# DRIVERS OF WATER USE IN THE AGRICULTURAL SECTOR OF THE EUROPEAN UNION 27

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Agricultural and Applied Economics
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2019

Urbana, Illinois

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ABSTRACT

Population growth and the uncertain hazards that accompany climate change have put increasing pressure on the management and sustainability of water, a vital but scarce environmental resource. A decrease in the water quality and quantity would have a direct impact on agriculture, the economic sector that uses the most of it, and its domestic and international supply chain linkages. As one of the largest agricultural producer in the world (14% of world agricultural production), the European Union and its twenty-seven members (EU27) are particularly sensitive to changes in water availability. To better understand the evolution of the latter, we perform a structural decomposition analysis over the 1995-2010 period. Based on the recently-released EXIOBASE 3 database, we examine in depth how changes in water input coefficients, in final demand and in technology have affected changes in water use in agriculture and more especially in crop production. Indeed, while agriculture represents 70% of all the water use, crop production consumes as much as 99% of the former while only 1% is attributed to livestock. Our results show that the more developed EU members who are also the largest crop producers have experienced an increase in water use that is mostly driven by changes in technology, i.e. the water content of the inputs used in the production process has increased over time. One exception is Germany where it is an increase in water intensity, the amount of water used per unit of output, that has driven the increase in water use. On the other hand, several Mediterranean countries, where water scarcity has been a problem for years, have decreased their water consumption mostly thanks to an improvement in their water intensity. The only exception is Spain where its agricultural sector continues to consume vast amounts of water in spite of its increasing scarcity (Dietzenbacher and Velasquez, 2007). Results by crop are consistent with the

results at the aggregated level except for vegetables of which water use changes have been primarily driven by changes in final demand and water intensity.

# Contents

# CHAPTER 1: INTRODUCTION

Over the last 50 years, the global demand and usage for fresh water have increased more than 40% due to socio-economic development, population expansion and the demand for food associated to it (Feng and Klaus, 2015; Shiklomanov, 1993). In addition, the uncertain hazards that accompany climate change have put increasing pressure on the management and sustainability of water, a necessary input for the production of crops (Antle and Stöckle, 2017; Olmstead, 2010). A comprehensive exploration of the water needed for the production of crops as well as the identification of the forces driving recent changes in the quantity of water used is necessary to better grasp the water resource challenges ahead of us.

The concept of virtual water flow, as initiated by Allan (1993, 1998), allows us to describe the volume of water used in the production of commodities and services and to also account for the water embedded in both domestic and international supply chain linkages. The latter corresponds to the transfer of water across national boundaries and is known as virtual water trade (Hoekstra, 2010; Dalin *et al*. 2012; Wan *et al*., 2016). As global demand for food increases sharply, the need for virtual water trade necessarily grows since, in theory (Heckscher-Ohlin principle of local competitive advantage), it can alleviate water stress in water-scarce regions and increase demand for water-intensive goods from water-rich regions (Qian *et al*., 2018).

However, empirical evidence does not always confirm theory. Recent virtual water trade studies such as Feng and Klaus (2015), Mekonnen and Hoekstra (2010), Zhan-Ming and Chen, (2013), Lenzen *et al.* (2013), Dietzenbacher and Velasquez (2007), Bae and Dall'erba (2018) show that several countries or regions within these countries behave against this logic. For instance, China faces serious water resources shortages as a result of the enormous local and foreign demand for its manufacturing and agriculture, both of them require large amounts of water (Shao *et al*., 2017; Zhang and Anadon, 2014; Feng *et al*., 2012; Zhao *et al*., 2010). In the United States, agriculture- and trade-induced water shortages have been highlighted in some parts of the country such as in Arizona (Bae and Dall'erba, 2018), drought-prone California (Mubako *et al*., 2013) and in three aquifers of the High Plains, the Mississipi Embayment and the Central Valley (Marston *et al*., 2015).

In the European Union, which constitutes the focus of this study, this problem is particularly relevant in the Mediterranean countries as their geographical location leads them to experience higher temperature and lesser precipitation than the rest of the region (Cazcarro *et al*., 2013). Among these countries, Spain is the largest net exporter of agricultural products to the rest of Europe (Novo *et al*., 2009) and Andalusia, its most southern region, experiences the greatest water challenge. It specializes in water-intensive sectors (agriculture and tourism) whose demand for water overlaps during summer, the period of greatest shortage (Velázquez, 2006; Dietzenbacher and Velázquez, 2007). Overall, all the studies above suggest policy measures such as a better irrigation system, producing less water-intensive crops and more imports from water-abundant places that could improve the efficiency of local water use in agriculture.

While virtual water flow studies are very informative at highlighting which sectors and associated supply-chain linkages are responsible for the largest use of water, they do not provide information about the factors at the origin of the change in water use. Structural Decomposition Analysis (SDA), on the other hand, is a powerful approach that addresses this point (Yang and Zehnder, 2007) by quantifying and analyzing driving forces such as water intensity, technology, and final demand effects. This approach has been used on virtual water flows at the global level (Wan *et al.,* 2016; Duarte *et al*., 2016; Incera *et al*., 2017; Distefano *et al*., 2018) and on some specific countries such as China (Yang *et al*., 2015; Feng *et al*., 2017; Qian *et al*., 2018) and the United States (Wang *et al.,* 2014; 2015; Marston *et al*., 2015). Results of the latter study indicate that it is the increase in final demand and more especially changes in the consumption structure (increasing demand for farm products and more especially red meat, Marston *et al*., 2015) that drove the observed increase in total water use in agriculture over 1995-2009. On the other hand, the total water use in China has slightly decreased between 2002 and 2011 because of technological progress.

A relatively lesser number of SDAs have focused on European countries. Duarte et al. (2016) applies it to Spain and find out that the evolution of total water use in the agricultural and livestock sector over 1965-2010 is mostly driven by an increase in the volume of export (foreign final demand). The decreases in water intensity and the technology effect (as measured by changes in product trade patterns) were not large enough to compensate for it. More recently, Duarte et al. (2018) propose another SDA, but it is applied to the EU27 countries this time. Their results show that the period of growth experienced in Europe over 1995-2010 has increased global demand for water resources and has contributed to water resources depletion worldwide. When they identify the main sources of that change, they find that the scale effect (final demand effect) is the main driver while the technology effect is almost null. The authors justify it based on overall stable global production structures. The third element, water intensity, did mitigate the water footprint through higher efficiency but to the extent that did not compensate for total water increase.

The goal of this study is twofold. First, while Duarte *et al.* (2018) perform an SDA on the overall agricultural sector, our focus is on crop production as it consumes 99% of the water needed in agriculture.  Moreover, we will perform our SDA on the five types of crop our database allows us to explore in order to get as much insights as possible and provide crop-specific results. Among these crops, wheat and cereal grains require 32% and 31% of the total crop water use respectively, followed by vegetables-fruits-nuts (17%) and oil seeds (9%). These figures are averaged over 1995-2010. The second contribution consists in exploring further the traditional three elements of change used by Duarte *et al*. (2018) and so many other SDAs by dividing two of them into seven elements at least. Only the water intensity effect will remain unchanged. To our knowledge, only Qian *et al*. (2018) and Yang *et al*. (2015) offer an SDA with such a fine decomposition; however, their work is applied to another part of the world, China. This approach allows us to identify very clearly the sources of water use change and, as a result, to suggest more detailed and crop-specific water saving strategies.

