Sustainable water management in industry using Industrial Water Footprint

NYDRIOTI I.[1] and GRIGOROPOULOU H.[1]

[1] School of Chemical Engineering, National Technical University of Athens, Athens, 15780, Greece

*corresponding author: Ioanna Nydrioti
e-mail: inydrioti@chemeng.ntua.gr

Abstract Large quantities of water are consumed directly or indirectly by production and distribution plants. Industries are rapidly required to comply with the principles of sustainable development through United Nations Sustainable Development Goals (UN SDGs), focusing on sustainable water management, such as SDG 6 (clean water and sanitation), 12 (responsible consumption and production), 13 (climate action) and 14 (life below water) Industrial Water Footprint (IWF) is an important tool for estimating and analyzing water consumption, thus enabling the industry to move to a more sustainable direction. Operational WF focuses on the WF resulting from industrial processes i.e. manufacturing & packaging while supply chain WF represents the WF of the raw materials and products used in the production.

The aim of this paper is to present and compare the operational and supply chain WF of different industrial branches, showcasing its applicability as an environmental pressure indicator. Selected industrial branches, worldwide and also in Greece, where significant water quantities are needed for production will be analyzed, given that water consumption is not only an economic parameter but also a tool to determine process performance within the branch.

Through WF assessment, increased water consumption spots and water recycling potential can be identified, resulting to process or management alternatives, with significant economic and environmental impacts on the production and/or consumer behavior.

Keywords: Water management, Water footprint, Industrial processes, Supply Chain, Environmental pressure indicator

1. Introduction

Water is an essential resource to sustain life and development, being a key element of ecosystems. Freshwater is also crucial for drinking water provision, for hygiene, and for food supply as irrigation water in agriculture. Industrial production and many services depend on continuous availability of freshwater (Sala et al., 2013). However, despite its readily acknowledged importance, water resources management is often insufficient leading to numerous environmental challenges related to water. The main drivers for water overexploitation and pollution are population growth and economic development. Population increase leads to augmented consumption of goods and services requiring water for their production. Climate change is also affecting water use; extreme weather events and warmer temperatures raise water demand in agriculture, industries and households. Despite the noticeable impact of climate change on water use, the current water crisis is mainly due to growing populations and consumption of water-intensive goods and services (Hogeboom, 2020).

Industries are rapidly required to comply with the principles of sustainable development focusing on broad water accounting in production and distribution so as to better manage and reduce their freshwater consumption.

The United Nations Sustainable Development Goals (UN SDGs) are a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere. The 17 Goals were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development which set out a 15-year plan to achieve the Goals (United Nations, 2021). Therefore, SDGs set the directions on corporate and industrial sustainability.

Great proportion of the SDGs focuses on sustainable water management, such as SDG 6 (clean water and sanitation), 13 (climate action) and 14 (life below water) in line with responsible consumption and production (SDG 12) (United Nations, 2021a). Thus, industrial ecosystem need to move to a more sustainable direction on water management by following a bottom up approach on monitoring and estimating water consumption in their production line and supply chain.

2. Industrial Water Footprint – An environmental pressure indicator

The basic idea of all "footprints" developed for environmental assessment is to evaluate human pressure on resources, related to production and/or consumption, and at micro, meso or macro scale (Sala et al., 2013).

Water footprint (WF) is a multidimensional indicator of volumetric water use and pollution. It measures the amount of water used to produce each good and service we use. It can refer to a process, a product, an entire company, a sector, a community, even a nation. Both direct and indirect water use are included in the indicator representing water consumption and pollution throughout the full production cycle from the supply chain to the end-user (Hoekstra et al., 2011).

The initial studies on WF were focused on the quantification of WFs of crops and national consumption (Hoekstra and Hung, 2002). Hoekstra and Chapagain (2007, 2008) improved the national WF accounts by considering all forms of consumption and trade, including animal and industrial products as well as municipal water uses. Until 2008, the focus remained on national WFs in relation to consumption and accounting. Afterwards, the scope broadened, whereby also the production perspective received increasing attention focusing on production within certain geographic areas in order to expand the WFs in the context of the limited water availability per area (Hoekstra, 2017).

