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Water footprint determination by quarry operation in island regions

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ABSTRACT

The mining sector in contemporary areas is characterized by intensification of mineral production to meet the growing human needs, while bringing significant changes in the natural environment as well as in the metabolism of the urban areas. Water, as one of the most valuable natural resources, plays a dynamic role in human existence, social progress, economic development and urban metabolism. However, the needs for freshwater resources, associated with the reduction of supply, brought adverse impacts both on the quantity and quality of water resources. This paper focus on the island of Milos which was chosen as a case study in order to determine the water footprint (volumetric approach) of several quarries (using ISO 14046) where bentonite, perlite and pozzolan (type 1 and 2) are mined as Milos considered by limited water resources. The results indicated that the total water consumption in the case of bentonite was 0.048 m^3/t, for perlite was 0.07 m^3/t, for pozzolan 1 was 0.03 m^3/t and the pozzolan 2 was 0.18 m^3/t of mineral production. Furthermore, the use of water is identified during wettings at the quarry areas, at the stage of milling for dedusting and the process of rehabilitation, therefore, the specific processes should be systematically controlled.

Keywords: Quarries; Water footprint; Water consumption; ISO 14046

1. Introduction

Quarry operations involve complex processes that may affect several environmental parameters. Quarry is the area in which research and excavations take place aiming at detecting and extracting minerals [1]. For example, during the production process of bentonite and perlite the steps that are followed include mining, transfer from the mining area to be treated, milling, during which breakage adding soda and drying for bentonite and crushing, drying and sieving for perlite, storage, loading on ships while for pozzolan 1 the production process of the pozzolan includes several steps like mining, internal transfer, breakage when breaking and sifting is performed, storage, loading on ships. The life span of a quarry mainly depends on the nature of the stocks and the local conditions [2,3]. According to Cubukcu et al. [1], the effects and the impact of the activity related to water resources are mainly the water pollution. The mining process huge quantities of water in several steps which at the end it discarded in surface areas, lagoons, etc. The pollution occurs through the drain as soluble toxic elements enter into the aquifers. In addition, depending on local geological and topographic conditions, the hydrology is also affected (surface runoff, springs and groundwater's). In several cases, such as in open pit quarries especially in segments with impermeable rocks, temporary or permanent lakes/lagoons are formed [1,2]. A remarkable example of such cases constitutes the limestone quarry in Meryl and of Texas, where permanent lakes were formed and enhance

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the water resources of the region while also attract a variety of birds, trout's and beavers [1].

The concept of water footprint (WF) was introduced to the scientific community in 2002 by the UNESCO Hoekstra, at the International Congress of Scientists on Virtual Water Trade, held at the University of Delft, the Netherlands [4]. The WF is an index that refers to water consumption and considers both direct and indirect water consumption and used [5]. According to Zhang et al. [6], WF is a concept closely linked with virtual water and WF is the volume of freshwater used to produce the product measured over the full supply chain. Water consumption is defined as the freshwater taken from groundwater or surface water sources, either permanently or temporarily, and conveyed to the place of use, while water use refers to use of water by agriculture, industry, energy production and households, including in stream uses such as fishing, recreation, transportation and waste disposal [7,8]. It is a complex index, which describes the consumption of surface and underground water, includes quantitative, qualitative, geographical and time data and is considered to be a new tool for the management of water resources upon a sustainable way [9]. Additionally, it does not refer to water as a general concept, but particularly the freshwater, which is a scarce natural resource and occupies only 2.5% of the total volume of planet water [10]. The WF is usually expressed in units of water volume per unit of product (e.g., m^3/t) or water volume units per time unit (e.g., $m^3/year$) of the freshwater used to produce the product, including full supply of product on the market m [11]. Also, the WF can be expressed at the level of individual consumption, in terms of a product, a business, even a country. According to Jefferies et al. [12], the WF calculates the water consumption of the country, but also the actual amount of water consumed by the particular country, even those who spent overseas to create products imported and consumed in the country. WF can also provide a global dimension in terms of consumption goods and identify the geographic origin of the water used in the production of goods but also the impact on water resources both within a country and abroad [13]. Therefore, the WF can be used as a basic tool in the decision-making regarding whether the production of various goods or the rational use of water resources [5]. The WF is divided into three components (Eq. (1)) and include the blue, green and gray water as indicated by Zhang et al. [6] and Mekonnen and Hoekstra [14]. The blue component refers to the consumption of blue water (WFblue) that the water that is bound by water resources (surface and underground) of a basin. Green component concerns the green body of water (WFgreen) and in particular water coming from rain or precipitation (is in the form of moisture in the soil). Finally, the gray component is an indicator of the water contamination (WFgray). The concept was first introduced as "water dissolution" [4] and defined as the volume of water needed to dissolve the contaminant load (pollution) on the existing water quality levels that the water quality remains above thresholds.

