The water footprint of agricultural products in European river basins

D Vanham and G Bidoglio

European Commission, Joint Research Centre, Institute for Environment and Sustainability, Via E. Fermi 2749, 21027 Ispra (VA), Italy

E-mail: davy.vanham@jrc.ec.europa.eu and davy.vanham@yahoo.de

Received 3 February 2014, revised 9 April 2014
Accepted for publication 30 April 2014
Published 5 June 2014

Abstract

This work quantifies the agricultural water footprint (WF) of production (WF_{prod, agr}) and consumption (WF_{cons, agr}) and the resulting net virtual water import (netVW_i, agr) of 365 European river basins for a reference period (REF, 1996–2005) and two diet scenarios (a healthy diet based upon food-based dietary guidelines (HEALTHY) and a vegetarian (VEG) diet). In addition to total (tot) amounts, a differentiation is also made between the green (gn), blue (bl) and grey (gy) components. River basins where the REF WF_{cons, agr, tot} exceeds the WF_{prod, agr, tot} (resulting in positive netVW_i, agr, tot values), are found along the London–Milan axis. These include the Thames, Scheldt, Meuse, Seine, Rhine and Po basins. River basins where the WF_{prod, agr, tot} exceeds the WF_{cons, agr, tot} are found in Western France, the Iberian Peninsula and the Baltic region. These include the Loire, Ebro and Nemunas basins. Under the HEALTHY diet scenario, the WF_{cons, agr, tot} of most river basins decreases (max −32%), although it was found to increase in some basins in northern and eastern Europe. This results in 22 river basins, including the Danube, shifting from being net VW importers to being net VW exporters. A reduction (max −46%) in WF_{cons, agr, tot} is observed for all but one river basin under the VEG diet scenario. In total, 50 river basins shift from being net VW importers to being net exporters, including the Danube, Seine, Rhone and Elbe basins. Similar observations are made when only the gn + bl and gn components are assessed. When analysing only the bl component, a different river basin pattern is observed.

Keywords: water footprint, EU, river basin, diet, indicator, sustainability, virtual water

1. Introduction

The water footprint (WF, table 1) concept has been brought into water management science in order to show the importance of consumption patterns and the global dimensions in good water governance (Galli et al 2012, Hoekstra and Mekonnen 2012, Vanham and Bidoglio 2013a). It is an indicator of direct and indirect water use. An assessment of the WF of all nations has recently been conducted by Hoekstra and Mekonnen (2012). It is important to distinguish between the WF of production (WF_{prod}) and the WF of consumption (WF_{cons}) of a geographical region. The first refers to the total use of domestic water resources within the region (for producing goods and services for either domestic consumption or for export). The second refers to the use of domestic and foreign water resources behind all goods and services that are consumed domestically. A balance between the two is reached by virtual water (VW) flows (imports (VW_i) and exports (VW_e)), and more particularly by the netVW_i (VW_i minus VW_e), which equals WF_{cons} minus WF_{prod}. WFs consist of blue, green and grey components. 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.
agriculture receives blue water (from irrigation) as well as green water (from precipitation), while rainfed agriculture only receives green water. The green WF is thus the rainwater consumed by crops. The grey WF is an indicator of the degree of water pollution (Hoekstra et al. 2011).

This paper conducts the following analyses for the river basins (partly) located in the EU and remaining Balkan countries (basin size larger than 1000 km²) (figure 1): the reference (REF) WF of production for agricultural products (WFprod, agr), the reference WF of consumption for agricultural products (WFcons, agr) and the resulting reference net VW import for agricultural products (netVWi, agr). Additionally the WFcons, agr for two diet scenarios is analysed: a healthy diet (HEALTHY) and a vegetarian diet (VEG). The resulting change in netVWi, agr is also assessed for all river basins. All these analyses are carried out for the total WF (WFprod, agr, tot, WFcons, agr, tot, netVWi, agr, tot), the green WF (WFprod, agr, gn, WFcons, agr, gn, netVWi, agr, gn), the blue WF (WFprod, agr, bl, WFcons, agr, bl, netVWi, agr, bl) and the green plus blue WF (WFprod, agr, gn + bl, WFcons, agr, gn + bl, netVWi, agr, gn + bl).

