Water and Carbon footprint perspective in Italian *durum wheat* production

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Abstract

Agriculture has a strong influence on water consumption; the scarcity of water in some areas is a problem, which affects the balance of entire production areas. Global water resources are widely used for food production; some areas of the Mediterranean are scarce in water and the water demand is expected to increase in the future due to population growth. In addition, carbon emissions related to agricultural production represent about 35% of total greenhouse gas emissions. Starting from these considerations, this study investigates Water and Carbon footprint in Italian *durum wheat* cultivation, taking into account the production from 2011 to 2015. Results showed an extreme variability of these indicators across the Country. The Regions below 5,000 m^3 ha^{-1} of water consumption (dedicated to *durum wheat* production) are located in the South, whilst the highest values are recorded in the Centre and in the North. With regard to the values of the water surface consumption, the situation is quite the opposite: indeed, these are mainly the Southern and the Adriatic regions that have a high value of the ratio between water footprint and total agricultural area. Carbon footprint showed a similar trend; its highest value was found in Northern Italy (2,462 kgCO2 ha^{-1}), the ratio between the North and the Centre-North is 1.30. Policy suggestions that address management of water resources and sources of carbon emissions could increase the environmental sustainability of Italian *durum wheat* production.

Keyword: Water use; Carbon footprint; Environment policy; sustainability; durum wheat.

1. Introduction

Ryan et al. (2008) predict that the future challenge for agriculture will be to produce without reducing the capacity of natural resources (soil and water), and to avoid creating a fragile and uncertain environment for production. In the Mediterranean, cereals account for over half of the total area of land that is irrigated (Daccache et al., 2014), and although considerable efforts have been made to develop and disseminate several modern wheat varieties (Shiferaw et al., 2014) to increase productivity, few studies have been carried out on the environmental sustainability of cereals production.

The Mediterranean area contributes to 60% of the global production of *durum wheat* (FAOSTAT, 2013). The production of which is expected to experience an increased variability in yield and quality as a consequence of climate change (Toscano et al., 2015). Italian wheat production during 2015 covered an area of 1,327,389 hectares and yielded 44,537,266 tons of cereals (ISTAT data).

Water resources are widely used for food production and, consequently, its demand is expected to increase in the future due to population grows (Bocchiola et al., 2013; Curmi et al., 2013; Khan and Hanjra, 2009). Agriculture is the main consumer of freshwater in the world, as pointed out by Rodriguez et al. (2015) and accounts for about 70% of water withdrawals (Chen and Chen, 2013). Some Mediterranean areas are water scarce, particularly in Southern and Eastern countries (García-Ruiz et al., 2011). A failure to manage many water systems optimally results in environmental damage (Xu et al., 2016); this is more evident in the case where activities can cause the degradation of hydrological habitats (Chapagain and Orr, 2009). Ercin and Hoekstra (2014) predict that freshwater scarcity and pollution will be worsened in the future and this will decrease its quality. Moreover, some authors have estimated that human dependency on water resources will increase significantly in the future (Alcamo et al., 2003; Bruinsma, 2009; Rosegrant et al., 2009). Chapagain et al. (2006) point out that the majority of costs and impacts of water use and pollution caused by agriculture and industry is not translated into the price of products. However, it is still possible to remain at sustainable levels even with increasing populations through changes in water management (Ercin and Hoekstra, 2014). In order to limit the unsustainable use of global freshwater resources, indicators are needed, which make consumption patterns transparent (Ridoutt and Pfister, 2010).

Global water cycles and carbon energy cycles are inextricably linked (Khan and Hanjra, 2009). Scientific evidence has shown that the climate is rapidly changing mainly due to increasing anthropogenic greenhouse gas emissions (Ruddiman, 2003), which stem from various human activities, including agriculture (Janzen et al., 2003).

An issue closely linked to the greenhouse gas balance is related to the carbon cycle and the ability to store it in carbon sinks (IPCC 2014). It is known (Pattara et al., 2012) that carbon dioxide is absorbed by plant tissue and it is converted into cellulose and lignin and other compounds. The duration of carbon sequestration outside the atmosphere determines whether the cycle is short or long. Unfortunately, in the case of durum wheat, all carbon stored in plant tissues is released into the atmosphere in the timespan of a season or a few years. This implies that in open field crops no direct benefits can be achieved in terms of carbon sinks. As it is well known (Weidema 2008), carbon footprint (CF) is a very effective tool from a communication point of view, but within the complexity of environmental issues it is only one part of the whole. Environmental impact indicators (fresh water contamination, eutrophication, soil salinisation, etc.) that have developed as result of the use harmful plant protection products and the mismanagement of fertilisers and plant protection products should not be neglected.

Directly associated with the theme of changing crops, the possibility of changing dietary habits towards low CF products can be raised. The issue has been addressed by several authors (Grebitus et al., 2015, Cerutti et al., 2016, Nijdam et al., 2012); however, it seems clear that the influence generated by environmental components in labelling of food products is still marginal compared to product price. There is still not enough done terms of consumer awareness campaigns to clarify labels relating to environmental issues or performance. Although the European Commission (with the single market for green products) and other nations around the world are making great efforts towards a standardisation of environmental certification procedures for products of the same category and for emission mitigation measures related to food production, consumers are still largely uninformed when it comes to environmental labels (Grebitus et al., 2015). Furthermore, a proliferation of environmental labels have contributed to an increase in consumer confusion have made making product choices even more difficult, needs to be taken into account.

The responsible use of water and the reduction/mitigation of carbon dioxide emissions is important in the context of social responsibility and of the guidelines aimed at sustainable management of natural resources. The Water Footprint (WF) has been widely used as an indicator that contributes to safe and sustainable of water, and CF for as an indicator for carbon dioxide emissions. Although the various footprint concepts are related, significant differences in origin exist between ecological WF and CF.

Rural development plan is an extremely important tool to regulate the environmental policy. Depending on the purpose for which the rural development plan (RDP) model is used, it can be modulled for specific features, such as the assessment of more complex relations in ecosystems and in environment-economy and environment-society interactions. Since the late 1990s, Italian producers have struggled to improve the environmental performance of their production processes, an objective which has now been extended to the entire supply chain (Bevilacqua et al., 2007). Regarding products intended for direct consumption (pasta, rice and bread), the phases of the life cycle considered start from the production of raw materials, and conclude with cooking (as specified in the studies of Espinoza Orìas et al. 2011) and the disposal of packaging.

New policies can make food production more sustainable within the carrying capacity or ecological threshold of land and water resources (Khan and Hanjra, 2008) and with this in mind, The aim of this paper is to assess the WF and CF of Italian *durum wheat* production, identifying both the location and the character of the impacts.

2. Literature review

2.1 Water use in cereal productions

Allan (1998) introduced the concept of virtual water to describe the total volume of water in agricultural products; he suggested that regions, which are poor in water, should import water intensive agricultural products. The water footprint is one of the most common tools used to analyse water management and the WF of a product is defined as the volume of freshwater used to produce it and should be measured over the full supply chain. This is more frequently expressed in water volume per unit of product (m^3 t^{-1}) (Mekonnen and Hoekstra, 2011).

Hoekstra et al. (2011) define the concept of the Blue, Grey and Green WF. The Blue WF measures the amount of available water consumed in a certain period and therefore not immediately returned to the catchment; Grey WF of a process step is an indicator of the degree of freshwater pollution associated with it and is defined as the volume of freshwater that is required to assimilate the pollant load; Green WF is an indicator of human water use and refers to precipitationthat does not run off or recharge the groundwater, but is stored in the soil or temporarily stays on the soil surface or vegetation. The sum of these three components gives the total WF.