Industrial Water Footprint (IWF) is an environmental pressure indicator recently introduced, for estimating and analyzing water consumption and savings in industry. IWF is defined as the total volume of freshwater used, directly and indirectly, to produce its products and services and is expressed as the volume of freshwater used per year. It consists of Operational WF which focuses on the WF resulting from industrial processes i.e. manufacturing & packaging and Supply Chain WF which represents the WF of the raw materials and products used in the production line (Gerbens-Leenes and Hoekstra, 2008).

Both Operational and Supply Chain WF comprises of 3 components i.e. blue, green and grey. The first two are related to the origin and use of water by the industry while the third is related to water pollution caused during its operation or production of raw materials for Supply Chain WF as presented in Figure 1 (Hoekstra et al., 2009).

IWF can be an important tool for manufacturing industries to better understand the management and distribution of water in all their processes in order to make timely decisions regarding water management in each unit, cooperate with the appropriate suppliers and interact efficiently with the local communities (Ruini et al., 2013).

3. IWF applied in different production branches

IWF studies have been published for various products, including food and beverage products (Ercin et al., 2011, 2012), fibre products like textiles (Chico et al., 2013) and paper (Van Oel & Hoekstra, 2012), packages, minerals, construction materials and manufactured products like cars and computers.

In this study, the branches analyzed are the food & beverage industry, the textiles industry and the cosmetics & chemicals industry as their production processes consume large water quantities and their supply chain mainly comprises of crops, which need a lot of irrigation water. Especially, in Greece, food & beverage industry and cosmetics industry have a large share of the market and their production plants are located in water scarce areas (e.g. Attica, Pelion, Khalkidhiki, river basin) (Stathatou, 2017), so sustainable water management is essential.

3.1. Food & beverage industry

Large amounts of water are consumed in the production line of food products and beverages as well as in their supply chain which is mainly comprised of agricultural products. Water is mainly used for cleaning and cooling of the production equipment and for the cultivation of crops used as raw materials.

According to Aivazidou and Tsolakis 2020 review on Water Footprint of Italian Wine, only 5 studies estimate the WF of viticulture and vinification production stages, which range from 450.6 L / bottle (0.75L) to 988 L / bottle (0.75L) for green WF, 3.4 L / bottle (0.75L) to 181 L / bottle (0.75L) for blue WF, and 7.4 L / bottle (0.75L) to 120.4 L / bottle (0.75L) for grey WF ().

The WFs of processes involved in pasta production are evaluated by Ruini et al. (2013) indicating that the total WF of 1 kg of Barilla pasta ranges between 1.336 and 2.847 L of water. The large variation of the pasta water footprint indicates the importance in understanding the spatial variability of local environmental conditions and agricultural techniques adopted during the wheat cultivation phase. Virtual water fluxes are involved in pasta and durum wheat trade among countries, with the external WF representing about 30% of the total footprint.

For a Sugar-Containing Carbonated Beverage the total WF is assessed from 169 L to 309 L depending on the origin of sugar used in production. The operational WF of the product is 0.5 L, which forms 0.2–0.3% of the total WF and the supply-chain WF constitutes 99.7–99.8% of the total WF of the product. The results of this study underline the importance of a detailed supply-chain assessment in WF accounting, as industries focuson assessing water consumption of the production processes (Ercin et al., 2011).

3.2. Textiles

In the study of Hossain and Khan (2020), annual WF of apparel products was assessed from the supply chain to the final product (garment). About one-third of IWF in Ready-Made Garment (RMG) sector is related to grey WF as large amount of wastewater are generated during cotton cultivation and textile operation. Around 91% of total IWF of RMG production is associated with cotton cultivation accounted at 25 billion m^3. In the textile operation, grey WF constitutes 91% of total WF and usually occurs (99.5%) during the production phase highlighting the importance of reduction and proper treatment of industrial wastewater.

Concerning the textiles used in jeans production, Cellulose-based Lyocell fibre has a notably lower WF than cotton fibres, on average 1384, 34.5, and 35.3 m^3/tn compared to 263, 2767 and 203 m^3/tn for green, blue, and grey WF, respectively (Chico et al., 2013).