According to Mekonnen and Hoekstra [14], WF determination was based on the use of blue water. The use of green waters was first reported in 2004 by Chapagain and Hoekstra as sited by Agoramoorthy [4]. Daniels et al. [10] were included later on the gray waters. Moreover, Okadera et al. [15] indicated that there are two other approaches to determined WF; the bottom-up and the top-down approach. The top-down approach refers to an economic input–output analysis frequently used for environmental analyses. Bottom-up approach is easier because the required data are more readily accessible (like water requirement per unit production).

In small medium enterprises (SMEs), WF is defined as the total volume of freshwater used by the company to produce products [16]. The investigation of WF for industrial products, such as minerals, has not applied enough, due to the limitations of the accounting method and the difficulties that exist to collect raw data [3] and include the typical structure of the SMEs. The measurement of the WF for industrial activities and products is important due to the fact that effects on water resources caused by industrial processes [11], while at the same time can help to improve the sustainable use of water [13]. Pfister and Bayer [17] mentioned that WF is directly associated with potential environmental impacts as well as is affected from the final product process for the determinations of those impacts life cycle assessment (LCA) is been used. Moreover, when WF is calculated the total product life cycle must be taken into consideration (from raw materials to final disposal). According to Pfister and Bayer [17], the evaluation of the WF based on the international standard, includes four phases (defining the objectives and context of the evaluation, census data analysis, impact assessment, interpretation of results). Furthermore, Vanham and Bidoglio [9] indicated that during the determination of WF several parameters must be considered: (i) the limits of the system which is under study, (ii) components and module, (iii) temporal and geographical coverage of the study, (iv) quality of data, (v) detailed procedures, (vi) impact assessment methodology (like LCA), (vii) initial conditions, comparing them to the current situation caused by the activities, etc.

This research focuses on the determination of WF of the operation of a quarry and specifically in the case of open mines as there few available data. Through this study the overall consumption of water, the types of water and the use of water were examined. The results can be used from mining companies to design a specific strategy plan in order to reduce their adverse impact on the environment.

2. Materials and methods

2.1. Description of the area

As study area was chosen the island of Milos (volcanic origin and hilly island), which is an island in the Cyclades in Greece. 86% of the area of Milos is elevation lower than 200 m and just 2.2% of the total area has an altitude of 400 m. The island's climate is Mediterranean, presenting low and infrequent rainfall during the cold season and drought during the summer (affected from climate changes) and the average annual rainfall on the island does not exceed 500 mm. The hydrographic network of Milos (Fig. 1) consists mainly of wadis shows radial form and its development is largely due to the topography, climate, tectonic structure and mineralogical composition of rocks.

Milos has limited water resources (from rainfall and the sea). This is because rainfall is limited (supraorbital climates), and the available water resources are insufficient for the needs of the local population, as well as soils presented with small water holding capacity to retain water due to volcanic origin. To cover the needs of the region in water a desalination unit was established. Furthermore, each house collects rainwater's for private use. The mining activity on the island is intense because of the large deposits that occur in the region. The quarrying sites, as presented in Fig. 2, occupying a total area of approximately 20 km^2 and located mainly in the eastern part of the Island. The method of exploitation includes opencast with righteous consecutive open pit stages. During this method opening levels are performed, which start upstream and descends down to the bare deposit or learned to exploit the rock. At the beginning of the vegetation process topsoil is removed (top soil is stored and is been used for restoration). Then the mineral materials are removed. The extraction in been supported mechanically using promoter and occasionally use of explosives.

