Intra-EU agricultural trade, virtual water flows and policy implications

Antonelli M.^{a*}, Tamea S.^b, Yang H.^{a,c}

^a Eawag, Swiss Federal Institute of Aquatic Science and Technology, Department of Systems Analysis, Integrated Assessment and Modelling, Überlandstrasse, 133, 8600 Dübendorf, Switzerland.
martaantonelli84@gmail.com

^b Politecnico di Torino, Department of Environment, Land and Infrastructure Engineering, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy. stefania.tamea@polito.it

^c University of Basel, Faculty of Sciences, Klingelbergstrasse, 50, 4056 Basel Switzerland.
hong.yang@eawag.ch

* Corresponding author

E-mail: martaantonelli84@gmail.com (MA)

Abstract

The development of approaches to tackle the European Union (EU) water-related challenges and shift towards sustainable water management and use is one of the main objectives of Horizon 2020, the EU strategy to lead a smart, sustainable and inclusive growth. The EU is an increasingly water challenged area and is a major agricultural trader. As agricultural trade entails an exchange of water embodied in goods as a factor of production, this study investigates the region's water–food–trade nexus by analysing intra-regional virtual water trade (VWT) in agricultural products. The analysed period (1993-2011) comprises the enactment of the Water Framework Directive (WFD) in the year 2000. The implications of VWT for implementation of the WFD are explored. Intra-EU VWT more than doubled over the period considered and is mainly associated with crops and luxury foods, while trade with extra-EU countries did not show such a marked trend. In the same period, blue VW trade increased significantly within the region but decreased with the rest of the world, indicating that EU is becoming more and more

reliant on internal water resources than in the past. Intra-regional VWT represents 46% of total imports and 75% of total exports of virtual water (VW) in the EU. Five countries account for 60% of total VW imports (Germany, France, Italy, the Netherlands, Belgium) and 65% of total VW exports (the Netherlands, France, Germany, Belgium and Spain). The study also finds that water scarce countries, such as Spain and Italy, are major exporters of blue water (as opposed to soil “green” water) in the region. The quantity has been increasing almost monotonically over the years, and with a substantial increase after the year 2000. The overall trend in changes in VWT does not seem to be in accordance with the WFD goals. Our study demonstrated that VWT analyses can help evaluate intertwining effects of water, agriculture and trade policies which are often made separately in respective sectors.

Key words

Water resources; agricultural trade; virtual water trade; blue water; European Union; Water Framework Directive

1. Introduction

The world’s water resources are subject to increasing pressure due to growing demand for water and degradation from human activities. Problems related to freshwater resources use and management have, until recently, only been approached at the local, national and river basin scale. The recognition that international trade in goods entails an exchange of virtual water (VW) (Allan 2001), i.e. the water embodied in the different products as a factor of production, between countries (a phenomenon referred to as virtual water trade, VWT) has highlighted the need to broaden the boundaries of water management and to consider the global dimension of water consumption patterns (Hoekstra & Mekonnen 2012).

Despite the fact that the European region is generally considered to have adequate water resources, many countries of the European Union (EU) suffer from severe water scarcity and

drought, and are also vulnerable to climate change (Alcamo et al. 2007; Iglesias 2009; Schmidt & Benítez-Sanz 2012). Around 20 river basins, mainly in the Mediterranean and other densely populated areas, are affected by water stress and, in summer, about 70 million inhabitants (approximately 14% of the EU population) live under water stress conditions (EC 2016a). Agriculture is the major water user, accounting for about 44% of total withdrawals (EC 2016a). This proportion reaches up to two thirds of total withdrawal in the water-challenged southern countries (e.g. Cyprus, Greece, southern-France, Italy, Portugal, and Spain), where crop production heavily relies on irrigation (EEA 2009; EC on Agriculture and Rural Development 2010). In 2013, the area equipped for irrigation was 12% of the total agricultural area and was mainly concentrated in Mediterranean countries (Eurostat 2016). Besides competing with other water uses, agriculture also has a detrimental effect on water quality due to the input of fertilizers and pesticides. About 20% of all groundwater bodies in the EU have poor chemical status and, in 2009, only 43% of EU surface water exhibited a good ecological status (EC 2016b; EEA 2012). Water protection is “one of the great challenges for the EU in the new millennium” (EC 2016c).

With a combined value of imports and exports amounting to €242 billion in 2015, the EU is the world’s top agricultural importer and exporter (EC 2016d). Its share of global agricultural export value rose from 20% in the 1960s to over 40% in the 21st century, with intra-EU trade covering an important fraction of global trade (FAO 2005). Such evolution of agricultural trade implies an increased VWT, thus a displacement of (virtual) water resources. Europe is also the largest importer of agricultural goods per capita, as compared to other regions of the world (Antonelli & Tamea 2015).

Water resources and agriculture are regulated by two of the most important EU policies: the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). The WFD was established in the year 2000. It is an institutional framework for the protection and

restoration of water bodies, and integrates and partly replaces the existing EU water legislation. It is one of the most ambitious pieces of EU legislation in the field of water resources (Boeuf & Fritsch 2016). The WFD requires Member states to achieve good ecological status in surface water bodies and good chemical and quantitative status in groundwater bodies by 2015. This goal has not been achieved as hoped. The CAP is one of the EU's oldest policies and played a key role in the development of the EU in the post-war period. It is still currently the most expensive policy, absorbing about 40% of the EU budget (70% in the 1980s). It has evolved, through several reforms, from a productionist approach (leading to surplus agricultural products) to social and environmental support (post-2013 CAP). The intensification of agricultural production supported by the CAP across the EU has led to concerns about the impacts on biodiversity, land use, water resources quality and quantity, and wildlife. It is important to understand the relationship between the WFD and the CAP for an integrated water management.