In the agriculture, many studies emphasise the importance of a responsible use of water resources (Ababaei and Etedali, 2014). The water footprint is also calculated in products derived from *durum wheat*, such as pasta (Ruini et al., 2013). The water footprint indicator is a tool that provides interesting information for policy makers (Steen-Olsen et al., 2012) and economists and is useful for water management.. Rodriguez et al. (2015) emphasised the relevance of agricultural practices, such as irrigation and fertilisers on the WF of the crop.

Companies and consumers can be advantaged by finding ways of reducing their environmental impacts, as well (Ridoutt and Pfister, 2010). In the context of social responsibility, the WF has been widely used as an indicator that contributes to safe and sustainable use of water (Marano and Filippi, 2015). Freshwater (adequate in terms of qualities-quantities) is a prerequisite for human societies and natural ecosystems.

Despite the importance of WF as an environmental sustainability indicator, it should be considered as a partial tool - one that can be used together with other indicators to allow for a more in depth look atintegrated policies (Perry, 2014).

2.2 Carbon footprint in agricultural production

The carbon footprint is a versatile tool that can also be used for communication purposes due to its direct correlation with the phenomenon of climate change (Pattara et al., 2012). It is particular useful for communication to stakeholder groups who do not have a high-level scientific knowledge. Its easy use has rendered it quite popular even within the scientific research community, which has contributed to its application in different fields and sectors (Accorsi et al., 2015).

The CF of a product is defined as the greenhouse gas (GHG) emissions associated with the life cycle of that product that is calculated from cradle to grave (Pattara et al., 2012; Zubelzu et al., 2015). As a general rule, it is expressed as the amount of CO_2eq for a previously defined unit of measurement.

In this sense, the CF is part of the Life Cycle Assessment (LCA) method, already applied in many production sectors and which continues to spread even with analyses of food products. Its application has been in use in the cereals sector since the 2000s (Brentrup et al. 2000), contributing significantly to the improvement of information on the environmental impacts related to cereal production systems.

Along with the spread of LCA, there has been an exponential growth of tools specificly linked to one particular category of environmental impact (e.g. CF, WF, Ecological Footprint, etc.). In contrast to LCA (which is more complex and is connected to more environmental impact categories), these seem to be more easily understood by the media and by the organized retail.

This was precisely what was seen in these indicators, as marketing the tools can encourage public support. Therefore, brands and standards for CF certification were created all over the world (Huella de Carbono in Spain, Bilan Carbone in France, CF in the UK, etc.), all regulated nationally and managed by NGOs. Only after a process that lasted several years, ISO issued the technical standard ISO/TS 14067:2013 relating to the accounting and disclosure of GHGs of a product (the rule relevant to organisations is ISO 14064:2006) in May 2013.

Moreover, at an international level, several sectoral organisations have attempted to define (even without a recognised standard) the rules of application (PCR - product category rules) of the various national standards for GHG emissions accounting. Since 2008, the *Organisation International de la Vigne et du Vin* has been working on the definition of a specific protocol for the accounting of greenhouse gases, both for the company and the product. Furthermore, in the next few months it will release the these documents with the relevant technical specifications regarding the emission factors.

Similarly, the IOC (International Olive Oil Council) is in the process of defining the PCR related to extra virgin olive oil, thanks to a process of consultation carried out with leading international experts. However, the International Grains Council (IGC) has not yet developed any reference PCR for the production of cereals. Despite this growing interest in the methodology of CF, CF labelling for cereal its products is still not widely seen. Noteworthy efforts of this are *Barilla* and *De Cecco* for pasta products (regarding the Environmental Product Declaration standard) and some certifications carried out by flour mills.

There are many applications of the CF along the supply chain of the cereals sector. The products that have been considered include pasta, bread, various types of flour and by-products of corn used as biofuels (Ruini and Marino, 2010; Espinoza Orìas et al., 2011). Therefore, the functional unit (FU) and the phases included within the boundaries of the system and the GHG emissions associated with them, tend to differ significantly, thus rendering it impossible to make comparisons between the final emissions associated with the various products.

3. Methodology

3.1 Water use calculation

WF has three components: Virtual Green Water Content (VWC_{Green}), Virtual Blue Water Content (VWC_{Blue}) and Virtual Grey Water Content (VWC_{Grey}). WU_{Green}, WU_{Blue}, WU_{Grey} are the Green, Blue and Grey Water Use respectively, for a hectare of production (Rodriguez et al., 2015).

WU_{Green}= Green Water use (m^3 ha^{-1}).
WU_{Blue}= Blue Water use (m^3 ha^{-1}).
WU_{Grey}= Grey Water use (m^3 ha^{-1}).

The total WF for the process of growing crops or trees is the sum of the Green, Blue and Grey components in relation to the volume of the WF of the product/mass (Rodriguez et al., 2015):

$WF = VWC_{Green} + VWC_{Blue} + VWC_{Grey}$ (volume/mass).

VWC_{Green}= Virtual Green Water content (m^3 t^{-1}).
VWC_{Blue}= Virtual Blue Water content (m^3 t^{-1}).
VWC_{Grey}= Virtual Grey Water content (m^3 t^{-1}).

Water Use in relation to a hectare of production were calculated as follows (Rodriguez et al., 2015):

$WU_{Green\ \mathit{Region\ i}}$ (m^3 ha^{-1})= $VWC_{Green\ \mathit{Region\ i}}$ (m^3 t^{-1}) × $Y_{p\ \mathit{Region\ i}}$ (t ha^{-1}).
$WU_{Blue\ \mathit{Region\ i}}$ (m^3 ha^{-1})= $VWC_{Blue\ \mathit{Region\ i}}$ (m^3 t^{-1}) × $Y_{p\ \mathit{Region\ i}}$ (t ha^{-1}).
$WU_{Grey\ \mathit{Region\ i}}$ (m^3 ha^{-1})= $VWC_{Grey\ \mathit{Region\ i}}$ (m^3 t^{-1}) × $Y_{p\ \mathit{Region\ i}}$ (t ha^{-1}).

Where:
WU=Water Use ($WU=WF \times Y_p$).
$Y_{p\ \mathit{Region\ i}}$= productivity of *durum wheat* per hectare (t ha^{-1}) of *Region i*.

$WU_{\mathit{Region\ i}} = WU_{Green\ \mathit{Region\ i}} + WU_{Blue\ \mathit{Region\ i}} + WU_{Grey\ \mathit{Region\ i}}$

WU_{Green}, WU_{Blue} and WU_{Grey} of a Region in relation to the TAA (*Total Agriculture Area*) were then calculated as follows:

$WU_{Green\ \mathit{Region\ i}} \times TAA_{\mathit{Region\ i}}^{-1}$ = [$VWC_{Green\ \mathit{Region\ i}}$ (m^3 t^{-1}) × D.W. $_{prod\ \mathit{Region\ i}}$ (t)] / $TAA_{\mathit{Region\ i}}$ (Km^{-2}).
$WU_{Blue\ \mathit{Region\ i}} \times TAA_{\mathit{Region\ i}}^{-1}$ =[$VWC_{Blue\ \mathit{Region\ i}}$ (m^3 t^{-1}) × D.W. $_{prod\ \mathit{Region\ i}}$ (t)] / $TAA_{\mathit{Region\ i}}$ (Km^{-2}).
$WU_{Grey\ \mathit{Region\ i}} \times TAA_{\mathit{Region\ i}}^{-1}$ = [$VWC_{Grey\ \mathit{Region\ i}}$ (m^3 t^{-1}) × D.W. $_{prod\ \mathit{Region\ i}}$ (t)] / $TAA_{\mathit{Region\ i}}$ (Km^{-2}).

