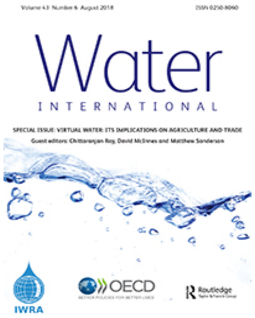

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PRESENTATION

The water footprint of the EU: quantification, sustainability and relevance

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Introduction

This presentation was delivered on behalf of the European Commission's Joint Research Centre (JRC) at the conference Virtual Water in Agricultural Products: Quantification, Limitations and Trade Policy at the University of Nebraska in Lincoln, Nebraska, USA, 14–16 September 2016, sponsored by the Organisation for Economic Co-operation and Development's (OECD) Co-operative Research Programme. It provides an overview of the quantification, sustainability and relevance of the water footprint (WF) concept, for the case study of the European Union (EU), with a focus on agricultural products. The WF concept provides the opportunity to link the use of water resources to the consumption of goods, thereby addressing supply chain thinking and showing options to remain within planetary boundaries from the perspective of consumers and companies. It provides a strong communication tool for policy-makers and citizens.

The presentation is organized by means of the following sections:

- Water footprint (WF) assessment.
- Sustainability assessment.
- One indicator to be used with others.
- Relevant scenarios.
- Conclusions.

Water footprint (WF) assessment

Introduction

Two different approaches to conduct a WF assessment exist in parallel (see Figure S1 in the supplemental data online). The volumetric approach as described in *The Water Footprint Assessment Manual* (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011) was first developed and published in 2011. The Life Cycle Assessment (LCA) community

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started later with the development of a methodology in parallel, and published in 2014 its procedure in the ISO 14,046 document (ISO, 2014). The different stages of both methodologies show that both consist of an inventory and impact assessment stage.

The Water Footprint Assessment Manual was developed within the framework of integrated water resources management (IWRM), the ISO 14,046 was not. The latter provides an assessment and reporting standard related to the WF of products, processes and organizations based on LCA. It focuses on product LCAs and environmental impact, while the Water Footprint Network (WFN) standard offers a broader framework in which WFs can be studied with a different focus (product, producer, consumer or geographical) and from different perspectives (environmental sustainability, social equity, resource efficiency or water risk) (Hoekstra 2017). As the present special issue is situated within the context of IWRM, only the WFN approach is discussed here in detail.

Quantification of WF volumes for agriculture

For the quantification of the WF of the EU (the 'inventory' or 'water accounting' phase shown in Figure S1 in the supplemental data online), which refers to a geographical WF (the EU), the following definitions are important:

- WF of production (WF_{prod}): the sum of the direct and indirect water use of domestic freshwater resources of a geographical region.
- WF of consumption (WF_{cons}): the total volume of freshwater used to produce the goods consumed by inhabitants of a geographical region. It is the sum of direct and indirect water use of domestic and foreign water resources through domestic consumption. WF_{cons} equals WF_{prod} plus virtual water (VW) imports (VW_i) but minus virtual water exports (VW_e).
- Consumptive water use: WF amounts relate to consumptive water use (the difference between abstraction/withdrawal and return flow). In addition, these amounts also include the water incorporated into a product along the supply chain.
- Blue water: the liquid water in rivers, lakes, aquifers and reservoirs.
- Green water: the soil water held in the unsaturated zone, formed by precipitation and available to plants (Rockström et al., 2009). Irrigated agriculture receives blue water (from irrigation) as well as green water (from precipitation), while rainfed agriculture receives only green water. The inclusion of green water in IWRM is a necessity and now recommended by most authors (Gerten et al., 2013; Hoekstra, 2016; Jalava, Kummu, Porkka, Siebert, & Varis, 2014; Karimi, Bastiaanssen, & Molden, 2013; Porkka, Gerten, Schaphoff, Siebert, & Kummu, 2016; Ran, Lannerstad, Herrero, Van Middelaar, & De Boer, 2016; Rockström et al., 2014; Schyns, Hoekstra, & Booij, 2015; van Eekelen et al., 2015; Vanham, 2012).
- Grey water: the grey WF component is an indicator of the degree of water pollution (Hoekstra et al., 2011). It is defined as the volume of water needed to dilute a certain amount of pollution such that it meets ambient water quality standards (Hoekstra et al., 2011). The WFN's comprehensive guideline document on accounting the grey WF (Franke, Boyacioglu, & Hoekstra, 2013) states that it is

determined by the pollutant that is most critical (i.e., requires the most water for dilution).

