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Reviews

A review on the indicator water footprint for the EU28

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ABSTRACT

The water footprint (WF) is an indicator that accounts for both the direct (domestic water use) and indirect (water required to produce industrial and agricultural products) water use of a consumer or producer. This paper makes a review on the WF indicator and its applicability for EU28 (EU27 and Croatia) policy. More particularly the volumetric WF assessment approach of the Water Footprint Network (WFN) is reviewed. A synthesis of existing national WF accounting quantities results in an EU28 WF of production (WF_{prod}) of 3420 lcd (609 km^3/yr) and a WF of consumption (WF_{cons}) of 4815 lcd (857 km^3/yr). Of the latter 60% is internal and 40% is external to Europe. The EU28 is a net virtual water importer. The WF of agricultural products contributes by far the largest fraction of the total WF, i.e. 91% of the total WF_{prod} and 89% of the WF_{cons}. With traditional water use statistics, awareness campaigns and policy have always focused on increasing water efficiency in domestic and industrial water use. However, much more water can be saved in agricultural production processes, by reducing food waste and by a change in diet of the average EU consumer. Together with a comprehensive overview on possible ways to reduce WF, this paper provides a critical review on the WF methodology, showing that the development of the WF concept is still not complete. Practical complexities with data (availability of and inconsistencies in the underlying databases) are a concern. Some conceptual aspects need to be further developed and tested, not at least the indicators for sustainability assessment. The most important limitation is the fact that it is a partial tool to be used in combination with other analytical means or indicators when determining integrated policy options. Nevertheless, its main strength is the possibility to show the importance of consumption patterns and global dimensions in water governance.

Contents

1. Introduction

The Water Framework Directive (WFD) is a key piece of EU legislation aimed at improving water quality across EU Member States (European Commission, 2010). It is now recognized that the 2015 objectives of Good Ecological Status will be hardly achievable due

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to old and emerging challenges both related to water quality and quantity (e.g. over-abstraction, water scarcity, impacts of climate change) (EEA, 2010). The 2012 Blueprint to Safeguard Europe's Water is the EU policy response to such challenges. It is closely related to the EU 2020 strategy and in particular to the Roadmap to a Resource Efficient Europe.

The concepts of water footprint (WF) and virtual water (VW) may be relevant in the implementation of the policy options identified by the Blueprint. Indeed, by addressing water efficiency across commodity supply-chains, they can influence drivers of consumption and foster implementation of sustainable water management solutions. An assessment of the efficacy of the WF approaches and how they can be applied in policy is essential.

Within this paper an overview of WF definitions and approaches is given. The volumetric WF assessment approach of the Water Footprint Network (WFN) is reviewed taking the EU28 countries as study case (Croatia will join the EU27 on the 1st July 2013). A water balance is quantified based upon existing data and values for WF accounting are synthetized based upon national data from the WFN. Such a synthesis for the EU is currently not available in the literature. In view of its strengths and weaknesses, the approach is then discussed for its potential support to impact assessments of water policies.

Detailed national WF studies have been conducted for European countries, e.g. Aldaya et al. (2008), Sonnenberg et al. (2009), Van Oel et al. (2009), and Vanham (in press) and countries outside Europe, e.g. Bulsink et al. (2010), Liu and Savenije (2008), and Verma et al. (2009). These studies include blue and green water. Following the definition of Rockström et al. (2009), green water is the soil water held in the unsaturated zone, formed by precipitation and available to plants, while blue water refers to liquid water in rivers, lakes, wetlands and aquifers. Irrigated agriculture receives blue water (from irrigation) as well as green water (from precipitation), while rainfed agriculture only receives green water. The latter is the dominant type of cultivation in northern and western European countries. Traditional water use statistics only account for blue water. Conventional approaches to water management have focused on managing solely the blue component of the water cycle. Different authors – e.g. Falkenmark and Lannerstad (2007), Vanham (2012), Falkenmark (2003) – however, recommend to include green water in water management studies. Rainfed agriculture is the largest (green) water user worldwide. Irrigated agriculture is the largest blue water user worldwide. There are now many studies that include the green component of the water cycle, e.g. Glavan et al. (2012) and Willaarts et al. (2012).

2. WF definitions and approaches

Two main approaches for the assessment of the WF exist in the literature (UNEP, 2012; Postle et al., 2012): (1) the volumetric approach as developed by the Water Footprint Network (WFN) (Hoekstra et al., 2011) and (2) the Life Cycle Analysis approach as developed by the LCA community (which includes the weighted WF approach). The different stages in WF assessment (WFA) and life cycle assessment (LCA) are displayed in Fig. 1. In this paper only the volumetric approach of the WFN – a well-established methodology (Gleeson et al., 2012) – is reviewed, as most of existing WF studies to-date follow this approach (Hastings and Pegram, 2012). Relevant for the EU28 review is the WF for a geographical region/community/nation, in this case the EU28.

The WF was introduced in 2002 as an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer (UNEP, 2012). The WF of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business. An important distinction needs to be made between the WF of production (WF_{prod}) and the WF of consumption (WF_{cons}) (Fig. 1) of a geographical region (EU28). The first is the sum of direct and indirect water use of domestic water resources. The second is the sum of direct and indirect water use of domestic and foreign water resources through domestic consumption. A balance between the two is reached by virtual water flows (import and export), which result from the trade in industrial and agricultural products. The WF_{cons} can be calculated by means of the top-down or bottom-up approach. Within the top-down approach, the WF_{cons} equals the WF_{prod} plus the virtual water import (VW_i) minus the virtual water export (VW_e). The bottom-up approach is based upon direct underlying data on consumption.

The WF consists of three (green, blue and grey water) components (Fig. 1). The WF can be presented as one aggregate number, but in fact it is a multidimensional indicator of water use, showing different sorts of water consumption and pollution as a function of space and time. For developing strategies for sustainable water use, one will need to use the more detailed layer of information embedded in the composite (green, blue and grey) WF indicator.

Fig. 2 shows the WF accounting scheme for a geographical area. It shows the various balances that hold for the WF. The WF_{prod} plus VW_i equal the WF_{cons} plus VW_e. A geographical area imports and exports virtual water. Net virtual water import or export is defined as the difference between import and export. If a geographical area imports more virtual water than it exports, it is a net virtual water importer. If it exports more than it imports, it becomes a net virtual water exporter.

The WF is an indicator of water use. In order to have an idea what this footprint size means, it needs to be compared with available resources (sustainability assessment). WF sustainability assessment is the phase in WF assessment (Fig. 1) that aims to evaluate whether a certain WF is sustainable from an environmental, social, as well as economic point of view. The latter is discussed in detail in Hoekstra et al. (2011) and UNEP (2011).

Of the geographical environmental sustainability indicators (green and blue water scarcity and water pollution level), the blue water scarcity indicator is the most developed and currently applied, e.g. in Hoekstra et al. (2012). It is calculated by dividing the blue WF_{prod} by the ecological blue water availability (hydrological water availability minus environmental flows) in the geographical area (Fig. 3). It provides an indication of the degree of violation or non-violation of environmental flow requirements. It differs from predecessors (listed in UNEP, 2012) in the sense that (1) the WF_{prod} incorporates water consumption and not water withdrawal; (2) natural rather than actual runoff is assessed; (3) it takes environmental flows into account; (4) the time step should be monthly rather than annual.

The green water scarcity indicator is calculated by dividing the green WF_{prod} by the green water availability of a geographical region, where the latter is defined as the total evapotranspiration (ET) of rainwater from land (ET_{green}) minus the ET from land reserved for natural vegetation (ET_{env}) and minus the ET from land that cannot be made productive. This indicator has however not yet been applied in case studies (UNEP, 2012). The water pollution level indicator is obtained by dividing the sum of all grey WF_{prod} in a catchment to its actual runoff. Social and economic indicators are still to be further developed. More conditions to address total (environmental, social, economic) sustainability of the WF are: (1) the total WF_{cons} remains below a fair share in the world and (2) the WF (all green, blue and grey) of production processes – of products produced and consumed in the region – cannot be reduced or avoided (at acceptable societal cost). The latter refers to the global context of scarce water and land resources. When the green, blue or grey WF in a catchment does not fulfil one of the criteria of environmental, social or economic sustainability, the WF cannot be considered as 'geographically sustainable'.

