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WATER FOOTPRINT: A NEW APPROACH FOR A MORE SUSTAINABLE FUTURE

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ABSTRACT

Sustainability of water use has got into focus recently, as availability of fresh water resources is under depletion. Population growth, extreme weather conditions (drought), increasing global meat demand all results in higher water consumption of humanity and ecosystem. Water footprint is a promising indicator, which assesses both qualitative and quantitative deterioration of fresh water supplies. By identifying blue, green and grey water components, water use can be assessed in a more comprehensive way. Furthermore impact assessment of different components during production and processing let us identify crucial points of water use, where more efficient solution should be found. As a consequence of a more conscious and sustainable water use assessment considering water footprint, there is a chance, that future generations will inherit fresh water supplies at least in the same condition as we got it from our ancestors.

Keywords: water management, water footprint, blue water, green water, gray water

1. INTRODUCTION

Sustainability is a balance between economy, environment and society by approaching one segment e.g. agriculture considering all of its pillars or analysing that sector only based on each pillar (economic, environmental or social) separately. Two from sustainable development goals defined by UN (United Nations) in 2015 were related to water. Namely the sixth; Clean water and sanitation and the fourteenth; Life below water [31]. However these will be influenced by global trends in agriculture such as climate change. For increasing production capacity of crop production and animal husbandry, reasonable water use is crucial, especially if it is considered, that fresh water resource availability is under depletion. Higher average temperature, lower amount of precipitation, extreme weather conditions such as drought, flood or internal water all influence water availability and decrease water supply ability of natural ecosystems for humanity.

As it was highlighted above, dealing with water resources in a sustainable way is one of the biggest challenge in the 21th century. Water footprint is a comprehensive tool for understanding issues related to global water use and water consumption. However for finding the right solution, understanding definitions related to water footprint and analysing its components in appropriate way is inevitable and I hope this paper will help this process.

2. THEORY

2.1. What is water footprint?

A new concept was developed to better understand the impact of water consumption by human activities, both direct and indirect, starting from the idea of virtual water trade [2] and Ecological footprint [37]. This concept is the Water Footprint (WF), introduced by Ref. [17], which is quantitative and qualitative

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indicator. It is quantitative since it calculates the volume of water consumption to produce goods or services during their total supply chains, and it is qualitative since it assesses the amount of water required to assimilate pollutants based on the water quality standard in an ecosystem [8] [23] [24].'*The water footprint is comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal. The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint are specified geographically and temporally'* [16].

According to Ref. [4], the possible reduction of wasting water caused by production and consumption activities is a global issue considering water footprint. It refers to a quantitative amount of impact, however it also means a qualitative load according to the local water resource availability [12]. Research on water-energy-food nexus has become into focus recently [11]. The approach assesses the links between different aspects of the sustainability of food products and their impact on water resources. According to Ref. [34], *'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.'* The WF can be interpreted as an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer [30]. The WF of an individual, community or business is 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. For being able to develop strategies for sustainable water use, green, blue and grey water footprint elements of WF indicator should be analysed in more details.

2.2. Blue, green and grey water

Water footprinting methods have been developed to account for green, blue, or grey water [25] [16], where the green water is defined as the rainfall that is held within the soil profile and used by the plants, and the blue water is defined as water used from groundwater and surface water resources. Blue water is made available to the plant via irrigation. The grey water is defined as the volume of water required to assimilate contaminants loads to the accepted (standard) levels in receiving water bodies [16]. Within the water footprint methods, both direct and in-direct water uses for a product or process are accounted for. The direct water use is defined as the water used directly in the production of a product, such as the green water from rainfall and the blue water from irrigation that is used to grow grass. Whereas in-direct water use is defined as the water used indirectly, such as in the manufacturing of fertiliser and production of the electricity that is used on the farm. Blue water is abstracted from rivers, lakes and groundwater. Agriculture accounts for approximately 85% of global blue water consumption [27]. Green water is used at the point where rain falls. According to Ref. [26], 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 is based on blue water (from irrigation) and green water (from precipitation), while rainfed agriculture is based only on green water. Traditional water use statistics only take into account blue water. Conventional approaches to water management have focused on managing only the blue element of the water cycle. Ref. [19] did dairy specific interpretation of blue and green water by which blue water is the *'fresh surface water, groundwater and rainwater stored in artificial ponds'* and green water is *'water from precipitation that does not run-off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation'*. In simply way blue water is abstracted from rivers lakes and groundwater and green water is used at the point where rain falls.