The rest of the paper is structured as follows: section 2 describes the methodological framework of the structural decomposition analysis in a multi-regional context (2-by-2 region with n+1 sectors in each region). Section 3 presents the data and their sources. Section 4 reports and comments on the main findings while section 5 summarizes the results and offers some concluding remarks.

# CHAPTER 2: METHODOLOGY

A structural decomposition analysis builds on the input-output (IO) techniques developed by Leontief (1936, 1964) and our application to water derives from the water input requirement initiated by Lofting and Mcgauhey (1968). SDA is defined by Rose and Chen (1991) as "the analysis of economic change through a set of static and comparable changes in key parameters of an input-output table". It has been widely used in a multiregional IO context to quantify and analyze the underlying sources of a change in a wide variety of variables over a specific period (Rose and Casler, 1996). In this paper, we follow the notation suggested by Rose and Chen (1991) but adapt it to our water use focus.

Let us note the vector of direct water input coefficients as $\boldsymbol{c}$. It indicates the amount of water used in sector i to produce a \$1 amount of gross output[1] in sector i :

$$\mathbf{c}_i = \mathbf{w}_i / \mathbf{x}_i \tag{1}$$

Where $\boldsymbol{w}$ denotes the vector of total water use (in million m$^3$) and $\mathbf{x} = \mathbf{Lf}$ the vector of total gross output by industry (in \$). Moreover, $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ corresponds to the Leontief Inverse matrix (where I is the identify matrix and A the direct input coefficient matrix) and $\mathbf{f}$ is the vector of final demand. Sub-indices 0 and 1 indicate, respectively, the first and last years of the study period. Thus, by forming the vector of total water use as $\mathbf{w} = \mathbf{cx} = \mathbf{cLf}$, the observed change in total water use over the period is:

$$\Delta\mathbf{w} = \hat{\mathbf{c}}_1 \mathbf{L}_1 \mathbf{f}_1 - \hat{\mathbf{c}}_0 \mathbf{L}_0 \mathbf{f}_0 \tag{2}$$

Let us assume that, for simplicity:

[1] Therefore, the water input coefficient does not account for the water used by the inputs needed for the production of a \$1 amount of gross output in sector i.

$$\boldsymbol{\gamma} = \hat{\mathbf{c}}\mathbf{L} \tag{3}$$

Then,

$$\Delta\mathbf{w} = \boldsymbol{\gamma}_1\mathbf{f}_1 - \boldsymbol{\gamma}_0\mathbf{f}_0 \tag{4}$$

If we use year-0 weights exclusively, then $\boldsymbol{\gamma_1}$ and $\mathbf{f_1}$ are replaced by $(\boldsymbol{\gamma_0} + \Delta\boldsymbol{\gamma})$ and $(\mathbf{f_0} + \Delta\mathbf{f})$. As a result, Eq. 4 becomes:

$$\begin{aligned}
\Delta\mathbf{w} &= (\boldsymbol{\gamma_0} + \Delta\boldsymbol{\gamma})(\mathbf{f_0} + \Delta\mathbf{f}) - \boldsymbol{\gamma}_0\mathbf{f}_0 \\
&= \boldsymbol{\gamma}_0\mathbf{f}_0 + \boldsymbol{\gamma}_0\Delta\mathbf{f} + \Delta\boldsymbol{\gamma}\mathbf{f_0} + \Delta\boldsymbol{\gamma}\Delta\mathbf{f} - \boldsymbol{\gamma}_0\mathbf{f}_0 \\
&= \boldsymbol{\gamma}_0\Delta\mathbf{f} + \Delta\boldsymbol{\gamma}\mathbf{f_0} + \Delta\boldsymbol{\gamma}\Delta\mathbf{f} \\
&= (\hat{\mathbf{c}}_0\mathbf{L}_0)\Delta\mathbf{f} + \Delta(\hat{\mathbf{c}}\mathbf{L})\mathbf{f_0} + \Delta(\hat{\mathbf{c}}\mathbf{L})\Delta\mathbf{f} \\
&= \hat{\mathbf{c}}_0\mathbf{L}_0\Delta\mathbf{f} + \Delta\hat{\mathbf{c}}\mathbf{L}_0\mathbf{f_0} + \hat{\mathbf{c}}_0\Delta\mathbf{L}\mathbf{f_0} + \Delta\hat{\mathbf{c}}\Delta\mathbf{L}\mathbf{f_0} + \Delta(\hat{\mathbf{c}}\mathbf{L})\Delta\mathbf{f} \qquad (5)
\end{aligned}$$

Eq. 5 indicates the basic SDA decomposition in which the total change in water use ($\Delta\mathbf{w}$) is decomposed into three general drivers: the water intensity effect ($\Delta\hat{\mathbf{c}}\mathbf{L_0}\mathbf{f}_0$), the technology effect ($\hat{\mathbf{c}}_0\Delta\mathbf{L}\mathbf{f}_0$) and the final demand effect ($\hat{\mathbf{c}}_0\mathbf{L}_0\Delta\mathbf{f}$). While calculated, the interaction terms ($\Delta\hat{\mathbf{c}}\Delta\mathbf{L}\mathbf{f_0}$ and $\Delta(\hat{\mathbf{c}}\mathbf{L})\Delta\mathbf{f}$) are never commented upon as their magnitude is small and their economic interpretation is not straightforward (Miller and Blair, 2009). The water intensity effect is the change in the water necessary per dollar of production (i.e. direct water consumption) in each sector, acting as an indicator of the (inverse of) water efficiency or productivity. A decrease of that effect could reflect, among other reasons, that the irrigation system is becoming more efficient following a shift to a low-flow (especially drip) irrigation system as highlighted in Bae and Dall'erba (2018). Or it could be that the goods produced have become less water-intensive through genetic modification (e.g. transgenesis and intragenesis) which improves crop tolerance to drought conditions, lessening at the same time the water requirements needed for their production (Ricroch and Henard-Damave, 2015; Nuccio *et al*., 2018). The technological effect computes the impact of the changes in the Leontief inverse (i.e. structural and technological composition of production) on water demands. This element captures the change in a sector's own technology and in the local and foreign inter-industrial linkages. More specifically, it indicates the total production of each of these two regions needed to satisfy the final demand in the local economy (Feng and Klaus, 2015). An increase in water use due to the technological effect could come from, among others, the use of increasingly water-intensive (domestic and international) inputs in the production process. Finally, the final demand effect is the change in domestic and foreign final demand. Final demand could lead to an increase in water use due to a growing population or additional exports.