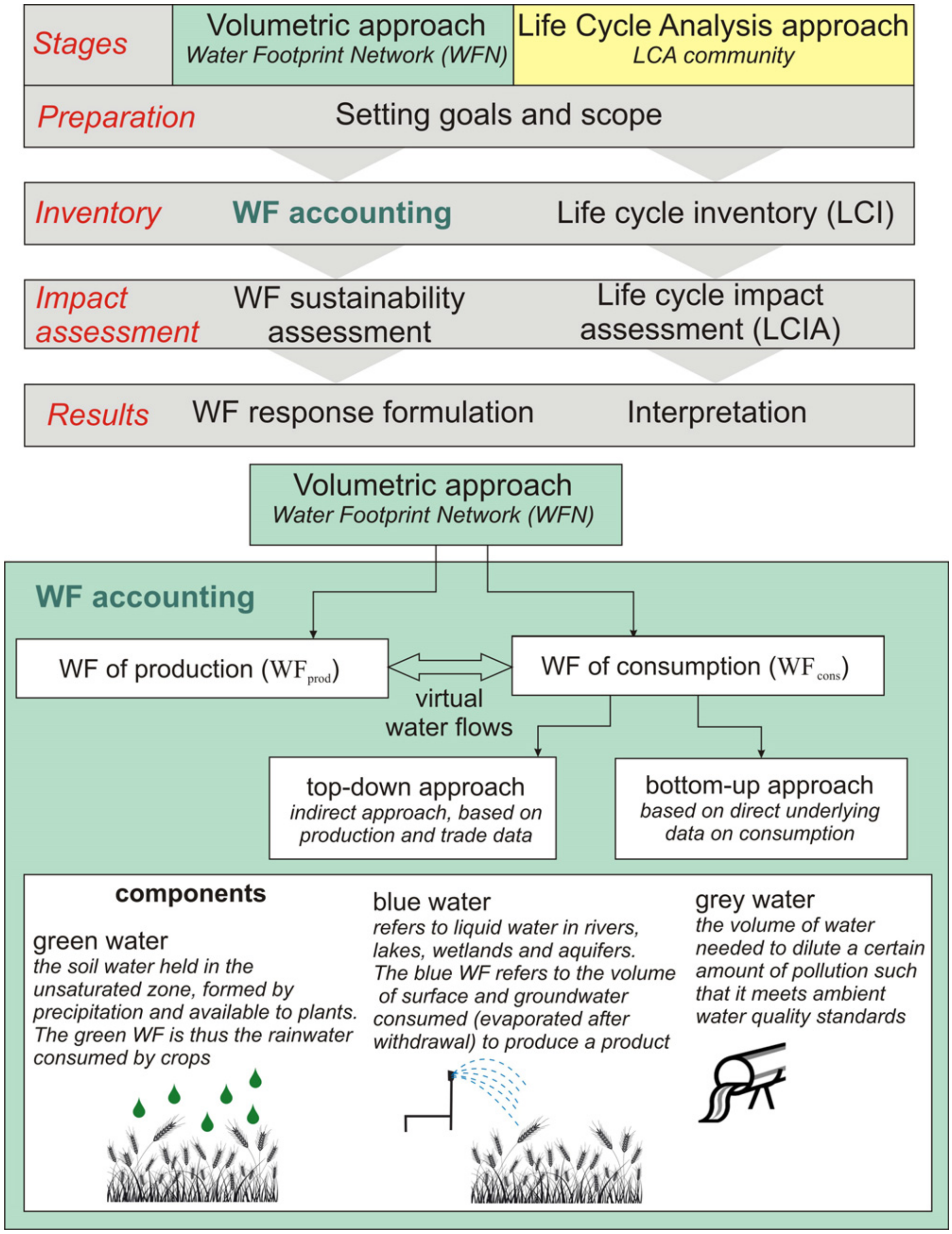

Fig. 1. Different stages in life cycle assessment (LCA) and in the water footprint assessment (WFA). For the volumetric WFA approach details on WF accounting for a region/community are displayed.

Sources: Hoekstra et al. (2011) and UNEP (2012).

3. Quantification of the water balance and WF accounting of the EU28

3.1. Data sources

Detailed data on national agricultural production and consumption are available from FAOSTAT (2012). EUROSTAT assembles data on water quantity from national statistical offices. An overview on data sources to quantify the EU28 water balance and WF accounting is given in Table 1. These quantifications are the result of a synthesis of national values from the EU Member States as depicted in Fig. 4.

National average annual values for the hydrological water balance components – precipitation (P), evapotranspiration (ET) and (internal and external) renewable water resources (RWR) – were obtained from EUROSTAT (2012). Water use statistics (water withdrawals) for the period 1996–2005 for the different sectors – municipalities, agriculture, manufacturing industries and cooling water for electricity generation – were also obtained from EUROSTAT (2012). Within the paper, water use for municipalities or domestic water use is defined as the water use of households and small businesses. Agricultural water use is defined as water use by irrigation and livestock. The water use for manufacturing industries is defined as the water use in all facilities producing industrial products. National water consumption values (blue water and green water) were obtained from the reports (Mekonnen and Hoekstra, 2010, 2011), which are average annual values for the period 1996–2005.

National WF accounting values were obtained from the WF Network publications, more specifically the report (Mekonnen and Hoekstra, 2011). The WF_{cons} of agricultural products is

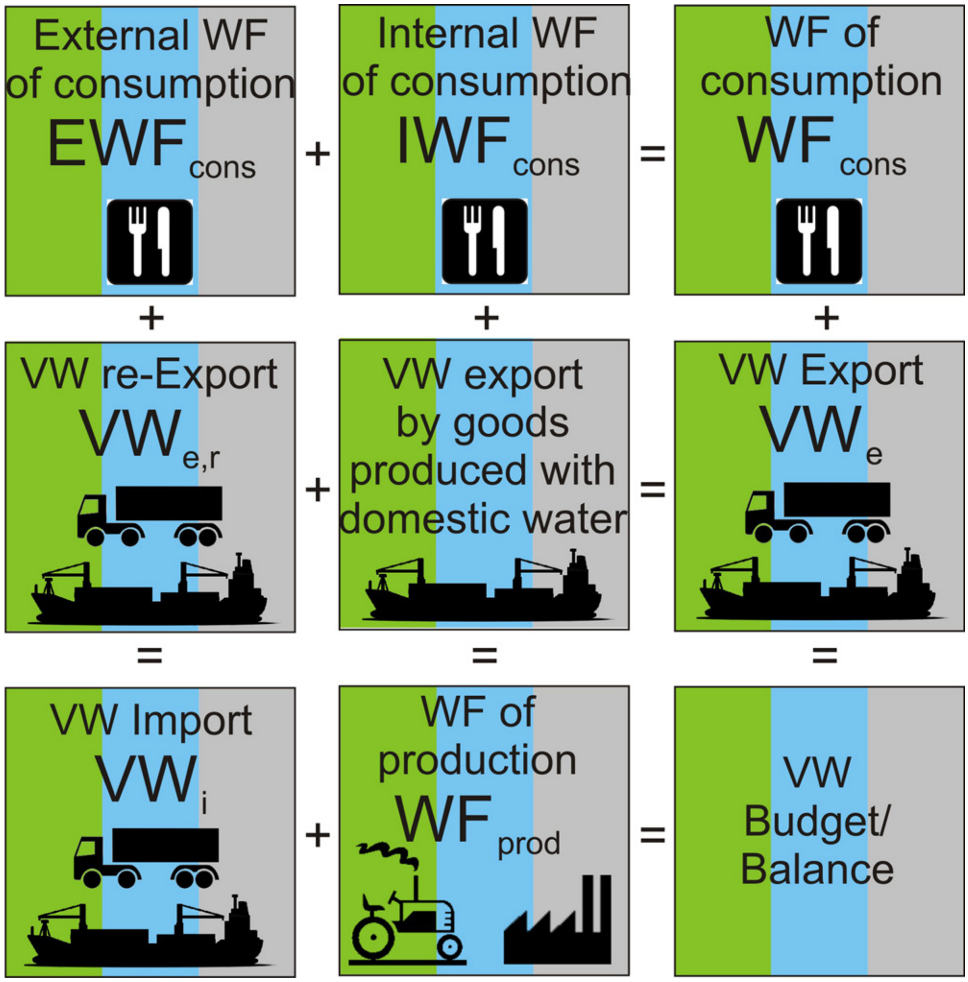

Fig. 2. Geographic WF accounting scheme for a geographical area. The colours green, blue and grey represent the green, blue and grey components of the WF and VW. Adapted from Hoekstra et al. (2011) and UNEP (2011). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

here calculated by means of the bottom-up approach, while the WF_{cons} of industrial products by means of the top-down approach (Hoekstra et al., 2011; Mekonnen and Hoekstra, 2011). Data on production, consumption and trade of agricultural products were obtained from EUROSTAT (2012) and FAOSTAT (2012). VW flows calculated in these reports are based on trade data.

3.2. Water balance

A general water balance for the EU28 including blue water use withdrawals (and consumption) as well as green crop water consumption is shown in Fig. 5. Of an annual average precipitation of 3521 km^3, 2045 km^3 is evapotranspirated and 1481 km^3 are internal renewable water resources (RWR). Of the latter, 251 km^3 (17%) of blue water are withdrawn for different purposes. The largest fraction of blue water withdrawals is cooling water for electricity generation (100 km^3). Municipal water withdrawals account for 49 km^3, of which 4 km^3 (8%) are consumed and the remaining 45 km^3 returned to the water system. Water withdrawals for the manufacturing industry (12% of total abstraction) account for 31 km^3 of which 7 km^3 are consumed. More than 50% of the latter water withdrawals occur in IT, DE and FR. Since the mid-1990s, the amount of these water withdrawals in Europe has steadily been falling despite continued expansion of industrial output (EEA,

Table 1
Data sources used within the paper, for the EU28 water balance or WF accounting.