Many authors (e.g., Hoff et al., 2014; Thaler, Zessner, Bertran De Lis, Kreuzinger, & Fehringer, 2012; Vanham & Bidoglio, 2013) regard the grey WF component critically for various reasons:

- The water quantity it represents is not associated with the actual physical water volume of return flows. Therefore, it represents an amount of water that physically cannot be compared/added to blue and green WF components. The latter are actual physical volumes (water flows) within a hydrological water cycle/balance; the grey WF component is not.
- The water quantity is very dependent on data availability and the chosen (available) water quality standard (Thaler et al., 2012). In the past, the grey WF was generally computed based on nitrogen leaching (Hoekstra & Mekonnen, 2012; Mekonnen & Hoekstra, 2015), thereby discarding other water pollutants. Recently, efforts have been made to include other elements, for example, phosphorous (Mekonnen, Lutter, & Martinez, 2016b; Senta, Terzic, & Ahel, 2013) and other chemicals. A recent assessment of the WF of Austria (Thaler et al., 2013) results, for example, in much higher grey WF amounts as compared with a previous assessment (Vanham, 2013b), as the authors included phosphorus in addition to nitrogen. Data availability on pollutants to be included (Franke et al., 2013) is thus a restricting factor.
- When the WF is used in combination with other footprint indicators, the so-called footprint family (Galli et al., 2012; Gephart et al., 2016; Leach et al., 2016), the grey WF could be regarded as double counting. As an example, Vanham, Bouraoui, Leip, Grizzetti, and Bidoglio (2015), who quantified the water and nitrogen footprint of the EU's consumer food waste, chose not to include the grey WF because the nitrogen (N) footprint accounts for N pollution in receiving water bodies.

Although water quality as an issue is very important, we choose not to use the grey WF component, especially in an assessment combined with other footprints. Other scholars include this component in WF assessments.

A quantification of the WF_{prod}, WF_{cons} and VW flows for the EU was presented by Vanham and Bidoglio (2013). Figure S2 (in the supplemental data online) shows that the WF_{prod} for agricultural products adds up to 487 km^3/yr, of which crops constitute 426 km^3/yr (369 km^3/yr green and km^3/yr blue water) and livestock 61 km^3/yr (of which 55 km^3/yr green and 6 km^3/yr blue water). Green water consumption for crop production is spread all over the EU, whereas irrigated blue water consumption is concentrated around the Mediterranean.

The highest livestock water consumption is concentrated in Western Europe.

Figure S3 (in the supplemental data online) shows a VW balance for agricultural products for the EU consisting of WF_{prod}, WF_{cons}, VW_i and VW_e. The WF_{cons} is larger than the WF_{prod}, which means that the EU is a net VW importer for agricultural products. This has several reasons:

- The EU is for some products not self-sufficient (although it is for many products).
- Overconsumption in the EU of water-intensive products (e.g., meat, more than 50% of cereals production in the EU is for feed) (Vanham & Bidoglio, 2013; Vanham, Mekonnen, & Hoekstra, 2013b).
- The production of agricultural products is very water efficient in the EU as compared with the countries from which it imports. Domestic water productivity depends on production methods (irrigated versus rainfed, conservation agriculture, nutrient application etc.), higher yield, and agroclimate conditions (soil, climate etc.) (Vanham & Bidoglio, 2013).

The main agricultural products that account for the largest VW imports include wheat and soybeans from the Americas, cotton from Asia and cocoa and coffee (see Figure S4 in the supplemental data online).

The main agricultural products that account for the largest VW exports from the EU include cereals to Northern Africa, Turkey, Switzerland, China and Japan, as well as meat and wine to the United States, Russia and Japan (see Figure S5 in the supplemental data online).

The status of a region as a net VW importer or exporter says nothing about the sustainability of water use within that region or the regions it imports VW from and/or exports VW to. For that, a WF sustainability assessment needs to be made.

Other important components/sectors to be included in a geographical WF assessment

Although the focus of this paper is on the WF of agriculture, it should be noted that in geographical WF assessments other sectors also account for a WF.

