Water Footprint of Food Quality Schemes

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Abstract

WF (WF, henceforth) has recently taken ground as an indicator of water consumption to be used in assessing the impact of productions over freshwater resources, and to design more sustainable production policies in respect to water use. In this study WFWF is applied to compare the impact on water resources of non-conventional and certified products with that of reference products obtained through conventional production schemes. To perform this comparison, we analysed 23 products selected among Organic, PDO and PGI, and defined as FQS (Food Quality Schemes), and their conventional counterparts. In this paper we focus on the on-farm phase of the production chain. The results of the analysis show that no significant differences emerged between the FQS and the REF products except for Organic products, which showed a better performance than their conventionally produced references for one of the indicators, the blue WF. WF is computed as the amount of water needed for a product unit (m^3/kg), we computed also the impact that the different production systems exert per unit area (m3/ha). In this case significant differences emerged between FQS and REF products.

Key Words: agricultural production, crop water requirement, evapotranspiration, irrigation, yield, water footprint.

1. Introduction

In the last years, consumers' attitude has been gradually including environmental issues among the priorities for selecting food products. This tendency is witnessed by the growing larger of the market of organic products, which, historically, have taken ground mainly because of the real and perceived risk associated with use of chemical in agriculture and that of new genetic varieties (Tregear et al. 1994, Magkos et al. 2012, Shafie and Rannie, 2012). Other products that traditionally have encountered consumers' appreciation are the Protected Designation of Origin (PDO, henceforth) and the Protected Geographical Indication (PGI). The former definition identifies products that have the strongest links to the place in which they are made and every part of the production, processing and preparation phases must take place in that specific region. The latter designates products for which the relationship between the specific geographic region and the name of the product, where a particular quality, reputation or other characteristic that is essentially attributable to its geographical origin is emphasized. For most products, at least one of the stages of production, processing or preparation takes place in that region. (https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/quality-schemes-explained, Grunert, and Aachmann 2016).

More recently the debate around sustainability has contributed to broaden environmental requirements that agricultural production should incorporate, and water scarcity is one of the most prominent (Tilman et al. 2002, Brauman et al 2013). The present production patterns are inexorably raising the demand for water to grow food, supply industries and sustain urban populations. In addition, climate alteration conspires to make the problem of water scarcity worse (Vörösmarty et al. 2000, Gosling and Arnel 2013). Water demand is one of the key issues for the years to come as it is demonstrated by the interest that governments, corporations and communities show about the future availability and sustainability of water supplies (Turton et al. 2007).

During the last twenty years, researchers have developed a number of metrics to help characterize, map and track water scarcity. These have included, for example, the ratio of population size to the renewable water supply (Abughlelesha and Lateh 2013) and the ratio of water withdrawals to the renewable supply (Doreau et al. 2012). These water scarcity indicators have highlighted the mismatch between water availability and water demand, and have contributed to focus attention over water scarcity (Pollard and du Toit 2005, Suweis et al. 2013).

If global indicators have the merit to present a whole system perspective, to effectively counteract freshwater consumption in food production baseline knowledge of the intensity at which this precious resource is used in specific production processes is needed. In this work we present the results of an investigation conducted on a sample of 23 of products, 10 PGI, 6 PDO and 7 Organic, whose focus was to estimate the intensity at which such product use water in comparison with that of analogous products obtained through conventional production processes. The aim was to highlight whether the particular production processes that characterise Organic, PDO and PGI products also imply a reduced intensity of water use.

The comparative analysis involving the 23 selected products was conducted by computing their WF. This indicator is always expressed as water volume per unit product (usually m3/ton or litre/kg, Hoekstra et al. 2011), and gives an estimate of how much water is needed to complete the entire production cycle. However to alleviate pressure on water resources it is also useful to have a measure of the efficiency at which water is used in agricultural practices and for the sample of the 23 products we also computed the water consumption per unit area (m3/ha). Estimating water consumption per unit area may provide administrators and national agencies with indications to shape policies concerning water management in agriculture.

This research may help clarifying whether and for which aspects WF computation can be used proficiently to assist the implementation of more sustainable food quality schemes. In particular, this work highlights which steps are the most critical in constructing the water inventory so that it can produce a reliable assessment of the water usage in the supply chain of the food quality schemes in relation to their conventional counterparts.