Since our analysis is conducted in a multi-regional case, the technology effect measures the impact of changes in both intra-regional and inter-regional linkages. In order to isolate their singular role, we will decompose the technological effect further. For each sector $h$ in region 1 (see Figure 1), we express the change in technology as follows:

$$\Delta\mathbf{L} = \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LO}}\mathbf{L}_0 + \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{EO}}\mathbf{L}_0 + \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LS}}\mathbf{L}_0 + \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{ES}}\mathbf{L}_0 + \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LI}}\mathbf{L}_0 + \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{EI}}\mathbf{L}_0 + \mathbf{L}_1\Delta\mathbf{A}^{\mathrm{AT}}\mathbf{L}_0 \quad (6)$$

Where:

$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LO}}\mathbf{L}_0$ (local own effect): it isolates the contribution of a change in the mix of domestic inputs purchased directly by sector $h$ in region 1;
$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{EO}}\mathbf{L}_0$ (external own effect): it isolates the contribution of a change in the mix of foreign input (imports) purchased directly by sector $h$ in region 1;
$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LS}}\mathbf{L}_0$ (local substitution effect): it measures the impact of a change in the direct sale of sector $h$ to other domestic sectors in region 1;

$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{ES}}\mathbf{L}_0$ (external substitution effect): it measures the impact of a change in the direct sale of sector $h$ from region 1 to foreign sectors (i.e., changes in the export[2] structure of $h$);
$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LI}}\mathbf{L}_0$ (local interrelational effect): it isolates the contribution of a change in the production structure of all of region 1's sectors except $h$;
$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{EI}}\mathbf{L}_0$ (external interrelational effect): it isolates the contribution of a change in the production structure of other countries (except international trade flows);
$\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{AT}}\mathbf{L}_0$ (trade effect): it isolates the contribution of a change in international trade flows of all sectors but $h$ of region 1;

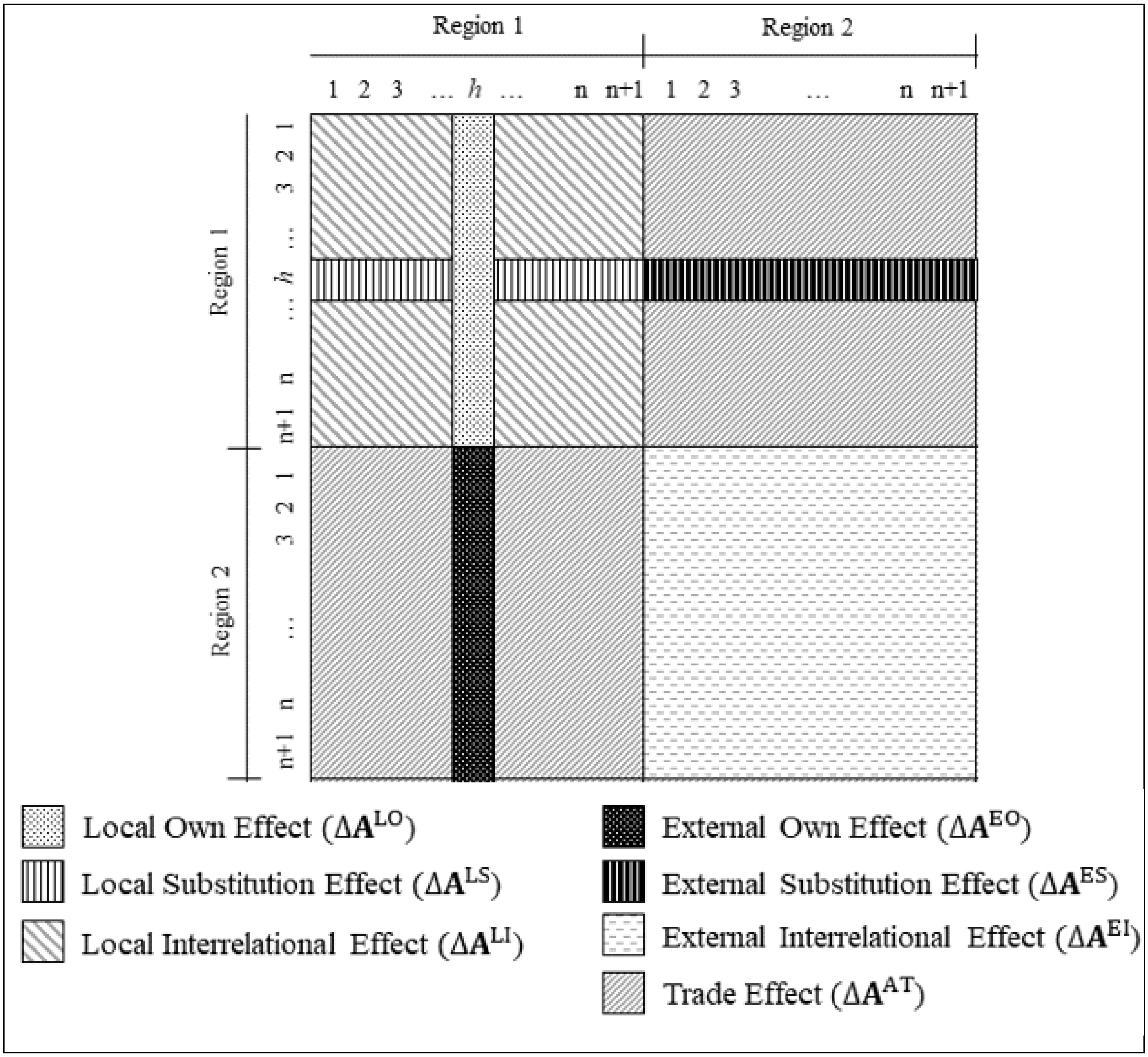



**Figure 1.** Partition of basic technological changes

[2] Exports from country 1 includes exports to the remaining 26 European Union members as well as to the Rest of the World.

Furthermore, we split final demand into local and foreign households' total expenditures ($\mathbf{f}^{\mathrm{LH}}$ and $\mathbf{f}^{\mathrm{EH}}$ respectively) and group the remaining components (aggregate of government, change in inventories and gross fixed investments) into the rest of the local and foreign final demand ($\mathbf{f}^{\mathrm{LR}}$ and $\mathbf{f}^{\mathrm{ER}}$ respectively).

$$\mathbf{f} = \mathbf{f}^{\mathrm{LH}} + \mathbf{f}^{\mathrm{EH}} + \mathbf{f}^{\mathrm{LR}} + \mathbf{f}^{\mathrm{ER}} \tag{7}$$

Finally, we split the changes in households' expenditures into changes in total local (L) and external (E) per capita income expenditures ($\Delta\omega$), changes in population size ($\Delta p$) and changes in expenditure shares ($\Delta$s):

$$\Delta\mathbf{f} = (\Delta\omega^{\mathrm{L}} p_0^{\mathrm{L}} \mathbf{s}_0^{\mathrm{L}} + \omega_1^{\mathrm{L}} \Delta p^{\mathrm{L}} \mathbf{s}_0^{\mathrm{L}} + \omega_1^{\mathrm{L}} p_1^{\mathrm{L}} \Delta\mathbf{s}^{\mathrm{L}}) + (\Delta\omega^{\mathrm{E}} p_0^{\mathrm{E}} \mathbf{s}_0^{\mathrm{E}} + \omega_1^{\mathrm{E}} \Delta p^{\mathrm{E}} \mathbf{s}_0^{\mathrm{E}} + \omega_1^{\mathrm{E}} p_1^{\mathrm{E}} \Delta\mathbf{s}^{\mathrm{E}}) + \Delta\mathbf{f}^{\mathrm{LR}} + \Delta\mathbf{f}^{\mathrm{ER}} \tag{8}$$

A summary of all the factors used in our decomposition is shown in Table 1 below.