Data	Period	Data source	Purpose
Hydrological water balance components	Long term average annual values	EUROSTAT (2012)	Water balance
Water withdrawal statistics	1996–2005	EUROSTAT (2012)	Water balance
Blue water consumption statistics	1996–2005	Mekonnen and Hoekstra (2011)	Water balance & WF accounting
Crop green water consumption statistics	1996–2005	Mekonnen and Hoekstra (2010)	Water balance & WF accounting
Population and surface area	1996–2005	FAOSTAT (2012)	WF accounting
Production and consumption values for agricultural products	1996–2005	FAOSTAT (2012)	WF accounting
Virtual water content (VWC) of agricultural products, WF_{prod} and WF_{cons} values, VW flows (import and export)	1996–2005	Mekonnen and Hoekstra (2011)	WF accounting
Trade data	1996–2005	EUROSTAT (2012) and FAOSTAT (2012)	WF accounting

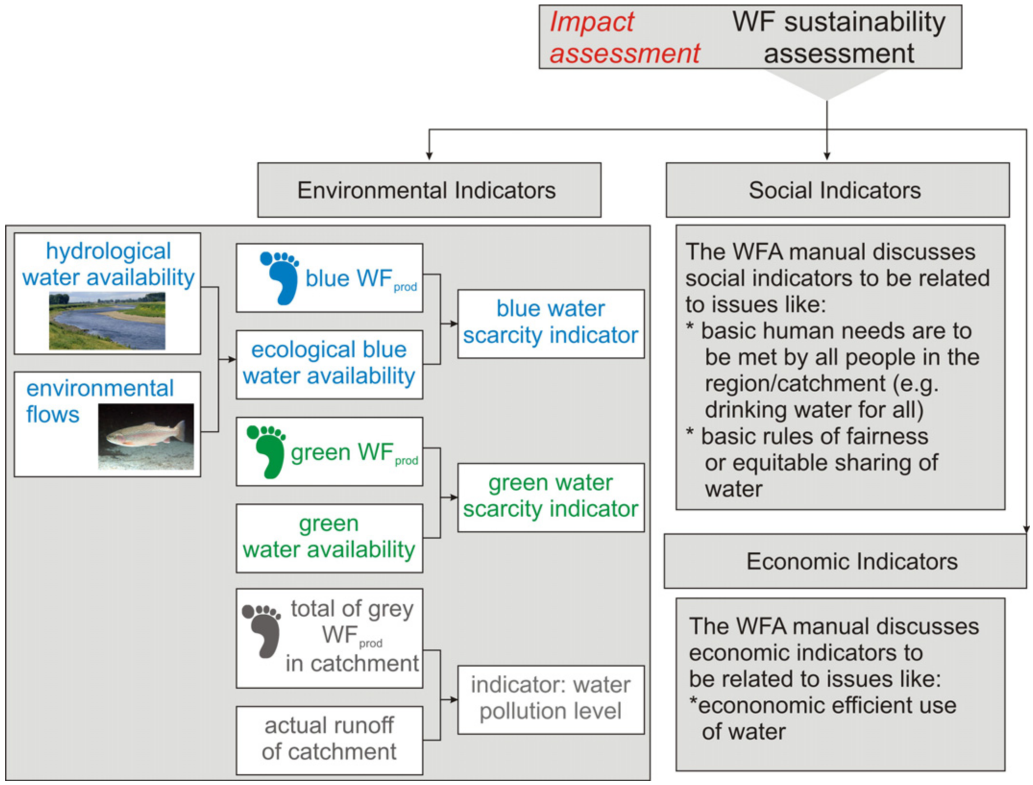

Fig. 3. Environmental, social and economic indicators for WF sustainability assessment.
Sources: Hoekstra et al. (2011) and UNEP (2011).

2009; EUROSTAT, 2012), basically due to higher water efficiencies, but also due to the decline of water-intensive heavy industries (like steel manufacturing) in favour of extra-EU countries. Water withdrawals for agriculture (28% of total abstraction) account for 71 km^3, of which 30 km^3 are consumed by irrigation and 6 km^3 by livestock. The largest blue water consumer in the EU is thus irrigation. The crops maize, olives, cotton, rice and grapes account for more than 50% of blue water consumption in the EU. ES and IT account for two thirds of irrigation water withdrawals in the EU. Together with GR, PT and FR they account for 96% of EU irrigation withdrawals.

According to Mekonnen and Hoekstra (2011), productive grazing in the EU accounts for a green water consumption of 55 km^3, whereas green crop consumption amounts to 396 km^3. The latter is more than 10 times the blue water consumption (irrigation) of crop production, i.e. in the EU, green crop consumption accounts for 93% of total crop water consumption and blue water consumption only for 7%. Worldwide these values are 86% and 14%. Crop green water consumption in the EU accounts for 7% of total global crop green water consumption, whereas the EU value for irrigated consumption is 3% of the global value. The most important crops regarding green water consumption in the EU are wheat, fodder crops, barley and maize. Substantial amounts can be accounted to olives, grapes, rapeseed, sunflower, potato, sugar beet and rye. Most important countries regarding green crop water consumption are FR, ES, IT, PL, DE and RO.

3.3. The volumetric approach for WF accounting

3.3.1. WF accounting for the EU28

Fig. 6 shows production and consumption amounts for the different agricultural product groups for the EU28. Fig. 7 shows the most important products in terms of quantity produced, consumed, or WF quantity as well as their virtual water content (VWC) as a global average or as a EU28 average. The figure shows that specific agricultural products are very water intensive (require high amounts), like meat (e.g. bovine meat 15,409 m^3/ton), but also stimulants (e.g. coffee 15,897 m^3/ton) or vegetable oils (olive oil 14,725 m^3/ton). Certain products, which are produced in large quantities within the EU28 (e.g. potatoes 76 million ton (Mt)) have a relative low VWC (VWC_{EU28} for potatoes 175 m^3/ton). The WF_{prod} of wheat, e.g. is quite high because it is produced in very high amounts (131 Mt) with a considerable VWC (VWC_{EU28} 928 m^3/ton). The figure shows that for almost all products the VWC_{EU28} is considerably lower than the VWC_{glob}. This means that it requires less VW to produce the same amount of product in the EU28 as compared to globally. The value of the VWC is a measure for water efficiency, and is dependent on production methods (yield, method of irrigation, etc.), but also natural conditions (climate and soil). Therefore it can differ substantially for different regions, even for neighbouring farmers. This means that also within the EU28 important differences exist. Wheat, e.g. has a lower VWC in western Europe (e.g. DE 788 m^3/ton) and northern Europe (e.g. UK 607 m^3/ton) as compared to southern Europe (e.g. ES 1476 m^3/ton) or eastern Europe (e.g. RO 1779 m^3/ton).

The geographic WF accounting scheme for the EU28 (Fig. 8) shows a WF_{prod} of 3420 l per capita per day or lcd (609 km^3) and a WF_{cons} of 4815 lcd (857 km^3). The internal WF_{cons} is 2869 lcd (60% of the total WF_{cons}) and the external WF_{cons} is 1946 lcd (40% of the total WF_{cons}). Products which contribute to a high external proportion of the WF_{cons} in the EU28 are coffee and cocoa beans. Other products that are almost entirely imported include cotton and soybeans. The latter are generally used for feed: e.g. the average annual net import of soybeans and soybean cake was 33 Mt, primarily from Brazil. Based on trade data calculations, the VW_i amounts to 2364 lcd and the VW_e to 645 lcd. The EU28 is thus a net VW importer. However, the balance WF_{prod} plus VW_i equals WF_{cons} plus VW_e does not hold. The component values are not absolute and

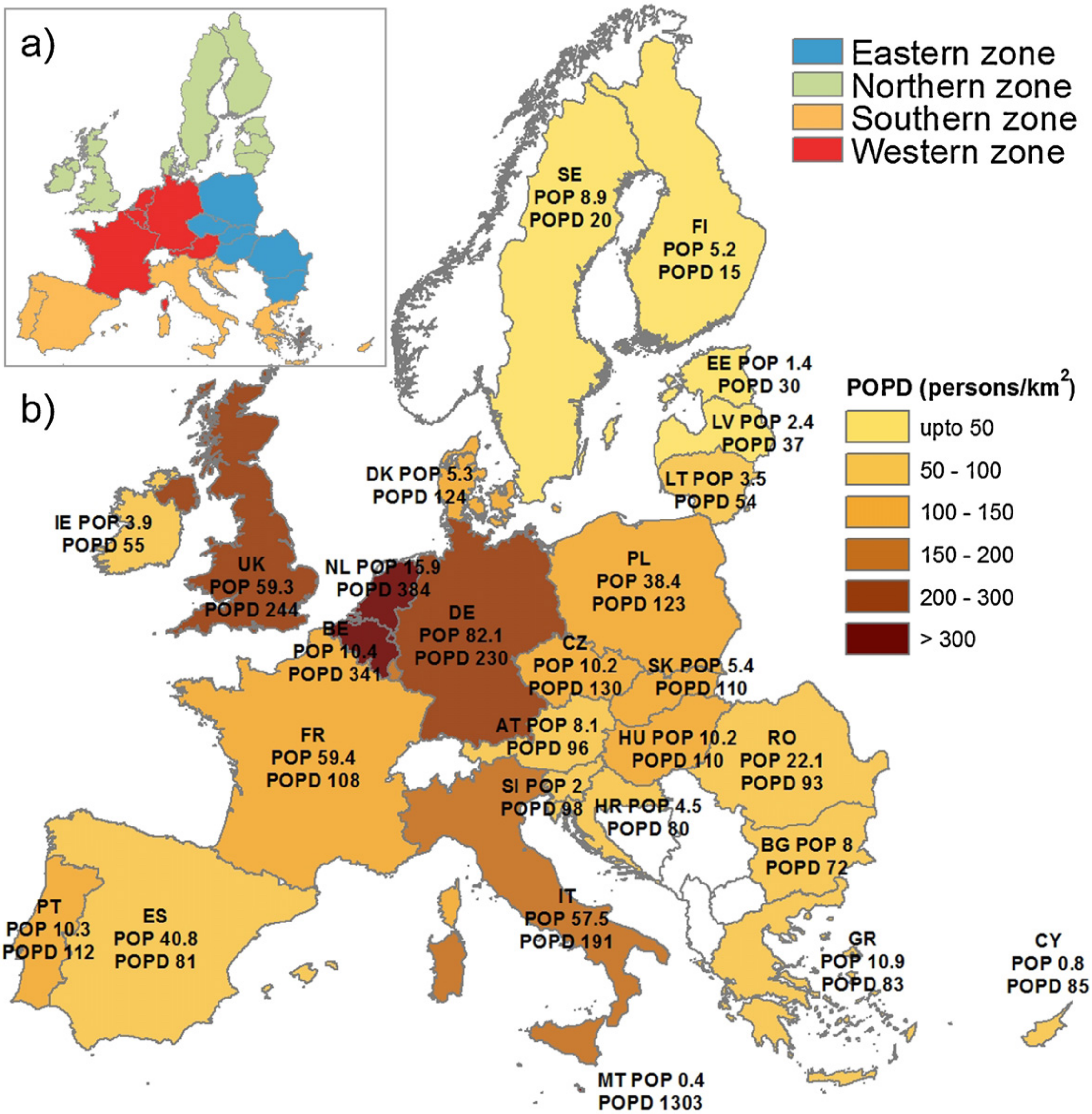

Fig. 4. (a) The four different zones of the EU28. The countries are divided in 4 geographical zones (according to the UN standard country or area codes and geographical regions): eastern, northern, southern and western. (b) The countries of the EU28 with their respective codes, population (POP, in 10^6) and population density (POPD, in persons per km^2). POP and POPD are average values for the period 1996–2005.