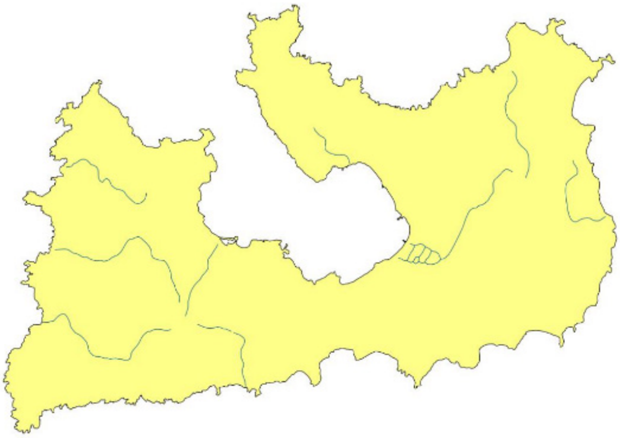

Fig. 1. Hydrographic network of the region (Source: QGIS).

2.2. WF determination using ISO 14046

To identify and quantify WF of quarries operations the requirements of ISO 14046 [8] were followed. The main objectives when this technique is used, according to Imura [18] are to provide complete picture of the interactions between the activity and the environment, decisions with the help of information that determine the environmental impact of their activities and identify any potential for environmental improvements as well as to understand the contribution of the interdependence that characterizes the nature of environmental impacts as a whole, resulting from human activities and the creation of integrated development indicators.

Klemes and De Benedetto [19] state that the credibility of the process largely depends on how modeling and the degree of simplification of test systems, all the assumptions and estimates used in each step of the analysis and the availability of modern and reliable data. In addition, the LCA results help