3.3. Cosmetics & Biochemicals

In the cosmetics industry, Francke et al. (2013) assess the WF of the saponification and formulation of a soap bar (450g). The green, blue and grey WF of the saponification process are estimated at 1.473L, 31L, 323L respectively and of the formulation process at 1.563L, 95L, 363L for a soap bar of 450g.

In the biochemicals industry, Mandade et al. (2015) estimate ethanol WF between 230 and 7150 L per liter of ethanol for various feedstock and allocation approaches Dominguez-Faus et al. (2009) assessed the WF of ethanol produced from switchgrass to be about 1400 L per liter of ethanol in the US. Gerbens-Leenes and Hoekstra (2011) reported the water footprint of ethanol produced from sugar beet in EU to be around 857 L per liter of ethanol. Chiu and Wu (2012) reported a much lower value of water ethanol produced from cassava and sweet sorghum in China. Their values ranged between 1760 and 5290 L per liter of ethanol, also highlighting the high levels of variability.

4. Conclusions

IWF is an important tool for estimating and analyzing water consumption in an industrial environment assessing water needs both in production processes and throughout the supply chain. This water-related pressure indicator, which is not so commonly used in industry as accounting method, needs to be clarified and a unified WF assessment framework needs to be developed for each type of industry.

Operational and supply chain WF was assessed for different industrial branches, mainly those which consume large amounts of water for the production of their products i.e. food & beverage, textiles, cosmetics & chemicals.

In the wine making industry, the assessment of water consumption during viticulture and vinification is crucial to enhance water stewardship within wine sector. WF could be used as an environmental pressure indicator in validating its important role for economic and environmental sustainability.

Both pasta industry and carbonated beverages industry underline the importance of a detailed supply-chain assessment in WF accounting, showcasing the importance of the origin of raw material in order to control the water impact in production.

In textiles industry, WF could play a strategic role in industrial decision making as WF assessment for different textiles / raw materials could influence the inputs used in production processes so as to be more sustainable.

In the biochemicals industry, the phase which contributes most to WF is agriculture of raw materials, therefore is highly variable and depends strongly on the irrigation practices, climate, and other region-specific factors.

In cosmetics branch, great concern should be given to the after-use of the products by consumers, as a large grey WF is generated in the disposal phase which is no longer under industry's outreach.

In all branches, WF of supply chain is greater than operational WF, since large water quantities are needed for cultivation and irrigation of crops. Also, grey WF could vary significantly, as industries in different countries follow different policies for wastewater treatment and disposal.

Despite the wide acceptance of IWF as an indicator for sustainability and its application in many instances, only agricultural products are thoroughly studied and there is still very limited availability of data and assessments for industrial processes and products.

Using IWF, increased water consumption spots and water recycling potential can be identified, resulting to process or management alternatives, with significant economic and environmental impacts on the production and/or consumer behavior.

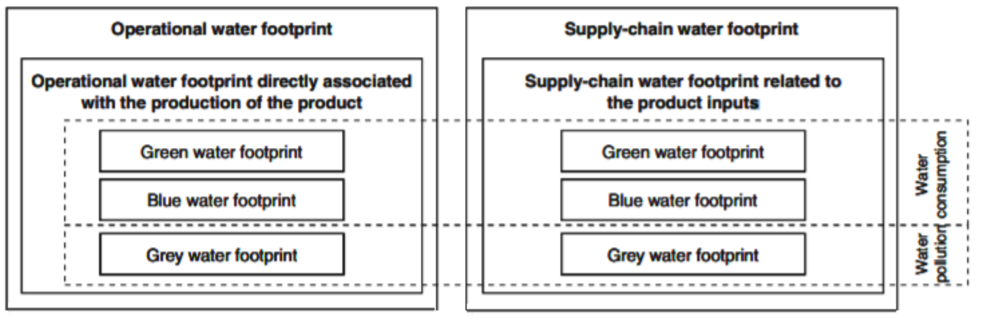

Figure 1. Composition of IWF (Ercin et al., 2011)

References

Aivazidou E., and Tsolakis N. (2020). A Water Footprint Review of Italian Wine: Drivers, Barriers, and Practices for Sustainable Stewardship. *Water*, **12**, 369.