2. Material and methods

2.1 Strategy of implementation

Two main approaches for the assessment of the WFexist in the literature (McGlade et al., 2012, Postle et al., 2012): (1) the volumetric approach, as developed by the WF Network (WFN) (Hoekstra et al., 2011) and (2) the Life Cycle Analysis approach as developed by the LCA community (Pacetti et al. 2015). In this paper the two methodologies have been employed not in an integrated manner, that is used in association to compute WF, but, rather, in a complementary fashion, as they were used separately to evaluate different issues responsible for water consumption in the production chain. A comprehensive assessment of water consumption requires the use of both techniques for aspects that due to the lack of data would remain uncovered and thus could not be included in a whole evaluation of the performances of the two series of products. Although the WF analysis for the selected products considered both on-farm and off-farm stages, the study presented here focuses only on-farm. This choice was made considering the largely heterogeneous dataset that we collected for the off-farm phase. For some of the product, in fact, we had an excess data for the processing phase, whereas for others the amount of data could not allow a reliable computation of the WF.

The WF comprises three fraction: green, blue and grey. The green WF accounts for consumption of the rainwater through the process of evapotranspiration by the plants; the blue WF refers to the consumption of surface and groundwater along the supply chain of a product; the grey WF accounts for pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards. The on-farm phase implies water consumption in all the three forms of the footprint.

2.2. Methods applied

2.2.1 The Water Footprint Network Approach

The Water Footprint Network (WNF) approach was applied using CROPWAT (http://www.fao.org/land-water/databases-and-software/cropwat/en/), a Decision Support System (D.S.S.) that was developed by the FAO for planning and the management of irrigation projects. In this analysis CROPWAT 8.0 was used in the most straightforward way, which allows calculating crop water requirements and irrigation requirements based on soil, climate and crop data. While we address the reader to the technical literature for the details of calculation (Allen et al. 1998, Hoekstra et al. 2011, Steduto et al. 2012) we provide here below some basic concepts that summarize the procedure of calculation.

The green and blue WF were calculated under the Crop Water Requirement option in CROPWAT 8.0 (http://www.fao.org/land-water/databases-and-software/cropwat/en/). This option allows estimating evapotranspiration under optimal conditions: disease-free, well-fertilized crops under optimum soil water conditions. Under this assumption, crop evapotranspiration (ET_c) equals the crop water requirement (CWR, Allen et al, 1998). ET_{green} is called green evapotranspiration and identifies the fractions of water required to compensate for plant evapotranspiration over the whole growing period. It is computed as the minimum between effective rainfall $\left(P_{eff}\right)$ and the crop water evapotranspiration (ET_c):

$$ET_{green} = min\left(ET_c, P_{eff}\right) \quad (1)$$

The portion of CWR that is compensated for by the rainfall represents green evapotranspiration. When effective precipitation is higher than ET_c there is an excess precipitation and ET_c corresponds to green evapotranspiration. When ET_c is higher than the effective precipitation, evapotranspiration requirements must be fulfilled by irrigation and the green evapotranspiration correspond to the effective precipitation, which all goes to satisfy plant water requirement. In this latter case irrigation is needed to allow crops to growing optimally. This irrigation requirement (IR) is equal to the difference between crop evapotranspiration and effective rainfall:

$$ET_{blue} = IR = max\left(0, ET_c, -P_{eff}\right) \quad (2)$$

And correspond to the fraction of evapotranspiration that is fulfilled by irrigation. When the effective rainfall is greater than the crop total crop evapotranspiration $ET_{blue}$is equal to zero. The blue and green crop water requirements (ET_{blue} and ET_{green}, respectively) are then transformed into blue and green water use $\left(CWU_{blue,green}\right)$ by multiplying their values by 10, which converts water depths in millimetres into water volumes per land surface in m^3/ha. Finally the two fractions of the WF are obtained through

$$WF_{green,blue} = \frac{CWU_{blue,green}}{Y} \quad (3)$$

in which Y is the crop yield.

The computation of the WF for vegetal productions comes simply from the application of the using the above formulas. For animal production, however, the WF must be computed considering the overall amount of dry matter needed to complete the production cycle of the animals. This amount is computed considering how much of the different crops is consumed per life stage in a production cycle (tons of dry matter*head^{-1}). Multiplying the total matter intake by the fraction of a given crop in the diet of the animals in the different life stages and by the duration of each specific life stage we obtained the amount of each crop consumed in all the life stage of the production cycle. By adding up the different amounts pertaining every crop consumed in each life stage we obtained the total amount by which every single crop takes part in the diet of the animals. This amount is given in ton/head. Multiplying this quantity by the WF associated to each crop (and computed using the procedures described above) yielded the WF of each crop entering the diet of the animals.