**$\Delta\mathbf{w}$ (total water change)**

| $\Delta\hat{\mathbf{c}}\mathbf{L}_0\mathbf{f}_0$ *noted* **Wr** (Water Intensity Effect) | $\hat{\mathbf{c}}_1\Delta\mathbf{L}\mathbf{f}_0$ *noted* **L** (Technology Effect) | $\hat{\mathbf{c}}_1\mathbf{L}_1\Delta\mathbf{f}$ *noted* **F** (Final Demand Effect) |
|---|---|---|
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LO}}\mathbf{L}_0$ *noted* **LO** (Local Own Effect) | $\Delta\omega^{\mathrm{L}}p_0^{\mathrm{L}}\mathbf{s}_0^{\mathrm{L}}$ *noted* **L_INC** (Local Per Capita Income Expenditures Effect) |
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{EO}}\mathbf{L}_0$ *noted* **EO** (External Own Effect) | $\omega_1^{\mathrm{L}}\Delta p^{\mathrm{L}}\mathbf{s}_0^{\mathrm{L}}$ *noted* **L_POP** (Local Population Effect) |
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LS}}\mathbf{L}_0$ *noted* **LS** (Local Substitution Effect) | $\omega_1^{\mathrm{L}}p_1^{\mathrm{L}}\Delta\mathbf{s}^{\mathrm{L}}$ *noted* **L_EXP** (Local Expenditure Share Effect) |
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{ES}}\mathbf{L}_0$ *noted* **ES** (External Substitution Effect) | $\Delta\omega^{\mathrm{E}}p_0^{\mathrm{E}}\mathbf{s}_0^{\mathrm{E}}$ *noted* **E_INC** (External Per Capita Income Expenditures Effect) |
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{LI}}\mathbf{L}_0$ *noted* **LI** (Local Interrelational Effect) | $\omega_1^{\mathrm{E}}\Delta p^{\mathrm{E}}\mathbf{s}_0^{\mathrm{E}}$ *noted* **E_POP** (External Population Effect) |
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{EI}}\mathbf{L}_0$ *noted* **EI** (External Interrelational Effect) | $\omega_1^{\mathrm{E}}p_1^{\mathrm{E}}\Delta\mathbf{s}^{\mathrm{E}}$ *noted* **E_EXP** (External Expenditure Share Effect) |
| | $\mathbf{L}_1\Delta\mathbf{A}^{\mathrm{AT}}\mathbf{L}_0$ *noted* **AT** (Trade Effect) | $\Delta\mathbf{f}^{\mathrm{LR}}$ *noted* **L_OTH** (Other Local Final Demand Effect) |
| | | $\Delta\mathbf{f}^{\mathrm{ER}}$ *noted* **E_OTH** (Other External Final Demand Effect) |

**Table 1.** Summary of SDA factors

# CHAPTER 3: DATA

Data comes from the global multi-regional input-output EXIOBASE 3 database (Stadler *et al*., 2018). Access to water input coefficients allows us to create an environmentally extended version of it (EE-GMRIO). Only four EE-GMRIO databases with water indicators and international trade flows are currently available in the world. These are the WIOD (Timmer *et al*., 2015), Eora (Lenzen *et al*., 2012), GTAP-MRIO (Peters *et al*., 2011) and EXIOBASE 3 (Stadler *et al*., 2018). A detailed comparison of these datasets can be found in Tukker *et al*. (2018). Among them, we chose EXIOBASE 3 for our analysis because it provides the most disaggregated number of sectors in agriculture, a necessary feature for the rest of the analysis.

EXIOBASE is composed of 165 sectors for 45 countries and 4 aggregated "rest of the world" regions. Due to the current lack of information on industrial and final demand deflators directly embedded in the database, we deflate the tables to the 2010 constant prices using the procedure and data from the World Input-Output Database Release 2013 (Timmer *et al*., 2015).[3] This procedure involves deflating the entire GMRIO system for a given year using price deflators in national currency and then adjusting for exchange rate variations with the US dollar. The Social Economic Accounts (SEA) of WIOD are available for 35 industries, 40 countries and a single rest of the world region for 1995-2009. The year 2010 was built by bridging the SEA of WIOD Release 2016 with the previous industrial classification system (ISIC Rev.4 to ISIC Rev. 3). Therefore, the countries of EXIOBASE are aggregated to the same regional distribution as WIOD to account for deflation. We also aggregate the original 165 sectors of EXIOBASE into 35 after applying the same price deflator to all the disaggregated sectors that belong to each of WIOD's SEA 35

[3] The recommended procedure can be found here:
http://www.wiod.org/protected3/data/update_dec14/Sources_methods_pyp_dec2014.pdf

industries. Since WIOD displays information for agriculture at the aggregate level only, it means that, within each country, prices in agriculture and among its sub-sectors are deflated in the same way.

When it comes to the water data, they are from the EXIOBASE satellite accounts on water data which are based on Mekonnen and Hoekstra's (2011) water use by crop averaged over 1996-2005 and scaled for each year over 1995-2011 by Stadler *et al*. (2018) using country-specific crop yield and total production data from the Food and Agricultural Organization). The data for water, which is measured in a million cubic meters (million $m^3$), corresponds to green and blue water. Blue water is stored in wetlands, streams, lakes and aquifers and can be diverted to irrigate crops as a supplement to rainfall (Weiskel *et al.*, 2014; Rockström *et al*., 1999). It refers to the surface and ground water, which is used for agricultural production, industry and service activities (Feng and Klaus, 2015). Green water is found in watersheds and sustains rainfed crop production (Weiskel, 2014; Falkenmark 2013). It refers to the total rainwater evapotranspiration from fields and plantations used for agricultural production (Feng and Klaus, 2015).

Due to the lack of annual data for the average crop water use, these values are assumed to be equal for all the years over the 1995-2011 period. However, in our calculations the water coefficient $\mathbf{c}_{i(t)} = \mathbf{w}_{i(t)}/\mathbf{x}_{i(t)} = \frac{\boldsymbol{wi}\times\boldsymbol{yieldi}}{\boldsymbol{Pi(t)}\times\boldsymbol{yieldi}}$ is not constant over the period because $\boldsymbol{Pi}$ changes over time and the I-O table in EXIOBASE requires to be balanced across each sector for consistency purposes (Stadler *et al*., 2018).