To date, the WFprod, agr has been assessed for some selected large river basins (Aldaya and Llamas 2009, Dumont et al. 2013, Zeng et al. 2012, Zhao et al. 2010, Hoekstra et al. 2012), but not covering the whole EU like in this study. The WFcons, agr has only been assessed in the literature on a national basis but not for river basins. The netVWi, agr, tot has been analysed in Vanham (2013a) for EU river basins. However, the author acknowledges that for policy options there is a need to compute the different components (green, blue and grey), which was not done in that study. The effect of diets on the WFcons has been carried out for the city of Milan (Vanham and Bidoglio 2014), China (Liu and Savienie 2008), Austria (Vanham 2013b), the EU as a whole (Vanham et al. 2013b) and for four EU zones (Vanham et al. 2013a). In the latter study, the importance of a regional analysis is stressed. The effect of different diets on the WFcons, agr (and the resulting change in netVWi, agr) of a river basin has not been carried out to date. River basins, not administrative borders, are the key geographical entities for water management. The main instrument for the implementation of the European Water Framework Directive is the River Basin Management Plan (EC 2012). This study presents a first comprehensive agricultural WF accounting analysis of 365 European river basins, including the effect of various diet scenarios.
Indeed, in the framework of the global water-food-energy-ecosystem nexus, the analysis conducted in this paper gives essential information.

2. Methodology

2.1. General

The methodology to compute \( WF_{\text{prod, agr}} \) and \( WF_{\text{cons, agr}} \) (and resulting net VWI, agr) river basin values based upon national values (as obtained from Hoekstra and Mekonnen (2012a) and a WF\(_{\text{prod, agr}}\) geodataset for crops (WF\(_{\text{prod, agr-crops}}\)) is presented in figure 2. To assess the effect of the two diets (HEALTHY and VEG) on the national WF\(_{\text{cons, agr}}\) the approach of Vanham et al (2013a) is applied. The most detailed geographical level for such an analysis is the national level, due to data restrictions. In this paper such an analysis is conducted for each of the 40 nations separately—based upon regional Food-Based Dietary Guidelines (FBDG) for HEALTHY as presented in table A.1—and results then transposed to river basin level. To date, such a detailed national assessment with respect to these 40 nations has only been conducted for Austria (Vanham 2013b). For the VEG, all meat of the healthy diet is substituted by an increase in the intake of products from the group pulses, nuts and oilcrops with equal caloric value and protein content.

2.2. River basins

The catchment database for continental Europe (CCM2), developed by Vogt et al (2007) (based on the digital elevation model SRTM—Shuttle Radar Topography Mission—of 90 m resolution), was used to identify the river basins (figure 1). Selected basins have to fulfill two conditions: (1) they are fully or partly located in the EU28 and remaining Balkan countries; (2) they have a surface area larger than 1000 km\(^2\).

2.3. Accounting framework

We follow the Global Water Footprint Standard developed by the Water Footprint Network (Hoekstra et al 2011). National data on the green, blue and grey WF\(_{\text{cons, agr}}\) for each nation are obtained from Hoekstra and Mekonnen (2012) and Mekonnen and Hoekstra (2011b). The WF\(_{\text{cons}}\) of agricultural products is calculated with the bottom-up approach, based upon direct underlying national data on consumption from FAO food balance sheets (FBS) FAO (2014). Three geodatasets (GIS-rasters) for the green, blue and grey WF\(_{\text{prod, agr}}\) for crops (WF\(_{\text{prod, agr-crops}}\)) (Mekonnen and Hoekstra 2011a, Mekonnen and Hoekstra 2010) with a 5 arc minute spatial resolution were obtained from the Water Footprint Network. These geodatasets are calculated based upon the crop growing areas (on a 5 by 5 arc minute grid cell resolution) from Monfreda et al (2008) and Portmann et al (2010). These geodatasets also comprise the crops which are used as feed. National blue (service water) and green (grazing) WF\(_{\text{prod, agr}}\) data for livestock (WF\(_{\text{prod, agr-liv}}\)) were obtained from Mekonnen and Hoekstra (2012) and Mekonnen and Hoekstra (2011b). The period for which the analyses were made is 1996–2005. This period is identified as REF within this study.

2.4. River basin WF and VW values

The methodology to compute river basin values based upon raster values (for the green, blue and grey WF\(_{\text{prod, agr-crops}}\)) and national values (for the green, blue and grey WF\(_{\text{prod, agr-liv}}\) and WF\(_{\text{cons, agr}}\)) is presented in figure 2. The application of this methodology is presented in online supplementary figure A.1, available at stacks.iop.org/ERL/00/000000/mmedia for green water and in figure A.2 for blue water. To assess a green and blue WF\(_{\text{prod, agr-liv}}\) faster, national WF\(_{\text{prod, agr-liv}}\) data for grazing and livestock service water were extrapolated by means of the gridded livestock of the world (GLW) rasters (with a 1 km spatial resolution (year 2000)) for different livestock types FAO (2013). The group horses, donkeys and mules is not represented by a GLW raster. To spatially distribute this livestock type, national stock data FAO (2014) are interpolated by means of the cattle GLW raster. Raster geodata of the green, blue and grey WF\(_{\text{cons, agr}}\) are obtained by multiplying national WF\(_{\text{cons, agr}}\) values (Hoekstra and Mekonnen 2012a, Mekonnen and Hoekstra 2011b) with the population raster of CIESIN (2005).
2.5. Diets