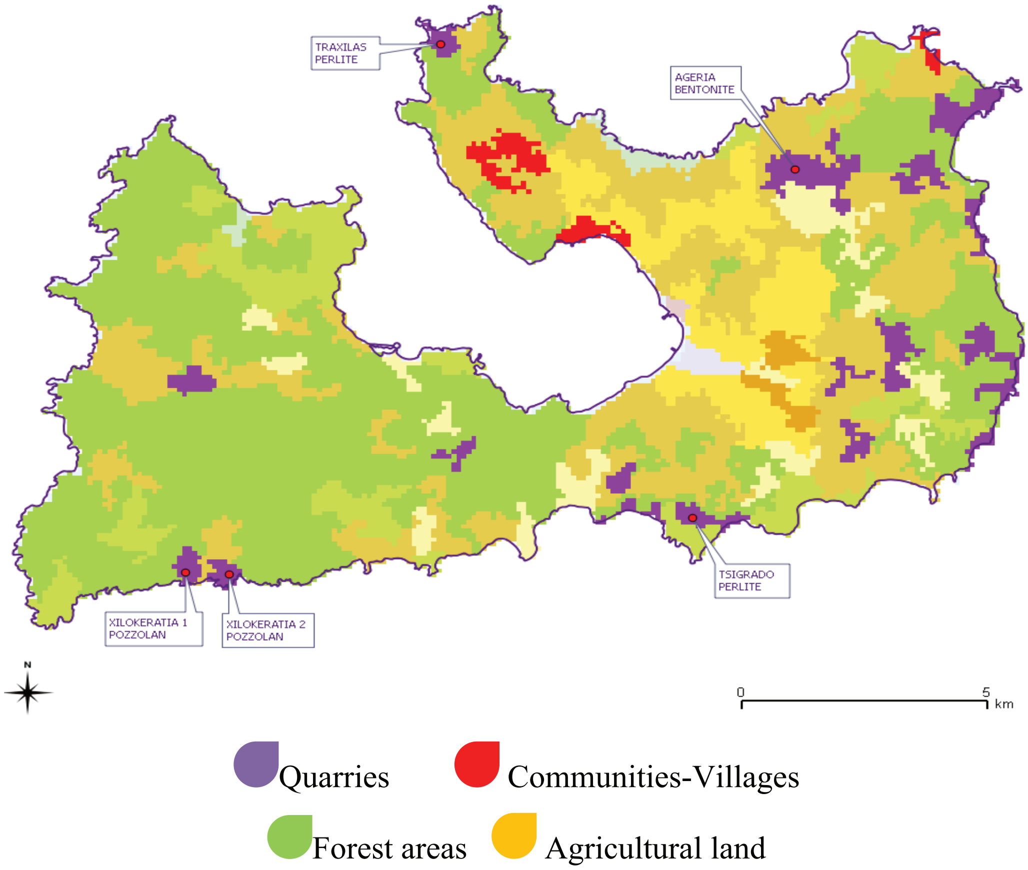

Fig. 2. Map covers land use base of Corine classification system and scope of the study – under consideration quarries (Source: QGIS).

to improve the design process of a system, and minimize the impact on the environment [20]. LCA of primary minerals and their production is wide spread. As part of this assessment, the impact of the operation of quarries and production stages are controlled. Such assessments are the basis for a comprehensive assessment of the life cycle of a product [21].

The ISO 14046:2014 [8] standard issued (on 07.24.2014 and it is a part of the standards ISO 14000 series of environmental management) from the International Standardization Organization [8] in order to cover the lack of a widely accepted method for determining the WF, namely more efficient water consumption for an activity with the smallest environmental impact [22]. This standard establishes the principles, requirements and guidelines on the assessment of products, processes and organizations for their WF, based on LCA [23]. As a result of the evaluation of the WF, take a single value or a profile based on the results of impact indicators on the environment with respect to water [5].

According to the requirements of ISO 14046 [8] (paragraph 5.2: Goal and scope definition) had been identified the reasons for carrying out this research and was the WF of quarries in specific area (the Island of Milos). Furthermore, is defined that this research will be a volumetric approach for the estimation of WF. According to the ISO 14046 [8] to review the WF is based on LCA, identifies the environmental effects in relation to water, include relevant geographic dimensions, determine the quantities of water used and the changes in quality, while exploiting existing hydrological knowledge [17]. Such evaluation may be multi-dimensional input like: (i) evaluation of the size of the potential environmental impact in relation to water, (ii) identifying reduction potential of these impacts at various stages of the life cycle, (iii) developing risk assessment strategy in relation to water, (iv) optimization of water management, (v) inform decision makers on the potential environmental impacts of their activities and (vi) provide scientifically credible and consistent information for the analysis of the WF. ISO 14046 is an internationally recognized method for evaluating the measures and actions that an undertaking of the rational use of water in its production process [23]. During the definition phase of the objective and scope should be examined by the unit operating procedures where primary data required for detailed assessment because of the significant expected contribution to the results and operating procedures of the unit for which the inventory can be based on secondary data or estimate data, as they do not significantly affect the result or are difficult to obtain as primary data. When assessing the WF of a system is required to define the limits of application of the study. The limits of the system determine the operating procedures of the unit which will be included in the assessment of the WF [16].

ISO 14046 give emphasis on the quality of the data (paragraph 5.2.4 of the standard). Primary data should be collected where possible. Secondary data should only be used for the inputs, where the collection of primary data is not feasible, and may include bibliographic data, measurable data, estimates, forecasts model or other representative data. The reasons for the use of secondary data for important procedures should be justified and documented [16]. It is important to known, as ISO 14046 indicated and supported from Finkbeiner [22], the quantity of water, types of water resources used, data describing water quality, forms of water consumption and use, changes in water flows, resulting from land management activities and changes of use, from where the water came from, seasonal changes that occur in the flow and pumping the water and variations in water quality, temporal aspects of water use (including, if appropriate, the time of use). Also, it is important to know the technology used in each quarry is that is possible. A typical questionnaire was used to collect those data after during the survey audit in each quarry.