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2.3. Blue, green and grey water footprint

Ref. [6] defined blue water footprint as blue water consumption from surface and groundwater resources through the total supply chain of a product. Consumption refers to water loss from groundwater body in catchment area by evaporation, returning to another catchment area or incorporation into a product. The green water footprint considers rainwater as green water resource, till it does not become run-off. The grey water footprint considers freshwater volume required to assimilate a certain pollutant load, which meet water quality standards of the region or country. There is more research on blue water resources as it has higher opportunity cost than green water and it is available in limited volume. However green water resources are scarce as well, especially if we consider that blue water can be substituted by green water in agriculture. Historical datasets only focused on blue water, thus green water as a factor influencing production has been under valuated [10]. Ref. [10] and Ref. [35] started to emphasise the importance of green water in water management studies. The reason of this was that rainfed agriculture is the largest (green) water user worldwide. Irrigated agriculture is the largest blue water user worldwide. Therefore research started to assess the green component of the water cycle, e.g. Ref. [13] and Ref. [38].

Water footprint studies of European countries, such as Ref. [1], Ref. [28], Ref. [33], and countries outside Europe, such as Ref. [7], Ref. [21], and Ref. [36] all included both blue and green water in their water footprint assessment. The concept of grey water footprint expresses a pollution volume, thus can be compared with volume of water consumption [8]. Grey water footprint is interesting, if polluted water can be reused after different kinds of waste water treatments. If treated water reach the quality standards of irrigation water, it will decrease the negative impact of the system on the environment. Freshwater appropriation consists of both consumptive water use and the water required to assimilate pollution so all green, blue and grey water footprints [23]. Assessing grey water footprint has got into focus recently by analysing the importance of pollution as a driver of water scarcity. Ref. [29] revealed that water consumption is not the only factor causing water scarcity; pollution plays an important role as well. Taking into account grey water footprint, production could be more sustainable environmentally. If this treated grey water can substitute blue water for irrigation, the production might be more sustainable in an economic way as well.

3. WATER FOOTPRINT METHODOLOGIES

3.1. WFN-Water footprint Network

According to Ref. [14] most research on water footprint follow volumetric approach of the Water Footprint Network (WFN). Ref. [34] made a review on the WF indicator and its applicability for EU28 policy using this approach as well. They differentiated WF of production (WFprod) and the WF of consumption (WFcons) of a geographical region (EU28). WF of production is the sum of direct and indirect water use of domestic water resources. WF of consumption 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.

EU28 is a net virtual water importer as it imports more virtual water than it exports. The WF of agricultural products is 91% of the total WFprod and 89% of the WFcons. This study also assessed geographical environmental sustainability indicators such as green and blue water scarcity and water pollution level. The blue water scarcity indicator is calculated by dividing the blue WFprod by hydrological water availability minus environmental flows in the geographical area. The green water scarcity indicator is calculated by

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dividing the green WFprod by the green water availability of a geographical region. The water pollution level indicator is obtained by dividing the sum of all grey WFprod in a catchment to its actual runoff.
The above mentioned indicators used by Ref. [34] certify that all blue, green and grey water components represent important roles in volumetric approach of the Water Footprint Network. Applying them let one better understand environmental sustainability of agricultural products. Ref. [4] interpreted WF regarding the water consumption of agricultural products from "cradle to gate" using also WFN database for the WF indicator as main reference. They provided a free dataset of the WF indicators available for agricultural products. This study revealed that sustainability of an agricultural product is closely related to its impact on water resource.

3.2. LCA: Life Cycle Analysis

The Life Cycle Analysis approach as developed by the LCA community (which includes the weighted WF approach [34]. Life Cycle Assessment is a 'compilation and evaluation of the inputs, outputs and potential environmental impact of a product system throughout its life cycle' [19]. LCA is relevant in comparing the environmental performance of a product during its entire production chain. Impact of water consumption and degradation are usually assessed within the framework of water footprint assessment. Ref. [19] interpreted three main levels of impact assessment adapted from Ref. [3]. Inventory consists of entering and exiting flows focusing on direct and indirect water sources water sources and uses in order to present where reductions can occur. Midpoint assessment illustrates indicators regarding degradation cause-effect chains. Endpoint assessment analyses specific indicators for potential damage to human health, ecosystem quality and resources. Besides ecosystems and human health, water serves as natural resource for several economic activities. Thus population growth and economic development results in increasing human freshwater use. However, at regional scale, main part of global freshwater withdrawal occurs in watersheds, which already experiencing high water scarcity. According to Ref. [25], *'the humanity's water footprint (referred as the sum of withdrawals multiplied by local water stress indices) must be globally reduced by approximately 50 % to achieve a sustainable water use.'* Thus assessing environmental aspects of freshwater use is inevitable. Diverse initiatives are available for developing and standardising analytical tools to measure and assess freshwater use at both regional and global scale. Furthermore these initiatives aim to improve freshwater resource management and the environmental performance of products and operations. According to Ref. [5] water scarcity considering domestic use could be influenced by shifting environmental burdens to other LC stages and impact categories. Withdrawn and released water can be associated with loss of functionality associated with water stress. Modelling approach of their study presented impact of diseases and malnutrition as years of life lost. The so called AWARE (available water remaining) method was based on the quantification of relative available water remaining per area, once the demand of humans and aquatic ecosystems has been met. Ref. [6] WULCA (Water Use in Life Cycle Assessment) consensus characterization model for water scarcity footprints: The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). Water scarcity results when cumulative human impacts decrease water supply or quality to the point that water demand of humans and the environment cannot be satisfied [32]. Water scarcity is generally related to harsh climatic conditions, but is sometimes increased by low economic development that limits exploitation of groundwater resources or optimal management of available water. Understanding links between inventory analysis and impact assessment is crucial to get plausible conclusions regarding water footprint process. The reason of why it is assessed, the unit of assessment such as product, organisation, community or activity and system boundaries of investigated process all have to be clearly identified in order to get the goal and scope of definition (ISO 14046). During