The grey WF was computed according to Franke et al.(2013). In particular, we followed the Tier 1 approach which allows a first estimate of the amount of a given substance entering the groundwater or surface water system when spread on or into the soil. It however does not describe the different pathways of a chemical substance from the soil to surface or groundwater and the interaction and transformation of different chemical substances in the soil or along its flow path. This second step was impossible to apply due to the difficulty to construct specific computations for every single product. Tier 1 is essentially based on the formula

$$WF_{grey} = \frac{[(\alpha\, Appl/(C_{max}-C_{nat}))]}{Y} \quad (4)$$

in which the variable $Appl$ represents the quantity of chemical substances applied on or into the soil (in mass/time), i.e. artificial fertilizers, manure or pesticides put on croplands; α is the leaching-runoff fraction, defined as the fraction of a given chemical reaching freshwater bodies. This product assumes that a certain fraction of the applied chemical substances reaches the ground- or surface water, and it is a simplified procedure (Franke et al. 2013). The terms C_{max} and C_{nat} stand for the maximum acceptable concentration and the natural concentration in a receiving water body respectively. The former is the maximum acceptable concentration of a given pollutant and it is defined through the water quality standards that legislation establishes for a given territory. The latter is the concentration in the water body that would occur if there were no human disturbances in the catchment. For human-made chemical substances that naturally do not occur in water it should be equal to 0.

2.2.2 The Life Cycle Approach

This approach was applied to compute the water consumption due to all the activities that are essential for production, from the field to the stable. The main items that we considered in this work are: fertilizers and pesticides, diesel consumed by machinery, electricity consumption, drinking water and water for other uses (i.e. washing). All these items require water to be manufactured; this water enters the accounting as as blue water. The procedure adopted is a typical LCA process in which input data are collected by the case study conductor or derived from national accountings or from the literature,

For the impact analysis (i.e. water consumption to obtain a given output) we used the Ecoinvent 3.1 database (https://www.ecoinvent.org/), in which specific processes and associated elementary flows are stored for a vast array of the products. In particular, the dataset serves as a complete list of all environmental flows related to the provision of the functional unit of the item. To give an explanation of the procedure, consider an agricultural production which requires a specific amount of mineral nitrogen per ha. Because Ecoinvent includes in its databank a process that produces fertilizers with a mean content of Nitrogen equal to 24,8%, the amount of nitrogen applied to grow a given crop (primary data) is transformed in the overall quantity of fertilizer of which the primary data in Kg/ha represents the 24,8%. This result must be further divided by the yield to get the amount of fertilizer that serve to obtain one unit output (functional unit, which is the reference quantity). The software Open LCA thus returns the amount of water needed to manufacture the amount of fertilizer that contains the quantity of mineral nitrogen corresponding to the primary data.

The same applies, for example, to electricity consumption. The amount consumed in a production process is the primary data that is associated to a process of electricity production in Ecoinvent 3.1. It is possible to assign a given electricity mix from which the amount of electricity used (primary data) is obtained (e.g. Italian energy mix for production located in Italy). This procedure yields the amount of water needed to produce that quantity of electricity.

2.2.3 The per hectare Impact

Formally the WF is expressed as the amount of water used per unit of final product. In this paper by final product we mean what is produced on farm and does not include the processing phase. So our approach followed recommendations of the WFN; nonetheless we were interested in estimating how much water each product requires per unit surface (ha). This can be an important indicator for the implementation of more sustainable policies at the level of agricultural land management. However we kept this estimate separate from the WF and we called it Water Impact (WI), that we divided in green, blue and grey contributions as well but, as said, WI it is something different form the WF, both conceptually and operationally. The calculation in fact is much simpler than that of the WF in the case of animal products because it does not include crop proportions in the animal feeding, but only the intensity at which water is used to grow the crops that feed the animals. The computation is simpler because the green and the blue component of the WI correspond to the ET_{blue} and ET_{green} which are expressed as m^3/ha. The grey fraction is computed in the same way as described in section 2.2.1 without dividing by crop yield.