Data source: FAOSTAT (2012). For the EU27 POP 483.3 and POPD 112; for the EU28 POP 487.9 and POPD 111.

have to be regarded as best estimates based upon direct underlying data on production, trade or consumption.

For both the WF_{prod} and WF_{cons} (Fig. 9), the WF of agricultural products is by far the most dominant (3100 lcd or 91% for the WF_{prod} and 4265 lcd or 89% for the WF_{cons}). Agricultural green water consumption accounts for about 74% of both the WF_{prod} and WF_{cons}. The green WF_{prod} (451 km^3 or 2534 lcd) as displayed in Fig. 9, corresponds to the green water consumption value given in Fig. 5 for crop production (396 km^3) and grazing (55 km^3). Also the blue water WF of the WF_{prod} for agricultural products (36 km^3 or 202 lcd) as displayed in Fig. 9, corresponds to the sum of the blue water consumption for irrigation (30 km^3) and livestock (6 km^3) as presented in Fig. 6. Additionally the blue WF of industrial products (7 km^3) and domestic water use (4 km^3) as displayed in Fig. 9, are also presented in Fig. 6 by the blue water consumption of manufacturing industries and of municipal water use. As such, the values for the green and blue WF of the WF_{prod} of Fig. 9 have already been presented in Fig. 6. Only the grey WF is added within Fig. 9.

The WF_{cons} of the average EU citizen adds up to 4815 lcd (Fig. 6). Compared to the domestic WF (113 lcd) this is a factor of about 40–1. Compared to the average water withdrawal by households – on average 120 lcd in many western European countries (Vanham et al., 2011) – this is also a factor of about 40–1. In other words, the direct daily water use (drinking, cooking, washing, etc.) of the average EU citizen is just a small fraction of his indirect water use through the agricultural and industrial goods that he or she consumes.

An analysis of the EU WF_{cons} of specific agricultural product groups is displayed in Fig. 10. Animal products represent more than 50% (2290 lcd) of the total value. Within the EU28 a total of 41.2 Mt of meat (or 84.5 kg/cap) and 114.2 Mt of milk (234.1 kg/cap) are consumed every year (Fig. 7). Extremely high WF values are related to the consumption of milk (569 lcd), bovine meat (478 lcd) and pork (464 lcd).

The product group cereals and beer represents the second largest WF (11%, 450 lcd). Within the EU28 a total of 60.3 Mt of cereals (or 123.6 kg/cap, as food) and 36.4 Mt of beer (74.6 kg/cap)

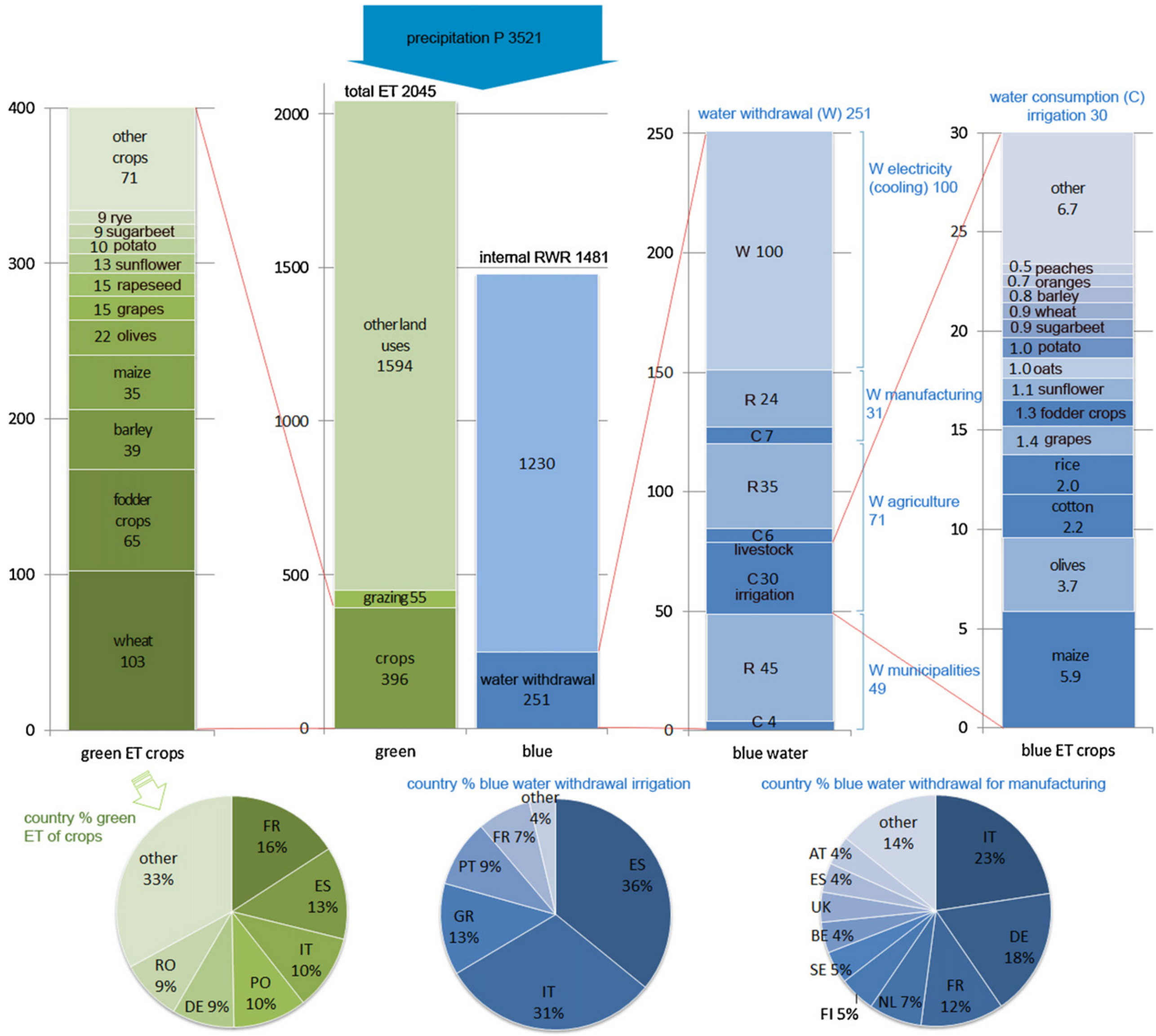

Fig. 5. Hydrological water balance components and water use values for the total area of the EU28 (EU27 and Croatia). Average annual values in km^3; period 1996–2005 for agricultural consumption values (Mekonnen and Hoekstra, 2010, 2011); long time average values for EU national hydrological components (EUROSTAT, 2012) and period 1996–2005 for EU national water withdrawal and consumption values (EUROSTAT, 2012); P = precipitation; ET = evapotranspiration; RWR = renewable water resources; W = withdrawal; C = consumption; R = return flow.

are consumed every year (Figs. 6 and 7). Wheat (also representing flour of wheat, bread, etc.) is here the dominant crop (339 lcd). The consumption of beer represents a WF of 32 lcd. Vegetables (EU28 yearly consumption of 58.9 Mt or 120.8 kg/cap, Fig. 6), fruit (EU28 yearly consumption of 48.2 Mt or 98.8 kg/cap, Fig. 6), nuts and wine represent the third largest group (9%, 364 lcd). Wine (EU28 yearly consumption of 14.0 Mt or 28.8 kg/cap, Fig. 7) is responsible for a WF of 72 lcd. Other WF values include tomatoes (9 lcd), onions (5 lcd), apples (24 lcd), oranges and mandarines (33 lcd). Although consumed in relative large amounts in the EU, the WF of most of the latter products is not very high as their VWC is not very high.

The groups oilseeds and oils as well as coffee, tea, cocoa and tobacco both represent 8% of the total WF_{cons}. Especially olive oil (127 lcd) and sunflower seed oil (74 lcd) have a high WF. The EU28 yearly consumption of olive oil is 3.4 kg/cap and of sunflower seed oil 4.5 kg/cap (Fig. 7). For both products the VWC is extremely high. Within the other group, coffee and cocoa are two water intensive products (they have high virtual water contents) and their WF are, respectively, 203 lcd and 107 lcd. Tea (EU28 yearly consumption of 0.6 kg/cap, Fig. 7) is not as widely consumed as coffee (EU28 yearly consumption of 4.8 kg/cap) in the EU and has a lower VWC. Its WF is only 13 lcd. The group sugar and sweeteners accounts for 5% of the total WF and other crops for 6%. Of the latter, potatoes account for 52 lcd. Although consumed in large amounts (EU28 yearly consumption of 39.9 Mt or 81.9 kg/cap), the WF of potatoes is not so high because its VWC is relatively low.

3.3.2. *Regional differences within the EU28*

The EU28 WF accounting values represent average EU values, but there are substantial differences between the different nations of the EU. There are however similarities between different regions of the EU.

