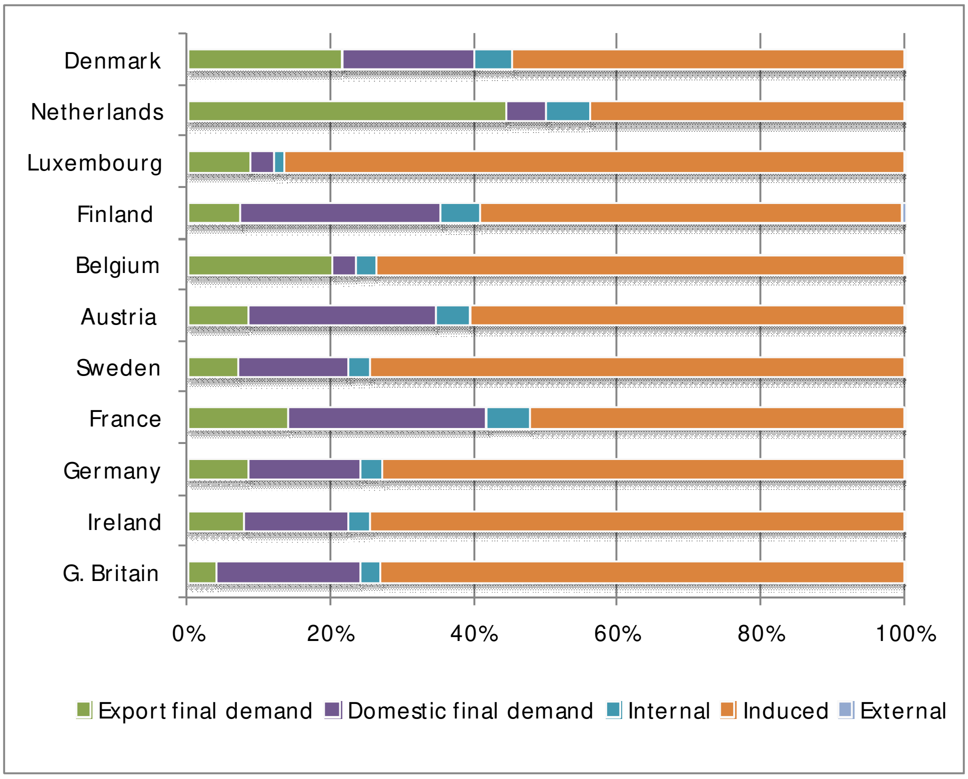


Figure 3: Decomposition of water use in the agricultural sector – central/eastern Europe