To date, the intra-EU VWT associated to agricultural goods has been under-investigated by the scientific community. Previous studies have focused on the EU VWT for individual countries, river basins, cities, as well as related to different dietary patterns. VWT has been analysed at the national level (as well for specific regions) in Spain (e.g. Velázquez 2007; Aldaya et al. 2010), Italy (Allamano et al. 2015), France (Ercin et al. 2013), the Netherlands (Van Oel et al. 2009); and for a number of cities (Vanham et al. 2016; Hoff et al., 2014). It has been shown that the EU, both at the city and country level, is very much dependent on external water resources for its food consumption and water is often not sourced from water abundant countries. For example, water-scarce areas (for instance, in Spain) produce and export water-intensive crops, despite the negative consequences to environmental sustainability (Biewald et al. 2014). The EU has been shown to be a net importer of VW (e.g. Serrano et al. 2016; Duarte et al. 2016). The impacts of EU consumption patterns on international watersheds (e.g. the

Indus) and European watersheds (The Danube, Guadalquivir, and Po) have been analysed by Lutter et al. (2016). The consumption-based VWT assessment provided by Serrano et al. (2016) is, to our best knowledge, the only regional study on the intra EU-VWT. With a focus on the year 2009, it showed that 14% of the region's total water use moves within the EU as a result of intra-regional trade in goods.

Against this background, the current study presents the first comprehensive investigation of the agriculture-related intra-EU VWT from a historical perspective. It aims to understand the relationship between water resources and agricultural trade in the EU, in the attempt to provide insights for more integrated and sound water policy-making. The concept of VWT will be employed for this purpose. The analysis will focus on the major agricultural commodities traded within the EU over the timespan 1993-2011, which includes several reforms of the CAP and enlargement rounds of the EU, as well as the enactment of the WFD in the year 2000. It is of significance to investigate trends in agricultural trade in line with these policy evolvments over the years. As the different sources of water embodied in agricultural trade (namely, soil "green" water and "blue" surface and groundwater) have different externalities and opportunity costs, the analysis will be conducted both for total VWT (sum of green and blue VW flows) and for blue VWT alone. The implications of VWT for water policy will be discussed. The study seeks to contribute to achieving a better understanding of the potential implications of VWT for implementing the WFD and to pursuing a more effective integration of the EU water and agricultural policy.

2. Materials and Methods

The present study focuses on the 32 economies that currently operate in the EU single market, which includes the EU member states (EU28) and the countries that are part of the European Free Trade Agreement (EFTA), namely Iceland, Lichtenstein, Norway, and

Switzerland. This region is hereby referred to as the “EU region”. EFTA countries have been included as they are important partners for the EU. In 2012, for instance, Switzerland and Norway accounted for about 10% of the EU agricultural exports and 5% of imports (EC 2013). The process of enlargement of the EU over the period considered (1993-2011) included three rounds, from 12 to 27 countries. The number of countries considered here in the VW assessment is fixed to 32 over the whole timespan and also includes Croatia, which joined the EU in 2013.

The trade patterns of products were constructed by considering all products traded internationally, as reported by the Statistics Division of the Food and Agricultural Organization of the United Nations (FAOSTAT, 2013). Nine categories of agricultural products are differentiated: cereals; fruits and vegetables; animal-based products (meat, live animals, dairy and eggs); luxury foods, such as, sugar and coffee (hereby referred to as lux-foods); seeds and oils; and non-edible products (such as, fibres, brans, tobacco). The international bilateral trade of EU countries and trade to/from countries in the rest of the world, for a total of 255 countries ever been active, was obtained for each year in the period 1993-2011 from FAOSTAT. Yearly trade data of goods quantities were converted into VW flows by multiplying each commodity by its virtual water content (VWC) (m^3/ton), as provided by the global assessments of the Water Footprint Network (Mekonnen & Hoekstra, 2010a; 2010b). Conversions were differentiated among the countries, assuming that commodities are produced in the countries of origin of the flows. Where the VWC is not available for the origin countries, the world average VWC is used. This leads to approximated results when countries export goods not locally grown/produced, but the approximation is inevitable given that the FAOSTAT database does not allow distinguishing the re-export of imported goods.

The VWC assessment by Mekonnen & Hoekstra (2010a; 2010b) accounts for both direct and indirect water use throughout the full commodity supply chain and in particular, as regards crops, it is based on a distributed model of soil water balance forced by hydrological

inputs, which expresses evapotranspiration from cultivated areas and the associated agricultural yields. Country-specific estimates are obtained from the spatial average over the cultivated areas of each country and from the temporal average over a period of 10 years (1996–2005), which levels out inter-annual fluctuations of hydrological forcing and agricultural yield. Being the range of temporal average fully contained in the timespan of the present analysis (1993–2011), these estimates of the virtual water content of commodities are taken as reliable throughout the whole span, similarly to previous studies (Hoekstra & Mekonnen 2012; Carr et al. 2013; Tamea et al. 2013).

The VWC considered in the present study includes green and blue water, namely soil water from precipitation, and surface and groundwater (Hoekstra et al. 2011). Green and blue VW volumes are then summed up across all commodities to define the green and blue VWT among countries in each year, respectively, while the total volume of embodied water is given by the sum of green and blue volumes of virtual water. For further details on virtual water data sources and specific arrangements, the reader is referred to e.g., Tamea et al. (2013) and Carr et al. (2013).

Virtual water trade flows exchanged within the EU (and between the EU and the rest of the world) are computed assigning the flow to/from each country to the region (EU or non-EU) the country belongs to. Intra-EU trade thus results as the portion of import of EU/EFTA countries originated within the EU/EFTA region and it equals the portion of EU export directed to the EU countries (clearly it does not equal the sum of import and export, as this would lead to a double counting of VW flows). When considering the net flow of single countries, the net import is computed as the (positive or negative) difference between import and export.