In this study three diets—the current diet (REF, 1996–2005), a healthy diet (HEALTHY) based on regional FBDG (table A.1 and figure 3) and a VEG are assessed. A detailed description on the methodology how to analyse the WF\textsubscript{cons, agr} for HEALTHY and VEG can be found in Vanham \textit{et al} (2013a). In Vanham \textit{et al} (2013a), three regional FBDG were used for the EU28: (1) the recommendations of the German nutrition society (DGE—Deutsche Gesellschaft für Ernährung, Elmadfa \textit{et al} 2009, WHO 2003), (2) the recommendations for a Mediterranean diet (MED) based upon Willett \textit{et al} (1995), Bach-Faig \textit{et al} (2011) and Aranceta and Serra-Majem (2001), (3) the recommendations of Scandinavian countries for northern Europe (NORTH) (Barbieri and Lindvall 2005, Astrup \textit{et al} 2005). Figure 3 shows which HEALTHY FBDG were used for which countries. In this paper, an additional FBDG for HEALTHY for Turkey (The Ministry of Health of Turkey 2006) was used. An overview on the four FBDG is given in table A.1, as taken from Vanham \textit{et al} (2013a) and adapted with FBDG from the Ministry of Health of Turkey (2006).

In this paper, a diet scenario analysis and its effect on the WF\textsubscript{cons, agr} is conducted for each of the 40 nations separately based upon regional FBDG (figure 3). This assessment is much more detailed than in Vanham \textit{et al} (2013a), where such an analysis was only done for four aggregated EU zones. The amount of fish recommended by the respective FBDG are substituted by meat. The reason for this is that no WF data for fish have been published thus far. Like in Vanham \textit{et al} (2013a), a VEG includes the intake of milk and milk products (cheese, butter, yoghurt, etc). All meat is substituted by the group pulses, nuts and oilcrops, by an increase in the intake of pulses and soybeans. National data on food consumption (period 1996–2005)—on which basis the WF\textsubscript{cons} is calculated—were taken from the FAO FBS (FAO 2014).

3. Results

3.1. WF\textsubscript{prod, agr}, WF\textsubscript{cons, agr} and netVWi, agr for the REF

The results for 22 major river basins in table form are presented in table A.2 (WF\textsubscript{prod, agr}), table A.3 (WF\textsubscript{cons, agr}) and table A.4 (netVWi, agr).

Figure 4 shows that river basins where the WF\textsubscript{cons, agr, tot} exceeds the WF\textsubscript{prod, agr, tot} substantially (resulting in positive netVWi, agr, tot values), are found along the densely populated and heavily industrialized London–Milan axis. Major river basins include the Thames (WF\textsubscript{prod, agr, tot} = 130 363 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 1025 948 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = 895 585 m\textsuperscript{3} km\textsuperscript{−2}), Scheldt (WF\textsubscript{prod, agr, tot} = 200 524 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 704 998 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = 504 474 m\textsuperscript{3} km\textsuperscript{−2}), Rhine (WF\textsubscript{prod, agr, tot} = 109 720 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 369 261 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = 259 541 m\textsuperscript{3} km\textsuperscript{−2}) and Po basins (WF\textsubscript{prod, agr, tot} = 219 630 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 465 324 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = 245 694 m\textsuperscript{3} km\textsuperscript{−2}). Other such basins include the Tajo basin (which encompasses the city of Madrid) or small urban river basins like the Besòs river basin in which a large part of the city of Barcelona is located.

Large river basins where the WF\textsubscript{prod, agr, tot} exceeds the WF\textsubscript{cons, agr, tot} (resulting in negative netVWi, agr, tot values) are found in Western France, the Iberian Peninsula and the Baltic region. These include the Loire (WF\textsubscript{prod, agr, tot} = 153 663 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 49 031 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = −94 344 m\textsuperscript{3} km\textsuperscript{−2}), Ebro (WF\textsubscript{prod, agr, tot} = 170 756 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 76 412 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = −94 344 m\textsuperscript{3} km\textsuperscript{−2}) and Nemunas basins (WF\textsubscript{prod, agr, tot} = 140 047 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 75 291 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = −64 757 m\textsuperscript{3} km\textsuperscript{−2}). They are characterized by low population densities and are important agricultural production regions.

Generally the same observations are made for assessments when excluding the grey WF component (figure 4, bottom row). Figure A.3 shows that similar observations are made for assessments when excluding the grey WF component (figure A.3). These \textit{are} found in Western France, the Iberian Peninsula and the Baltic region.