2.3. Data collection and approximations

Data necessary to compute the WFWF were collected by the case study conductors within the framework of the Strength2Food project. For each case study they selected also an appropriate reference product to be used as a benchmark for comparison. The set of information required in the computation ranged from climatic data to crop and soil features as well as amount of fertilizers and pesticides employed, water, electricity and diesel consumption. For computing green WF crucial are the climatic information, which must include minimum and maximum monthly temperature (for a selected reference year), humidity, sun hours, wind speed and rainfall measures. These data constitute part the input to the software CLIMWAT 8.0 that computes evapotranspiration and crop water requirement. The other part of the input are cultural data, which include planting and harvest date, duration of the developmental stages of the plants, considering that the growing season is intended divided in initial, development, mid-season and late season periods. Initial stage runs from planting date to approximately 10% ground cover. The development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. The mid-season stage runs from effective full cover to the start of maturity. The late season stage runs from the start of maturity to harvest or full senescence. Other essential information includes the critical depletion fraction and the yield response factor. The former is the critical soil moisture level where first drought stress occurs, affecting crop evapotranspiration and crop production. The latter relates relative yield decrease to relative evapotranspiration deficit. In practice, this index describes over the total growing period, how yield would decrease in relation to water deficit. Water deficits in crops, and the resulting water stress on the plant, have an effect on crop evapotranspiration, which is the key parameter to compute WF. Given the difficulty associated to the computation of the yield response factor (Allen et al. 1998) we assumed for most of the cases yield reduction as directly proportional to reduced water use (yield response factor $Ky = 1$) and assumed the actual yield (data available for each crop) as the optimum yield. In this way we could compute the actual evapotranspiration coincides with the value of crop evapotranspiration under standard conditions disease-free, well-fertilized crops under optimum soil water conditions and achieving full production under the given climatic conditions (ET_c)

In several cases the search for the values at local level of the above described parameters could not be complete and we had to rely on existing databases. When meteorological data were lacking (no meteorological stations in the production areas or impossibility to gather such data) we used the climatic database CLIMWAT which provides the meteorological data from over 5000 climate stations worldwide. It is used in combination with CROPWAT and provides for the stations in its database long-term monthly mean values of the mean daily maximum temperature, mean daily minimum temperature, mean relative humidity, mean wind speed, mean sunshine hours or solar radiation, monthly total and effective rainfall.

We used existing data sets when crop parameters could not be provided. We browsed FAO publications (Allen et al. 1998, Doorenbos and Cassan 1979) and the web site http://www.fao.org/land-water/databases-and-software/crop-information/en/ in which crop parameters for several of the world cultivars are reported.

Computing the grey WF required several approximations. Primary data were the amount of fertilizers (nitrogen based and phosphorus based) and of the several types of pesticides used in crop productions. However the computation was conducted on nitrogen only. We excluded pesticides because of the great heterogeneity of the data: in some cases we had information on the active principle; in others the information concerned the amount of the substance containing the active principle. Also problems emerged in finding the maximum allowable concentration for either chemical compounds or active principles. In addition in some cases the amount applied were not available from case study conductors. However pesticides were not completely discarded form the analysis; in fact through the LCA approach we had the opportunity to quantify the impact on water resources as blue water that is employed to produce the substances used to protect crops from pests. So pesticides enter the WF calculation as blue water. This however only partially compensates for the underestimated grey WF impact due to the exclusion of pesticides.

Phosphorus as well was not included in the computation. Difficulties in this cases emerged in searching for the maximum allowable concentration in water bodies because such value varies in relation to the trophic state of the receiving water body (Franke et al. 2013), an information that was impossible to achieve from case study conductors. Recent studies quantifying grey WF (Van Oelet al. 2009, Dabrowski et al. 2009, Gerbens-Leenes et al. 2009, Aldaya and Hoekstra 2010, Bulsink et al. 2010 and and Hoekstra 2010, 2011) focused on nitrogen and others outlined the approximations required to include phosphorus in the computation (Liu et al. 2012). For Nitrogen we explored the literature (Chapman 1996, Chapagain et al. 2006, Heffer 2009, FAO 2006, 2009, Franke et al. 2013) to define standards to be used in the computation. We assumed that the quantity of the chemical that reaches free flowing water bodies is 10 per cent (α=0,1) of the applied fertilization rate (amount applied in kg/ha/yr, primary data) (Hoekstra and Chapagain, 2008). For the maximum allowable concentration in the free flowing surface water bodies the EU set up a value of 50 mg/l of $N\text{-}NO_3$ (which correspond to 11,3 mg-N/l). This however is a standard imposed for drinking water. For this study we set up a slightly higher reference value and equal to 13 mg/l (measured as N), according to Franke et al. (2013). As for the background concentration data on fresh surface water from the EU monitoring stations indicate that 64.3% were below 10 mg nitrate per litre, while 2% showed concentrations between 40 and 50 mg per litre and 1.8% exceeded 50 mg per litre. Considering these data and also indications by Franke et al. (2013) we set up the background concentration for this study equal to $(c_{nat} = 0{,}023\ mg/lt)$ which corresponds to $(c_{nat} = 0{,}1\ mg/lt\ N - NO_3)$.