Where:

$TAA_{Region\ i}$ = *Total Agriculture Area* of *Region i* (Km^{-2}).
D.W. $_{prod\ Region\ i}$ = Total *durum wheat* production of *Region i* (t).

$$WU \times TAA_{Region\ i}^{-1} = WU_{Grey} \times TAA_{Region\ i}^{-1} + WU_{Green} \times TAA_{Region\ i}^{-1} + WU_{Blue} \times TAA_{Region\ i}^{-1}$$

Data for VWC_{Grey}, VWC_{Green} and VWC_{Blue} for different areas of Italy were taken from Mekonnen and Hoekstra (2011), who highlighed in their study Grey, Green and Blue WF in different *durum wheat* production areas in Italy. The *durum wheat* production from 2011 to 2015 in different areas of Italy (Data ISTAT) was taken into account in the present study.

3.2 Carbon footprint calculation

Cereals represent one of the most important agricultural commodities and their cultivation is widespread worldwide both in developed and in developing countries. Although the final destination of cereals can differ, their cultivation practices are quite standardised in the different geographical areas and involve significant GHG emissions (Notarnicola et al., 2015).

The CF is typically calculated through the application of the LCA method applied to only one component of the Global Warming. The CF quantifies the greenhouse gases associated with a product or service in its life cycle considered (Weidema et al., 2008). Its calculation is performed through the sum of emissions associated with the various phases of the life cycle through this formula:

$$CF_n = \text{Emission Factor}_n \ (kgCO_2eq/kg \text{ of product}) \times \text{Mass of product (kg)}$$

$$CF_{total\ life\ cycle} = CF_1 + CF_2 + CF_3 + CF_n \quad \text{where 1,2,3...n are the life cycle phases}$$

Several international studies have made a CF assessment for *durum wheat* and in general for cereal crops. This paper will take into account both greenhouse gases emitted by the cultivated areas (kg CO_2eq/ha) and for the final product (kg CO_2eq/tonnes of *durum wheat*). To date, there are no detailed scientific studies on the CF of *durum wheat* in Italy. However, EPD certifications of finished products such as pasta and flour have been made by some major companies in the industry.

Based on the studies found in the literature, the GHG values connected to the production of *durum wheat* referring to the Italian context were processed; after which, it was possible to obtain quantities of GHGs emitted at a surface level by referring to the ISTAT data on production of *durum wheat* in the years 2011-2015.

4. Results

4.1. Water footprint in relation to yield production

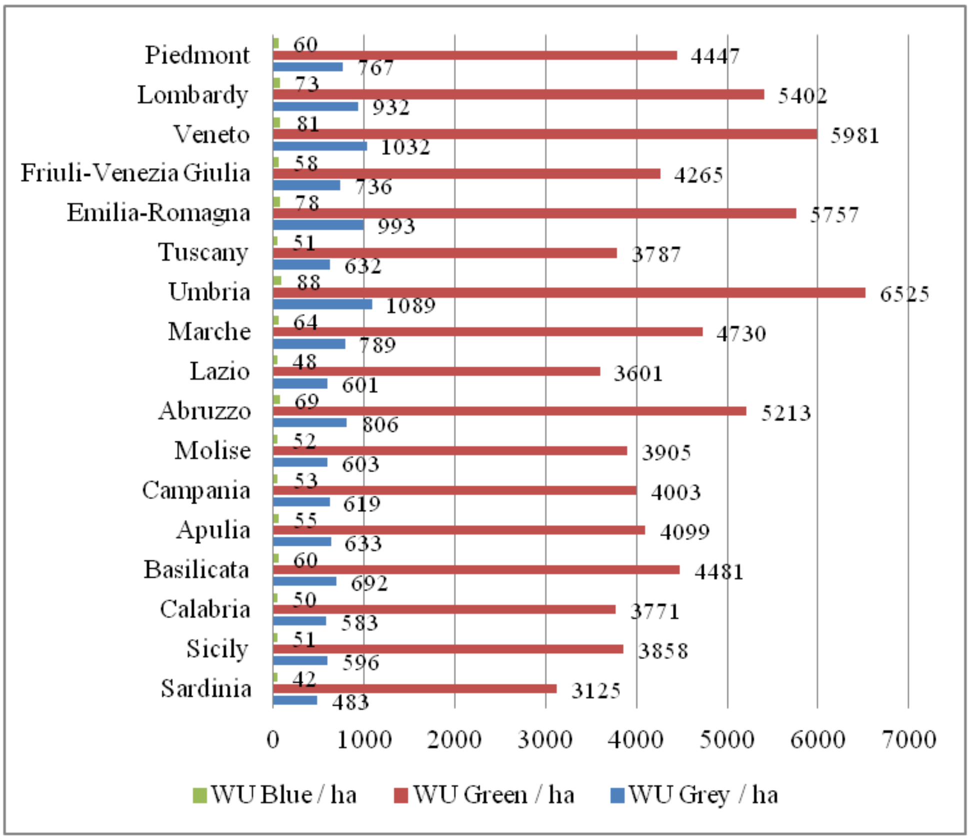
Water use for *durum wheat* in different areas of the Italy are shown in Table 1. The highest average value of WU_{Grey} was observed in Northern Italy (892 m^3 ha^{-1}). WU_{Green} in the North is 5,170 m^3 ha^{-1}. A high standard deviation was observed for WU_{Green} in the Centre (st. dev.=1337.8). The average WU of the Italian Regions is 5,327 m^3 ha^{-1}, with a ratio of 1.29 between North and South. WU_{Blue} presents a negligible value.

Table 1
WU_{Grey}, WU_{Green} and WU_{Blue} of *durum wheat* production in different areas of Italy (m^3 ha^{-1}).

	WU_{Grey} (m^3 ha^{-1})		WU_{Green} (m^3 ha^{-1})		WU_{Blue} (m^3 ha^{-1})		Total WU (m^3 ha^{-1})	
	Mean	st. dev.	Mean	st. dev.	Mean	st. dev.	Mean	st. dev.
North	892	133.6	5170	774.3	70	10.5	6132	918.4
Centre	777	223.2	4661	1337.8	63	18.0	5501	1578.9
South	627	93.0	4057	601.6	54	8.0	4738	702.6
Italy	**740**	**177.6**	**4526**	**942.4**	**61**	**12.9**	**5327**	**1130.5**

Graphic 1 reported WU_{Grey}, WU_{Green} and WU_{Blue} (m^3 ha^{-1}) for Italian *durum wheat* production. Umbria, which is located in Central Italy, has the highest value of WU_{Grey} (μ=1089 m^3 ha^{-1}), followed by Northern Regions, such as Veneto (μ=1032 m^3 ha^{-1}), Emilia-Romagna (μ=993 m^3 ha^{-1}) and Lombardy (μ=932 m^3 ha^{-1}).
Umbria (μ=*6525*=m^3 ha^{-1}), located in the Centre, detains the highest value of WU_{Green}, while Sardinia (μ=3125 m^3 ha^{-1}), a southeast Region, holds the lowest one (ratio of 2.1).
WU_{Blue} presents values between 42 m^3 ha^{-1} and 88 m^3 ha^{-1}.

Graphic 1
WU_{Grey}, WU_{Green} and WU_{Blue} of *durum wheat* production in different Italian Regions (m^3 ha^{-1}). From North to South (up to down).