The condition of water scarcity of the EU countries is here measured by the Falkenmark indicator of water stress (Falkenmark 1989). This is built by dividing the total (actual) renewable water resources of each country (in km³/y), as given by the Food and Agricultural

Organization of the United Nations (AQUASTAT, 2014), by the average population of the country over the 1993-2011 period. The indicator identifies the countries affected by water stress as those having less than 1,700 m³/y per capita.

3. Results

3.1 EU engagement in global and intra-regional virtual water trade

Table 1 provides an overview of the annual total VWT (sum of green and blue VW flows) between the EU region and the rest of the world, averaged during 1993-2011, as well as for the periods before and after enactment of the WFD (1993-2000 and 2001-2011). The EU is involved in 36% of global VWT during 1993-2011, with intra-regional VWT accounting for 15% of global VWT in agricultural products (Tab 1). Relative to 1993-2000, the global trade has increased markedly, with the share of intra-EU VWT remaining almost equal; whereas the share of EU participation in global VWT decreases after the year 2000. The total VW import (589.32 km³/y) and export (365.86 km³/y) of European countries averaged over the whole period account, respectively, for 32% and 20% of the average global VWT and the region is a net importer of VW (-223.462 km³/y), i.e. import from non-European countries exceeds export towards them. It is worth noticing that despite the increase of global and local VW trade after year 2000, the export of European countries towards the rest of the world decreased by 5%. Composition of European trade with extra-EU countries is detailed in Fig S1.

Blue VWT represents 8% of global VWT and 7% of intra-EU VWT both before and after the year 2000 and the EU is a net importer of blue virtual water (Table 2). In absolute terms, however, blue VWT increased from around 115 km³/y to 167 km³/y at the global level, and from about 15 km³/y to 23 km³/y at the intra-EU level. The proportion of EU VW exports (both within and outside the region) that is blue water sourced slightly decreased from 8% in

1993-2000 to 7% in 2001-2011. It increased in absolute terms from about 24 km³/y to over 30 km³/y.

Table 1. Annual agricultural VWT to/from the EU and at the global level in three different year ranges (average 1993-2011, 1993-2000 and 2001-2011, km³/y)

	1993-2000	2001-2011	1993-2011
From EU to EU countries	206.38	323.12	273.97
From EU to non EU countries	94.66	89.87	91.89
From non EU to EU countries	294.90	330.23	315.35
From non EU to non EU countries	876.03	1422.70	1192.50
Global	1170.9	2165.9	1873.70

Table 2. Annual agricultural blue VWT to/from the EU and at the global level in three different year ranges (average 1993-2011, 1993-2000 and 2001-2011, km³/y)

	1993-2000	2001-2011	1993-2011
From EU to EU countries	14.73	22.76	19.38
From EU to non EU countries	9.05	7.56	8.19
From non EU to EU countries	18.68	15.14	16.63
From non EU to non EU countries	72.27	121.43	100.73
Global	114.72	166.89	144.93

The temporal evolution of total VWT in agricultural products in the EU region is illustrated in Fig 1. Intra-regional VWT is compared with the VW imports and exports, traded with countries outside the region. Over the period considered, intra-regional VWT more than doubled, increasing from about 180 km³/y in 1993 to 426 km³/y in 2011 while trade with the rest of the world varied to a much lesser extent. Intra-regional VWT accounts by far for the largest share of total VW export of the EU countries over the whole period, from an initial 68% to a final 80% (see also Tab 1). VW imports from outside the area instead exceed intra-regional

VWT until the year 2008, in correspondence of a reduction of imports from non-EU countries. On average, intra-regional VWT represents 46% of the total VW imported by the EU countries. Intra-EU VWT increased by 25% in 1993-2000 and by 40% in 2001-2011 and the linear trends fitted before and after year 2000 have rates that are markedly different (18.0 after year 2000 and 7.9 up to such year). It should also be noted that average total VW exports from the EU increased far more in the second decade (+37%) compared with the first decade (+19%).

Fig 1. Annual virtual water import and export of the EU region from/to the rest of the world, and intra-EU VWT, including green and blue water (1993-2011)

Fig 2 shows that intra-regional blue VWT grew quite sharply and continuously over the timespan considered, from about 12 to 29 km³/y (+59%), correspondingly, the blue VW import from the rest of the world decreased by 17% and the blue VW export remained stable. The significant increase of intra-EU blue VW trade and slow decrease of import from the rest of the world indicates that EU is becoming more and more reliant on internal water resources than in the past. The blue VW import from the EU-region overtook the blue VW import from the rest of the world in year 2000, i.e. in the year of introduction of the WFD. In the second half of the timespan considered, blue VW imports soared by 20%, compared with an increase of 12%

between 1993 and 2000. The same holds true also for intra-EU blue VWT and for blue VW exports.

Fig 2. Blue annual virtual water import and export of the EU region from/to the rest of the world, and intra-EU blue VWT (1993-2011)

3.2 Intra-EU virtual water trade

Fig 3 illustrates the different categories of products embodied in intra-EU VWT and their temporal evolution. First of all, it is noteworthy to say that food products cover the largest share of intra-EU VWT as non-edible agricultural products only represent a time-averaged 4% of the annual VWT (Figure 3, left panel). Over the period considered, crops (sum of cereals, fruits, vegetables, seeds and oils) represent, on average, about 40% of total intra-EU VW exchanges followed by lux-foods and animal-based products (sum of meat, live animals, dairy products and eggs) (29 and 27% respectively). Seeds and oils account for the largest share of the average intra-EU VWT embodied in crops (38%), followed by cereals (32%), vegetables (14%) and fruits (16%). Meat represents over half of intra-EU VWT in animal-based products (53% average), with almost equal contributions of dairy and eggs (25%) and live animals

(21%). The percentage composition of intra-EU agricultural trade is shown in Figure S2. Over the period considered, intra-EU VWT in all the categories of products grew by at least 45%, with the largest increase being observed in seeds and oils, which almost quadrupled. Lux foods, dairy products and eggs, and meat more than doubled.