Domestic and industrial water uses are generally included in geographical WF assessments. However, within the water–energy–food–ecosystem (WEFE) nexus context (see Figure S6 in the supplemental data online), other sectors/components should also be included (see Figure S7 online). This is discussed in detail by Vanham (2016). The inclusion of these other components is not common praxis. This is recognized in recent research (e.g., Schyns, Booij, & Hoekstra, 2017). Other scholars refer to the water–energy–food (WEF) nexus (Taniguchi, Endo, Gurdak, & Swarzenski, 2017) or the food–energy–water (FEW) nexus (Chini, Konar, & Stillwell, 2017; Scanlon et al., 2017).

Sustainability assessment

The SDGs for water, energy and food security

In order to provide the Sustainable Development Goals (SDGs) for water, food and energy security in a nexus setting (Vanham, 2016) to a growing and urbanizing global population (UN, 2014), within global planetary boundaries with limited (water) resources availability (Rockstrom et al., 2009), solutions need to come from both the production and consumption sides (Foley et al., 2011;Godfray et al., 2010).

Production-side solutions include (Foley et al., 2011; Godfray et al., 2010):

- The sustainable intensification of agriculture. Increasing water productivity (expressed in, e.g., kg/l, kg/m^3, ton/m^3,, the inverse of WF$_{prod}$) by closing yield gaps and integrated land and water management on existing agricultural lands (rainfed and irrigated) is key to this development. Often,the increase in water productivity (decrease in WF$_{prod}$) is referred to as 'more crop per drop'. In the wider context of the WEF nexus (Vanham, 2016), the expression 'more biomass per drop' (apart from crops also fish, livestock, fibre, tree biomass etc.) is more appropriate.
- Production processes along the supply chain need to become more resource efficient and sustainable. Water scarcity and water pollution need to be eradicated.

In order to achieve sustainable WFs in agriculture, water scarcity and the increase in water productivity (or the decrease of WF$_{prod}$) thus need to be addressed. Both should be an integral part of a WF sustainability assessment. It is also referred to as SDG target 6.4: 'By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.'

Demand-side solutions include:

- Consumer behaviour in water use, energy consumption, food consumption and (food) waste generation.
- Some scholars also state that family planning to lower per capita fertility should be part of the solution (Speidel, Weiss, Ethelston, & Gilbert, 2009). In many regions of the world, significant population increases are projected for the next few decades (UN, 2014). There are consequently more frequent calls to address environmental problems by advocating further reductions in human fertility (Bradshaw & Brook, 2014), including in the second notice of 'World Scientists' Warning to Humanity' (Ripple et al., 2017).

It is clear that the provision of water, energy and food security for people within a geographical region relates to the consumption side of this geographical region and not the production side. Trade between regions is thus essential to provide these three securities. Sustainability does not mean self-sufficiency.

Water-related sustainability of EU agricultural production

Many regions of the EU are confronted with physical (blue) water scarcity and/or groundwater depletion at least for some part of the year (Custodio et al., 2016; Hoekstra, Mekonnen, Chapagain, Mathews, & Richter, 2012; Mekonnen & Hoekstra, 2016; Wada, van Beek, & Bierkens, 2012; Werner et al., 2013). In addition, the EU imports agricultural products from regions where physical (blue) water scarcity and/or groundwater depletion occurs (Dalin, Wada, Kastner, & Puma, 2017; Mekonnen & Hoekstra, 2016; Wada et al., 2012).

Within the EU, agricultural production of crops and livestock attributes to pollution (e.g., nutrients) of freshwater bodies (see Figure S8 in the supplemental data online) and bordering seas (Bouraoui and Grizzetti, 2011; Bouraoui, Thieu, Grizzetti, Britz, & Bidoglio, 2014; Grizzetti, Bouraoui, & Aloe, 2012; Leip, Weiss, Lesschen, & Westhoek, 2014) (see Figure S9 online). In addition, agricultural products imported into the EU contribute to the pollution of freshwater bodies in regions where they are produced (Mekonnen & Hoekstra, 2015).