# CHAPTER 4: RESULTS

## 4.1 AGGREGATE CROPS SECTOR

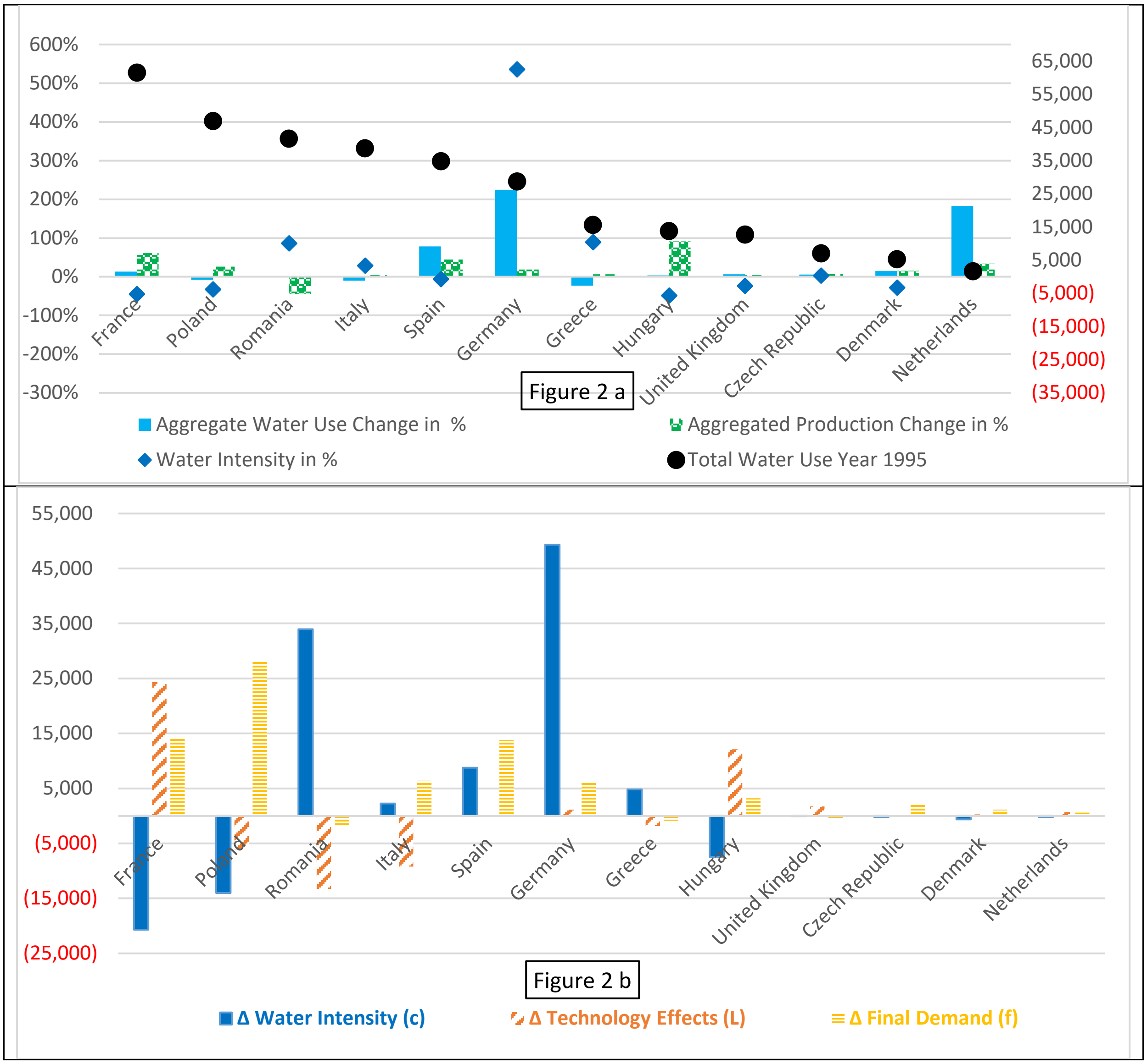
During the period 1995 to 2010 the total crop production increased in all but a few EU27 member states (see fig.2a where we focus on the 12 largest crop producers countries[4], and each of these countries is one of the largest producers both for the aggregate crop and at least for one sub-crop category (wheat, cereal grains, vegetables-fruits-nuts or oil seeds)). An interesting exception is Romania, one of the less developed country of the region, which remains one of the major agricultural producers although it has decreased its production by 44% over the study period. However, there has been close to no decrease in the total amount of water its agricultural sector consumes.

We also note that the total water used in agriculture increased in all countries except in the Southern part of Europe (Greece and Italy) that faces the greatest water scarcity problems. It is worth mentioning that Spain, Germany and the Netherlands have seen a dramatic increase in their total water use compared to the change in their agricultural production (see Figure 2a). Among them, Germnay showed the largest water use change due to the country's decision to increasingly use sprinklers for irrigation (Baldock and Skjemstad, 2000) as well as due to the severe droughts that it experienced over the study period (Spinoni *et al.*, 2015).

Figure 2b shows that, in France, Hungary and the Netherlands, countries that do not face any water scarcity problem, the decrease in water intensity is the main driver of the total water use change, but its magnitude is not as large as the increase in water use due to final demand and technology effects. More specifically, Hungary shows a dramatic increase in its agricultural production due to significant developments in its technology and its use of fertilizers and pesticides

[4] Complete results for the rest of the EU 27 member countries are available from the authors upon request.

(Stoate *et al*., 2001; Holland, 2004). France too has advanced its irrigation technology by using more often drip irrigation systems (Baldock and Skjemstad, 2000). On the other hand, in Italy and Greece, the main drivers of water use changes were changes in water intensity and final demand. However, they were more than compensated by technological changes, which led to an overall decrease in total water use of 10% and 23% in Italy and Greece respectively.




Source: own elaboration from EXIOBASE data

**Figure 2**: Aggregate Crop Sector.

Panel a: Total water use in million $m^3$ and percentage change, change in production (in %) and change in water intensity (in %) 1995-2010