As shown in Fig. 11a, per capita total WF_{cons} values are generally the highest in the southern zone and the lowest in the northern zone. The ratio of the external WF_{cons} to the total WF_{cons} is in the upper range in the western zone while the lowest values

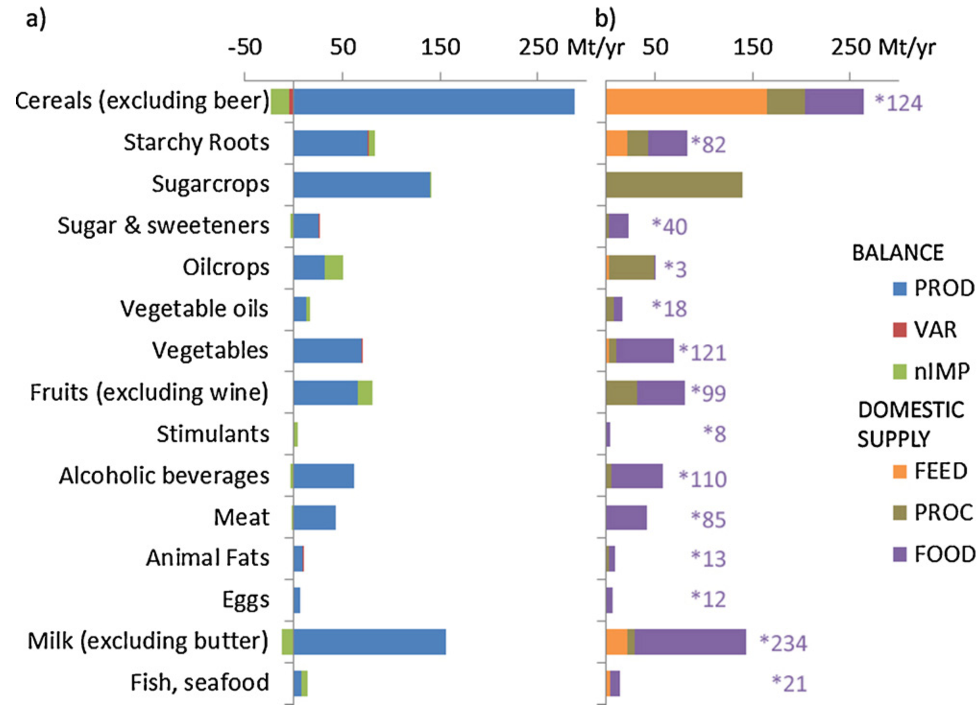

Fig. 6. Agricultural production and consumption of product groups in the EU28 for the period 1996–2005 (in Mt/yr): (a) the production balance with PROD = production, nImp = net import (import–export) and VAR = stock variation resulting in PROD + nIMP + VAR = DOM (domestic supply quantity) and (b) the different fractions of DOM being FEED = feed, PROC = processing, seed and other utilities; FOOD = food supply; * is FOOD expressed in kg/cap/yr.

Data sources: FAOSTAT (2012).

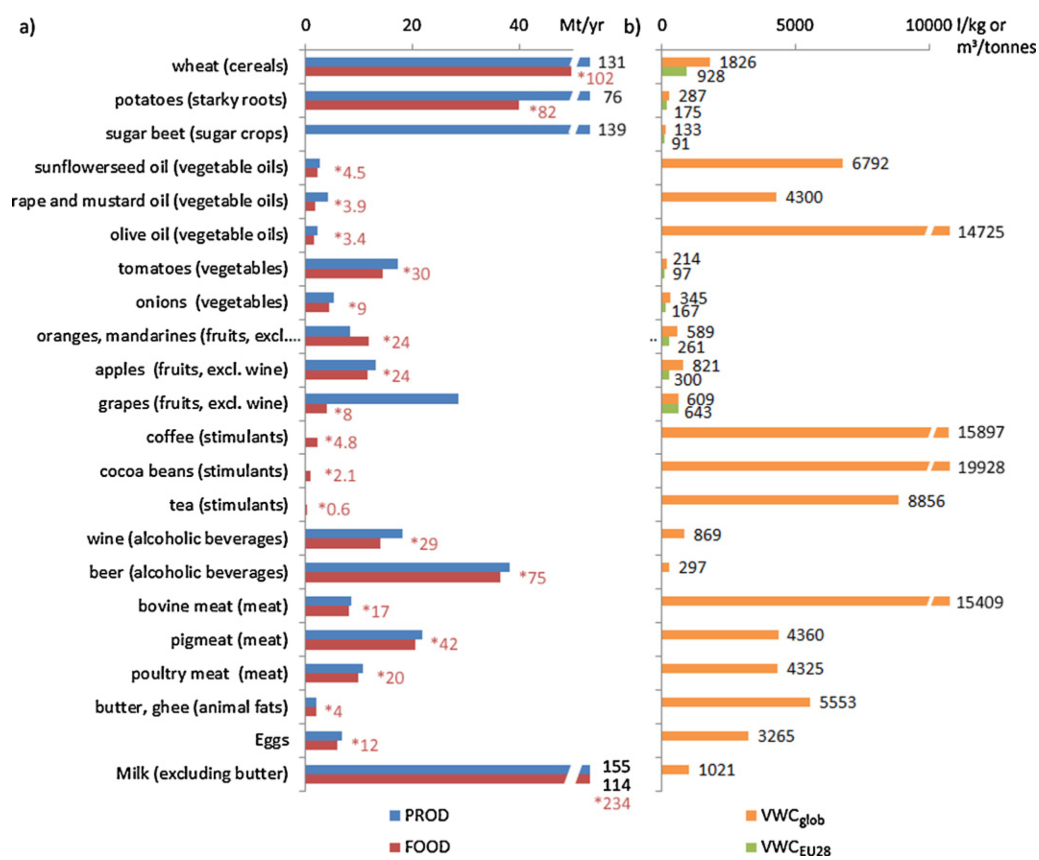

Fig. 7. Agricultural production and consumption of specific agricultural products in the EU28 for the period 1996–2005: (a) the production (PROD) and food supply (FOOD) in Mt/yr as well as FOOD in kg/cap/yr (marked by *) and (b) the virtual water content VWC for production of these products, VWC_{glob} and VWC_{EU28} = average global and EU28 VWC (l/kg or m^3/ton, includes green, blue and grey water).

Data sources: FAOSTAT (2012) and Mekonnen and Hoekstra (2011) for the VWC.

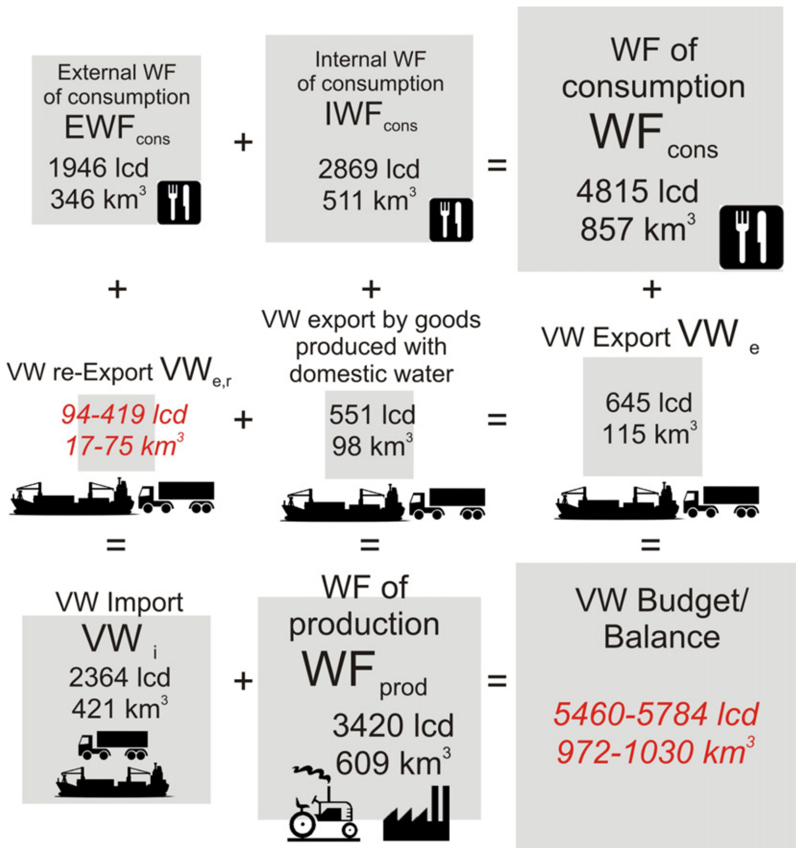

Fig. 8. Geographic WF accounting scheme for the EU28. The size of the grey boxes relates to the quantity of the components.