Finally, for each product, a thorough quality check procedure was implemented to limit the risk of misreporting data. The three key aspects of this procedure were 1) to record all data, their date and source in a shared spreadsheet, 2) to separate the person who collected data from the person who estimated the WFWF, and 3) to come up with a written and consensual interpretation of the results between these actors. All the spreadsheets including the raw data, their source, and the resulting estimated WFs can be found at https://www2.dijon.inra.fr/cesaer/informations/sustainability-indicators/.

2.3. Data structure and Statistical Analysis

We computed the green blue and grey WF and WI for the 23 products classified as Food Quality Schemes (FQS) and for their 23 reference products (REF, henceforth). The comparison between the values obtained for FQS and REF products was conducted using the Wilcoxon test. In particular, we applied the signed rank version of the test. The paired test better reflects the nature of the scientific question that is whether each FQS performs better than its REF counterpart. The small size of the samples and their non-normal distribution (and that of the sample of the differences, tested using the Shapiro-Wilx test) suggested to use the non-parametric test.. We performed several comparisons considering the main subdivision in three groups: organic products (and their conventional counterparts), PDO product and PGI products. Also we compered FQS and REF products in two larger group obtained by pooling together all animal products and all the vegetal products. The comparison between FQS and REF products was performed for each specific fraction, green, blue and grey WF and WI.

3. Results

The results of the Wilcoxon test applied to the groups of products are summarized in Table 1. A striking difference emerges between WF and WI, its per hectare counterpart. As for WF, the only significant difference (at 0,1 level of probability) concerns the blueWFin the Organic group; it is the only case in which FQS performs better than REF (i.e. FQS has a lower footprint than REF). In all the other comparisons no significant difference was detected between FQS and REF. When the impact per unit surface is considered, several comparison resulted significant (see Table 4, WI). The difference in green WI resulted significant only for the Animal pooled sample, whereas FQS performed better than REF in all the groups for blue WI (at 0,1 level of probability for Organic, and PGI products and at 0,05 level of probability for PDO and for the vegetal and animal pooled samples). As for grey WI we obtained no significant difference in the PDO groups whereas significance is at 0,05 level of probability for all the other groups.

Table 1. Results of the Wilcoxon tests. WF indicates the comparisons between FQS and REF products for WF values (m^3/kg of product); WI indicates comparisons for the Water Impact values (m^3/ha)

Indicator	Fraction	Organic	PDO	PGI	Animal	Vergetal
WF (m^3/kg)	Green	V = 28, p-value=1	V = 10, p-value=0,5	V = 29, p-value=0,94	V = 36, p-value=0,95	V = 61, p-value=0,86
	Blue	V = 5, p-value=0,078	V = 13, p-value=0,71	V = 23, p-value=0,76	V = 24, p-value=0,59	V = 35, p-value=0,25
	Grey	V = 12, p-value=0,66	V = 4, p-value=0,109	V = 25, p-value=0,84	V = 31, p-value=0,85	V = 23, p-value=0,112
WI (m^3/ha)	Green	V = 4, p-value=0,209	V = 4, p-value=0,109	V = 3, p-value=0,14	V = 1, p-value=0,017	V = 20, p-value=0,133
	Blue	V = 0, p-value=0,078	V = 1, p-value=0,031	V = 8, p-value=0,09	V = 2, p-value=0,014	V = 11, p-value=0,002
	Grey	V = 1, p-value=0,015	V = 0, p-value=0,031	V = 16, p-value=0,66	V = 1, p-value=0,017	V = 14, p-value=0,004

Figure 1 shows the distributions of the values for blue, green and grey water impact per hectare of the FQS and REF within the Organic, PDO and PGI pools.