Over the time period considered, intra-EU blue virtual water trade increased in all traded products, with lux foods representing the highest proportion of average blue VWT (23%) followed by cereals, seeds and oils and meat (between 123 and 17% each) (Figure 3, right panel). The relative share of each category (shown in Figure S2) does not change significantly over time, apart from seeds and oils (increasing), and cereals and fruits (decreasing). The average blue water ratio of total intra-EU trade is larger for fruits, non-edible products and cereals (16, 12 and 9% respectively).

Fig 3. Intra-EU virtual water trade by category of traded products, green and blue water (left) and blue water alone (right) (1993-2011)

3.3 Net virtual water traders and exporters in intra-EU trade

Fig 4 shows a geographical representation of net total virtual water imports resulting from intra-EU agricultural VWT, averaged over the period 1993-2000 (left) and 2001-2011 (right). The countries shown in light to dark blue have positive net VW imports and are thus net VW importers. The countries in light to dark red are net VW exporters; the colour scale is kept the same in the two panels to enable comparisons. Two thirds of the countries in the EU region are net VW importers in both periods. Italy and Germany are the two countries with the largest inflows of virtual water, increasing, respectively from 15 to 19 km³/y in 1993-2000, and from 8 to 11 km³/y in 2001-2011. Ten countries in the region are net exporters and the Netherlands, Spain, France, Hungary and Belgium are the largest net exporters. After year 2000, VW net outflows increased substantially in the Netherlands (from around 17 to 29 km³/y), Spain (from 5 to 12 km³/y), and to a smaller extent in Hungary and Belgium. Net VW exports decreased from 11 to 9 km³/y in France, which remains however the third largest net exporter in the region.

Fig 4. Net total virtual water importers and exporters of intra-EU trade, average 1993-2000 (left) and 2001-2011 (right). The countries shown in light to dark blue have positive net VW imports; the countries in light to dark red are net VW exporters (values are in km³/y).

As regards intra-EU VWT in blue water, Figure 5 shows that VW imports increased for a number of countries, especially Germany, Italy and the UK. Spain is by far the largest net exporter of blue water in both periods. Its outflow of blue water increased from 2.5 to over 5

km³/y, and represents about half of the country's overall net export of VW. France is the second largest exporter of blue water in the ranking (<1.5 km³/y), with a net outflow in slight decrease after the year 2000. Net VW exports increase in the Netherlands and Denmark, and slightly decrease in Greece and Cyprus.

Fig 5. Net blue virtual water importers of intra-EU virtual water trade, average 1993-2000 (left) and 2001-2011 (right). The countries shown in light to dark blue have positive net VW imports; the countries in light to dark red are net VW exporters (values are in km³/y).

3.4 Top virtual water importers and exporters of intra-EU trade

Fig 6 shows the top players (importers and exporters) in intra-EU VWT, in the period 1993-2011. The top five VW importers in the region are mainly found in Western EU, with the exception of Italy, and make up about 60% of total intra-EU VW imports. With an inflow of about 50 km³/y, Germany is the leading VW importer in the region, followed by France (32 km³/y), Italy (31 km³/y), the Netherlands (25 km³/y) and Belgium (22 km³/y). The composition of VWT for the top EU importers (Fig S3) highlights that the largest share of the VW imports of Germany (about 15 km³/y), France (about 12 km³/y), Belgium (7 km³/y) and the Netherlands (6 km³/y) relates to lux foods, and to a smaller extent seeds and oils. The import of seeds and oils is also relevant for Italy, as well as meat and live animals.

Five countries, mainly from Western EU with the exception of Spain, account for over 65% of total intra-EU VW exports. The Netherlands is the largest VW exporter, with an outflow of almost 50 km³/y. The other countries in the ranking are France (42 km³/y), Germany (40 km³/y), Belgium (26 km³/y) and Spain (24 km³/y). The composition of VWT for the top 5 EU exporters is shown in Fig S4. The analysis highlights that similarly to the case of imports, the largest share of the amount of VW exported by the Netherlands, Germany and Belgium relates to trade in lux foods. France's VW export shows almost equal contributions from cereals and lux foods; whereas Spain's outflow of VW mainly relates to seeds and oils and fruits. Bilateral intra-EU VW flows are presented in S5. The largest bilateral VW flows are those observed between the top exporters and the top importers, followed by the flows between these and contiguous countries.

Figure 6. Top importers and exporters in intra-EU VWT in 1993-2011

Fig 7 shows the leading importers and exporters of blue VW in the EU region in 1993-2011. Five countries account for over two thirds of the average total exports of blue water

embedded in intra-EU agricultural trade: namely, Spain (30%), France (20%), the Netherlands and Italy (8% each), and Germany (7%). It is noteworthy to say that, over the period considered, Spain's outflow of blue VW increased overwhelmingly, from about 2.6 km³ in 1993 to almost 10 km³ in 2011. The VW export from France also soared from 3 km³/y in 1993 to over 4.5 km³/y in 2011. All other countries increased their export of blue VW although to a much smaller extent. The top five importers in the region (Germany, Italy, France, the UK and Belgium) make up 60% of total blue intra-EU VW imports. The largest bilateral blue VW flows (Fig S6) are generally found between the top exporters and the top importing countries. A large difference with respect to the total VW emerges with Spain being the 1st top exporter of blue VW and only the 5th top exporter of total VW, with largest flows directed towards top importers plus Portugal.