The Region with the highest value of WU, as a sum of WU_{Grey}, WU_{Green} and WU_{Blue} is Umbria (7702 m^3 ha^{-1}); the ratio with the smallest (in Lazio) is 1.81.

Graphic 2
Total WU in *durum wheat* production in different Italian Regions (m^3 ha^{-1}). From North to South (up to down).

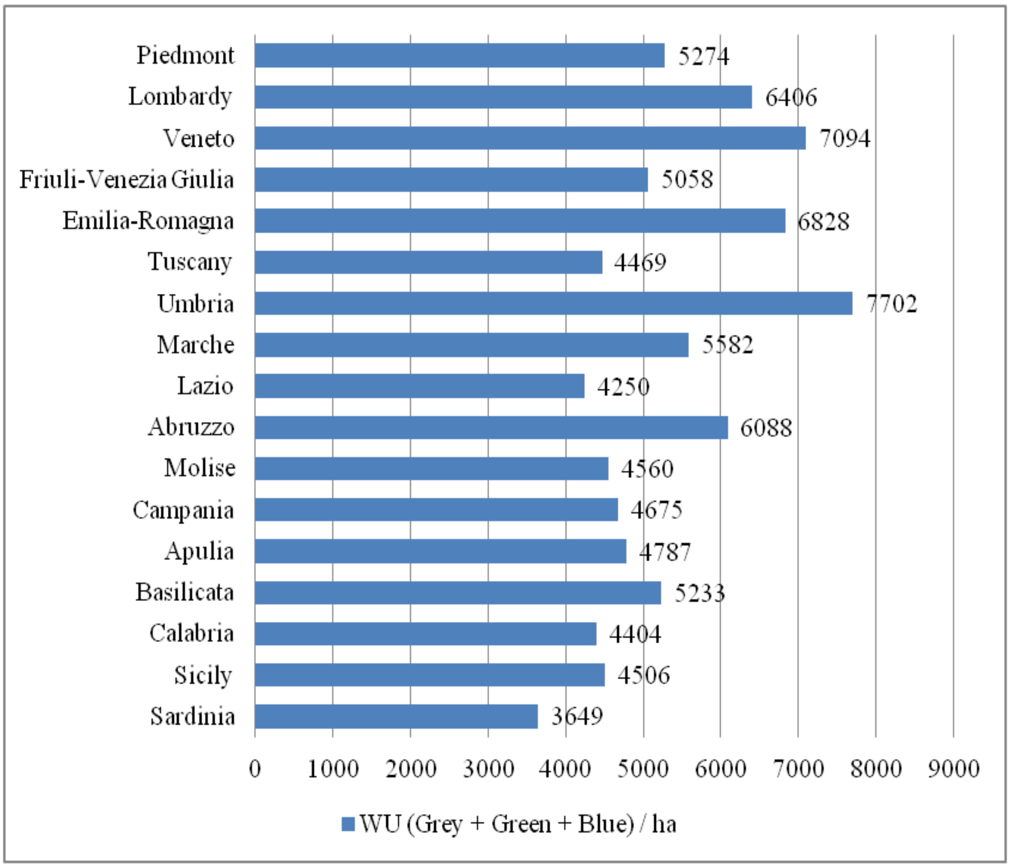
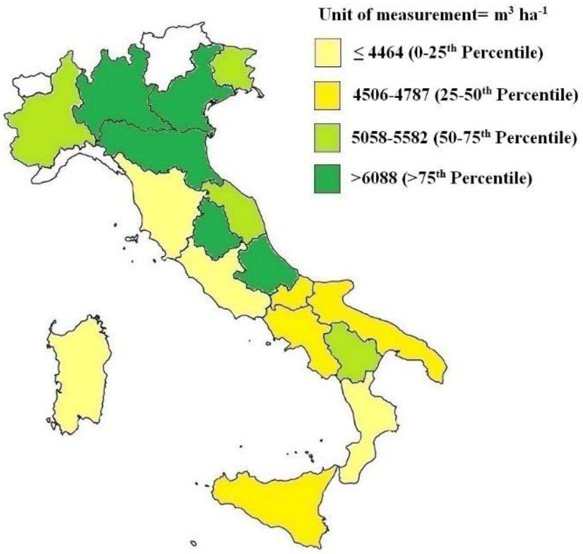


Figure 1 allows for an easier interpretation of WU in Italian *durum wheat* production, mapping the percentile of each Region. It can be observed that until the 50th percentile (less than 4,478 m^3 ha^{-1}) there are no regions located in the North, while between 50-75th and over 75th percentiles represent Regions mostly located in Northern Italy.

Figure 1. WU of *durum wheat* production in different Italian Regions at different percentile.



4.2 Water Use in relation to Total Agriculture Area

Table 2 shows WU_{Grey}, WU_{Green} and WU_{Blue} in Italian *durum wheat* production in relation to TAA (*Total Agriculture Area*). The Italian average value of WU_{Grey} is 58,681 m^3 km^{-2}. The area with the highest WU_{Grey} and WU_{Green} is the North, with a consumption of 83,456 m^3 km^{-2} and 540,099 m^3 km^{-2}, respectively.

The highest value of Blue water is in the South (7,183 m^3 Km^{-2}). With a ratio of 8.7 between the South and the North, the total WU TAA^{-1} in Italy is 433,510 m^3 km^{-2},.

Table 2

WU_{Grey}, WU_{Green} and WU_{Blue} in differents areas of Italian *durum wheat* production in relation to TAA (m^3 km^{-2}).

	WU_{Grey} TAA^{-1} (m^3 km^{-2})		WU_{Green} TAA^{-1} (m^3 km^{-2})		WU_{Blue} TAA^{-1} (m^3 km^{-2})		Total WU TAA^{-1} (m^3 km^{-2})	
	Mean	st. dev.	Mean	st. dev.	Mean	st. dev.	Mean	st. dev.
North	10549	13991.8	61147	81103.7	826	1095.4	72522	96190.9
Centre	69295	63399.2	415412	380066.8	5583	5108.3	490291	448574.3
South	83456	58977.0	540099	381681.6	7183	5076.0	630738	445734.6
Italy	**58681**	**58166.7**	**369893**	**370481.0**	**4937**	**4936.9**	**433510**	**433522.7**

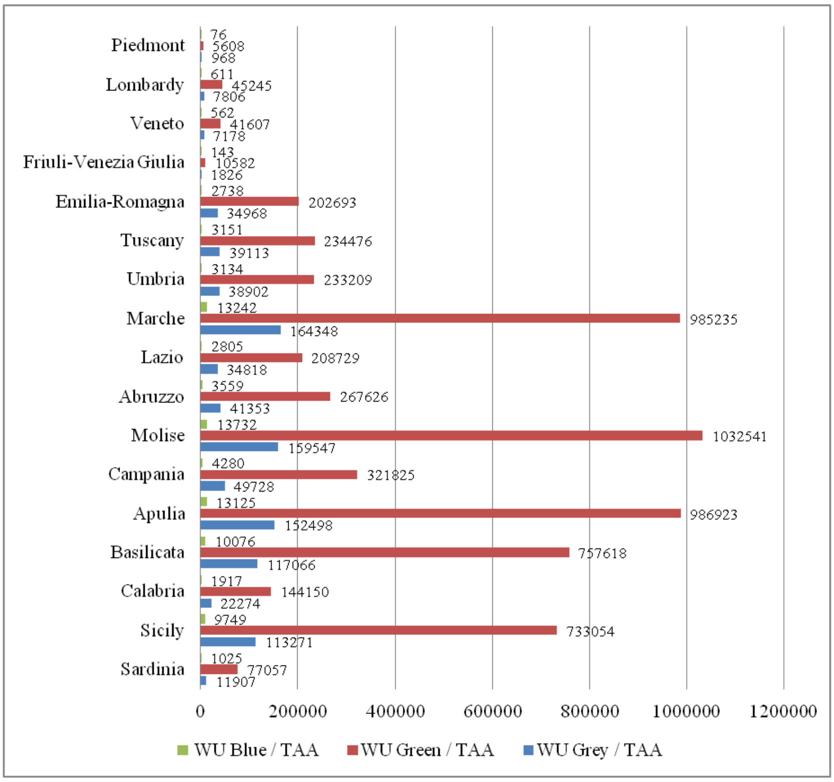
WU_{Grey}, WU_{Green} and WU_{Blue} in relation to TAA is represented in Graphic 3.