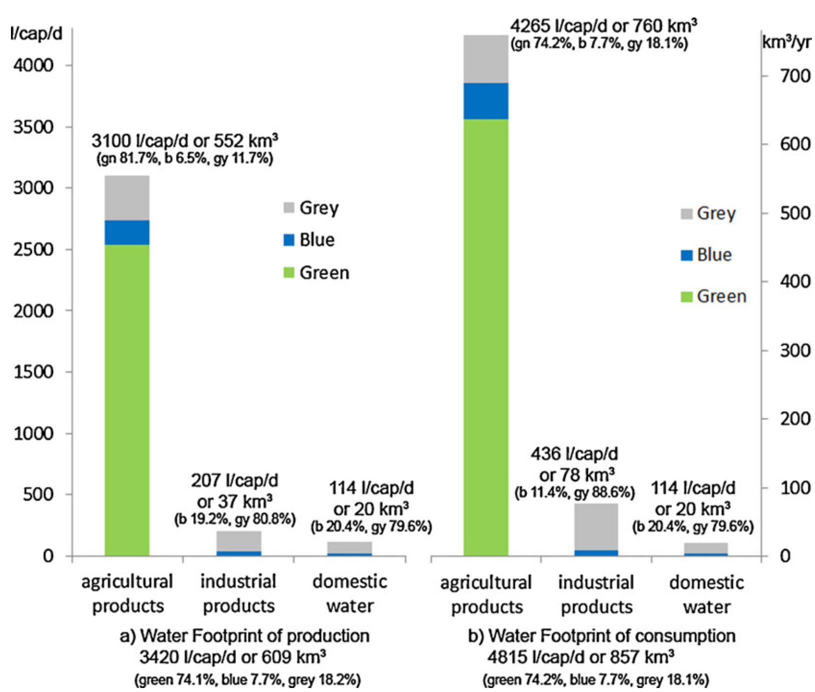

Fig. 9. WF of (a) production (WF_{prod}) and (b) consumption (WF_{cons}) for the EU28 (EU27 and Croatia) (in lcd and km^3/yr), for agricultural products, industrial products and domestic water.
Figure resulting from national average annual WF values (1996–2005) data in Mekonnen and Hoekstra (2011).

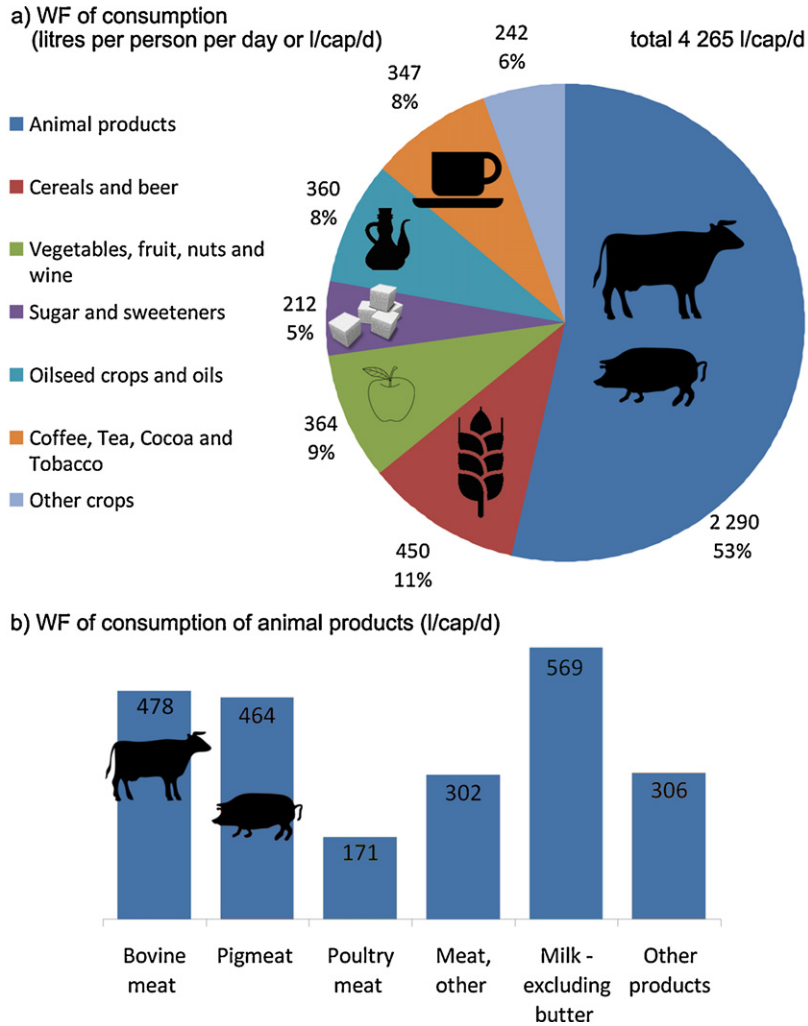

Fig. 10. WF_{cons} of different product groups for the EU28 (in lcd).
Based upon data from Mekonnen and Hoekstra (2011) for national average annual WF values of specific products (1996–2005).

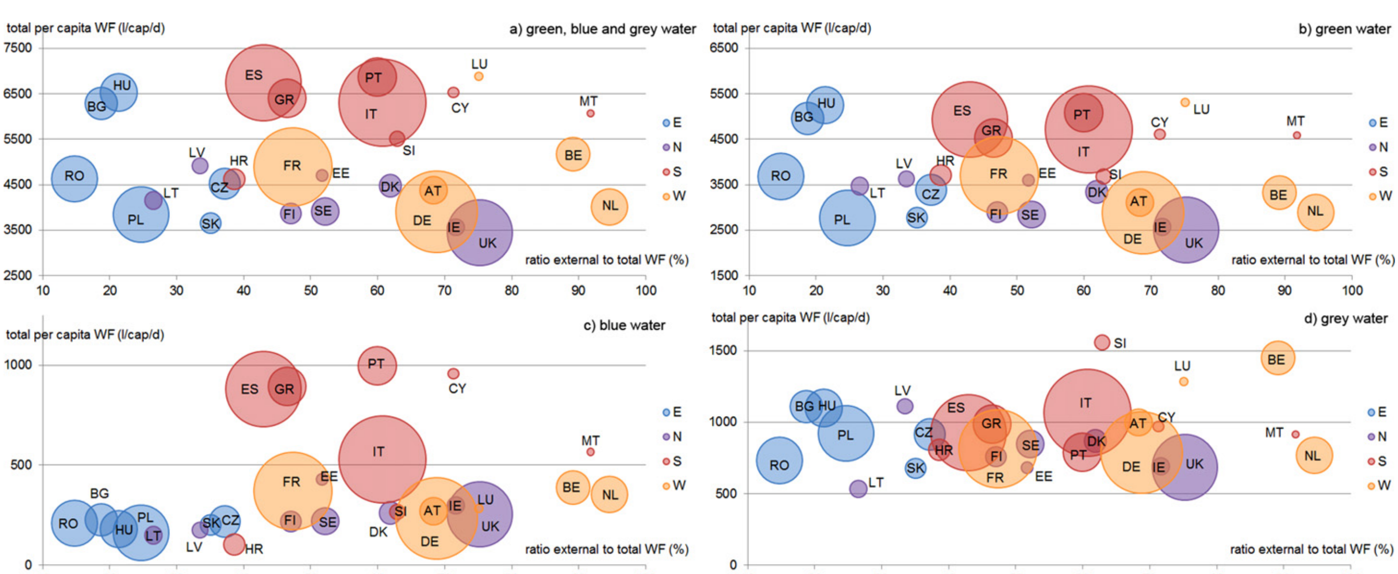

Fig. 11. Average annual WF_{cons} values (period 1996–2005) for the countries of the EU28 for (a) green, blue and grey water; (b) green water; (c) blue water and (d) grey water. The *X*-axis shows the ratio of the external part of the total WF to the total WF (in %), the *Y*-axis shows the total WF in lcd. The size of each circle relates to the total annual WF of consumption of the country in absolute volume (km^3) (e.g. in the above figures min. 0.9 km^3 for MT and max. 132.5 km^3 for IT).
Based upon data from Mekonnen and Hoekstra (2011).

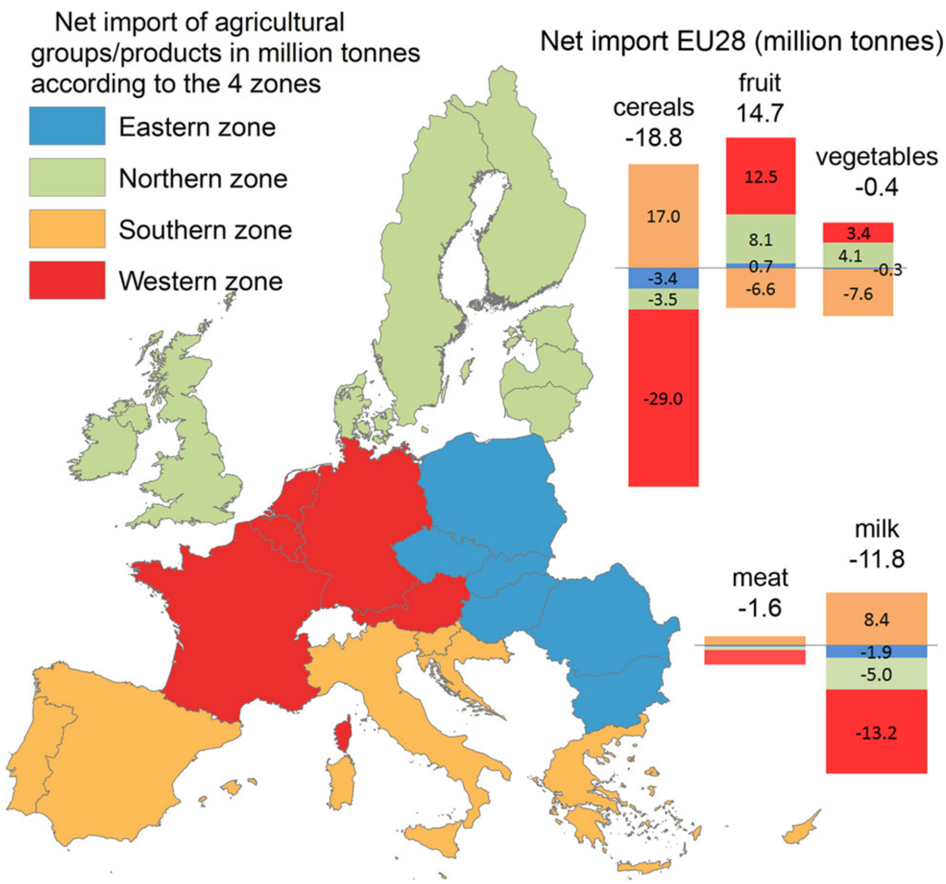

Fig. 12. Map on the net import (Mt/yr) of selected agricultural product groups/products for the four defined EU28 zones (period 1996–2005). Data source: FAOSTAT (2012).

are observed in the eastern zone. The two main factors explaining this divergence are the difference in virtual water content (VWC) of produced agricultural goods (generally lower in the northern and western EU zone as compared to the southern and eastern zone) and the difference in amount and type of agricultural products consumed. Fig. 11b shows the same observations for green water. Fig. 11c shows that the blue WF is significantly higher in the countries of the southern zone. Regarding grey WF (Fig. 11d) there is no clear difference between the four EU zones.