Large river basins where the WF\textsubscript{prod, agr, tot} exceeds the WF\textsubscript{cons, agr, tot} (resulting in negative netVWi, agr, tot values) are found in Western France, the Iberian Peninsula and the Baltic region. These include the Loire (WF\textsubscript{prod, agr, tot} = 153 663 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 49 031 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = −94 344 m\textsuperscript{3} km\textsuperscript{−2}), Ebro (WF\textsubscript{prod, agr, tot} = 170 756 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 76 412 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = −94 344 m\textsuperscript{3} km\textsuperscript{−2}) and Nemunas basins (WF\textsubscript{prod, agr, tot} = 140 047 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{cons, agr, tot} = 75 291 m\textsuperscript{3} km\textsuperscript{−2}, netVWi, agr, tot = −64 757 m\textsuperscript{3} km\textsuperscript{−2}). They are characterized by low population densities and are important agricultural production regions.

Generally the same observations are made for assessments when excluding the grey WF component (figure 4, bottom row). Figure A.3 shows that similar observations are made for assessments when excluding the grey WF component. A different pattern is observed for the river basins. High WF\textsubscript{prod, agr, tot} values are concentrated in the Mediterranean region due to irrigated agriculture and to a lesser extent in the Benelux region due to livestock service water. Examples are the Guadalquivir (WF\textsubscript{prod, agr-crops, bl} = 74 058 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{prod, agr-liv, bl} = 980 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{prod, agr, bl} = 75 037 m\textsuperscript{3} km\textsuperscript{−2}), Ebro (WF\textsubscript{prod, agr-crops, bl} = 22 799 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{prod, agr-liv, bl} = 2341 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{prod, agr, bl} = 25 140 m\textsuperscript{3} km\textsuperscript{−2}) or Scheldt basins (WF\textsubscript{prod, agr-crops, bl} = 1580 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{prod, agr-liv, bl} = 7597 m\textsuperscript{3} km\textsuperscript{−2}, WF\textsubscript{prod, agr, bl} = 9177 m\textsuperscript{3} km\textsuperscript{−2}). These WF\textsubscript{cons} are consumed throughout Europe. As a result, blue
net VW export basins (negative netVWi, agr, bl values) are concentrated in the Mediterranean, whereas other basins are predominately blue net VW import basins (positive netVWi, agr, bl values).

3.2. WFcons, agr for the diet scenarios

Table 2 shows national WFcons, agr values for different diet scenarios (REF, HEALTHY and VEG), as a result of separate national analyses. To date, such an analysis was only available for Austria (Vanham 2013b). Transposed to river basins, the effect of HEALTHY and VEG on the WFcons, agr, tot and WFcons, agr, gn+bl is shown in figure 5. For HEALTHY, the WFcons, agr, tot of most river basins decreases (maximum -31.9%), although in eastern and northern Europe some basins show an increase (similar for WFcons, agr, gn+bl). High decreases are e.g. observed in large basins like the Loire (−30.5%) or Po basin (−31.7%). The increase in some eastern and northern basins is for some basins the result of high meat intake recommendations in the FBDG of NORTH (basins in e.g. the Balkan countries, Finland and Norway). Within other basins this is the result of a general under-nutrition of products like crop oils, fruit, eggs, pulses and nuts, and for some milk and meat (basins in e.g. upper middle income countries like Albania, Bosnia and Herzegovina, Macedonia and lower middle income countries like Ukraine).

For VEG, in all but one river basin a reduction (maximum −46.4%) is observed. High reductions are observed in e.g the Loire (−46.4%), Rhone (−44.6%), Scheldt (−44.6%) or Po basins (−44.3%). Similar observations are made for the WFcons, agr, gn+bl.
Table 2 National WF$_{cons, agr}$ Values for different diets (REF, HEALTHY and VEG) (in l.c/d).

| Country            | REF     | HEALTHY | VEG     |
|--------------------|---------|---------|---------|
|                    | green   | blue    | grey    | total   | green   | blue    | grey    | total   | green   | blue    | grey    | total   |
| Albania            | 3000    | 456     | 208     | 3663    | 3239    | 472     | 236     | 3947 (+8%) | 2487    | 387    | 215     | 3090 (-16%) |
| Austria            | 3108    | 181     | 366     | 3655    | 2309    | 157     | 267     | 2733 (-25%) | 1931    | 142    | 220     | 2293 (-37%) |
| Belarus            | 3581    | 123     | 575     | 4279    | 3429    | 124     | 692     | 4245 (-1%)  | 2717    | 9     | 669     | 3482 (-19%) |
| Belgium            | 3331    | 254     | 294     | 3879    | 2386    | 202     | 222     | 2810 (-28%) | 1822    | 176    | 186     | 2184 (-44%) |
| Bosnia-Herzegovina | 2924    | 79      | 263     | 3267    | 3834    | 99      | 365     | 4298 (+32%) | 3107    | 8      | 323     | 3511 (+8%)  |

Note: (*) for Luxembourg rubber is substituted by the EU-average

Figure A.4 shows generally the same observations for the green and blue WF components. For HEALTHY, the decrease/increase in WF$_{cons, agr, gn}$ ranges between -32.2% and 23.9% (288 basins decrease, 77 increase) and in WF$_{cons,agr, bi}$ between -27.4% and 37.7% (212 basins decrease, 153 increase). For VEG, the decrease/increase in WF$_{cons, agr, gn}$ ranges between -48.0% and 0.2% (364 basins decrease, 1 increase) and in WF$_{cons,agr, bi}$ between -36.5% and 16.0% (358 basins decrease, 7 increase).