The highest WU_{Grey} TAA^{-1} was observed in Marche (μ=164,348 m^3 km^{-2}), located in the Centre, following by Molise (μ=159,547 m^3 km^{-2}) and Apulia (μ=152,498 m^3 km^{-2}), located in the South; the smallest value was osbserved in Piedmont (μ=968 m^3 km^{-2}).

The regions with the highest value in WU_{Grey} TAA^{-1} are Molise (μ=1,032,541 m^3 km^{-2}), Apulia (μ= 986,923 m^3 km^{-2}) and Marche (μ= 985,235 m^3 km^{-2}), while minor Grey Water consuption was observed in Piedmont (μ=5,608 m^3 km^{-2}) and in Friuli-Venezia-Giulia (μ=10,582 m^3 km^{-2}).

Graphic 3

WU_{Grey}, WU_{Green} and WU_{Blue} in relation to TAA (m^3 km^{-2}). From North to South (up to down).



Total WU (the sum of WU_{Grey}, WU_{Green} and WU_{Blue}) is shown in Graphic 4. Molise represents the Region with the highest value (over 1200000 m^3 km^{-2}).

Graphic 4

Total WU in relation to TAA (m^3 km^{-2}). From North to South (up to down).

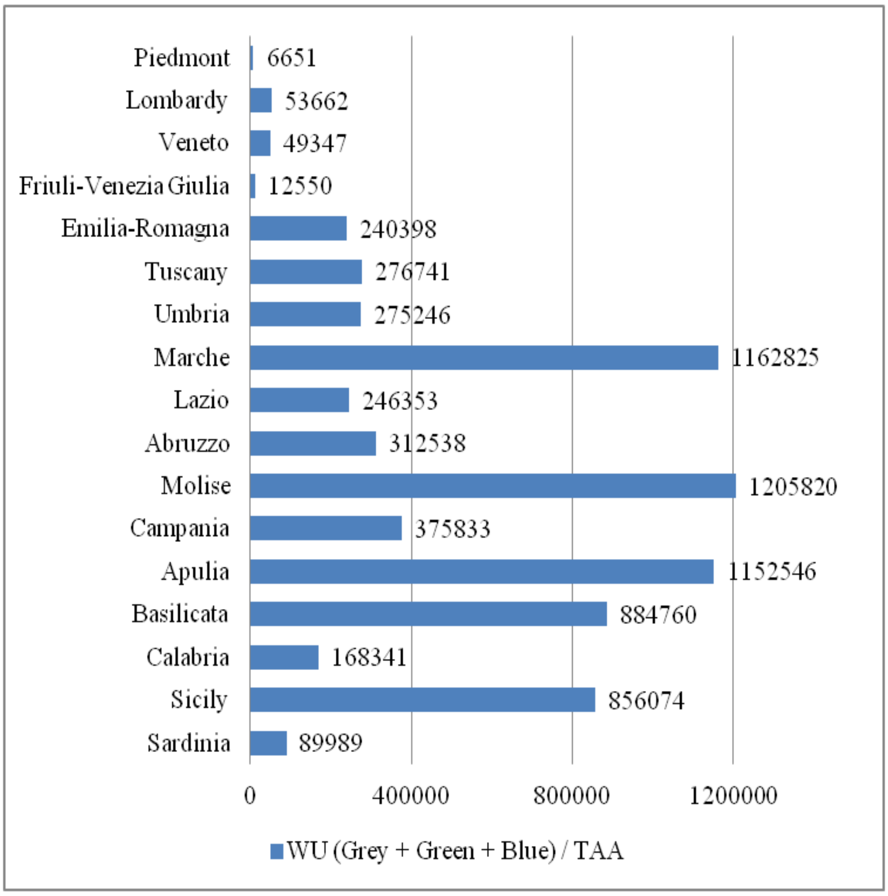
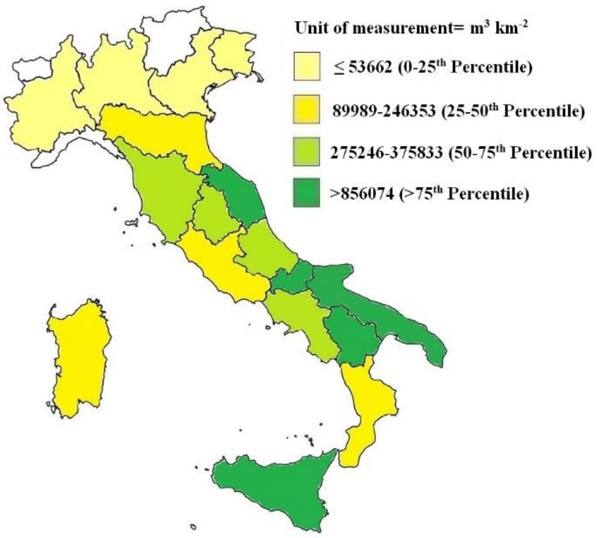


Figure 2 showed WU of *durum wheat* production in different Italian regions at different percentiles based on Total Agriculture Area (TAA). Areas within the 25th percentile (until 62,744 m^3 km^{-2}) are all located in the North. The second and third percentile comprehend regions that are mostly located in the Centre, while over the 75th percentile (736,014 m^3 km^{-2}) regions are mostly located in the South.

Figure 2. WU of *durum wheat* production in different Italian regions at different percentiles based on Total Agriculture Area (TAA).



4.3 Carbon Footprint in relation to yield production

In Table 3 the values of CF related to the various national areas arising from the production of *durum wheat*, are shown. The highest is found in Northern Italy (2,462 kg CO_2 ha^{-1}), while in Central Italy the value is 2,283 kgCO_2 ha^{-1} and in the South the value of 1,880 kgCO_2 ha^{-1} can be found.

The greater value for the standard deviation was found in the North (st.dev. = 759), while the national average is 546.

Table 3
CF of *durum wheat* production in different areas of Italy (kg CO_2 ha^{-1}).

	Mean	st. dev
North	2462	759
Centre	2283	479
South	1880	238
Italy	**1958**	**546**

From Graphic 5 it can be seen that Veneto has the highest CF value per hectare (3,032 kg CO_2 ha^{-1}), closely followed by Emilia-Romagna (2,944 kg CO_2 ha^{-1}) and Umbria (2,876 kg CO_2 ha^{-1}). The lowest value is that of the Valle d'Aosta (971 kg CO_2 ha^{-1}), which, however, is not significant for the limited production area. Therefore, the lowest values are those of Apulia and Basilicata (1,666 and 1,665 kg CO_2 ha^{-1}).

Graphic 5
CF of *durum wheat* production in different Italian regions (kgCO_2 ha^{-1}). From top to bottom: North to South.