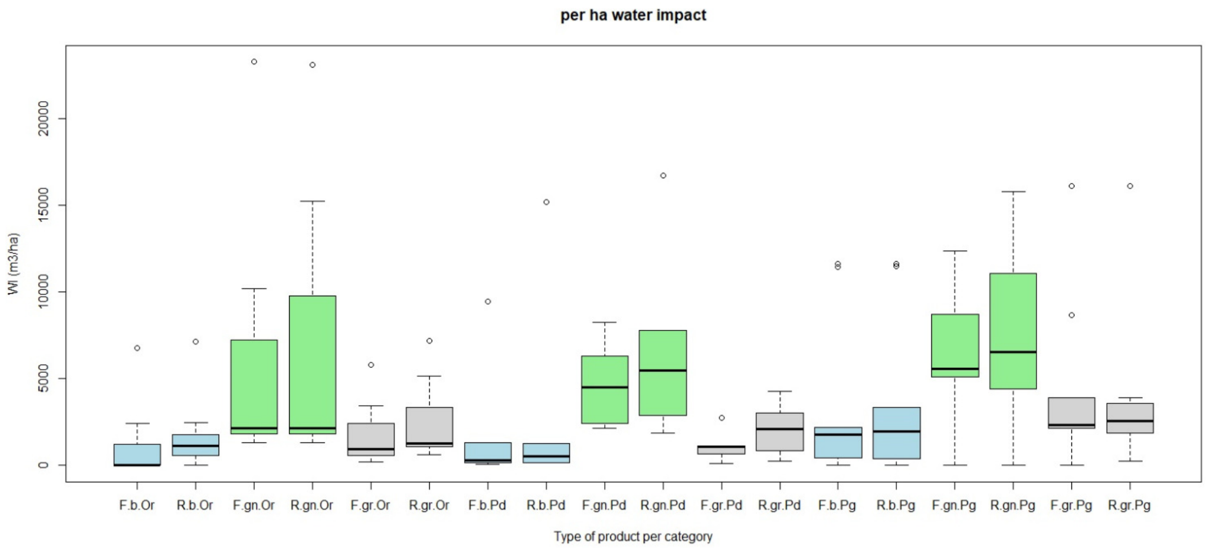

Figure 1. Box-plots of the "per hectare" WI. Colours identify the blue (b), green (gn) and grey (gr) fraction of the water impact. Each couple of plots refers to a FQS (F) and REF (R) distribution within the Organic (Or), PDO (Pd) and PGI (Pg) group.

Figure 2 shows the box plots for the distributions of the blue, green and grey WI for FQS and REF products within the pooled animal and vegetal groups.

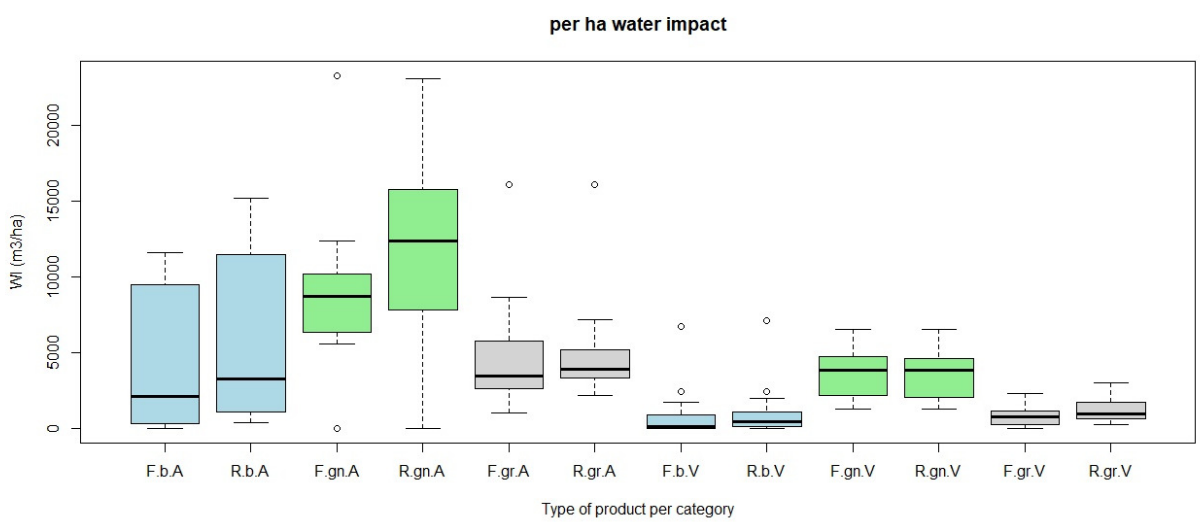

Figure 2. Box-plots of the "per hectare" WI. Colours identify the blue (b), green (gn) and grey (gr) fraction of the indicator. Each pair of plots refers to FQS (F) and REF (R) products within the animal (A) and vegetal (V) group.

Comparing the values of the two indicators (WF and WI) for any single couple FQS and REF we obtained that for only 10 products out of 69 cases the WI for the FQS is higher than that of the REF counterpart. As for WF the number of comparisons in which the WF is higher for FQS increase to 35.

4. Discussion

We computed WF and WI considering as divided in the green, blue and grey fractions for FQS and REF products in the groups of Organic, PDO, PGI, pooled Animal and pooled Vegetal products. The striking evidence of this analysis is that a clearer pattern emerges when the focus is on the impact per unit area (ha). In particular, FQS products have a significantly lower impact than REF for the blue and grey WI, whereas, with the exception of the pooled animal products, FQS and REF do not show significant difference as for green WI. This outcome is important because blue and grey are the two fractions of the WI upon which management can exert much control. Accordingly, the results highlights that the different strategies by which Organic, PDO and PGI are produced perform better in terms of water consumed per hectare.