Eastern Europe is identified as a region with considerable intensification opportunities for major cereals (Mueller et al., 2012). Amongst the greatest opportunities for increases in global absolute production (from closing yield gaps to 100% of estimated attainable yields) is wheat in Eastern Europe (predominately due to nutrient limitation). Romania, for example, has average wheat yields of 2–3 ton/ha, whereas in Ireland, average yields are in the range 7–8 ton/ha (see Figure S10 in the supplemental data online). The WF_{prod} of many crops can therefore be decreased (water productivity increased) by integrated land and water management (including nutrient management), as the example of wheat shows (see Figure S10 online). Ireland, for example, has amongst the lowest wheat WF_{prod} in the world (460 m^3/ton), whereas in Romania it averages 1980 m^3/ton.

A WF sustainability assessment is an integral part of a WF assessment (see Figure S1 in the supplemental data online). To make a WF sustainability assessment, theoretically environmental, social and economic indicators are required. This is discussed in more detail by Hoekstra et al. (2011) and Vanham and Bidoglio (2013). The indicators used for an environmental impact assessment are discussed below. The increase of agricultural water productivity as part of a WF sustainability assessment, is briefly discussed below.

To increase water productivity for agricultural production and tackle water scarcity and water pollution, integrated land and water management is a necessity. This refers to the promotion of system-based farming practices that integrate land, water, nutrient, livestock and crop management within a river basin management approach. The following farm-level actions are relevant (amongst others) (Vanham & Bidoglio, 2013):

- Management of irrigation systems: choice of technology (e.g., drip), irrigation scheduling, deficit irrigation, use of soil moisture and canopy sensors.
- Soil moisture conservation: e.g., by conservation tillage that optimizes soil carbon content or mulching (organic residues, plastic films).
- Nutrient management: including on-farm nutrient cycling or precision agriculture, to increase yields and water productivity and reduce water pollution.
- Cropping strategies: including the avoidance of growing high-water-demand crops during summer (e.g., maize) when water availability is low; and growing drought-tolerant or low-water-demand crops.
- Optimal use of available water resources: including rain water harvesting, wastewater recycling and artificial groundwater recharge (natural water buffer for use during dry periods).
- Limit the intensification of livestock production to animal welfare constraints.
- Riparian buffers (Weissteiner, Bouraoui, & Aloe, 2013) or constructed wastewater treatment wetlands to control water quality.

Environmental impact assessment of WF_{prod}

For an environmental impact assessment, the following indicators are required:

- Blue water scarcity: generally defined as the ratio between water use (water abstraction or consumption) and water availability (total or ecological, the latter being total water availability minus ecological/environmental flows). It has been used in different variations (Alcamo, Flörke, & Märker, 2007; EEA, 2003; Mekonnen & Hoekstra, 2016; Raskin, Gleick, Kirshen, Pontius, & Strzepek, 1997; Rijsberman, 2006; Smakhtin, Revenga, & Döll, 2004; Vanham, Fleischhacker, & Rauch, 2009a,2009b; Wada et al., 2011). It is now generally recognized that also environmental flows need to be taken into account (Vanham & Bidoglio, 2013). In addition, the sustainability of groundwater use needs to be addressed. Groundwater is often connected to surface water. In such connected systems, river surface water can feed groundwater, and vice versa. When groundwater levels sink below riverbeds, the connection is generally lost. This is often the case in heavily depleted aquifers. Specific indicators addressing the sustainability of groundwater use have been developed (e.g., Gleeson, Wada, Bierkens, & van Beek, 2012; Wada & Bierkens, 2014). Indicator 6.4.2 of the SDGs ('Level of water stress') is a recommended metric to assess blue water scarcity. However, with respect to the WF, water consumption and not water abstraction needs to be used (Vanham et al., 2018a).
- Green water scarcity/impact of green WF: there is no clear recommendation how this should be addressed. An overview of possible relevant indicators/assessments was recently made by (Schyns et al., 2015). Some authors argue that a green WF impact assessment refers to the difference in green ET between current agricultural land use (crop or livestock production) and a reference state.
- Water pollution level: as we do not use grey water, this also applies to this indicator.

Water productivity

A setting to achieve higher water productivity for crops is achieved by determining benchmarks. A global assessment of WF benchmarks for crops was made by Mekonnen and Hoekstra (2014). Crop WF benchmarks are, however, dependent on agro-climatological conditions.

The terminology 'more biomass per drop' refers to other sectors than only crop production; it also includes livestock production, aquaculture or tree biomass (apart from crops also fish, livestock, fibre, tree biomass etc.).