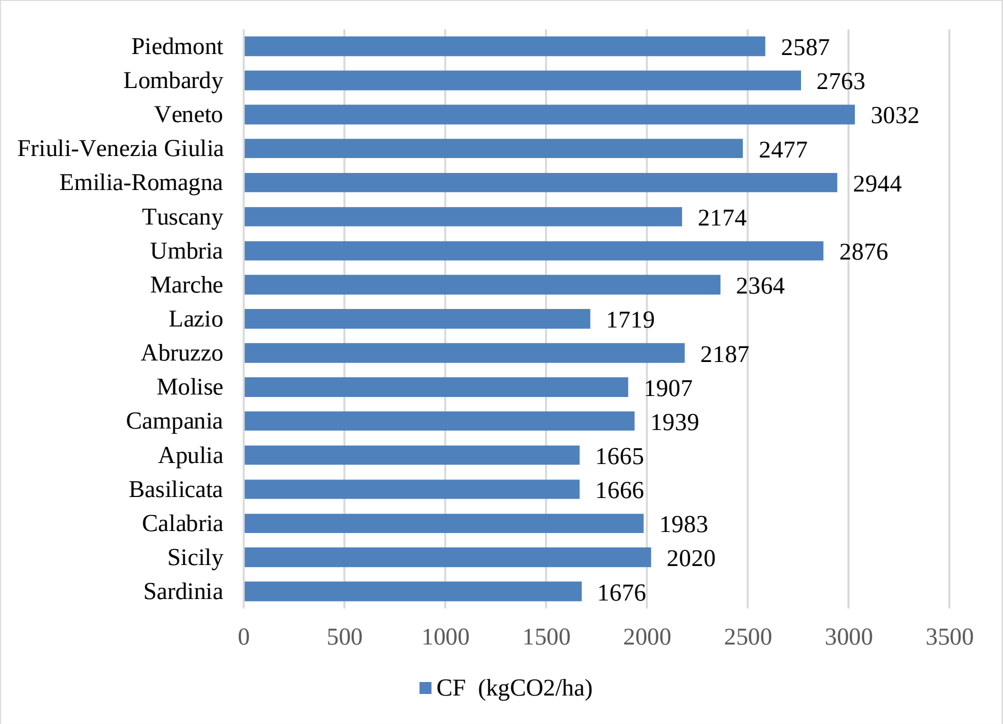
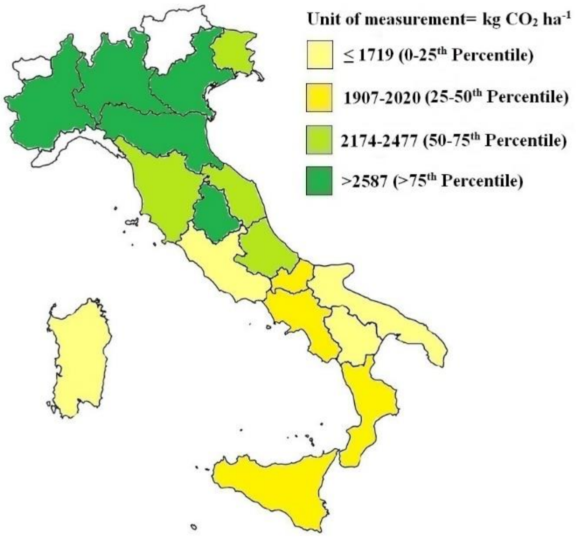


Figure 3 shows the CF of *durum wheat* production in different Italian regions based on the regional area. It can be observed that the 25th percentile of CF (<1,719 kg ha^{-1}) and the 25th -50th percentile are reflected by regions that are mostly located in the South and one in Central Italy. For values between 1,907 and 2,020, there are two regions of the Center, one of the North and one of the South.

Figure 3. CF of *durum wheat* production in different Italian regions at different percentiles of production in relation to a hectare (kg CO_2 ha^{-1}).



4.4 Carbon footprint in relation to Total Agriculture Area

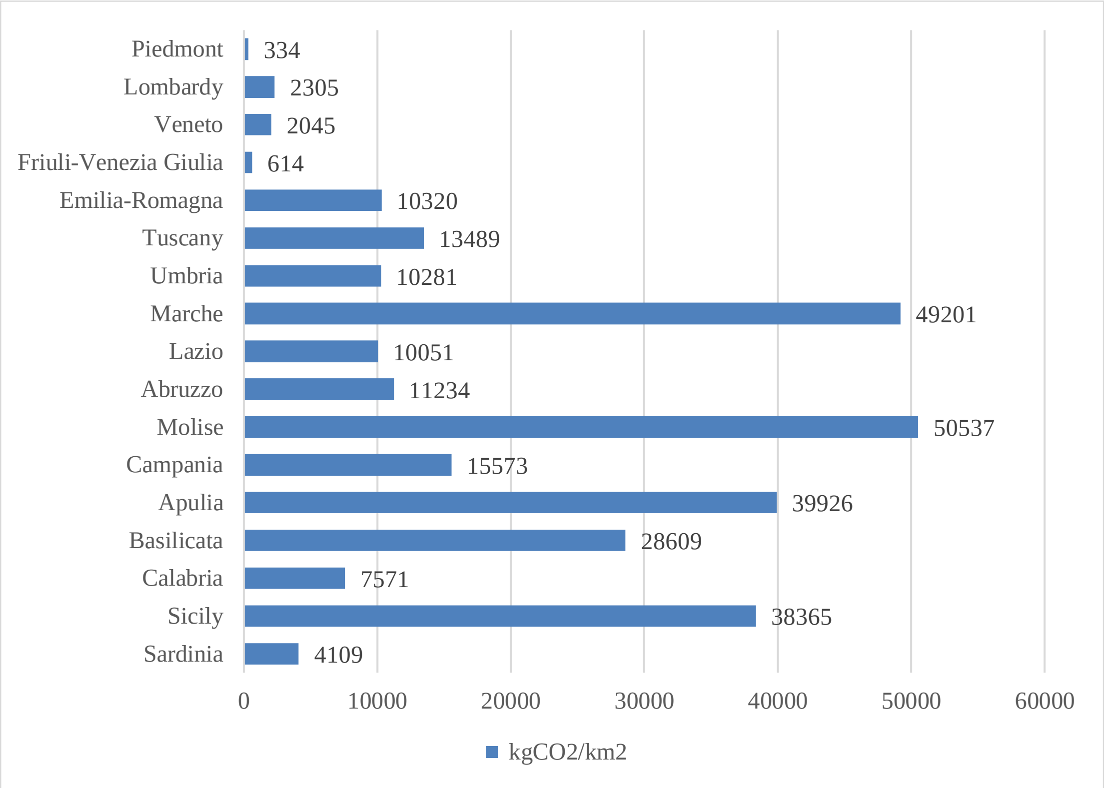
Below are the results from the use of CF in relation to the total regional agricultural area. It can be deduced from the table that the highest values are found in the southern regions.

Table 4
CF in differents areas of Italian *durum wheat* production in relation to TAA (kg CO2 km^{-2}).