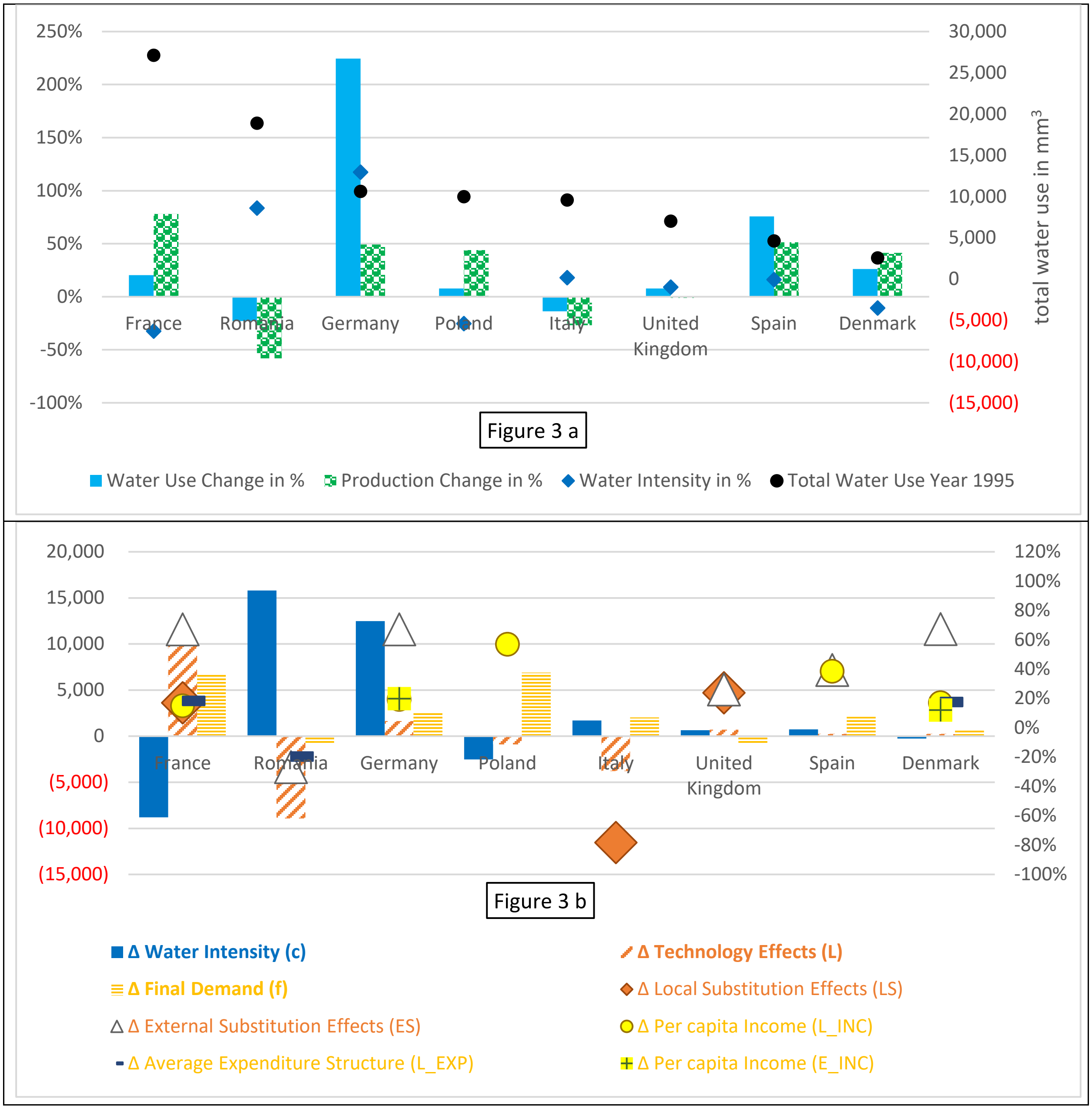
Panel b: Determinants of Total Water Use Changes in million $m^3$

Even though it faces major water scarcity problems (Duarte *et al*., 2016), Spain increased dramatically its total water use by 78%. All factors but mostly final demand changes (changes in the per capita income in the local households) contributed to it. At 138 million cubic meters, the technology effect is barely visible on fig. 2b. One element that is common to all the major agricultural producers is that the final direction of total water use change (increase or decrease) is driven by the technological effect. The exceptions are Germany and Romania where water intensity is the largest contributor of the increase in their agriculture's total water use.

## 4.2 CULTIVATION OF WHEAT

The European Union 27 accounts for 21.5% of the world's wheat production. Within the EU, the major producers of wheat are both developed (France, Germany, United Kingdom, Denmark) and less developed countries (Poland, Italy, Spain, Romania). Among them, only Romania and Italy have seen a decrease in both wheat production and water use over our study period (see Figure 3a). On average over our study period and across countries, wheat consumed 32% of the aggregate crop water. This share goes up to 45-55% in France, Denmark and the United Kingdom. Therefore, wheat is by far the largest water user among the various crops we investigate in this study.

Figure 3b indicates that the reason for the majority of the large producers to see an increase in water use is a larger final demand effect and, to a lesser degree, technological change. The earlier effect is primarily due to changes in domestic per capita income (L_INC, 15-57% of its main category) and in the household's consumption structure (L_EXP, 18%). Note that, in the case of Germany, the overall change is also driven by changes in foreign per capita income (E_INC, 20% of the changes in final demand).




Source: own elaboration from EXIOBASE data

**Figure 3**: Cultivation of Wheat.

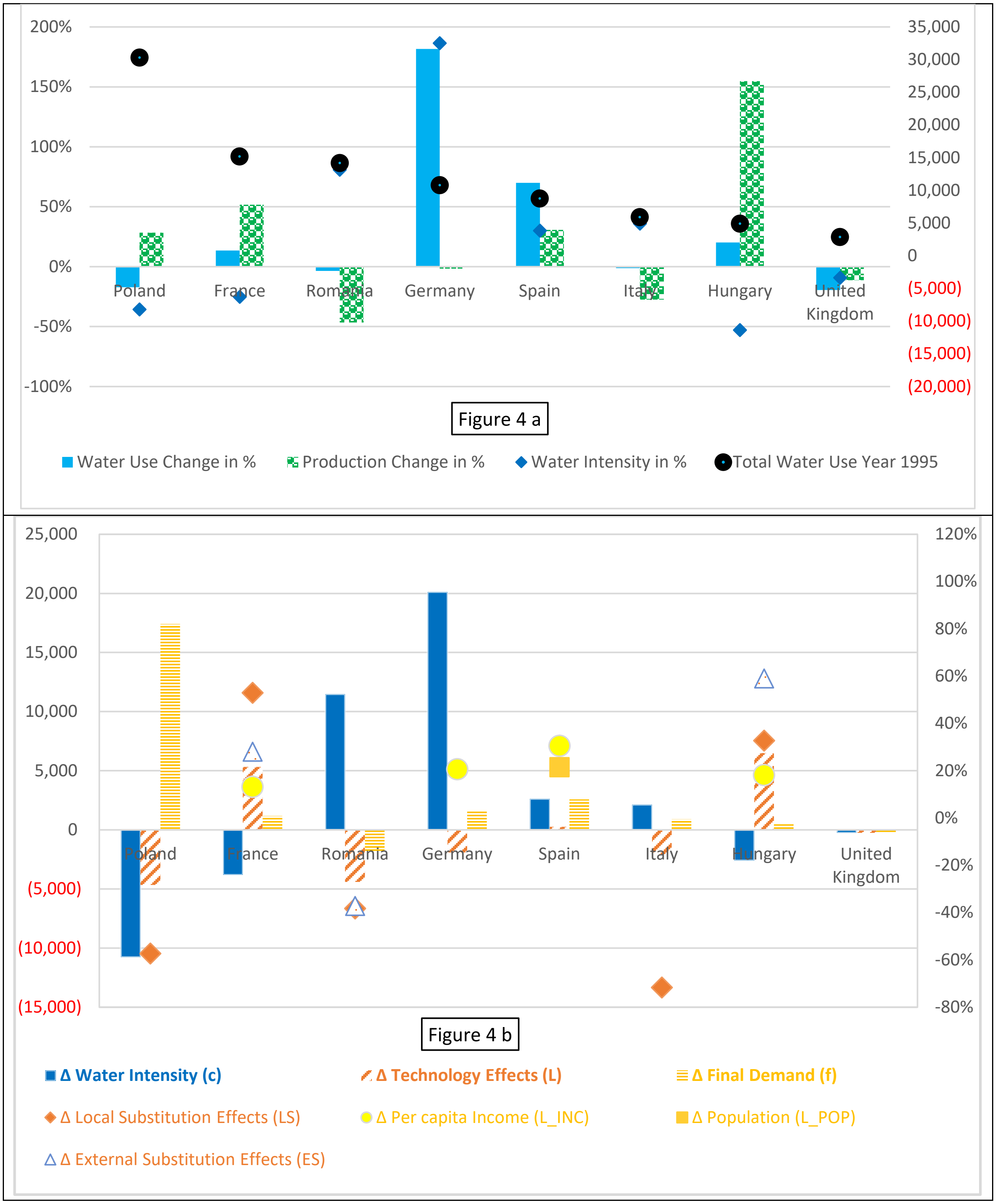
Panel a: Total water use in million m$^3$ and percentage change, change in production (in %) and change in water intensity (in %) 1995-2010

Panel b: Determinants of Total Water Use Changes in million m$^3$

At the same time, the positive effect of technological change resulted from changes in local sales (LS, 24%) and direct exports to industries in other regions (ES, 25-65%). Germany is a remarkable example because its total water use change (+226%) was affected mostly by an increase in water intensity, a final demand effect (driven by domestic and foreign income changes) and a change in technology (mostly direct exports to foreign industries, ES). For Italy and Romania, their 14% and 23% decrease in total water use come mostly from a change in technology due to domestic sales LS (-78% in the case of Italy) and direct exports to foreign industries ES (-27% in the case of Romania) respectively.