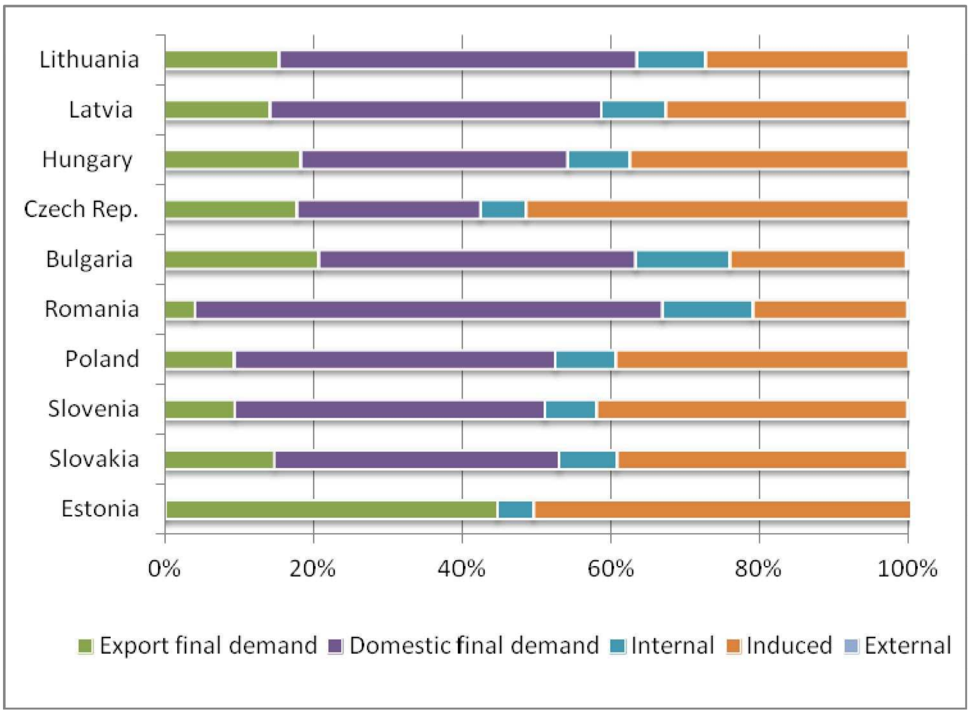
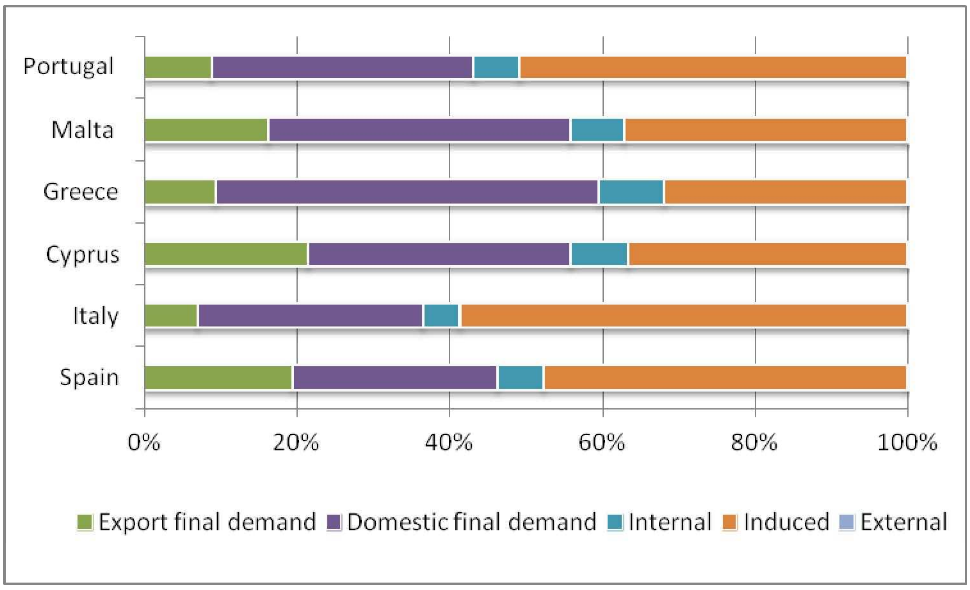


Figure 4: Decomposition of water use in the agricultural sector – Mediterranean Europe



Figures 2 to 4 show that patterns of water use differ in the three European regions analysed. In all countries in northern Europe, with the exception of the Netherlands, the induced component is the largest. This reflects the fact that many of the outputs of agricultural production are used as inputs in other sectors. Therefore, in northern Europe, while the agricultural sector uses larger quantities of water than other sectors, much of this is to satisfy the demand from other sectors for inputs into their production processes. The database used shows that the food, beverages and tobacco sector is a particularly large consumer of output from the agricultural sector. Thus, while this sector is responsible for the direct consumption of a very small amount of water, it is driving water use in other sectors, and particularly in agriculture.

Looking at water usage patterns of agriculture in central/eastern Europe (Fig. 3) the induced component is generally much smaller than in northern European countries, whereas the demand-level component is much higher. This is an indication that the output of the agricultural sector of countries in this region is not generally processed further by other sectors before being sold to final domestic consumers or exported. Thus, in countries in this region, much of the water being used by the agricultural sector is being driven by demand for agricultural produce. It is also worth noting that the internal component is generally larger for countries in this region than in other regions.