Figs. 12 and 6 show that cereals, meat and milk are net exported products outside EU28, whereas oil crops and fruits are amongst product groups, which are net imported. However, there are also important intra-EU28 flows, resulting from the trade in agricultural and industrial goods between Member States/regions. A shown in Fig. 12, the western and northern EU zones are net exporters and the southern zone a net importer for cereals, meat and milk. On the other hand, the western and northern zones are net importers and the southern zone a net exporter for fruit and vegetables.

4. Possible ways to reduce water footprints

In the wake of climate change and global demographic changes, it is necessary to act on a reduction of the blue, green and grey WF of the EU28. The global objective to sustainably provide a healthy diet (with eradicating hunger and obesity) to the 9.3 billion people (UN, 2012) projected for 2050, can only be achieved by closing the yield gap on existing agricultural lands by means of sustainable intensification (Foley et al., 2011; Godfray et al., 2010). To tackle the twin challenge of food security and environmental sustainability, the key element water needs to be regarded as a global resource and conventional approaches to intensify agriculture (which have contributed to environmental degradation in the past) must be adapted. The competition of land and water for food, feed and bio-energy needs to be critically reviewed.

One can argue, e.g. that it is not necessary to reduce blue WF in catchments where no water scarcity occurs. However, a more efficient water use of a specific product in water-abundant areas results in an increased production with the same amount of water, thereby (1) possibly reducing blue WF in water scarce-areas as less (virtual water) imports are required and (2) giving the possibility to allocate water for the production of other goods. The WF of water-intensive products like meat can, e.g. not lead to water scarcity in a certain region, but in a global context they imply that less water remains to be allocated to other purposes, such as growing cereal crops to fulfil basic food demands (Hoekstra et al., 2011).

There is also a need to reduce green WF, because of two reasons. The first is that green water is also a scarce resource, because it competes with other land uses like forests. Since part of the land in any river basin is occupied by other land uses, automatically a certain amount of green water is not available for agriculture. The second reason is that increased production based on green water resources (e.g. in northern Europe) reduces the need for production with blue water resources (e.g. in southern Europe). Therefore the reduction of the green WF is also useful in areas where green water is abundantly available. Also in the wake of climate change this is an important factor. Increased summer droughts, e.g. in the Mediterranean region can lead to increased blue water

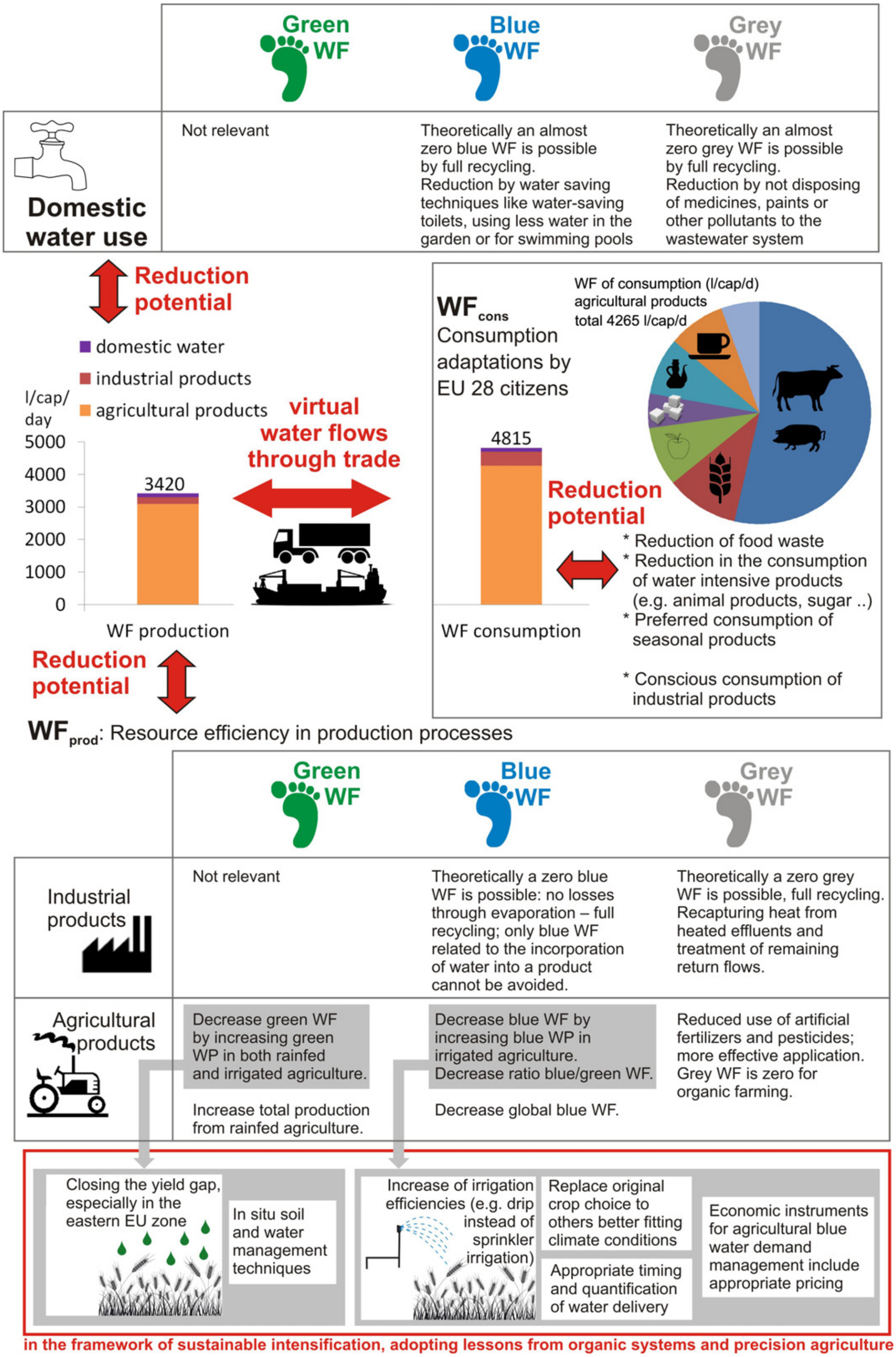

Fig. 13. Possibilities to reduce the WF_{prod} and WF_{cons} per sector and WF component. Figure with input from Hoekstra et al. (2011); water productivity WP (ton/m^3) of a product is defined as the inverse of the virtual water content or VWC (m^3/ton).

consumption for irrigation, therefore stressing the necessity of the reduction of all WF components within the whole EU zone.

Potential ways to reduce the WF components are displayed and described in Fig. 13, and include:

- a reduction in the domestic WF,
- an increase in green and blue water productivity of agricultural products at farm level including the closure of yield gaps within the EU or the increase of irrigation efficiencies. However, there is a need for sustainable intensification, adopting lessons from organic systems and precision agriculture,
- an increase in industrial processing water productivity,

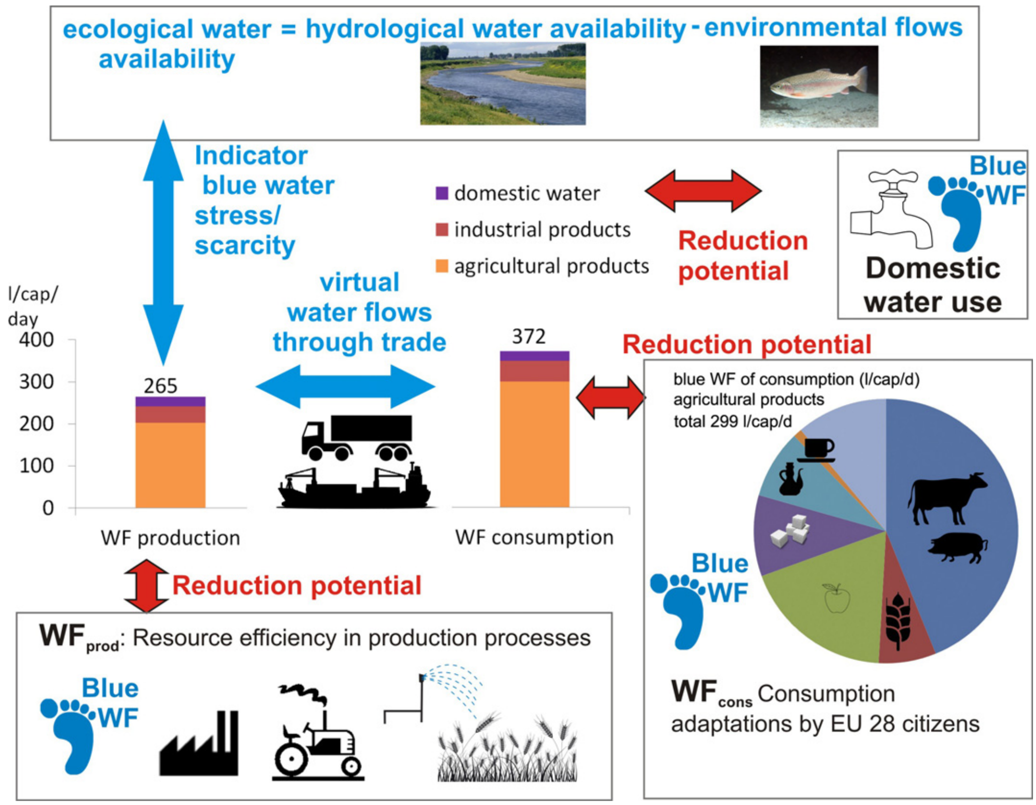

Fig. 14. Schematization of the different components to assess the indicator blue water scarcity.