3.3. Net VW$_{i, agr}$ for the diet scenarios

The changes in WF$_{cons, agr}$ for the diet scenarios also lead to changes in the netVW$_{i, agr}$ of river basins. Figure 6 shows these changes for netVW$_{i,agr, tot}$ and netVW$_{i,agr, gn+bi}$. For the netVW$_{i,agr, tot}$, HEALTHY results in a shift from netVW$_{i}$ to netVW$_{e}$ for 22 of 365 river basins, amongst which the Danube basin (from 2243 m$^3$ km$^{-2}$ to -9387 m$^3$ km$^{-2}$) (table A.4). Two small basins shift from netVW$_{e}$ to netVW$_{i}$, VEG results in a shift from netVW$_{i}$ to netVW$_{e}$ for 50 river basins,
amongst which large basins like the Danube (from 2,243 m$^3$ km$^{-2}$ to −35,331 m$^3$ km$^{-2}$), Seine (from 111,225 m$^3$ km$^{-2}$ to −36,746 m$^3$ km$^{-2}$), Rhone (from 66,148 m$^3$ km$^{-2}$ to −25,853 m$^3$ km$^{-2}$) and Elbe basins (from 57,855 m$^3$ km$^{-2}$ to −23,410 m$^3$ km$^{-2}$). For the netVW$_i$, agr, gn + bl, generally the same observations are made.

When only the green and blue WF components are assessed (figure A.5), the shifts in netVW$_i$, agr, gn are predominantly similar as shown in figure 6. For the netVW$_i$, agr, bl, most basins remain netVW$_i$ for HEALTHY (262 basins) and VEG (244 basins). For HEALTHY, 15 basins shift from netVW$_i$ to netVW$_e$, amongst which the Loire basin (from 150 m$^3$ km$^{-2}$ to −1,253 m$^3$ km$^{-2}$). For VEG, 33 basins shift from netVW$_i$ to netVW$_e$, of which the largest the Loire (from 150 m$^3$ km$^{-2}$ to −2,115 m$^3$ km$^{-2}$) and the Tajo basins (from 9,965 m$^3$ km$^{-2}$ to −746 m$^3$ km$^{-2}$).
4. Discussion

4.1. General

This paper shows that there are substantial differences in the amounts and characterizations of the current (REF) \(WF_{\text{prod, agr}}\), \(WF_{\text{cons, agr}}\) and resulting \(\text{net } VW_i, \text{ agr}\) in European river basins. The diet scenarios show substantial shifts in the \(WF_{\text{cons, agr}}\) with resulting shifts in \(\text{net } VW_i, \text{ agr}\) amounts. From the perspective of FBDG, the \(WF_{\text{cons, agr}}\) for both the HEALTHY and VEG scenarios can be regarded as being sustainable. From the water use perspective, the \(WF_{\text{cons, agr}}\) can be regarded as being more sustainable under the VEG than under the HEALTHY scenario. Not assessed in this paper is the preferred consumption of local and seasonal food.

Figure 6 Shift in \(\text{net } VW_i, \text{ agr, tot}/\text{net } VW_e, \text{ agr, tot}\) (above) and \(\text{net } VW_i, \text{ agr, gn+bl}/\text{net } VW_e, \text{ agr, gn+bl}\) (below) within the river basins due to different diets (left HEALTHY; right VEG).
which can have some additional effect on the quantity and composition (green, blue, grey) of the WF\textsubscript{cons, agr}.

As a next step, the sustainability of the current river basin WF\textsubscript{prod, agr} should be assessed, with the relevant blue, green and grey WF sustainability indicators (Vanham and Bidoglio 2013a). Already today several of the analysed river basins experience (blue) water stress (Hoekstra et al 2012). The maximum sustainable WF\textsubscript{prod, agr} should be addressed per river basin. This can mean that the reference WF\textsubscript{prod, agr} of some river basins will have to be reduced while that of others can still be increased. Different pathways to achieving such an outcome are available. Sustainable agricultural intensification is identified as the way forward by different authors (Foley et al 2011, Godfray et al 2010, Tilman et al 2011). Yield gaps need to be closed on underperforming lands, while also reducing the environmental impacts of agriculture. If such a maximum sustainable WF\textsubscript{prod, agr} as well as the WF\textsubscript{cons, agr} of a HEALTHY and/or VEG diet were to be implemented, it is anticipated that a sustainable situation from a water resources point of view is reached. Additionally other resources/indicators such as land use and GHG emissions need to be assessed. Only by evaluating different indicators, integrated policy options can be defined.