The pattern of water usage in Mediterranean countries (Fig. 4) is generally less clear. The induced component is largest in Portugal, Spain and Italy. This shows that, like many countries in northern Europe, water is being consumed in the agricultural sector in order to produce goods which will be used to satisfy final demand from other sectors. On the other hand, in Cyprus, Greece and Malta more water is being consumed to satisfy final demand – both for domestic consumption and for export. One quite surprising result is that in Spain and Malta a large quantity of the water used in the agricultural sector is used to produce agricultural goods, which are then exported. It seems surprising that large quantities of embodied water would be exported from countries in which water is relatively scarce.

This result for Spain confirms the analysis made by Velázquez (2006). In her work, she finds that in one of the most arid regions in Europe, Andalusia, a large quantity of water is used by the agricultural sector to export its products. Our input-output analysis highlights how exports and final demand are the main drivers of water intensive production in some arid countries; as a result, incentives to encourage the responsible usage of the countries' natural resources should be considered.

4.2.2 Food, Beverages and Tobacco

Another sector with water intensity above the EU median is the food, beverages and tobacco sector. We have applied the subsystem decomposition for all the EU 27 countries for this activity. We do not present results here for the decomposition of water use in this sector as, in all countries, direct water use is actually very small in absolute terms. Additionally, when we decompose the results from this sector the "external component" is by far the largest.[10]

4.2.3 Chemicals and Chemical Products

In 2005, the chemical sector in northern Europe was responsible for 67% of total water use by this sector within the EU, and contributed to 75% of EU output from this sector. In central and eastern Europe this sector was responsible for 21% of EU sectoral water use, and accounted for 5% of EU sectoral output. The figures for Mediterranean EU countries were 11% of water use and 20% of output.

The chemical sector mainly uses water indirectly, as the external component is quite large for all the countries analysed. Figures 5 to 7 show the decomposition of water use in the chemical sector in the three different sub regions identified in our analysis.

Figure 5: Decomposition of water use in the chemical sector – northern Europe

[10] The results of this decomposition are available upon request.

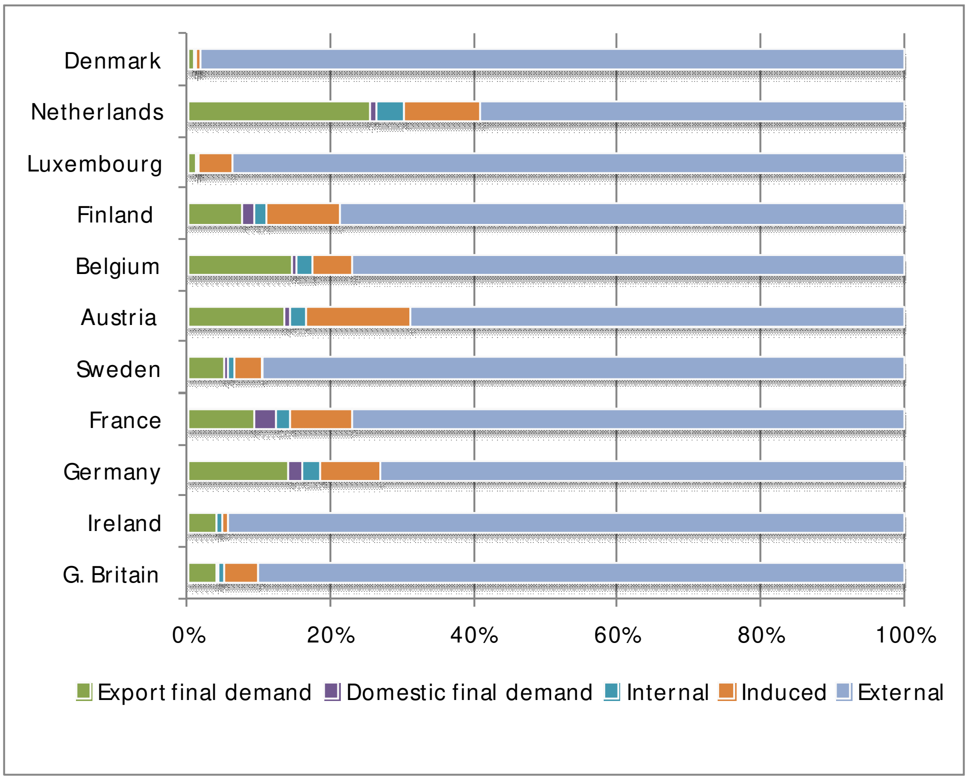


Figure 6: Decomposition of water use in the chemical sector – central/eastern Europe