Moreover, the volume of water that was used was estimated (in m^3) as well as the water resources. Hence, according to the requirements of LCA the scope of the study consists of five quarries (Fig. 2), which mined bentonite, perlite and pozzolan (type 1 and 2). The boundaries of the system cover the central and subsequent processes. The central processes include the steps of the production process and in particular the disclosure – mining, transportation, industrial processing, storage and loading in ships. Subsequent processes include the process of restoring the site. The functional unit is defined as a market producer production in tone (tn) as well as a 3 years data were used. Geographically, the case study of the WF covers the quarries in Milos island as indicated in the regions of Fig. 2. The data were collected through a questionnaire and concerning according to ISO 14046 [8] the quantities of water used (volumetric approach), the types of water resources consumed, forms of water consumed, the water use positions. The volumetric assessment [6] of WF is resulting from the accumulation of blue, green and gray component as indicated in Eq. (1).

$$\text{WFblue} + \text{WFgreen} + \text{WFgray} = \text{WF} \tag{1}$$

3. Results and discussion

3.1. Bentonite

In the case of bentonite, the water consumed comes from surface pits generated at the quarry which represents the green component of WF and the municipal water supply, which supplies water from the desalination plant that works on the island and represents the blue component of WF. The use of water is mainly for wetting the quarry, to cover the needs of administrations, to rehabilitation and at the stage of milling which wetting the area. For the blue water (WFblue) the consumption was calculated to be 0.002046 m^3/t (2,155 m^3) and for the green water (WFgreen) to be 0.045 m^3/t (4,7761.66 m^3). The WFgray is zero as wastewaters are not produced during the process. The total amount of water consumed was 49,916.66 m^3/t of bentonite production and the WF was 0.047 m^3/t (Table 1).

3.2. Perlite

In the case of perlite (Table 1), the water consumed arises from municipal water supply, from surface pits generated at the quarry and from the sea. The use of water is mainly for wetting the quarry, to cover administrative needs, for rehabilitation and at the stage of milling which wetting and dedusting the area. The WFblue was 0.003238 m^3/t and the WFgreen was 0.07176 m^3/t while WFgray was 0 m^3/t as no

Table 1
Water consumption during the process

	Surface from quarry lakes, %	Municipal water supply, %	Seawater, %	Quarry wetting, %	Restoration, %
Bentonite	95.68	4.32	0	0	0
Perlite	6	0.4	93.67	0	0
Pozzolan 1	0	0	0	96	4
Pozzolan 2	0	0	0	73	27

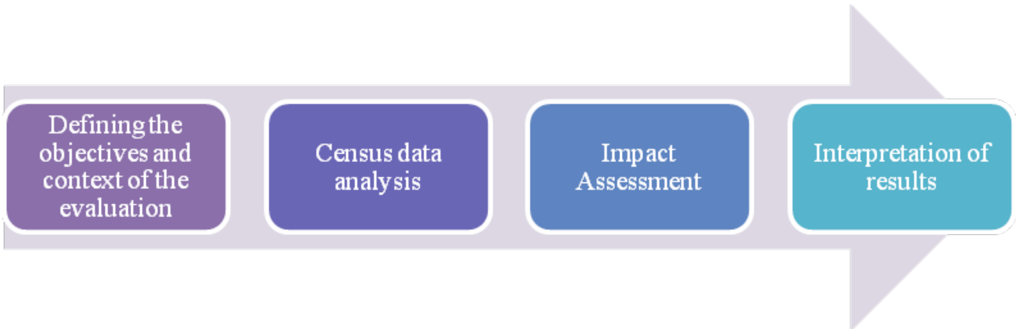

Fig. 3. LCA stages according to ISO 14046.

wastewater was produced. The total amount of water consumed was 3,327,833 m^3/t of perlite production and the WF was 0.075 m^3/t. However, in the case of perlite seawater was used (approximately 1.14 m^3/t) balancing the WF.

3.3. Pozzolan 1

In the case of pozzolan type 1, the water consumed arises from municipal water supplies (WFblue). Mainly it is used for wetting and for restoration. The total amount of water was 4,486.66 m^3. The water consumption for wetting the quarry was 4,333.33 m^3 and for rehabilitation was 153.33 m^3. The WF (Table 1) of pozzolan 1 was 0.03 m^3/t.