### 4.3 CULTIVATION OF CEREAL GRAINS

Generally speaking, cereal grains are a lower value crop. They rely more widely on irrigation to improve growth rates and productivity either on a seasonal basis at times of peak demand (mostly in the northern member states) or for most of the cropping period. The EU27 accounts for 13.5% of the worldwide cereal grain amount and eight countries are considered large producers. Among them, Hungary, France, Spain and Poland have seen their production increase over the study period while Germany, the United Kingdom, Italy and Romania experienced a decrease. At the same time, we see from Figure 4a that France and Spain have increased their use of water for that crop while Romania, Italy, and the United Kingdom have decreased theirs. On average, cereal grains consume 31% of the total crop water use within the EU. Poland is an outlier in that 60% of its aggregate crop water use was for cereal grains. Yet, this country has experienced a decrease in water at the same time as an increase in production. This effect comes from a large amount of nitrogen uptake (Schils *et al*., 2018) and from increasing virtual water imports from China and the rest-of-the-world (Duarte *et al*., 2018) over the last two decades. The opposite example is Germany, where water use changed by +182% and production by -2%. The reason for this change is the country's decision to increasingly use sprinklers for irrigation (Baldock and Skjemstad, 2000).




Source: own elaboration from EXIOBASE data

**Figure 4**: Cultivation of Cereal Grains.

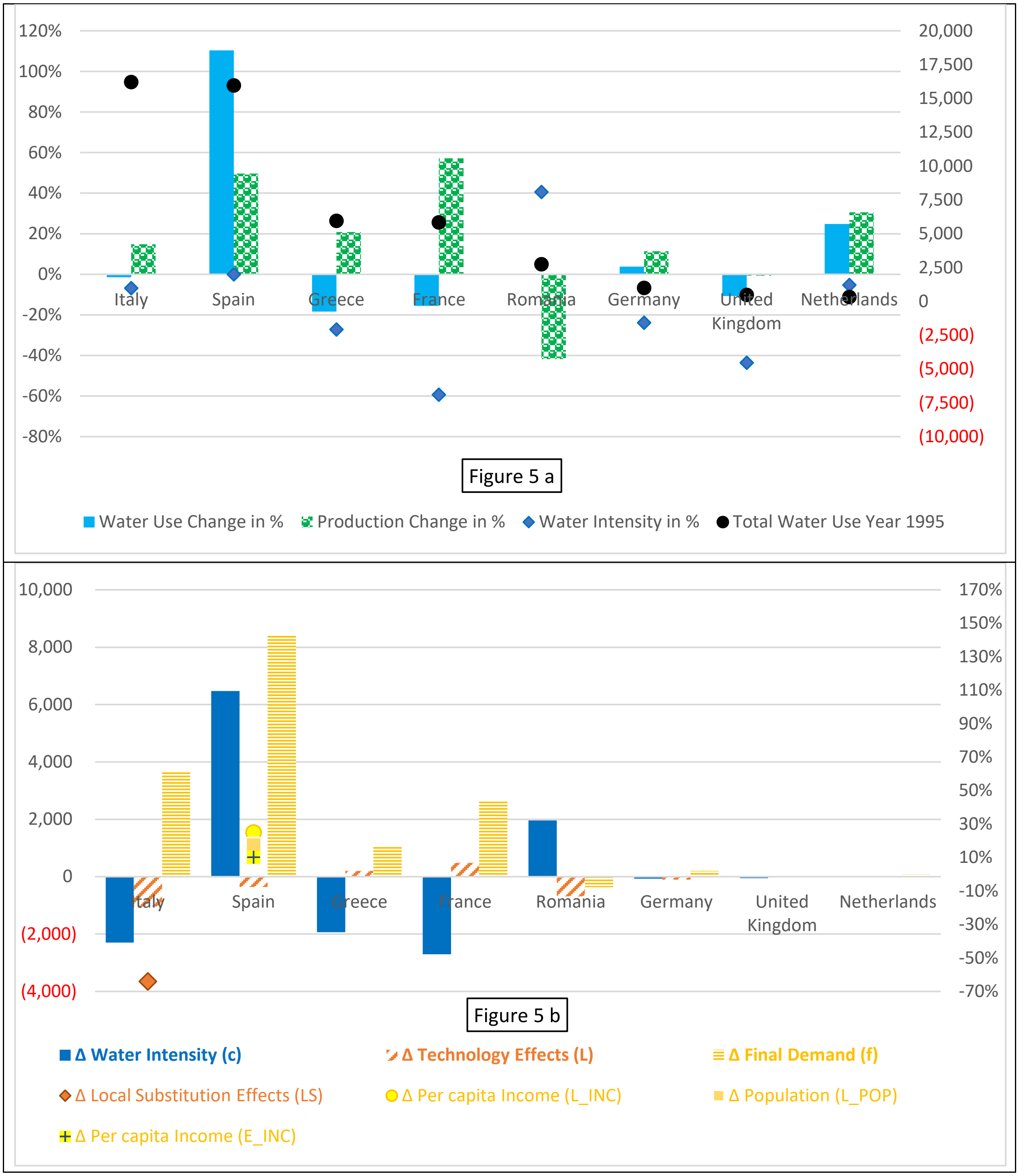
Panel a: Total water use in million m$^3$ and percentage change, change in production (in %) and change in water intensity (in %) 1995-2010

Panel b: Determinants of Total Water Use Changes in million m$^3$

As in the aggregated case, the main factor driving the change in water use in cereal grains is the technological effect (fig. 4b). More specifically, it is the change in the domestic sales of cereal grains (LS) to other domestic sectors such as food manufacturing and animal feeding (Schils *et al.*, 2018) that contributed the most to the technological effect in all the countries (by an order of -70 to 50%) except in Germany, Spain and Poland. The dramatic increase in total water use experienced in Germany and Spain is mainly due to an increase in the water coefficient and in the final demand. 20-40% of the latter effect resulted from an increase in domestic per capita income (L INC) and, in the case of Spain, 20% of it came from a population change (L POP). Finally, Poland has decreased its overall water use primarily because of the water intensity effect.