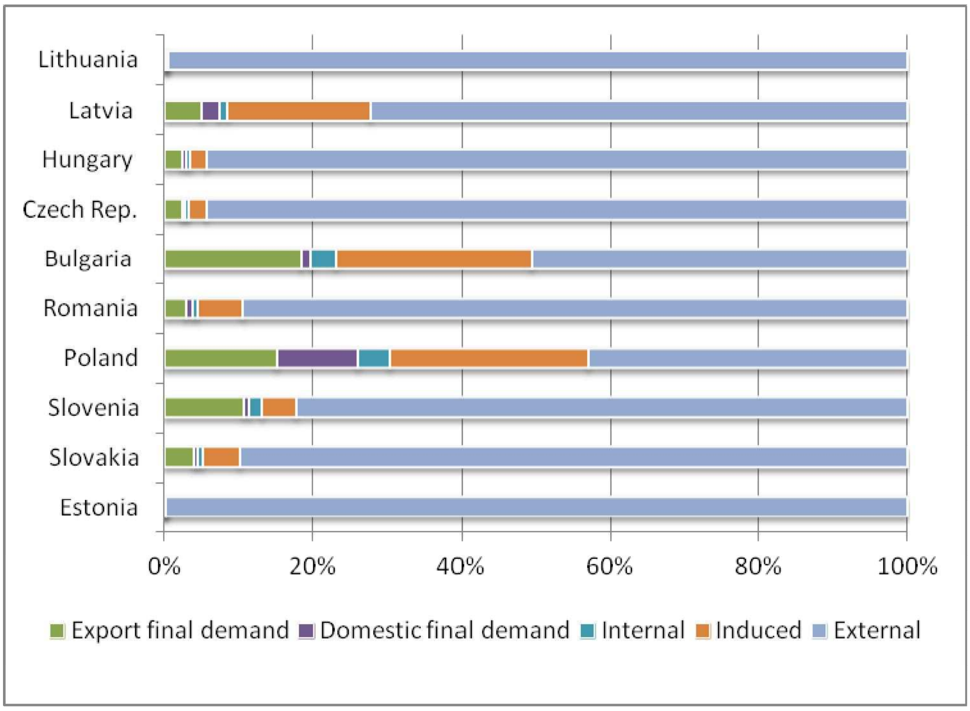
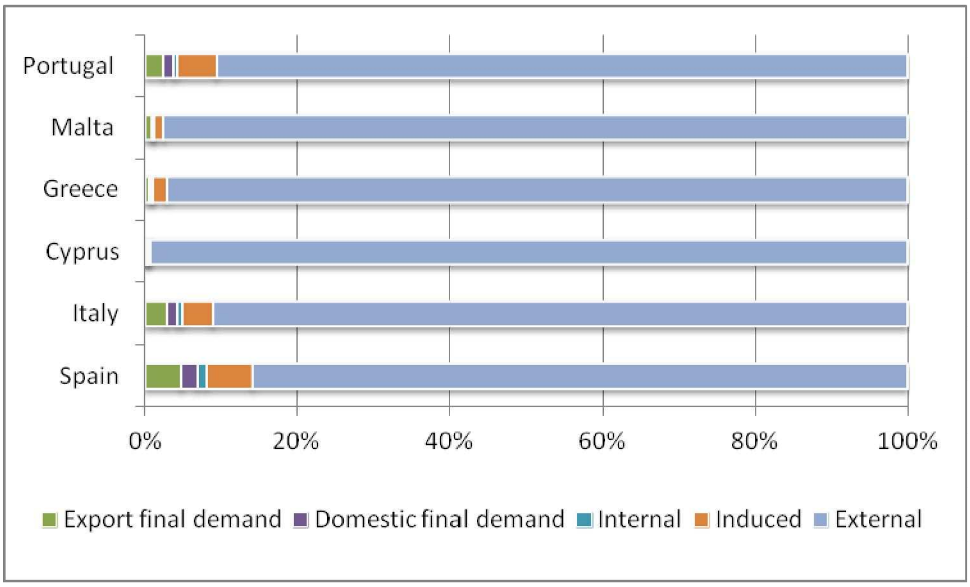