	Mean	st. dev.
North	1560	4114
Centre	20760	19028
South	24490	17250
Italy	**16078**	**17145**

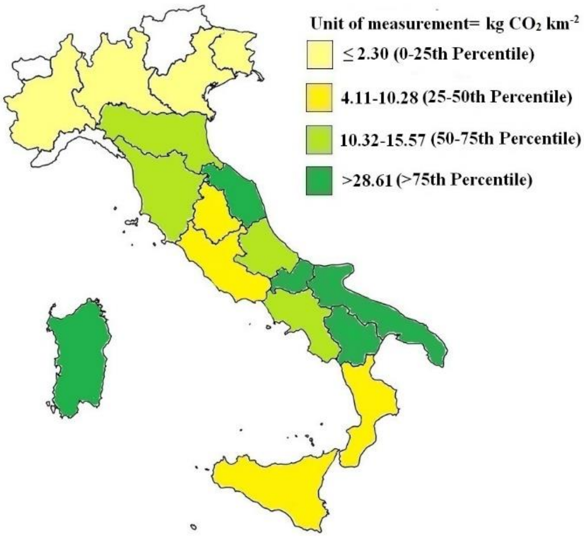
Graphic 6 shows that Molise and Marche have the highest values (50.54 and 49.20 t CO2eq/km2, respectively) compared to the rest of the country. Furthermore, it can be noted that in the northern regions these values are notably lower.

Graphic 6
Total regional CF of durum wheat in relation to TAA (kg CO_2 km^{-2}).



The analysis of the percentiles (Figure 4) shows that the Italian territory is divided into three main areas: the one of the North with values between 0 and 2,300 $kgCO_2/km^2$; the Adriatic coast, which includes regions with values greater than 286,10 $kgCO_2/km^2$ and the Tyrrhenian area between the values of the Adriatic and the northern Italy.

Figure 4. CF of *durum wheat* production in different Italian Regions at different percentile of production in relation to total agriculture area.



5. Discussion

Environmental sustainability in agriculture poses an important debate in the world of Policy. The aim of this paper is to assess the WF and CF of Italian *durum wheat* production, identifying both the location and the character of the impacts. New policies can render food production more sustainable within the carrying capacity or ecological threshold of land and water resources (Khan and Hanjra, 2008).

The water and the carbon cycle are closely connected and a policy could identify common strategies.

The analysis of the results leads to the conclusion that at a national assumes heterogeneous characteristic features, in terms of WU and CF in *durum wheat* production.

The first indicator used, WF and CF in relation to hectares, expressed the potential in terms of water consumption and GHG emissions for the production of *durum wheat* in different areas. The regions that consume below 5,000 m^3 ha^{-1} of water are all located in the South, while the highest values are recorded in the North (especially in the middle, landlocked area). In relation to the values of the water surface consumption, the situation is the opposite: it is mainly the Southern and the Adriatic regions that have a high ratio between WF and TAA; this can be attributed both to a high value of WU for the production of *durum wheat* and to a total agricultural area that is smaller than Northern Italy. In the same way, a marked distinction between the North and the South (including some Tyrrhenian regions) can be noted for WF related to *durum wheat* production. We can also note that in relation to the area, the regions within the first percentile in terms of value of WF and CF, are all in the North, while lower values were observed in the rest of Italy. The values of Grey Water show that the regions, which suffer more from pollution as a result of cereal production, are those of the North, while the least suffering ones include Sicily, Calabria and Sardinia, all in the extreme South. Mekonnen and Hoekstra (2014) sustain that if Grey WF in a crop production worldwide is reduced until the level of 25^{th} percentile of the current global production, water pollution will be reduced by 54%.

The intensification of *durum wheat* production generally leads to an increase of WF and CF. However, different strategies can be used at different sites, with the helpof policy instruments; from this point of view, an important resource would be the training of agriculture producers for the responsible use of these resources (Vrain and Lovett, 2016; Baird et al., 2016).

The drivers that influence the water consumption for agricultural crops are numerous, but the main ones include: the use of fertilisers, the type of cultivation (at a water requirements level) and the characteristics of the terrain (Hatfield et al., 2001; Sadras et al., 2003; Hoekstra et al., 2011). More specifically, the key factors for proper management of the total water balance are: soil nutrient management, optimising crop rotation, the use of crop residues, erosion control, appropriate tillage, proper application and timing of manure or synthetic fertilisers, improved irrigation techniques, proper tillage, biological pest control, reduction of non-beneficial evapotranspiration. Rodriguez et al. (2015) adapted the use of fertilisers to the potato production to reduce the Grey WF, depending on the characteristics of the soil.

Unlike other types of environmental impacts, the GHG emissions are meant -above all- as the release of CO_2, CH_4 and N_2O into the atmosphere and may not be limited by relevant legislation, because they are derive from production activities and energy production. The use of agricultural vehicles cannot be restricted, just as the use of fertilisers or cattle farming cannot be limited. Nonetheless, improving cropping systems may help mitigate greenhouse gas emissions. The analysis of the CF values related to wheat production in the Italian regions can provide interesting indications for environmental policy to assist in making strategic decisions. Although global warming is one of several environmental impact categories, it should be stressed that in recent years it has acquired a prominent place in public opinion, due to the IPCC reports (IPCC 2014) and due to the space that mass media has dedicate to extreme weather events that are often defined as manifestations of climate change and global warming. Within the *durum wheat* supply chain, there are two process inputs that typically determine 90% of the environmental load. The first is the diesel used by mechanical equipment to till the land (Lal, 2005), while the second is fertiliser use. The environmental impact related to fertiliser use depends not only on GHG emissions arising from the production phase, but above all on the release of nitrous oxides after field spreading. This issue contributes most to the balance of GHGs in the *durum wheat*.

Reducing in GHG emissions can be achieved through two different strategies. One option is by lowering diesel consumption through a reduction in the use of machinery (e.g. switching from conventional to no-till farming . Another option involves reducing the use of nitrogen (N) fertilisers, by improving N use efficiency, for example foliar and soil application of liquid fertilisers,. In this way, the quantity of fertilisers used (kg/ha) decreases and its absorption increases, rendering both quantitative and qualitative benefits (Assimakopoulos et al., 2003).

An alternative approach for reducing the greenhouse gas balance related to the production of *durum wheat* at a national level would be to use other cereal types that require less inputs and therefore provide a low carbon impact. However, this solution is impractical because the Italian *durum wheat* is a typical to Italy that cannot be replaced easily.

Among the various possible strategies for the reduction of environmental impacts related to the production of goods and services, there is also the possibility of taxation, which can find funds to offset or mitigate the damage arising by the system under study (Franks and Hadingham, 2012; Descateaux et al. 2016). In the cereal sector and more broadly within the context of basic food (where a reduced VAT taxation already exists), an additional taxation is inappropriate for ethical reasons, because *durum wheat* is considered a staple in the Italian diet and the price must be maintained at acceptable levels.

6. Conclusion

Over the past 30 years, international environmental policies have been largely driven by increased public awareness of environmental issues and their linkages with economic and social issues. The Rural Development Plan of the European Union has initially developed its work on environmental policies and reporting. It considers that human activities influence the environment and affect the quantity of natural resources.

Importantly, these considerations are necessary not only from an economic assessment point of view, but also because of the social impacts that the agricultural production represents at a national level. On the basis of these guidelines, it is necessary that the aforementioned tools (WF) and, in general, the LCA method (in its most complete sustainability assessment) be increasingly used as a policy instrument for the correct management of the territory (not only for the environment, but also for social and economic issues).

The integration between WF and CF has proved to be a very useful tool for analysing production of the country and for providing some beneficial indicators.

Major changes in agricultural technology, infrastructure, and farming management practices are needed now with the aim of ensuring sustainable food production, while at the same timereducing water consumption and carbon emissions.

References

Ababaei, B., & Etedali, H. R. (2014). Estimation of water footprint components of Iran’s wheat production: Comparison of global and national scale estimates. Environmental Processes, 1(3), 193-205.