One interesting aspect concerns the blue water WI. Its value is the sum of the irrigation requirement (ET_{blue}) and the quota computed through LCA and that refers to the amount of the blue water consumed to produce energy and materials needed to make crop production operational (e.g. fertilizers, pesticides, diesel for machinery and so forth). By considering these two parts of the blue WI we observed that the REF products contribute more than FQS products to make the blue LCA significantly higher than the irrigation requirement (Wilcox test applied to the difference between FQS and REF in the comparison between LCA fraction and irrigation requirement, V=47, p-value=0,0318). We already discussed that the grey WF and grey WI do not account for the impact of phosphorus fertilizers and pesticides. Instead, such impact was expressed as blue WI and WF. In the case of WI this part contributed noticeably to increase the blue LCA for REF but not for FQS, as many of these productions use these products in lesser amount, if not at all.

The performance in terms of WF between FQS and REF products does not show a definite pattern. There are cases in which FQS performs better than REF and others in which the opposite holds and this occurs irrespectively of the type of product, be it Organic, PDO or PGI. The large heterogeneity in the results emerges also by considering for each single product the percentage difference in WF values between FQS and REF. There are cases in which this percentage is less than 1%, as for example in the grey WF for the Italian Organic Tomato and its reference counterpart (the former performs worse than the latter) and other cases in which this percentage exceeds 1000% because the values we computed produce a difference between FQS and REF of several orders of magnitude. This is the case, for example, of the grey WF of the Horm Mali Rice (PGI product of Thailand), for which the FQS product requires an amount of water to dilute nitrogen pollution that is by two orders of magnitude lower then its REF counterpart.

The different results we obtained for WF in comparison with WI depend on several factors. For vegetal products yield is the most relevant. Thus, the lower yield that often accompanies non-conventional productions increases their water requirement per unit product. Of the 14 vegetal products that compose our sample, in 9 cases the FQS showed lower yield then REF. In all of them at least for 2 out of the three WF fractions the FQS showed higher value than REF. As for the animal products the analysis is more complex because animals are fed with a mixed diets involving multiple crops. Thus the different crop yield combines with the different proportion in which each crop enters the diet of FQS and REF animals to affect the final value of the indicator.Also conversion factors (e.g. product concentration and efficiency of transforming feed into food) play a role: the way efficiency characterizes a productive chain acts as a strong constraint to water needs per unit product in both conventional and non-conventional systems.

The distinction between green and blue - grey water is important because each type of water is associated with different environmental impacts, although the two fraction are linked with one another. We computed the share of the overall WF required for evapotranspiration (thus excluding the part of the blue WF computed through the LCA) by the green and the blue fraction for the three groups of products. Figure 3 summarizes this result.

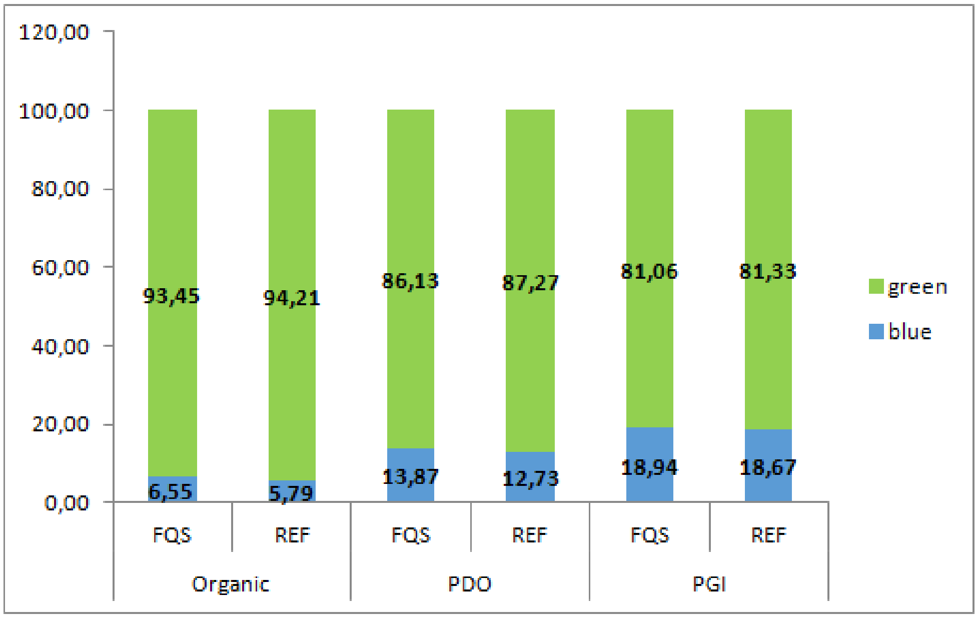

Figure 3. Share (%) of the total WF by the green and the blue fractions of the indicator for the three groups of products under investigation.