Figure 7: Decomposition of water use in the chemical sector – Mediterranean Europe



The decomposition analysis shows that water usage patterns in this sector are quite heterogeneous even between countries within the same region. One pattern that does clearly emerge from the countries in northern Europe is that the majority of the water used to satisfy final demand from this sector is in fact used to satisfy demand from abroad. In Northern Europe, on average, more than 90% of final production from this sector is exported.

Similar patterns can be seen from the decomposition of water use for the chemical sector in central/eastern Europe and in Mediterranean Europe; the largest component is the external component showing that, in addition to the water being consumed directly by this sector, it also drives the use of water in other sectors. Additionally, for most countries in these regions the majority of the final demand for goods from the chemical sector is from other countries.

4.2.4 Electricity, Gas and Water Supply

The electricity, gas and water supply sector includes the water used to produce electricity and gas, as well as the water used in the water distribution system. In northern Europe the electricity, gas and water supply sector was responsible for 65% of the total water used by this sector within the EU, and also contributed to 65% of EU output from this sector. In central and eastern Europe this sector was responsible for 14% of EU sectoral water use, and accounted for 10% of EU sectoral output. The figures for Mediterranean EU countries were 21% of water use and 25% of output.

With the exception of Malta and Cyprus, for which data are not fully reliable, our analysis shows that for all the other countries in northern and Mediterranean Europe, the induced component is generally the main driver of water usage, followed by the final demand component (i.e. the sum of domestic final demand and exports). The pattern is somewhat different in central/eastern Europe where the final demand component is the largest, followed by the induced component.

Figure 8: Decomposition of water use in the electricity, gas and water sector – northern Europe