4.2. Uncertainty in data and methodology

Different assumptions and simplifications were made in this study. Due to data availability restrictions, the results of this assessment are not absolute and must be regarded as best estimates based upon direct underlying data on production (for the WF\textsubscript{prod, agr}) and consumption (for the WF\textsubscript{cons, agr}). Both can be calculated by means of the top-down or bottom-up approach (Hoekstra et al 2011). In this Letter, both are calculated with the bottom-up which is based upon direct underlying data on production and consumption—FAOSTAT data (FAO 2014)—and is less sensitive to trade data than the top-down approach (Hoekstra and Mekonnen 2012). As described in Vanham and Bidoglio (2013b), the balance WF\textsubscript{prod} + VW\textsubscript{e} = WF\textsubscript{cons} + VW\textsubscript{e} within the geographic WF accounting scheme as calculated for the EU with the bottom-up approach does not hold 100%. For the EU28, for agricultural products, these values are 552 km\textsuperscript{3} (WF\textsubscript{prod, agr}), 360 km\textsuperscript{3} (VW\textsubscript{i, agr}), 759 km\textsuperscript{3} (WF\textsubscript{cons, agr}) and 95 km\textsuperscript{3} (VW\textsubscript{e, agr}) (Vanham and Bidoglio, 2013b). The balance therefore shifts between 855 and 912 km\textsuperscript{3} (range of about 6%). Theoretically this balance should close. This is however not the case due to practical complexities with data (availability of and inconsistencies in the underlying databases). As such the results of this assessment need to be regarded as best estimates.

The assumptions related to the methodology used to compute river basin values (figure 2, figure A.2 and figure A.3) were discussed in detail in Vanham (2013a). An important assumption is the fact that the WF\textsubscript{cons, agr} faster is obtained by spatially disaggregating national WF\textsubscript{cons, agr} data by means of a population raster dataset. This assumes that the consumption pattern is homogenous within each country. This is in reality not the case and thus a simplification. To account for this heterogeneity, regional statistics within a country could be used. Such detailed consumption data are however currently lacking (Hoff et al 2014, Vanham and Bidoglio 2014).

The grey WF methodology needs to be further standardized (Vanham and Bidoglio 2013a), therefore WF\textsubscript{prod, agr, tot} and WF\textsubscript{cons, agr, tot} results were additionally shown without the grey component (WF\textsubscript{prod, agr, gn+bl} and WF\textsubscript{cons, agr, gn+bl}).

Methodology assumptions and data availability for computing the WF\textsubscript{cons, agr} of the different diet scenarios were discussed in detail in Vanham et al (2013a). For the diets of the different zones e.g., average values were chosen from selected FBDG (table A.1), although recommendations for specific product groups often indicate a range of intake. Correction factors to compute intake values from consumption data are based upon a list of publications but are not available on a zonal/regional level (Vanham et al 2013a). An important issue is also that, although regional FBDG include fish, WF values for fish (and seafood) have not yet been published. In our analyses, these recommended amounts were substituted by meat. The WF\textsubscript{cons, agr} for the HEALTHY and VEG diets thus include the protein and energy intake of fish (substituted by meat), but the WF\textsubscript{cons, agr} calculated under the REF diet scenario does not represent the current intake of fish (and seafood) at all.

Figure A.6 shows the REF and recommended intake values of meat (including offals) and fish (including seafood) for the 40 countries. Indeed, substantial fish (including seafood) amounts are part of the REF diet in all zones. By not incorporating these values, the current WF\textsubscript{cons, agr} is in fact underestimated. Especially for different countries in the FBDG zone NORTH (Finland, Lithuania, Norway, Sweden), the recommended intake of meat including fish (49.3 kg per). The latter. This explains higher HEALTHY WF\textsubscript{cons, agr} values as compared to (underestimated) REF WF\textsubscript{cons, agr} values.

Figure A.7 shows that during the past decades the intake of meat (including offals) and fish (including seafood) has evolved to some extent. As compared to REF (1996–2005), countries with very high intakes (France, Spain) have decreased their intake whereas many with low intake values show a steady increase.

5. Conclusions

This study presents a comprehensive quantification and analysis of the WF\textsubscript{prod, agr}, the WF\textsubscript{cons, agr} and the resulting net\textsuperscript{VW\textsubscript{i, agr}} for 365 EU river basins for a REF (1996–2005) and two diet scenarios (HEALTHY and VEG). The analysis differentiates between the different green, blue and grey WF components. Such a comprehensive analysis on the river basin scale is the first in its kind.