Fig 7. Top importers and exporters of intra-EU blue virtual water trade in 1993-2011

4. Discussion

4.1. General findings

The present study assesses agricultural VWT of the EU and EFTA region from an historical perspective. Global VWT in agricultural products have been estimated to be 1,873 km³/year, which is consistent with the global assessment by Hoekstra & Mekonnen (2012), which is 1,763 Gm³/year. The study shows that the EU, the top agricultural trader in the world, is involved in around one third of global VWT in green and blue water. Accounting for regional trade is very important as intra-EU flows exceed both the VW flows leaving and entering the region, i.e. to/from the rest of the world. Within the study period, intra-EU VWT more than doubled, whereas extra-EU import and export did not show such a marked trend. Removal of trade barriers has benefitted intra-regional food imports in the EU, which increased from 51% in 1980-81 to 66% in 2005-06 (Pinstrup-Andersen & Watson 2011). The enlargement of the EU (from 12 to 27 Member States between 1993 and 2011) also played a role in the increase in intra-EU VWT. The Member States that joined the EU in 2004 (Cyprus, Czech Republic, Estonia, Latvia, Lithuania, Hungary, Malta, Poland, Slovakia, Slovenia), for instance, held over 20% of intra-EU trade in food products in 2013 (Eurostat 2017). Over the period considered, the composition of extra-EU VWT changed quite substantially, with a marked decrease in the import of live animals, dairy products and eggs, and to a smaller extent, meat.

The study has shown that the region is a net importer of VW, confirming previous assessments by Duarte et al. (2016), Hoekstra & Hung (2002) and Serrano et al. (2016). The study considers both green and blue water in accounting for agriculture-related VWT. With respect to traditional water use statistics, which generally focused on freshwater withdrawals, the inclusion of the green component in this study is important to inform water management (Hoff et al. 2010) as it represents the largest share of water embodied in both agricultural production and trade globally (Hoekstra & Mekonnen 2012).

The study has assessed intra-EU VWT relating specifically to blue water as this source of water has the higher opportunity cost. Compared with rainfed agriculture, irrigated

agriculture has generally higher economic productivity and is less vulnerable to climatological conditions, but it holds the major negative externalities (Molden et al. 2007). The import of blue water within the EU has markedly increased in time, exceeding the (decreasing) import from the rest of the world in the year 2000. The decrease in time of the extra-EU blue VW trade indicates that EU is becoming more and more reliant on internal water resources. Our analysis confirms the role of countries in Southern EU as major blue VW exporters, due to the fact that they are more dependent on irrigation systems than other EU countries. Spain accounts for the overwhelming large proportion of intra-regional blue VW exports (30%). Its exports of blue water increased fourfold between 1993 and 2011.

A particular situation occurred in the year 2009, when a crisis in the global food trade occurred (see Tamea et al. 2016). It resulted in the decrease of extra-EU import of both blue and total agricultural VW. In that year, trade from Argentina, Brazil and USA markedly decreased (mainly for cereals), with a corresponding increase in intra- EU intra-EU trade. The change in traded products, with an increase of cereals (little use of blue VW) and a decrease of soybeans and the related products (large use of blue VW), caused an increase in total VW and a decrease of blue VW embodied in intra-EU trade.

4.2 VWT and regional water scarcity

The study showed that countries in Western EU are the largest intra-regional traders of VW and that Southern EU is the area with the largest blue VW exports, despite the limited availability of freshwater resources. By relating blue VW exports to per capita freshwater availability at the country level, Figure 8 shows that water-stressed countries such as Spain, Greece and Italy, that are close to the threshold of 1,700 km³ per capita per year identified by the Falkenmark indicator (Falkenmark 1989), have relatively high blue water exports. The

volume increased after the year 2000. The Figure also shows that in a number of other EU countries the export of blue water increased from 1993-2000 to 2001-2011, with implications for the attainment of the WFD objectives. The reasons behind such intensive use of blue water resources can be found not only in the increase in the profitability of crop cultivation compared with rainfed agriculture (up to 700% according to Berbel 1999 in Massarutto 2003), but also in CAP which favours irrigation through subsidised prices for irrigation water and subsidies for installing irrigation equipment (among others, Velázquez 2007; Zoumides & Zachariadis 2009; Aldaya et al. 2010). The introduction of single farm payments decoupled from production started in 2005, should prompt farmers to shift from the production of water-intensive crops (Varela-Ortega 2007). A combination of over-exploitation, salinization and pollution of groundwater resources – which are particularly important for meeting agricultural water demands in arid and semi-arid areas – has also been reported in a number of intensively irrigated areas in Southern EU areas (such as Spain, Italy, Greece and Portugal), but also in localised areas in the North (EEA 1996, IEEP 2000). Irrigation accounts for 75% of groundwater abstractions in Spain; 89% in Portugal; 85% in Greece; 60% in Italy (EASAC 2010).

It should also be noted that in Western EU, agricultural yields are among the highest globally and the VWC of a number of main crops is very low compared with the rest of the world (Mekonnen & Hoekstra 2011; Mueller et al. 2012). In southern EU, climatological conditions (higher temperatures and lower rainfall) and the greater dependence on irrigation result in higher VWC of agricultural production for certain basic crops and high blue water footprints (Vanham et al. 2013; Mekonnen & Hoekstra 2011; Olesen et al. 2011). In this area, climate change is expected to increase water stress and extreme weather conditions that will lead to higher yield variability, an increased water demand for irrigation and crop-related nitrate leaching, as well as to a reduction in the areas suitable for cultivation (Alcamo et al. 2007; Iglesias 2009). It is thus of the utmost importance to adapt crop production in areas such as the

southern-Mediterranean EU, to local climatological and water conditions. The production of olives in Southern EU goes in this direction, as it is a suitable crop for the climate conditions (Vanham et al. 2013).