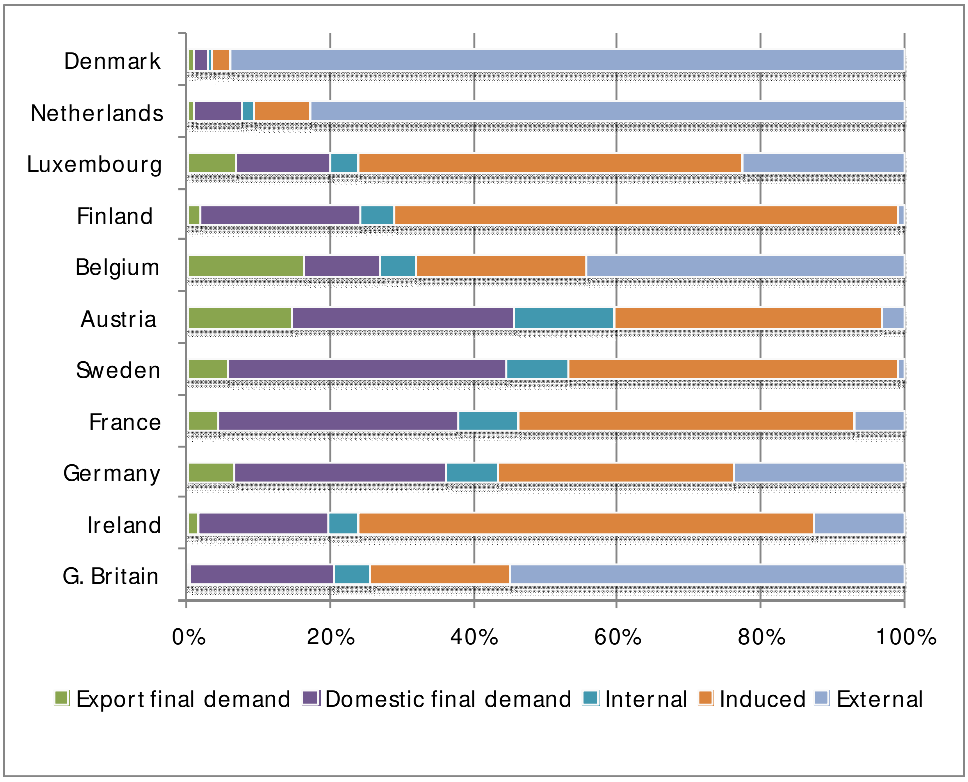


Figure 9: Decomposition of water use in the electricity, gas and water sector – central/eastern Europe

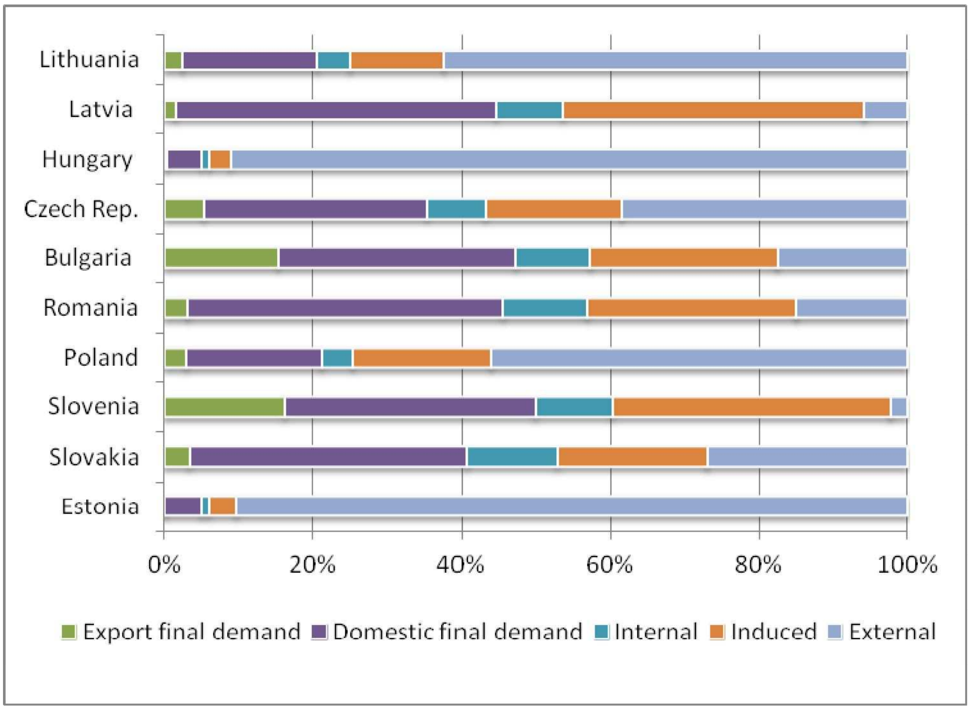
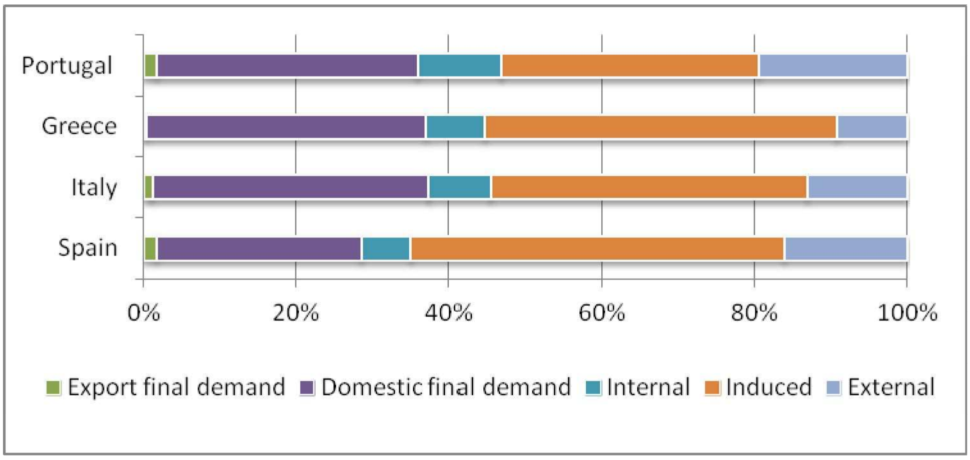