### 4.4 CULTIVATION OF VEGETABLES, FRUITS AND NUTS

Vegetables, fruits and nuts are high-value crops of which yield and quality depend critically on irrigation. Within the EU they require 17% of the total crop water use. However, they are mostly produced in France and in Mediterranean countries (Italy, Spain, Greece) which use 40-54% of their total crop water for it. Yet, a smaller amount is also produced in the Netherlands, Germany, the United Kingdom and Romania. Their cultivation in the EU27 accounts for 14% of the world's total production. All the major producers located in the European Union have increased their production in this sector except the United Kingdom (-1%) and Romania (-42%). The latter is still a fairly large producer by the end of our study period and its water use has remained stable throughout these fifteen years. Among the earlier countries, we note that Italy, France and Greece have reduced their water use but have increased their production (see Figure 5a). The increase in efficiency comes from the increasing use of the drip irrigation system (although in a slow rate yet) as a complement to sprinklers (Bradlock and Skjemstad*.,* 2000).




Source: own elaboration from EXIOBASE data

**Figure 5**: Cultivation of Vegetables, Fruits, Nuts.

Panel a: Total water use in million $m^3$ and percentage change, change in production (in %) and change in water intensity (in %) 1995-2010

Panel b: Determinants of Total Water Use Changes in million $m^3$

Unlike the other crops analyzed in this study, the change in water use in vegetables, fruits and nuts did not follow the direction of the technological change. Instead, the increase in total water use (mostly in Spain, Germany and the Netherlands) was driven mostly by final demand. On the other hand, the countries which experienced a decrease in total water use (Italy, France, Greece) were affected negatively and solely by the water intensity effect. We note that Spain experienced the largest total water use change (+110%) which was driven primarily by changes in water intensity and final demand. More specifically, the positive contribution of final demand is explained by changes in population domestically L_POP (17%) but also by changes in income domestically L_INC (25%) and externally E_INC (10%).

## 4.5 CULTIVATION OF OIL SEEDS

Oil seeds (soybeans, groundnuts, cotton, castor oil, rapeseed, sesame, olives, sunflower) are considered a semi-intensive crop. They account for 8.5% of its total worldwide production. They are mostly produced in the Eastern part of the European Union (Poland, Hungary, Romania, Czech Republic), in Spain, and in the three wealthiest member states (France, Germany and United Kingdom). Figure 6a indicates that all the major producers of oil seed have increased their production and the total amount of water needed for it. As oil seeds require only 9% of the total crop water use within the EU, none of its larger producers countries use more that 18% of their aggregate crop water for the cultivation of oil seeds. Large producing countries such as Poland and Spain devote as little as 5% of their total crop water use to oil seeds.

The results in Figure 6b indicate that oil seeds are the only crop for which the total water use increased in all the major producers, a change primarily driven by an increase in final demand and technology. The negative contribution of water intensity is minor in comparison to the previous two effects. We also find that in some of the less developed countries (Poland, Hungary,


Source: own elaboration from EXIOBASE data

**Figure 6**: Cultivation of Oil Seeds.

Panel a: Total water use in million m$^3$ and percentage change, change in production (in %) and change in water intensity (in %) 1995-2010

Panel b: Determinants of Total Water Use Changes in million m$^3$

Romania, Czech Republic) as well as in Spain, it is the change in the local per capita income L_INC (13 to 73%), in domestic sales of oil seeds LS (14 to 55%) and in direct exports to foreign industries ES (11 to 58%) that have driven the increase in water use in this sector. On the other hand, in the highly developed countries (France, Germany and the United Kingdom), it is the change in domestic sales LS (55 to 83%) that drove the results.

# CHAPTER 5: CONCLUSION

The agricultural sector has contributed significantly to the change in the amount of water embedded in the internal and external trade of the EU27 and it now accounts for as much as 70% of the area's total water use. This trend is driven by the increase, albeit small, in economic and population growth in the EU27 and the associated demand for food domestically and abroad. Yet, since the EU27 members do not grow the same crops and, when they do, the quantities they produce vary greatly, an analysis of the level and change in water use by country and crop is necessary. It reveals crop-and location-specific drivers hence allowing policymakers to take more tailored water saving measures.

Our study finds that more efficient irrigation techniques should be used in the agricultural sector of the EU27 as water scarcity, a problem that is already of great concern in Southern Europe (Milano *et al.*, 2013; Dietzenbacher and Velasquez, 2008), could spread to other European countries. Some of them, like Poland, Greece and Italy, have remarkably decreased their total water footprint thanks to a steady increase in the use of drip irrigation systems. A notable exception is Spain that continues to consume vast amount of water even though its scarcity has now reached record level (Novo *et al*., 2009; Velázquez, 2006).

When we explore further the reasons for the change in water use, our structural decomposition method reveals that, at the aggregate level, the change in total water use was driven mostly by the technology effect and, within it, by a change in domestic sales. Two exceptions are Germany and Romania where the high water use intensity is driven by a poorly efficient irrigation system.

When we complete the analysis with a disaggregated approach, we find that the technology effect is the main driver across all crops except for the cultivation of vegetables. In the latter, it is final demand and especially the increase in domestic per capita income as well as in household consumption that have contributed to the increase in total water use the most.

Therefore, the heterogenous sources and trends of water consumption that we have investigated in our analysis suggest that country- and crop-specific policies should be implemented to reach a more sustainable use of water in the future, more especially since changes in climate conditions have caused precipitation to be less predictable than before (Frei *et al*., 2003, 2006). In wealthy countries such as Germany, the United Kingdom, the Netherlands, and France, the severity of periodic drought is anticipated to increase irrigation requirements (Riediger *et al*., 2014). In the highly intensive (high valued) crops such as vegetables, fruits and nuts that require a lot of irrigated water when rainfall is insufficient, a tax on the sales of these products could be implemented to decrease the consumption of water-intensive products and hence reduce water scarcity. As suggested in Dietzenbacher and Velázquez (2007) and Bae and Dall'erba (2018) who simulate a water price increase in the arid regions of Andalucia and Arizona respectively, the receipts from this tax could be used to compensate farmers for their reduced sales or support more efficient irrigation systems. This strategy would affect primarily the Mediterranean countries where these crops are mostly cultivated. On the other hand, for the semi-intensive crops like cereal grains and oil seeds which are mostly produced in the eastern and northern EU countries, a plain reduction of their export could be considered to promote more responsible use of water in agriculture. This approach would be especially relevant in Germany, Romania and France where their water use increase is mostly due to foreign demand.

Another measure that the policymakers could also consider immediately is the switch of current sprinkler to a drip irrigation system. Based on this recommendation, Bae and Dall'erba (2018) find that in sun-scorched Arizona farmers could save up to 19% of their water by principally reducing evaporation before the water reaches the plant's roots. Another option that is increasingly considered in that region of the USA is taxing city dwellers and redistribute the revenue to farmers to prevent them from growing anything.

Considering that water scarcity and increasing global demand for food are phenomena with world-wide consequences, countries need to learn to adapt quickly any successful water-saving strategy initiated abroad to their own territory. However, first, they need to uncover the reason(s) why their agriculture may be using an increasing amount of water. As such, we hope the fine level factor decomposition we offer in this SDA will be used and even extended to other major crop producer countries and regions around the world.

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