Fig 8. Falkenmark water stress indicator and average blue VW export of EU before and after the year 2000 (only countries with indicator lower than 10000 m³/p/y are shown).

4.3. Policy considerations

The study showed that intra-regional VWT more than doubled since 1993, with the largest increase being observed in the second decade considered. It should be noted that despite increased intra-regional trade is a sign of further integration among countries, it does not necessarily bring to trading partners improved food security, as a country's interconnection and interdependence to other countries may also imply a greater exposition to crises occurring abroad. Countries in central EU, for instance, have been shown to have very high vulnerability

to crises in the whole system, due to the intense trading activity within the EU and the significance of the VW flows (Tamea et al. 2016).

It is important to shed light on the implications of the evolution of intra-regional agricultural trade in terms of water because VW exports can bring social and economic benefits, but also endanger water ecosystems in water-stressed exporting countries. This is the case of some of the major exporters of VW in the EU, such as Belgium, Spain, and Italy (EC 2010). This in turn poses significant risks for the implementation of the WFD. Agricultural production impacts both water quantity and quality. Understanding virtual water trade patterns and the role of the different countries can inform implementation of water policy in the EU and the achievement of good water status. Moreover, the study highlighted that a large share of the regional VWT is associated with trade in water intensive low-economic value crops, such as cereals. Changes and improvements of crop planning to better fit local (water and climate) conditions, is a management-level climate change adaptation measure that can also be beneficial for achieving the targets of the WFD.

The results of the study are also important to call for a better alignment of water with agricultural policy. Cropland distribution (and thus agricultural water use) has largely been influenced by CAP subsidies, which have shaped farmers' short-term cost effectiveness in producing specific crops for decades. Direct payments, for instance, have been one of the main CAP's instruments for supporting and enhancing the competitiveness of the agricultural sector since the early 1990s (EC 2010). However, by establishing direct payments linked to production based on area, the 1992 CAP reform has induced an intensification of irrigation and production of low value crops, such as cereals, in some Mediterranean areas of the EU (Aldaya et al. 2010). The share of direct payments is on average 30% of agricultural income in the EU countries (EC 2010). Since 2003, direct payments have gradually been decoupled from farmers' production decisions, however low economic crops are still largely produced and traded. It has also been

argued that CAP has often provided subsidies to produce water-intensive crops using inefficient techniques and also that some countries, such as Spain, have specialised in water-intensive, low economic value crops in part due to the legacy of earlier CAP subsidies (Aldaya et al. 2010; EEA 2009). This is further compounded by the EU water price that varies across countries, ranging from the highly subsidized water charges in Bulgaria (0.007 €/m³) to the adoption of environmental taxes on water in the Netherlands (1.04 €/m³) (Biewald et al. 2014). For these reasons, it is pivotal to integrate agricultural policy with water policy objectives shaped by the WFD. A recent audit revealed that the integration between the CAP and the objectives of the EU water policy is only partial, mainly due to the weakness of the instruments through which water concerns (and WFD objectives) are integrated into CAP (European Court of Auditors 2014).

Here we want to make a clear distinction between ‘support policy making’ and ‘determine policies’. Water is one of the production factors and in many places, it is a limiting resource, as elaborated in this study. It is, therefore, of importance to know where, how much and by whom the water is used and transferred through virtual water trade to support policy making on water and agricultural trade. By providing a comprehensive assessment on the intra-EU virtual water flows associate with agricultural trade, the information of this study is useful for supporting the relevant policy markings in the EU. However, water is only one factor, among many, in the complex water and trade systems. The information on water alone cannot determine the policies. Integrated analysis of all factors involved is needed to formulate appropriate water and trade policies that are in line with the goal of sustainable water management set by the EU WFD.

5. Conclusion

The development of approaches to tackle the EU water-related challenges and shift towards sustainable water management and use are one of the main objectives of Horizon 2020, the EU strategy to achieve a smart, sustainable and inclusive growth. Traditional approaches towards water accounting generally focus on surface and groundwater withdrawals for specific uses, while ignoring that international trade in water-intensive products can have an impact on domestic water resources. This study has argued that, in their capacity to account for water

flows across regions and economic sectors, VWT analyses have the potential to give insights for supporting water and trade policies and their integration with the CAP.

Acknowledgements

M.A. and H.Y. kindly acknowledge support from the Department of Systems Analysis, Integrated Assessment and Modelling of Swiss Federal Institute of Aquatic Science and Technology (Eawag). S.T. acknowledges Francesco Laio and his funding from the European Research Council (Grant ERC-2014-CoG, Project 647473).