Chico D., Aldaya M.M., and Garrido, A. (2013), A water footprint assessment of a pair of jeans: the influence of agricultural policies on the sustainability of consumer products. *Journal of Cleaner Production*, **57**, 238–248.

Chiu Y-W, Wu M (2012), Assessing county-level water footprints of different cellulosic-biofuel feedstock pathways, *Environmental Science and Technology*, **46** (16), 9155–9162

Dominguez-Faus R., Powers E. S., Burken G. J., and Alvarez J. P. (2009), The Water Footprint of Biofuels: A Drink or Drive Issue?, *Environmental Science and Technology*, **43** (9), 3005-3010

Ercin A.E., Aldaya M.M. and Hoekstra, A.Y. (2012), The water footprint of soy milk and soy burger and equivalent animal products. *Ecological Indicators*, **18**, 392–402

Ercin A.E., Aldaya M.M. and Hoekstra, A.Y. (2011), Corporate water footprint accounting and impact assessment: the case of the water footprint of a sugar-containing carbonated beverage. *Water Resource Management*, **25**(2), 721–741.

Francke, C. M., and Castrob F. W. (2013), Carbon and water footprint analysis of a soap bar produced in Brazil by Natura Cosmetics. *Water Resources and Industry*, **1-2**, 37-48.

Gerbens-Leenes W and Hoekstra A.Y. (2011), The water footprint of biofuel-based transport, *Energy and Environmental Science*, **4**, 2658–2668

Gerbens-Leenes, W. and Hoekstra, A.Y. (2008), Business water footprint accounting. A tool to assess how production of goods and services impacts on fresh water resources worldwide, Unesco-IHE Institute for Water Education, Delft, The Netherlands

Hoekstra A., Chapagain A., Aldaya M. and Mekonnen M. (2011), Water Footprint Assessment Manual. Water Footprint Network, Earthscan, London, UK

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2009), *Water Footprint Manual: State of the Art 2009*, Water Footprint Network, Enschede, Netherlands

Hoekstra A.Y. and Chapagain, A.K. (2008), *Globalization of water: sharing the planet's freshwater resources*, Blackwell, Oxford.

Hoekstra A.Y. and Chapagain, A.K. (2007), Water footprints of nations: water use by people as a function of their consumption pattern, *Water Resource Management*, **21**(1), 35–48.

Hoekstra A.Y. and Hung P.Q. (2002), Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade, *Value of Water Research Report Series No.11*. UNESCO-IHE, Delft, Netherlands.

Hogeboom R. (2020), The Water Footprint Concept and Water's Grand Environmental Challenges, *One Earth*, **2** (3), 218-223.

Hossain L., and Khan, S. M. (2020), Water Footprint Management for Sustainable Growth in the Bangladesh Apparel Sector, *Water*, **12**, 2760.

Mandade P, Bakshi B. R., and Yadav G.D. (2015), Ethanol from Indian agro-industrial lignocellulosic biomass: a life cycle evaluation of energy, greenhouse gases, land and water. International Journal of Life Cycle Assessment, **20**, 1649–1658

Ruini L., Marino M., Pignatelli S., Laio F. and Ridolfi, L. (2013), Water footprint of a large-sized food company: The case of Barilla pasta production, *Water Resources and Industry*, **1-2,** 7-24.

Sala S., Bianchi A., Bligny JC., Bouraoui F., Castellani V., De Camillis C., Mubareka S., Vandecasteele I., and Wolf M. A. (2013), *Water footprint in the context of sustainability assessment*, Report on the application of life cycle based indicators of water consumption in the context of integrated sustainability impact analysis. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

Stathatou P.-M. (2017), *Water Reuse. Environmental Protection & Performance Metrics*, Dissertation at National Technical University of Athens.

United Nations. (2021), *The Sustainable Development Agenda*, Sustainable Development Goals. Retrieved from: https://www.un.org/sustainabledevelopment/development-agenda/)

United Nations. (2021) a, *Take Action for the Sustainable Development Goals*, Sustainable Development Goals. Retrieved from: https://www.un.org/sustainabledevelopment/sustainable-development-goals/)

Van Oel P.R. and Hoekstra, A.Y. (2012), Towards quantification of the water footprint of paper: a first estimate of its consumptive component. *Water Resource Management*, **26**(3), 733–74.