Substantial differences in amounts and characterizations of the river basins’ REF WF\textsubscript{prod, agr}, WF\textsubscript{cons, agr} and resulting net VW\textsubscript{i, agr} are observed. The highly industrialized and
densely populated river basins along the London–Milan axis show higher WF\textsubscript{cons, agr} than WF\textsubscript{prod, agr} amounts (for tot, gn + bl and gn), identifying them as net VW importer basins. These include major basins such as the Thames, Scheldt, Meuse, Seine, Rhine and Po basins. River basins where the WF\textsubscript{prod, agr} tot exceeds WF\textsubscript{cons, agr} tot amounts (net VW exporter basins)(for tot, gn + bl and gn) are found in western France (Loire, Garonne), the Iberian Peninsula (Ebro, Duero, Guadiana, Guadalquivir) and the greater Baltic region (Nemunas). These basins are sparsely populated with extensive agricultural areas. A different pattern is observed for the river basins when only the blue WF component is analysed. High WF\textsubscript{prod, agr} bl values are concentrated in the Mediterranean region (Guadalquivir, Ebro) due to irrigated agriculture and to a lesser extent in the Benelux region (Scheldt) due to livestock service water. Blue net VW exporter basins are concentrated in the Mediterranean.

The different diet scenarios lead to substantial shifts in the WF\textsubscript{cons, agr} with resulting shifts in net VW\textsubscript{bl} agr amounts. For the HEALTHY scenario, the WF\textsubscript{cons, agr} tot of most river basins decreases with exceptions in northern and eastern Europe. High decreases are observed in e.g. the Loire (−30.5%) and Po (−31.7%) basins. As a result, 22 of the 365 river basins shift from being net VW importers to being net VW exporters. For the VEG scenario, a reduction is observed in 364 of 365 basins. High reductions are observed in e.g. the Loire (−46.4%), Rhone (−44.6%), Scheldt (−44.6%) or Po (−44.3%) basins. This results in a shift of 50 river basins from being net VW importers to being net VW exporters. Similar observations are made for the WF\textsubscript{cons, agr, gn + bl} (and netV\textsubscript{ag, gn + bl}) and for the WF\textsubscript{cons, agr, gn} (and netV\textsubscript{ag, gn}). With regard to the blue WF component, 15 basins (including the Loire) shift from being net VW importers to being net VW exporters under the HEALTHY scenario and 33 basins (including the Loire and Tajo) under the VEG scenario.

Such reduced river basin WF\textsubscript{cons, agr} can contribute to sustainable water management both within the EU and beyond its borders. They could help to reduce the dependency of EU consumption on domestic and foreign water resources or even increase virtual water exports from the EU to other regions, thereby contributing to the mitigation of the growing water scarcity in other parts of the world (Vanham \textit{et al} 2013b). As global land and water resources are finite, adaptations in both production and consumption need to be made.

Acknowledgements

The authors would like to thank MM Mekonnen for the provision of the WF\textsubscript{prod} of agricultural crops geodatasets (GIS-rasters for WF\textsubscript{prod, agr-crops}, gn, WF\textsubscript{prod, agr-crops, bl} and WF\textsubscript{prod, agr-crops, gy}). We would also like to thank Gráinne Mulhern for English proofreading.

References

Aldaya M M and Llamas M R 2009 Water footprint analysis (hydrologic and economic) of the guadalavia river basin (Scientific side paper series from WWDR-3) (UNESCO)

Araneta J and Serra-Majem L 2001 Dietary guidelines for the Spanish population Public Health Nutrition 4 1403–8

Astrup A, Andersen N L, Stender S and Trolle E 2005 Kostrådene 2005 Copenhagen, Energi- og Varmeområdet og Danmarks Fødevareforskning

Bach-Faig A et al 2011 Mediterranean diet pyramid today. science and cultural updates Public Health Nutrition 14 2274–84

Barbieri H E and Lindvall C 2005 Swedish Nutrition Recommendations Objectified (SNO) (Upplasa, Sweden: National Food Administration)

CIESIN 2005 Gridded Population of the World Version 3 (GPWv3) (Palisades, NY: Socioeconomic Data and Applications Center (SEDAC))

Dumont A, Salmoral G and Llamas M R 2013 The water footprint of a river basin with a special focus on groundwater: the case of guadalquivir basin (Spain) Water Resour. Ind. 1-2 60–76

EC 2012 River Basin Management Plans—REPORT on the Implementation of the Water Framework Directive (2000/60/EC) (Brussels: European Commission)

Elmadfa I et al 2009 European Nutrition and Health Report 2009 (Basel: Forum of Nutrition)

FAO 2013 Gridded Livestock of the World (GLW) (Rome: FAO)

FAO 2014 FAOSTAT On-Line Database (Rome: FAO)