3.4. Pozzolan 2

In the case of pozzolan type 2, the water consumed arises from municipal water supplies (WFblue) and presents similar usage like the other minerals. The total amount of water consumed (Table 1) was 6,908.66 m^3. The water consumption for wetting the quarry was 5,066.67 m^3 and for rehabilitation was 1,842 m^3. The WF (Eq. 1) of pozzolan 2 was estimated at 0.18 m^3/t.

The water consumption (total WF) per tn of mineral consumption is presented in Table 2. Table 2 indicated that pozzolan 2 has the highest WF and pozzolan 1 the lowest. From the results, it is observed that in the case of bentonite and perlite the WFgreen shows higher values than the others and have the main contribution to the final WF. The WFgray is considered to be zero for all cases as no wastewater were produced. In the cases of pozzolan 1 and 2, WFblue contribute to the final WF. Furthermore, the wetting process of quarry consumed significant quantities of water and affects a larger proportion of the WF. Processes consumed water in all cases is upon wetting the quarry, the process of restoration of the quarry and the stage of milling (in the cases of bentonite and perlite) for dedusting. Those processes affect the WF and should be systematically controlled and monitor. The WF when seawater is being used was 1.15 m^3/t in the case of perlite which typical means that is recommended in order to reduce WF.

Table 2
Water consumption per mineral

Mineral	Water consumption per ton
Bentonite	0.05
Perlite	0.07
Pozzolan 1	0.03
Pozzolan 2	0.18

For the case of open pit quarries there are no studies that determine WF to enable any comparison of results. However, at corporate level Mazzi et al. [23] and Ercin et al. [24] present a first attempt to perform WF in agric-food sector and specifically to a hypothetical sugar-containing carbonated beverage. The results were based on the same methodology that we followed and cover the blue, green and gray WF [24]. Moreover, according to Mekonnen and Hoekstra [14] at global level, the same methodology was applied to determine the WF of crop production. The results indicated that, for the most of the crops the WFgreen was >80% and had the major contribution toward the total WF. Additionally, the WF per ton of primary crop presents significant differences among crops and across production regions [14] which are similar to our research results. Each product presents different WF which is further influenced by the production process.

4. Conclusions

The types of water consumed during the quarrying activity in island of Milos, originates from surface pits created on the premises of quarries and from the municipal water supply. The total WF in the case of bentonite was 0.048 m^3/t, for perlite was 0.07 m^3/t, for pozzolan 1 was 0.03 m^3/t and for the pozzolan 2 was 0.18 m^3/t. The use of water is detected during wettings at the quarry areas, at the stage of milling for dedusting and during the rehabilitation process and those processes should be systematically controlled and monitored. The results can be used from mining companies to design a specific strategy plan in order to reduce their adverse impact on the environment. WF profile considers a range of potential environmental issues and impact associated with water. Moreover, this paper could be the beginning to develop a holistic strategy approach to any insular industrial activity as the issue of water and its management has become increasingly central to the global debate on sustainable development.

References

[1] A. Cubukcu, E. Kaya, O. Ozyaral, Environments Problems Caused by Cebeci Aggregate Quarries and Rehabilitation Works, 12th International Multidisciplinary Scientific GeoConference and EXPO – Modern Management of Mine Producing, Geology and Environmental Protection, SGEM 2012, Vol. 5, 2012, pp. 337–345.

[2] R. Sinha, D.K. Pandey, A.K. Sinha, Mining and the environment: a case study from Bijolia quarrying site in Rajasthan, India, Environmentalist, 20 (2000) 195–203.

[3] M. Tillotson, J. Liu, D. Guan, P. Wu, X. Zhao, G. Zhang, S. Pfister, M. Pahlow, Water Footprint Symposium: where next for water footprint and water assessment methodology?, Int. J. Life Cycle Assess., 19 (2014) 1561–1565.

[4] G. Agoramoorthy, The water footprint of modern consumer society by Arjen Y. Hoekstra, Water Resour. Manage., 27 (2013) 3847–3848.