The blue WF shows the lowest share in the group of Organic products (6%) while it increases above 10% in PDO products (13%) and reaches almost 20% in the PGI group. However the same computation applied to REF products yielded similar results (Figure 3). This indicates that the particular way of production (e.g. Organic vs conventional) does not change the balance between grey and blue WF. Rather, the specific products sampled are responsible for the difference observed between Organic, PDO and PGI products. It can be said that most of the differences between the types of productions come from the LCA blue fraction and the grey fraction of WI, because they mostly reflects the differences in production strategies between conventional and organic/certified products.

The scenario depicted in Figure 3 highlights that vegetal products and the crops used to feed the animals satisfy most of their water requirements through the rainfall and rely on irrigation for a rather small fraction of their needs. The he worst scenario under the effect of climate change is one in which an increasing temperature will be coupled with decreasing precipitation (Bocchiola et al. 2012). In this case the need for blue water would increase, but the sustainability of this increase requires that it will be compared with an index of water scarcity (Damkjaer and Taylor 2017), in the understanding that climate alteration may increase both water scarcity and blue WF due to augmented evapotranspiration and consequent higher irrigation demand.

5. Conclusions

This work constitutes a first attempt to make an extensive analysis of how non conventional or certified production impact water resources in comparison with conventional productions. The results we obtained highlight that the potential benefit associated with non conventional production is visible mostly when the focus is on WI as indicator, that is water requirement per unit area. The analysis of the results also suggests that this difference is mostly due to LCA blue WI and the grey WI, the two fractions that largely depends on the use of fertilizers and pesticides, which are applied in less quantities in non conventional productions.

When the focus is on WF, that is water required per unit of final products, non conventional and certified productions do not perform any better statistically than their conventional reference products. This depends on the yield of the cultivars but also on the different efficiencies to obtain the final product. We present this result with much circumspection, however, in the understanding that, for the reasons specified in the body of the paper, we did not take into account several factors that might have increased the impact of conventional products, especially in terms or their grey water requirement.
Studies like the one presented here are not easy to perform accurately. The amount of information required implies a great effort in collecting data and often they must be gathered from national or other databases, which make the final result a rough estimate of the real impact of the production systems. We believe however that increasing the accuracy of the estimation is possible and this may help improving the use of WF in management and decision making.

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Appendix

List of the Food Quality Schemes and their Reference counterparts within Organic, PDO, PGI.

ORGANIC

Case studied (FQS)	Country	Reference product (REF)
Organic flour	France	National average
Camargue rice	France	Non-organic rice (mostly PGI)
Organic pork	Germany	National average
Organic yoghurt	Germany	National average
Organic tomato from Emilia Romagna	Italy	Conventional processed tomatoes in the same region (Emilia-Romagna)
Organic pasta	Poland	Simulated conventional farms with sample characteristics
Organic raspberries	Serbia	National average

PDO

Case studied	Country	Reference product
PDO olive oil	Croatia	National average
Comte cheese	France	National average (cow cheese)
Zagora apple	Greece	Kissavos apples (non-GI apples from another region)
Kalocsai paprika powder	Hungary	Imported Chinese pepper milled in Hungary
Parmigiano Reggiano cheese	Italy	Biraghi cheese (similar non-PDO cheese)
Opperdoezer Ronde potato	Netherlands	Regular potato in neighbouring IJsselmeerpolders region

PGI

Case studied	Country	Reference product
Dalmatian ham	Croatia	Local non-PGI firm
Kastoria apple	Greece	Kissavos apples (non-GI apples from another region)
Gyulai sausage	Hungary	Non-PGI Hungarian sausage
Kaszubska strawberries	Poland	National average
Sjenica cheese	Serbia	National average (cow cheese)
Sobrasada of Mallorca	Spain	National average
Ternasco de Aragon	Spain	Non-PGI lamb in the same region (Aragon)
Thung Kula Rong-Hai (TKR) Hom Mali rice	Thailand	Non certified rice from the same region (90% of GI rice is organic as well)
Doi Chaang coffee	Thailand	Non-PGI coffee from the same province
Buon Ma Thuot coffee	Vietnam	Non-PGI coffee from Dak Lak province in Vietnam