- a reduction of food waste along the entire food chain (EC, 2010). Recently the European Parliament called for urgent measures to halve food wastage in the EU by 2025,
- consumption adaptations by the citizens of the EU28 (Vanham et al., submitted for publication). Especially a reduced consumption of animal products (especially meat) would have a large impact on the WF of the EU28, where more than 50% of cereal production is used as feed and additional feed imported.

5. Critical aspects on the WF concept

The WF concept is primarily intended to illustrate the hidden links between human consumption and water use and between global trade and water resources management (Galli et al., 2012). With this respect it is a powerful communication tool. The WF concept also has some limitations and challenges.

Practical complexities with data (availability of and inconsistencies in the underlying databases) are a first concern. Completing a WF assessment in practice can be difficult due to data availability and reliability. This is best shown in the WF accounting scheme of the EU28 (Fig. 8), where the different components are not absolute values. These differences are accounted to data quality. The bottom-up approach for the WF_{prod}, WF_{cons} and VW flows depends on the quality of production, consumption and trade data, whereas the top-down approach relies on the quality of production and trade data (Hoekstra et al., 2011). The bottom-up approach for the WF_{cons} is however generally recognized as more stable (Hoekstra et al., 2011; Van Oel et al., 2009). Where consumption over time is rather constant, the trade balance, domestic production and over-year storage vary more significantly. The outcome of the top-down approach can be vulnerable to relatively small errors in the trade data when the import and export of a country are large relative to its domestic production. The bottom-up approach enables also to assess the WF_{cons} in a detailed way per commodity or product category.

This data concern is also valid for the blue WF of domestic and industrial use. Data on blue water withdrawals and especially consumption (which is used for the WF) are – depending on the purpose and/or geographical range – not always very reliable. The national WF values obtained from the WFN publications to synthesize the EU28 WF were estimated using water withdrawal data from the AQUASTAT database and EUROSTAT (Hoekstra and Mekonnen, 2012). The authors assumed that 5% of the water withdrawn for industrial purposes is actual consumption (blue WF) and that the remaining fraction is return flow; for the domestic water supply sector, they assumed a consumptive portion of 10%.

A critical issue is also that the grey WF methodology needs to be further standardized (Thaler et al., 2012). Some authors criticize that representing the impacts of water pollution by transforming water quality into water quantity gives loss to important information. It does not consider factors such as ecotoxicity, biodegradability or water treatment (Hastings and Pegram, 2012). The quantification of the grey WF as presented in this paper is very conservative (potentially an underestimated value), as it only accounts for N but not, e.g. for P or pollution by pesticides. Dependent on the elements included, data and water quality standard used, the grey WF can therefore differ substantially (Thaler et al., 2012). Currently grey WF calculations heavily rely on assumptions and estimations (Galli et al., 2012). Further development and standardization are necessary.

Some authors argue that instead of “gross green water”, as defined by the WFN and applied in most studies, “net green water” should be better used for the green WF (Hastings and Pegram, 2012). This to account for the fact that also without cultivation, naturally occurring vegetation provides for ET (Postle et al., 2012). Net green thus refers to the difference between ET under cropped conditions and ET under natural conditions. This definition for the green WF however poses the problem that a negative net green WF is possible.

One of the major concerns in WF assessment is the fact that many of the indicators for the sustainability assessment (Fig. 3) have yet to be further developed, tested and established (UNEP, 2011). Only the indicator blue water scarcity is fully developed and tested, although the quantification of environmental flows needs further research. There is especially a need to further develop social and economic indicators for the WF sustainability assessment.

For developing strategies for sustainable water use, it is necessary to use the more detailed layer of information embedded in the composite (green, blue and grey) WF (sustainability) indicator. However, the total WF should not be discarded in this process. As an example, organic agriculture often leads to higher green WF as compared to industrialized agriculture (because yields are often lower), but the grey WF reduces to almost zero (and is substantial for industrialized farming). Sustainability should therefore be evaluated also for the sum of both WF components.

The most important limitation is the fact that it is still a partial tool (Hoekstra et al., 2011), as acknowledged by the WFN itself. It does not account for water aspects like flooding or lack of water infrastructure, nor does it account for other (finite) resources like land. The availability of agricultural land is a key factor for growing crops, which is not accounted for in the WF or VW assessments. The WF also quantifies water consumption, but gives no information on water withdrawals, although the difference between both is very substantial (Fig. 5). The product group fish and seafood is not assessed in WF analyses. A reduction of meat consumption but a shift to fish would indeed reduce the EU WF_{cons}, but would put an extra burden on already stressed fish populations (Vanham et al., submitted for publication). The WF assessment tool is thus a tool to be used in combination with other analytical means or indicators when making decisions.

6. Implications for EU28 policies

The WF and VW concepts provide the opportunity to link the use of water resources to the consumption of goods. These concepts have been brought into water management science in order to show the importance of consumption patterns and global dimensions in good water governance (Galli et al., 2012; Hoekstra, 2011; Hoekstra et al., 2011; UNEP, 2012). The strengths of the WF concept include (Galli et al., 2012):

- Representation of the spatial distribution of a region's (e.g. EU28) water demand/consumption.
- Expansion of traditional water use accounting (water withdrawals) by the inclusion of green and grey water.
- Visualization of the link between (local) consumption and (global) appropriation.

Traditionally, nations or regions formulate water plans considering options both to reduce water demand and increase supply, however without the inclusion of the global dimension of water management. By focusing on domestic water use, most governments are unaware of the sustainability of national consumption (which includes both domestic and foreign products). The EU28 has significantly externalized its WF_{cons} (Fig. 2), without considering whether these imported products contribute to the depletion or pollution of water resources abroad. The Water Framework Directive aims at improving domestic water quality throughout the EU and the new Blueprint to Safeguard Europe's Water will include water quantity issues. With so many global developments (climate change, global population increase, diet shifts, etc.) it is questionable whether the current production and consumption situation of the EU28 can be sustained in future.

The WF concept can contribute to sustainable solutions for EU policies like the Water Framework Directive (WFD) and the CAP (Common Agricultural Policy). It is nevertheless a partial tool, not taking into account other resources like land, considerations about greenhouse gas emissions or the consumption of fish. For integrated policy options, it requires the inclusion of other indicators, e.g. not to compete with policies like the Marine Strategy Framework Directive (MSFD).

It was shown that the methodology requires further development and testing. In its current status the indicator blue water scarcity can be implemented for case studies. Fig. 14 shows its relevance for the EU28. A project recently started at the JRC of the EC will conduct a blue WF sustainability assessment for the EU28 using this indicator. Consumption levels of regions in EU28 countries and the impacts of measures to reduce the WF will be assessed.

For a comprehensive WF assessment of the EU28 it has to be stressed that there are substantial geographical differences in WF_{prod} and WF_{cons} (Figs. 11 and 12) within its borders. These should be accounted for when formulating policies.

7. Conclusions

The water footprint (WF) and virtual water (VW) concepts provide the opportunity to link the use of water resources to the consumption of goods. These concepts have been brought into water management science in order to show the importance of consumption patterns and global dimensions in good water governance (Galli et al., 2012).

A synthesis of existing national WF accounting amounts provided by the volumetric WF assessment approach of the Water Footprint Network (WFN) results in the following WF quantification for the EU28:

- The WF of production (WF_{prod}) amounts to 3420 lcd (609 km^3/yr) and the WF of consumption (WF_{cons}) to 4815 lcd (857 km^3/yr). Of the latter 60% is internal and 40% external. Included in these values are the blue, green and grey WF components.
- The EU28 is a net virtual water importer
- The WF of agricultural products contributes by far the largest fraction of the total WF, i.e. 91% of the total WF_{prod} and 89% of the WF_{cons}. In other words, if consumers consider reducing their WF, they need to look at their diet rather than at their water use in the kitchen, bathroom and garden. Especially animal products are very water intensive. A comprehensive overview of possibilities to reduce the WF_{prod} and WF_{cons} is given in Fig. 13.
- There are considerable differences in the WF_{cons} between regions of the EU (Fig. 11). The 2 main factors explaining these differences are the difference in virtual water content (VWC) of produced agricultural goods (generally lower in the northern and western EU zone as compared to the southern and eastern zone) and the difference in amount and type of agricultural products consumed.

A critical review on the WF assessment methodology shows that to date, its development is still not completed, although the second issue of the WF manual was published recently (Hoekstra et al., 2011). A concern is practical complexities with data, which was documented in the EU28 WF accounting scheme (Fig. 8), where the components are not absolute values. Further development and standardization of the grey WF is necessary. Many of the indicators (especially social and economic indicators) for the sustainability assessment (Fig. 3) have yet to be further developed, tested and established.

It is also a partial tool, not accounting for other water related aspects like flooding or lack of water infrastructure. It also does not account for other resources like the availability of agricultural land, nor does it include considerations about greenhouse gas emissions or the consumption of fish. To contribute to sustainable solutions for EU policies like the Water Framework Directive (WFD) and the CAP (Common Agricultural Policy), it therefore requires the inclusion of additional indicators. The WF concept can support awareness and policy development and contribute to positive actions in watersheds.

Disclaimer

The conclusions and statements presented are those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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