Figure 10: Decomposition of water use in the electricity, gas and water sector – Mediterranean Europe*



* Cyprus and Malta were excluded from this graph because data on water used by this sector was missing in these countries.

In all regions and in most countries, the external component is close to zero, which indicates that the electricity, gas and water sector does not drive the consumption of water in other sectors. The majority of water used in this sector is generally accounted for by the domestic final demand and induced components, which shows that water used in this sector is primarily being driven by the demand for final goods/services and by the demand for production inputs from other sectors. Figures 8 to 10 illustrate that the share of the induced component varies significantly between countries, from a maximum of 70% in Finland to a minimum of only 2% in Denmark. On average, the induced component accounts for 35% of total water used in this sector in Mediterranean countries; 37% in northern European countries; and 21% in countries in central/eastern Europe. The amount of water which is used to satisfy the final demand for exported goods from this sector is lowest in Mediterranean countries (6%, compared to 13% in central/eastern Europe and 21% in northern Europe), as would be expected in countries where water is scarce.

Conclusions

The Water Framework Directive defines common objectives for water preservation across the European Union. Given this general approach to European water management, a common water policy can only succeed in its objectives if patterns of water use are parallel in all EU countries. Our paper addresses this point. Specifically, we analyse the patterns that explain water consumption in the production system of all EU members.

We use two methods to explain sectoral water drivers. The first is based on an accounting indicator that decomposes total water intensity in an economy into the addition of sectoral water intensities and output intensities. The second is based on a subsystem input-output decomposition to explore the different income channels behind sectoral water consumption.

Our results highlight that the most water-intensive sectors in Europe are agriculture, food and beverages, chemical products and electricity, gas and water supply. However, the amount of water used in these sectors varies quite substantially across EU countries. The indicator used also shows different water intensities in the three European regions considered.

The subsystem model shows that for most countries in northern and Mediterranean Europe, the majority of water used by the electricity, gas and water supply sector is accounted for by the induced component. This shows that while this sector is a large consumer of water resources in these regions, the consumption is largely driven by demand from other sectors for water-intensive inputs. This raises the question of whether water should be charged on the basis of a producer-pays or a consumer-pays principle in these countries.

Our results show that agriculture is the most water-intensive sector in both central/eastern and Mediterranean European countries. Additionally, the contribution of the agricultural sector to total output differs quite substantially between central/eastern and Mediterranean countries. In central/eastern European countries the agricultural sector accounts for an average output of 5%. The maximum is in Romania (9%). In the Mediterranean countries, agriculture on average counts for less than 3% of total output. Our subsystem decomposition shows that the water embedded in agricultural products is mainly destined for domestic consumption in the central/eastern European countries, and for exports in the Mediterranean countries.

The heterogeneity observed in our results suggest that different policies should be adopted in the various EU sub-groups in order to ensure sustainable consumption of water and, more generally, to achieve water savings. In central/eastern European countries attention should be given to the domestic consumption of agricultural produce, in order to promote the more responsible use of water in agriculture. In the Mediterranean countries, water tariffs should be adapted to take into account the water scarcity in these regions and the export of water-intensive products from some Mediterranean countries.

The results in this paper are extremely useful to the successful definition and implementation of water measures in the European Union. To ensure the efficient consumption of water resources across Europe, the general steps established in the Water Framework Directive should be implemented in specific policies that take into account not only the sector of production but also the country.