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inventory analysis, all water flows in and out of the operation need to be quantified by water source or destination.

3.3. Calculation of blue, green and grey water footprint of a process step

Basically water footprint of a process is expressed as water volume per unit of time. It can be expressed as water volume per product unit in case when it is distributed over the quantity of product that results from the process (product units per unit of time).

3.4. The blue water footprint in a process step

$$WF_{process\ blue} = Blue\ water_{Evaporation} + Blue\ water_{Incorporation} + Lost\ Return\ Flow \quad (1)$$

Unit: [volume/time]

The first component, blue water evaporation, is the most important one. All kind of evaporation is taken into account such as; the water that evaporates during water storage, transport, processing and collection or disposal. However other three components should be included when relevant. Blue water that is incorporated into the product, blue water that does not return to the same catchment area, for example, it is returned to another catchment area or the sea and blue water that does not return in the same period, for example, it is withdrawn in a scarce period and returned in a wet period. Thus the amount of available blue water consumed by humans, the groundwater and surface water flow that is left to sustain the ecosystems and water that is returned in another period of time are also considered.

3.5. The green water footprint in a process step

Calculating green water footprint in a process is relevant where the product is based on crops or wood, as it consumes rainwater by evapotranspiration, which then is incorporated into the harvested crop or wood.

$$WF_{process\ green} = Green\ water_{Evaporation} + Green\ water_{Incorporation} \quad (2)$$

Unit: [volume/time]

3.6. The grey water footprint in a process step

The grey water footprint is calculated by dividing the pollutant load (L, in mass/time) by the difference between the ambient water quality standard for that pollutant (the maximum acceptable concentration c_{max}, in mass/volume) and its natural concentration in the receiving water body (c_{nat}, in mass/volume). The natural concentration in a receiving water body occurs, if there were no human disturbances in the catchment thus $c_{nat} = 0$.

$$WF_{process\ grey} = \frac{L}{c_{max} - c_{nat}} \quad (3)$$

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3.7 Point sources of water pollution

In the case of point sources of water pollution, when chemicals are directly released into a surface water body in the form of a wastewater disposal, the load can be estimated by measuring the effluent volume and the concentration of a chemical in the effluent.

$$WF_{process,green} = \frac{L}{c_{max} - c_{nat}} = \frac{Effl \cdot c_{effl} - Abstr \cdot c_{act}}{c_{max} - c_{nat}} \tag{4}$$

L: the pollutant load (mass/time)

c_{max}*: the maximum acceptable concentration of pollutant* c_{max}*, in mass/volume*

c_{nat}*: natural concentration in the receiving water body (*c_{nat}*, in mass/volume*

Effl: the effluent volume (Effl, in volume/time)

c_{effl}*: the concentration of the pollutant in the effluent (*$_{ceffl}$*, in mass/volume)*

Abstr: the water volume of the abstraction (Abstr, in volume/time)

c_{act}*: actual concentration of the intake water (*c_{act}*, in mass/volume)*

3.8 The total water footprint of a process

The total water footprint of the process of growing crops or trees (WFproc) is the sum of the green, blue and grey components:

$$WF_{process} = WF_{process,blue} + WF_{process,green} + WF_{process,grey} \tag{5}$$

Unit: [volume/mass]

4. CONCLUSIONS

Qualitative and quantitative deterioration of water resources as a result of human activity will become more serious, basically since the water is essential for both plant and animal sectors, and especially, due to climate change. Other factors such as social situation and habits, technological leakage, water price and tourism all have impact on resident's water consumption. According to Ref. [29], *'Even without negative climate change effects, the water consumption for food production will increase to meet demands of a 50% larger global population'.* For producing much more food with high water requirement, applying sustainable water use management during its production and processing phase is crucial. Current water sources should be preserved for future generations at least in the same condition as it was inherited from ancestors. By understanding and applying water footprint indicator primary producers (farmers) and processors can assess water use of their activity. If they can calculate where are the points with the highest water demand during production and processing phase, they will be able to find solutions for more water efficient operation. Considering blue, green and grey water use separately let them analyse water use in a comprehensive way by which they can identify more precise consequences and recommendations.

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