Foley J A et al 2011 Solutions for a cultivated planet Nature 478 337–42

Galli A, Wiedmann T, Erçin E, Knoblauch D, Ewing B and Giljum S 2012 Integrating ecological, carbon and water footprint into a ‘footprint family’ of indicators: definition and role in tracking human pressure on the planet Ecol. Indica 16 100–12

Godfray H C J, Beddington J R, Crute I R, Haddad L, Lawrence D, Muir J F, Pretty J, Robinson S, Thomas S M and Toulmin C 2010 Food security: the challenge of feeding 9 billion people Science 327 812–8

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

Hoekstra A Y and Mekonnen M M 2012 The water footprint of humanity Proc. Natl. Acad. Sci. USA 109 3232–7

Hoekstra A Y, Mekonnen M M, Chapagain A K, Mathews R E and Richter B D 2012 Global monthly water scarcity: blue water footprints versus blue water availability PLoS ONE 7 e32688

Hoff H, Döll P, Fader M, Gerten D, Hauser S and Siebert S 2014 Water footprints of cities — indicators for sustainable consumption and production Hydrol. Earth Syst. Sci. 18 213–26

Liu J and Savenije H H G 2008 Food consumption patterns and their effect on water requirement in China Hydrol. Earth Syst. Sci. 12 887–98

Mekonnen M and Hoekstra A 2012 A global assessment of the water footprint of farm animal products Ecosystems 15 401–15

Mekonnen M M and Hoekstra A Y 2010 The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products (Delft: UNESCO-IHE Institute for Water Education)

Mekonnen M M and Hoekstra A Y 2011a Water footprints of cities Water footprints of cities — indicators for sustainable consumption and production Hydrol. Earth Syst. Sci. 15 1577–600

Mekonnen M M and Hoekstra A Y 2011b National Water Footprint Accounts: The Green, Blue and Grey Water Footprint of Production and Consumption (Delft: UNESCO-IHE Institute for Water Education)

Monfreda C, Ramankutty N and Foley J A 2008 Farming the planet: 2. geographic distribution of crop areas, yields, physiological

10

Environ. Res. Lett. 9 (2014) 064007
D Vanham and G Bidoglio
types, and net primary production in the year 2000 *Glob. Biogeochem. Cy.* 22 GB1022
Portmann F T, Siebert S and Döll P 2010 Mirca2000—global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modelling *Glob. Biogeochem. Cy.* 24 GB1011
Rockström J, Falkenmark M, Karlberg L, Hoff H, Rost S and Gerten D 2009 Future water availability for global food production: the potential of green water for increasing resilience to global change *Water Resour. Res.* 45 W00A12
The Ministry of Health of Turkey 2006 *Dietary Guidelines for Turkey* (Ankara, Turkey: The Ministry of Health of Turkey)
Tilman D, Balzer C, Hill J and Befort B L 2011 Global food demand and the sustainable intensification of agriculture *Proc. Natl. Acad. Sci. USA* 108 20260–4
Vanham D 2013a An assessment of the virtual water balance for agricultural products in EU river basins *Water Resour. Ind.* 1-2 49–59
Vanham D 2013b The water footprint of Austria for different diets *Water Sci. Technol.* 67 824–30
Vanham D and Bidoglio G 2013a A review on the indicator water footprint for the EU28 *Ecol. Indicators* 26 61–75
Vanham D and Bidoglio G 2013b A review on the indicator water footprint for the EU28 *Ecol. Indicators* 26 61–75
Vanham D and Bidoglio G 2014 The water footprint of Milan *Water Sci. Technol.* 69 789–95
Vanham D, Hoekstra A Y and Bidoglio G 2013a Potential water saving through changes in European diets *Environ. Int.* 61 45–56
Vanham D, Mekonnen M M and Hoekstra A Y 2013b The water footprint of the EU for different diets *Ecol. Indic.* 32 1–8
Vogt J et al 2007 *A Pan-European River and Catchment Database* (Luxembourg: IN JRC)
WHO 2003 *Food Based Dietary Guidelines in the WHO European Region* (Copenhagen: WHO Regional Office for Europe)
Willett W C, Sacks F, Trichopoulou A, Drescher G, Ferro-Luzzi A, Helsing E and Trichopoulos D 1995 Mediterranean diet pyramid: a cultural model for healthy eating *Am. J. Clin. Nutrition* 61 1402s–6s
Zeng Z, Liu J, Koeman P H, Zarate E and Hoekstra A Y 2012 Assessing water footprint at river basin level: a case study for the heilhe river basin in northwest China *Hydrol. Earth. Syst. Sci.* 16 2771–81
Zhao X, Yang H, Yang Z, Chen B and Qin Y 2010 Applying the input-output method to account for water footprint and virtual water trade in the haihe river basin in China *Environ. Sci. Technol.* 44 9150–6