A major trade-off in increasing water productivity, e.g., in nutrient-limited areas, is a potential increase in water pollution. When comparing Figure S8 (and Figure S2b as an indicator for the location of livestock production in the EU) with Figure S10b (all in the supplemental data online), it is clear that high water productivity in reality often results in high water pollution.

One indicator to be used with others

The indicator WF provides information on the use of the resource water along the supply chain as well as the impact of this water use. However, it is a partial tool. It does not account for water aspects such as flooding or lack of water infrastructure, nor does it account for other (finite) resources and the (environmental) impact of their use. An overview of resources required to provide the three essential human securities and associated environmental impacts is displayed in Figure S11 in the supplemental data online.

For integrated policy options, more indicators are required. Different authors therefore recommend using a family of environmental footprint indicators (Galli et al., 2012; Ibidhi, Hoekstra, Gerbens-Leenes, & Chouchane, 2017), the latter being an umbrella term for the different footprint concepts that have been developed during the last two decades (Hoekstra & Wiedmann, 2014). Other well-established footprint indicators include the nitrogen footprint (Leip et al., 2014), phosphorous footprint (van Dijk, Lesschen, & Oenema, 2016), land footprint (Weinzettel, Hertwich, Peters, Steen-Olsen, & Galli, 2013), carbon footprint and energy footprint. Indeed, policy recommendations developed based on one footprint indicator can make no sense when an additional indicator is analyzed (Mekonnen, Gerbens-Leenes, & Hoekstra, 2016a). In parallel, the LCA community developed methodologies that also include different resources and impacts, including for the resource water. To summarize:

- It is not recommended to develop integrated policy options based on the WF alone. Footprint families are better suited, possibly in addition to other indicators.
- The nitrogen and phosphorous footprints include a quantification of the impact on water pollution by use of these nutrients. As we do not use the grey WF component, these footprints account for this important pollution source.
- It is not recommended to develop trade policies based on only VW trade analyses.
- Risks in trade flows can, however, be detected, for example, for importing countries that import agricultural goods (partially) produced unsustainably (Hoekstra & Mekonnen, 2016; Vanham, Gawlik, & Bidoglio, 2017a) or with depleted groundwater (Dalin et al., 2017).
- There is a need to streamline the footprint and LCA methodologies.
- The strength of the LCA is that it integrates different resources and impacts in its analysis framework.

Relevant scenarios

Apart from scenario analysis on the production side (e.g., crop WF_{prod} benchmarking, as previously described), the WF provides a unique possibility to link the resource water with the consumption side, and thus scenarios on the consumption side. During the last years, the JRC has made several such analyses:

- Lost water resources due to EU consumer food waste (Vanham et al., 2015).
- The effect of different diets on the EU's WF_{cons} (Vanham et al., 2013b) (see Figure S12 in the supplemental data online).
- The effect of diets on the WF of different EU zones (Vanham, Hoekstra, & Bidoglio, 2013a), countries (Vanham, 2013b), EU river basins (Vanham, 2013a; Vanham & Bidoglio, 2014a) and cities (Mekonnen et al., 2016a; Vanham & Bidoglio, 2014b; Vanham, Gawlik, & Bidoglio, 2017b; Vanham et al., 2016a; Vanham, Mak, & Gawlik, 2016b; Vanham, Comero, Gawlik, & Bidoglio, 2018b).

Figure S12 online shows the following:

- EU citizens can save a lot of water by shifting to a healthier diet. Currently they consume too much sugar, oil, meat, animal fat and alcoholic beverages and not enough fruit and vegetables.
- The WF of food consumption is of a whole other magnitude than the amounts in domestic water use (130 l per capita per day EU average).
- In the past, information campaigns focused on the reduction of direct water use, with resulting effects, as displayed for the Netherlands. Also, the industry made important efforts to make, for example, washing machines or toilets, more water efficient.
- Water is probably the most recognizable resource for consumers. Consumers really understand water amounts (e.g., litres) because they are confronted with them in daily life, as opposed to numbers/amounts of other footprints/resources such as the carbon or nitrogen footprints. This is part of the success of the WF.
- The WF is a very strong communication tool and is also valuable for awareness raising.