[5] J. Fulton, H. Cooley, P. Gleick, Water Footprint, P. Gleick, Ed., The World's Water, Chapter 5, Island Press, Washington, Covelo, London, 2014, pp. 83–92.

[6] Z. Zhang, H. Yang, M. Shi, Analyses of water footprint of Beijing in an interregional input-output framework, Ecol. Econ., 70 (2011) 2494–2502.

[7] Organization for Economic Co-Operation and Development. Available at: https://stats.oecd.org/glossary/detail.asp?ID=2915 (Accessed April 2017).

[8] British Standards Institution (BSI), ISO 14046:2014 Environmental Management – Water Footprint – Principles, Requirements, Guidelines, UK, 2014.

[9] D. Vanham, G. Bidoglio, A review on the indicator water footprint for the EU28, Ecol. Indic., 26 (2013) 61–75.

[10] P. Daniels, M. Lenzen, S. Kenway, The ins and outs of water use – a review of multi-region input–output analysis and water footprints for regional sustainability analysis and policy, Econ. Syst. Res., 23 (2011) 353–370.

[11] Y. Yan, J. Jia, K. Zhou, G. Wu, Study of regional water footprint of industrial sectors: the case of Chaoyang City, Liaoning Province, China, Int. J. Sustain. Dev. World Ecol., 20 (2013) 542–548.

[12] D. Jefferies, I. Munoz, J. Hodges, V. King, M. Aldaya, A. Ercin, L. Canals, A. Hoekstra, Water footprint and life cycle assessment as approaches to assess potential impact of products on water consumption. Key learning points from pilot studies on tea and margarine, J. Cleaner Prod., 33 (2012) 155–166.

[13] D. Wichelns, Do the virtual water and water footprint perspectives enhance policy discussions?, Int. J. Water Resour. Dev., 27 (2011) 633–645.

[14] M. Mekonnen, A. Hoekstra, The green, blue and grey water footprint of crops and derived crop products, Hydrol. Earth Syst. Sci., 15 (2011) 1577–1600.

[15] T. Okadera, Y. Geng, T. Fujita, H. Dong, Z. Liu, N. Yoshida, T. Kanazawa, Evaluating the water footprint of the energy supply of Liaoning Province, China: a regional input–output analysis approach, Energy Policy, 78 (2015) 148–157.

[16] A. Hoekstra, A. Chapagain, M. Aldaya, M. Mekonnen, The Water Footprint Assessment Manual, Setting the Global Standard, Earthscan, London, Washington, 2011, pp. 2368.

[17] S. Pfister, P. Bayer, Monthly water stress: spatially and temporally explicit consumptive water footprint of global crop production, J. Cleaner Prod., 73 (2013) 1–11.

[18] H. Imura, Life Cycle Assessment, Environmental Systems Studies: A Macroscope for Understanding and Operating Spaceship Earth, Chapter 9, Springer, Switzerland, 2013, pp. 121–125.

[19] J.J. Klemes, L. De Benedetto, Environmental Assessment and Strategic Environmental Map Based on Footprints Assessment, Treatise on Sustainability Science and Engineering, Part II, Chapter 4, Springer, Switzerland, 2013, pp. 153–171.

[20] B. Ridoutt, S. Pfister, A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity, Global Environ. Change, 20 (2010) 113–120.

[21] G. Brent, Quantifying eco-efficiency within life cycle management using a process model of strip coal mining, Int. J. Min. Reclam. Environ., 25 (2011) 258–273.

[22] M. Finkbeiner, From the 40s to the 70s—the future of LCA in the ISO 14000 family, Int. J. Life Cycle Assess., 18 (2013) 1–4.

[23] A. Mazzi, A. Manzardo, A. Scipioni, Water Footprint to Support Environmental Management: An Overview, Pathways to Environmental Sustainability, Chapter 4, Springer, Switzerland, 2014, pp. 33–42.

[24] E. Ercin, M. Aldaya, A. Hoekstra, Corporate water footprint accounting and impact assessment: the case of the water footprint of a sugar-containing carbonated beverage, Water Resour. Manage., 25 (2011) 721–741.