References

- Alcamo, J., Moreno, J.M., Nováky, B., Bindi, M., Corobov, R., Devoy, R.J.N., Giannakopoulos, C., Martin, E., Olesen, J.E., Shvidenko, A., 2007. Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden P.J., Hanson, C.E. (Eds), Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp. 541–580.
- Aldaya, M., Martinez-Santos, P., Llamas, M., 2010. Incorporating the water footprint and virtual water in policy: reflections from the Mancha Occidental Region, Spain. *Water Resources Management*. 24, 5, 941–958. DOI 10.1007/s11269-009-9480-8
- Allamano, P., Claps, P., D’Odorico, P., Laio, F., Rifolli, L., Tamea, S., 2015. The Globalisation of Food and Water: The Italian Case. In: Antonelli, M., Greco, F. (Eds.), *The water we eat*. Springer Water, pp. 145–158. DOI 10.1007/978-3-319-16393-2_12
- Allan, J.A., 2001. *The Middle East water question: Hydropolitics and the Global Economy*. I.B. Tauris, London.
- Antonelli, M., Tamea, S., 2015. Food-water security and virtual water trade in the Middle East and North African region. *International Journal of Water Resources Development*. 31, 3, 326–342. DOI: 10.1080/07900627.2015.1030496
- Biewald, A., Rolinski, S., Lotze-Campen, H., Schmitz, C., Dietrich, J.P., 2014. Valuing the impact of trade on local blue water. *Ecological Economics*. 101, 43–53. <http://dx.doi.org/10.1016/j.ecolecon.2014.02.003>
- Boeuf, B., Fritsch, O., 2016. Studying the implementation of the Water Framework Directive in Europe: a meta-analysis of 89 journal articles. *Ecology and Society*. 21, 2, 19. <http://dx.doi.org/10.5751/ES-08411-210219>
- Carr, J. A., D’Odorico, P., Laio, F., Ridolfi, L., 2013. Recent history and geography of virtual water trade. *PLoS ONE*. 8, e55825. Doi:10.1371/journal.pone.0055825

Carr, J.A., D’Odorico, P., Laio, F., Ridolfi, F., 2012. On the temporal variability of the virtual water network. *Geophysical Research Letters*. 39, 6. DOI: 10.1029/2012GL051247

Duarte, R., Pinilla, V., Serrano, A., 2016. Understanding agricultural virtual water flows in the world from an economic perspective: A long term study. *Ecological Indicators*. 61, pp. 980–990. <http://dx.doi.org/10.1016/j.ecolind.2015.10.056>

Ercin, A.E., Hoekstra, A.Y., 2016. European Water Footprint Scenarios for 2050, *Water*, 8, 6, 226. doi:10.3390/w8060226

European Academies Science Academy Council [EASAC], 2010. Groundwater in the Southern Member States of the European Union: Country Reports France, Greece, Italy, Portugal and Spain. <http://www.easac.eu/home/reports-and-statements/detail-view/article/groundwater.html> (accessed 26.01.2017)

European Commission [EC], 2016a. European Commission website. Agriculture and Rural Development. Agricultural and Water. http://ec.europa.eu/agriculture/envir/water/index_en.htm (accessed 01.12.16)

European Commission [EC], 2016b. European Commission website. Water. Infographics. <http://ec.europa.eu/environment/water/infographics.htm> (accessed 01.12.16)

European Commission [EC], 2016c. Introduction to the new EU Water Framework Directive. http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

European Commission [EC], 2016d. European Commission website, Agriculture and rural development. Trade and international policy analysis. https://ec.europa.eu/agriculture/trade-analysis_en

European Commission [EC], 2013. Bilateral agricultural trade relations. EU agricultural trade with EFTA countries. http://ec.europa.eu/agriculture/bilateral-relations/pdf/efta_en.pdf

European Commission [EC], 2010. The CAP towards 2020. Direct Payments. http://ec.europa.eu/agriculture/rca/pdf/PO0202_direct_payments.pdf

European Commission on Agriculture and Rural Development, 2010. Agriculture and the Environment. http://ec.europa.eu/agriculture/envir/index_en.htm

European Court of Auditors, 2014. Integration of EU water policy objectives with the CAP: a partial success, Special report. http://www.eca.europa.eu/Lists/ECADocuments/SR14_04/SR14_04_EN.pdf

European Environment Agency, 1996. Water Resources Problems in Southern Europe. An Overview report. <http://www.eea.europa.eu/publications/92-9167-056-1> (accessed 26.01.2017)

European Environment Agency, 2009. Water resources across Europe – confronting water scarcity and droughts. EEA Report. <http://www.eea.europa.eu/publications/water-resources-across-europe>

European Environment Agency, 2012. European waters – current status and future challenges. Synthesis. EEA report. <http://www.eea.europa.eu/publications/european-waters-synthesis-2012>

Eurostat, 2016. Agri-environmental indicator – irrigation, Eurostat website. http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_irrigation

Eurostat 2017. Intra-EU trade of most traded goods, Eurostat website: http://ec.europa.eu/eurostat/statistics-explained/index.php/Intra-EU_trade_of_the_most_traded_goods

Falkenmark M., 1989. The massive water scarcity threatening Africa-why isn't it being addressed. *Ambio*, 18, 2, 112–118.

Food and Agriculture Organization of the United Nations [FAO], 2005. *The state of food and agriculture 2005. Agricultural trade and poverty. Can trade work for the poor?* FAO report, Rome. ftp://ftp.fao.org/docrep/fao/008/a0050e/a0050e_full.pdf

FAOSTAT on-line database. Food and Agriculture Organization of the United Nations, Statistics Division. Retrieved from <http://faostat3.fao.org/home/index.html> (accessed 25/09/2013).

AQUASTAT on-line database. Food and Agriculture Organization of the United Nations, Land and Water Division. Retrieved from <http://www.fao.org/nr/water/aquastat/main/> index.stm (accessed 20/10/2014).

Hoekstra, A.Y., Mekonnen, M.M., 2012. The water footprint of humanity, *Proc. Natl. Acad. Sci. U.S.A.* 109, 9, 3232–3237. doi:10.1073/pnas.1109936109/-/DCSupplemental

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M. 2011. *The Water Footprint Assessment Manual: Setting the Global Standard*. Earthscan, London, UK.