As overweight and obesity have been steadily increasing over the last decades to currently alarming rates in Organisation for Economic Co-operation and Development (OECD) countries (see Figure S13 in the supplemental data online) (NCD-RisC, 2016), a shift to healthier diets would mean the following:

- A massive positive impact on the overall health of the population.
- Reduce the WF of OECD countries, because the agricultural products that are over-consumed, such as meat and sugar, are very water intensive to produce.
- Have the potential to reduce health spending in OECD countries.

Conclusions

The EU is a region where both water scarcity and pollution due to agricultural processes prevail. Both are, however, spatially and temporally very heterogeneously spread. The western zone is, for example, characterized by the highest wheat water productivities in the world, whereas the eastern zone is identified as a hotspot for closing wheat yield gaps and increasing water productivity. In addition, the EU imports agricultural products from regions outside its borders affected by water scarcity and pollution.

With respect to the title of the conference ‘Virtual Water in Agricultural Products: Quantification, Limitations and Trade Policy’, it can be stated that trade is essential to provide for the SDGs’ food, energy and water security in a sustainable way, within a nexus (the water–energy–food, or WEF nexus) context (Vanham, 2016). Water is one resource to provide for these securities, but not the only one. Water scarcity and water pollution are two important impacts as a result of providing these securities, but not the only ones (see Figure S11 in the supplemental data online). Therefore, it can be concluded that for integrated policy recommendations, including trade policies, more indicators than only the WF need to be used.

There are two main approaches in WF assessment being developed, one described in the *Water Footprint Manual* (Hoekstra et al., 2011), which is developed within the framework of the IWRM, the other described in ISO 14,046 (ISO, 2014), which is developed by the LCA community. Both are based on supply-chain or life-cycle thinking, accounting for all water uses along the supply chain. Both include an inventory and impact assessment phase (see Figure S1 in the supplemental data online). Synergies between both include the following:

- A strength of the LCA approach is that it takes into account different resources and impacts, not only for water. For integrated policy recommendations, such an integrated approach is necessary. For the latter goal, the *Water Footprint Manual* (Hoekstra et al., 2011) approach should be used in combination with other indicators. Footprint family assessments have been done in the past for particular topics and are recommended. In addition, this would partially compensate for the grey WF, as, for example, the nitrogen and phosphorous footprints would partially compensate for the impacts on water quality.
- The inclusion of green water as a WF component is a necessity. This has been from the beginning included in the *Water Footprint Manual*, but has not originally been advocated by the LCA approach.
- For sustainability assessments, also a water productivity assessment of agricultural production is a necessity due to global challenges and SDGs. As increases in water productivity (decreases in WF_{prod}) can lead to increased water pollution (trade-offs), a simultaneous assessment of other indicators is necessary. This is also expressed in SDG target 6.4.
- The indicator blue water scarcity has been developed and used within the water management community for a few decades. As a method, the new SDG indicator 6.4.2 is recommended, but – in the case of a WF assessment – by using water consumption instead of water withdrawal (Vanham et al., 2018a).

For geographical WF assessments, apart from the WF of agricultural products, also other WF components from other sectors need to accounted for, as described by Vanham (2016).

The WF concept provides a unique opportunity to link the use of water resources to the consumption of goods. In order to achieve the three main human securities in a sustainable way, solutions also need to come from the consumption side, especially – regarding food – through the diet and food waste behaviour of global consumers. Therefore, the main strengths of the WF concept are the following:

- A visualization of the link between (local) consumption and (global) appropriation.
- As water is probably the most recognizable of our resources in terms of quantities (the average consumer has a very good idea of, for example, the volume of 1 litre of water), the WF is very valuable for communication and awareness raising of water appropriation related to consumed goods.
- Especially in OECD countries, where overweight and obesity with associated health problems have been increasing steadily during the last decades, a shift to

> a healthier diet of the general population would be of great benefit for general health, healthcare spending but also resource use and the environment. The WF provides for an additional indicator to show this necessity to policy-makers and the general public.

For the latter reasons, the European Commission has started specific communications using the WF indicator. It is, for example, part of the recently published *Urban Water Atlas of Europe* (European Commission, 2017; Gawlik et al., 2017), which was presented on 27 April 2017 during the meeting of ministers in charge of water management from the 43 members of the Union for the Mediterranean (UfM), hosted by the Maltese government in Valetta (UfM, 2017).

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