References

Alcántara, V. 1995. *Economía y contaminación atmosférica: hacia un nuevo enfoque desde el análisis input-output*. Doctoral Thesis Dissertation. University of Barcelona.

Alcántara, V. and Padilla, E. 2009. Input-output subsystems and pollution: an application to the service sector and CO_2 emissions in Spain. *Ecological Economics* 68, 905-914.

Butnar, I. and Llop, M. 2011. Structural decomposition analysis and input-output subsystems: an application to CO2 emissions of Spanish service sectors (2000-2005). *Ecological Economics* 70, 2012-2019.

Cardenete, M. A. and Fuentes, P. 2011. Energy consumption and CO_2 emissions in the Spanish economy. *In*: M. Llop, ed. *Air pollution: measurements and control policies*, Bentham E-Books, Pages 46-64.

Deprez, J. 1990. Vertical integration and the problem of fixed capital. *Journal of Post Keynesian Economics* 13, 47-64.

Dietzenbacher, E. and Velázquez, E., 2007. Analysing Andalusian Virtual Water Trade in and Input-Output Framework. *Regional Studies*, 41(2), 185-196.

European Union, 2012. "EU Energy in Figures – Pocketbook 2012". Luxembourg: Publications Office of the European Union.

EPA, 2012. "Nuclear Energy". Available at: http://www.epa.gov/cleanenergy/energy-and-you/affect/nuclear.html. Accessed: 11th September 2012.

Genty, A., Arto, I. and Neuwahl, F., 2012. Final Database of Environmental Satellite Accounts: Technical Report on Their Compilation. WIOD Documentation.

Guan, D. B. and Hubacek, K., 2007. Assessment of regional trade and virtual water flows in China, *Ecological Economics*, 61, 159-170.

Hoekstra, A.Y. and Hung, P.Q., 2002. Virtual water trade: a quantification of virtual water flows between nations in relation international crop trade. Value of Water Research Report Series No. 11. UNESCO-IHE, Delft, the Netherlands.

Lenzen, M. and Foran, B., 2001. An input-output analysis of Australian water usage. *Water Policy*, 3, 321-340.

Llop, M. and Tol, R., 2012. Decomposition of sectoral greenhouse gas emissions: a subsystem input-output model for the Republic of Ireland. *Journal of Environmental Planning and Manangement*, forthcoming.

Mendiluce, M; Pérez-Arriaga, I. and Ocaña, C. 2010. Comparison of the evolution of energy intensity in Spain and in the EU15. Why is Spain different? *Energy Policy*, 38 (1), 639-645.

Morilla, C., Llanes, G. and Cardenete, M. A., 2007. Economics and environmental efficiency using a social accounting matrix. *Ecological Economics*, 60, 774-786.

Pasinetti, L. 1973. The notion of vertical integration in economic analysis. *Metroeconomica* 25, 1-29.

Pasinetti, L. 1988. Growing subsystems, vertically hiper-integrated sectors and the labour theory of value. *Cambridge Journal of Economics* 12, 125-134.

Sánchez-Choliz, J. and Duarte, R. 2003. Analysing pollution by vertically integrated coefficients, with an application to the water sector in Aragon. *Cambridge Journal of Economics* 27, 433-448.

Scazzieri, R. 1990. Vertical integration in economic theory. *Journal of Post Keynesian Economics* 13, 20-46.

Sraffa, P. 1960. Production of commodities by means of commodities. Cambridge: Cambridge University Press.

Timmer, M. (Ed.), 2012. The World Input-Output Database (WIOD): Contents, Sources and Methods. April 2012, Version 0.9.

Velázquez, E. 2006. An input–output model of water consumption: Analysing intersectoral water relationships in Andalusia, *Ecological Economics,* 56, 226 -240.

Zhao, X., Chen, B. and Z.F. Yang, 2009. National water footprint in an input-output framework - A case study of China 2002. *Ecological Modelling*, 220 (2), 245-253.