Hoekstra, A.Y., Hung, P.Q., 2002. Virtual Water Trade: A Quantification of Virtual Water Flows between Nations in Relation to International Crop Trade. *Value of Water Research Report Series*. 11, UNESCO-IHE, Delft.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L., Rockström, J., 2010. Greening the global water system. *J Hydrol*; 384, 177–86, DOI:10.1016/j.jhydrol.2009. 06.026.

Hoff, H., Döll, P., Fader, M., Gerten, D., Hauser, S., Siebert, S., 2014. Water footprints of cities – indicators for sustainable consumption and production. *Hydrol. Earth Syst. Sci.* 18, 213–226. DOI: 10.5194/hess-18-213-2014

Institute for European Environmental Policy [IEEP], 2000. The Environmental impacts of irrigation in the European Union. A report to the Environment Directorate of the European Commission. <http://ec.europa.eu/environment/agriculture/pdf/irrigation.pdf> (accessed 26-01.2017)

- Iglesias, A., Garrote, L., Quiroga, S., Moneo, M., 2009. Impacts of climate change in agriculture in Europe. PESETA-Agriculture study, JRC Scientific and Technical Research series EUR 24107 EN. European Commission, Joint Research Centre.
- Lutter, S., Pfister, S., Giljum, S., Wieland, H., Mutel, C., 2016. Spatially explicit assessment of water embodied in European trade: A product-level multi-regional input-output analysis. *Global Environmental Change*. 38, 171–182. <http://dx.doi.org/10.1016/j.gloenvcha.2016.03.001>
- Massarutto, A., 2003. Water Pricing and Irrigation Water Demand: Economic Efficiency versus Environmental Sustainability. *Environmental Policy and Governance*, 13, 100–119. 10.1002/eet.316
- Mekonnen, M.M., Hoekstra, A.Y., 2011. The green, blue and grey water footprint of crops and derived crop products. *Hydrol Earth Syst Sci*, 15, 1577–600.
- Mekonnen, M. M., Hoekstra, A. Y., 2010a. The green, blue and grey water footprint of crops and derived crop products. In Value of water research report series. 47. Delft, the Netherlands: UNESCO-IHE.
- Mekonnen, M. M., Hoekstra, A. Y., 2010b. The green, blue and grey water footprint of farm animals and animal products. In Value of water research report series. 48. Delft, the Netherlands: UNESCO-IHE.
- Molden, D., 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London.
- Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N., Foley, J.A., 2012. Closing yield gaps through nutrient and water management. *Nature*, 490, 254–7.
- Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvåg, A.O., Seguin, B., Peltonen-Sainio, P., 2011. Impacts and adaptation of European crop production systems to climate change. *Eur. J. Agron.* 34, 96–112. <http://dx.doi.org/10.1016/j.eja.2010.11.003>.
- Pinstrup-Andersen, P. and D. D. Watson, II. 2011. Food policy for developing countries: The role of government in global, national, and local food systems. Ithaca, NY: Cornell University Press.
- Schmidt, G., Benítez-Sanz, C., 2012. Assessment of Water Scarcity and Drought aspects in a selection of European Union River Basin Management Plans. Study by Intecsa-Inarsa for the European Commission, under contract “Support to the implementation of the Water Framework Directive (2000/60/EC)”.
- Serrano, A., Guan, D., Duarte, R., Paavola, J., 2016. Virtual water flows in the EU27: A consumption-based approach. *Journal of Industrial Ecology*. 20, 3, 547–558. <https://dx.doi.org/10.1111/jiec.12454>
- Tamea, S., Allamano, P., Carr, J.A., Claps, P., Laio, F., Ridolfi, L., 2013. Local and global perspectives on the virtual water trade. *Hydrol. Earth Syst. Sci.* 17, 1205-1215. DOI: 10.5194/hess-17-1205-2013

- 667 Tamea, S., Laio, F., Ridolfi, L., 2016. Global effects of local food-production crises: a virtual
668 water perspective. *Scientific Reports*, 6, 18803. doi: 10.1038/srep18803
669
- 670 Vanham, D., del Pozo, S., Pekcan, A.G., Keinan-Boker, L., Trichopolou, A., Gawlik, B.M.,
671 2016. Water consumption related to different diets in Mediterranean cities. *Science of the Total*
672 *Environment*. 573, 96-105. <http://dx.doi.org/10.1016/j.scitotenv.2016.08.111>
673
- 674 Vanham, D., Hoekstra, A.Y., Bidoglio, G., 2013. Potential water saving through changes in
675 European diets. *Environment International*. 61, 45–56.
676 <http://dx.doi.org/10.1016/j.envint.2013.09.011>
677
- 678 Van Oel, P.R., Mekonnen, M.M., Hoekstra, A.Y., 2009. The external water footprint of the
679 Netherlands: Geographically explicit quantification and impact assessment. *Ecological*
680 *Economics*. 69, 1, 82–92. doi:10.1016/j.ecolecon.2009.07.014
681
- 682 Varela-Ortega, C., 2007. Policy-driven Determinants of Irrigation Development and
683 Environmental Sustainability: A Case Study in Spain. In: Molle, F. and Berkoff, J. (Eds.).
684 Irrigation Water Pricing: The Gap Between Theory and Practice, CABI, Oxford, pp. 328-346.
685 [10.1079/9781845932923.0328](http://dx.doi.org/10.1079/9781845932923.0328)
- 686 Velázquez, E., 2007. Water trade in Andalusia. Virtual water: An alternative way to manage
687 water use. *Ecological Economics*. 63, 1, 201–208.
- 688 Zoumides C., Zachariadis T., 2009. Irrigation Water Pricing in Southern Europe and Cyprus:
689 The effects of the EU Common Agricultural Policy and the Water Framework Directive. *Cyprus*
690 *Economic Policy Review*, 3, 1, 99–122.