Accorsi, R., Versari, L., & Manzini, R. (2015). Glass vs. Plastic: Life Cycle Assessment of Extra-Virgin Olive Oil Bottles across Global Supply Chains. Sustainability, 7 (3), 2818-2840

Alcamo, J., Pdöll, P., Henrichs, T., Kaspar, F., Lehner, B., Röscht., T., & Siebert S. (2003) Global estimates of water withdrawals and availability under current and future “business-as-usual” conditions, Hydrological Sciences Journal, 48(3), 339-348.

Allan, J. A. (1998). Virtual water: a strategic resource global solutions to regional deficits. Ground Water, 36(4), 545-546.

Assimakopoulos, J. H., Kalivas, D. P., & Kollias, V. J. (2003). A GIS-based fuzzy classification for mapping the agricultural soils for N-fertilizers use. Science of the Total Environment, 309(1), 19-33.

Baird, J., Jollineau, M., Plummera, R., & Valenti, J. (2016). Exploring agricultural advice networks, beneficial management practices and water quality on the landscape: A geospatial social-ecological systems analysis. Land Use Policy, 51, 236-243.

Bevilacqua, M., Braglia, M., Carmignani, G., & Zammori, F. A. (2007). Life Cycle Assessment of pasta production in Italy. Journal of Food Quality, 30, 932-952.

Bocchiola, D., Nana, E., & Soncini, A. (2013). Impact of climate change scenarios on crop yield and water footprint of maize in the Po valley of Italy. Agricultural Water Management, 116, 50-61.

Brentrup, F., Küsters, J., Lammel, J., & Kuhlmann, H. (2000). Methods to estimate on-field nitrogen emissions from crop production as an input to LCA studies in the agricultural sector. The international journal of life cycle assessment, 5(6), 349-357.

Bruinsma, J. (2009). The resource Outlook to 2050: by how much do land, water use and crop yields need to increase by 2050. In Expert meeting on how to feed the world in (Vol. 2050).

Cerutti, A. K., Contu, S., Ardente, F., Donno, D., & Beccaro, G. L. (2016). Carbon footprint in green public procurement: Policy evaluation from a case study in the food sector. Food Policy, 58, 82-93.

Chapagain, A. K., Hoekstra, A. Y., Savenije, H. H. G., & Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological economics, 60(1), 186-203.

Chapagain, A. K., & Orr, S. (2009). An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes. Journal of environmental management, 90(2), 1219-1228.

Chen, Z. M., & Chen, G. Q. (2013). Virtual water accounting for the globalized world economy: national water footprint and international virtual water trade. Ecological Indicators, 28, 142-149.

Curmi, E., Richards, K., Fenner, R., Allwood, J. M., Kopec, G. M., & Bajželj, B. (2013). An integrated representation of the services provided by global water resources. Journal of environmental management, 129, 456-462.

Daccache, A., Ciurana, J. S., Diaz, J. R., & Knox, J. W. (2014). Water and energy footprint of irrigated agriculture in the Mediterranean region. Environmental Research Letters, 9(12), 124014.

Descateaux P., Astudillo, M. F., & Ben Amor M., (2016). Assessing the life cycle environmental benefits of renewable distributed generation in a context of carbon taxes: The case of the Northeastern American market, Renewable and Sustainable Energy Reviews, 53, 1178-1189.

Ercin, A. E., & Hoekstra, A. Y. (2014). Water footprint scenarios for 2050: A global analysis. Environment international, 64, 71-82.

Espinoza-Orias, N., Stichnothe, H., & Azapagic, A. (2011). The carbon footprint of bread. The International Journal of Life Cycle Assessment, 16(4), 351-365.

FAOSTAT (2013). Production domain. In: Crops. FAO, Rome (accessed 20.12.14).

Franks, J.R., & Hadingham, B. (2012). Reducing greenhouse gas emissions from agriculture: Avoiding trivial solutions to a global problem. Land Use Policy, 29, 727-736.

García-Ruiz, J. M., López-Moreno, J. I., Vicente-Serrano, S. M., Lasanta–Martínez, T., & Beguería, S. (2011). Mediterranean water resources in a global change scenario. Earth-Science Reviews, 105(3), 121-139.

Grebitus, C., Steiner, B., & Veeman, M. (2015). The roles of human values and generalized trust on stated preferences when food is labeled with environmental footprints: Insights from Germany. Food Policy, 52, 84-91.

Hatfield, J.L., Sauer, T.J., & Prueger, J.H. (2001). Managing soils to achieve greater water use efficiency, Agronomy Journal, 93(2): 271-280.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., & Mekonnen M.M. (2011). The Water Footprint Assessment Manual. Setting the Global Standard.

IPCC - Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Janzen, H. H., Beauchemin, K. A., Bruinsma, Y., Campbell, C. A., Desjardins, R. L., Ellert, B. H., & Smith, E. G. (2003). The fate of nitrogen in agroecosystems: An illustration using Canadian estimates. Nutrient Cycling in Agroecosystems, 67(1), 85-102.

Khan, S., Hanjra, M.A. (2008). Sustainable land and water management policies and practices: a pathway to environmental sustainability in large irrigation systems. Land Degradation and Development 19 (3), 469–487.

Khan, S., & Hanjra, M. A. (2009). Footprints of water and energy inputs in food production–Global perspectives. Food Policy, 34(2), 130-140.

Lal, R. (2004). Carbon emission from farm operations. Environment international, 30(7), 981-990.

Marano, R. P., & Filippi, R. A. (2015). Water Footprint in paddy rice systems. Its determination in the provinces of Santa Fe and Entre Ríos, Argentina. Ecological Indicators, 56, 229-236.

Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. Hydrology and Earth System Sciences, 15(5), 1577-1600.

Mekonnen, M. M., & Hoekstra, A. Y. (2014). Water footprint benchmarks for crop production: A first global assessment. Ecological indicators, 46, 214-223.

Notarnicola, B., Salomone, R., Petti, L., Renzulli, P. A., Roma, R., & Cerutti, A. K. (Eds.). (2015). Life Cycle Assessment in the Agri-food Sector: Case Studies, Methodological Issues and Best Practices. Springer.

Pattara, C., Raggi, A., & Cichelli, A. (2012). Life Cycle Assessment and carbon footprint in the wine supply-chain. Environmental Management, 49, 1247–1258.

Perry, C. (2014). Water footprints: Path to enlightenment, or false trail? Agricultural Water Management, 134, 119-125.

Ridoutt, B. G., & Pfister, S. (2010). Reducing humanity's water footprint. Environmental science & technology, 44(16), 6019-6021. http://dx.doi.org/10.1021/es101907z.

Rodriguez, C. I., de Galarreta, V. R., & Kruse, E. E. (2015). Analysis of water footprint of potato production in the pampean region of Argentina. Journal of Cleaner Production, 90, 91-96.

Rosegrant, M. W., Ringler, C., & Zhu, T. (2009). Water for agriculture: maintaining food security under growing scarcity. Annual Review of Environment and Resources, 34(1), 205.

Ruddiman, W. F. (2003). The anthropogenic greenhouse era began thousands of years ago. Climatic change, 61(3), 261-293.

Ruini, L., & Marino, M. (2010). An overview of environmental indicators aimed to an easy life cycle assessment results presentation by an important food supplier: The example of durum wheat cultivation, VII International Conference on Life Cycle Assessment in the agri-food sector, Bari, Italy.

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

Ryan, J., Singh, M., & Pala, M. (2008). Long-term cereal-based rotation trials in the Mediterranean region: implications for cropping sustainability. Advances in agronomy, 97, 273-319.

Sadras, V., Baldock, J., Roget, D., & Rodriguez, D. (2003) Measuring and modelling yield and water budget components of wheat crops in coarse-textured soils with chemical constraints, Field Crops Research, 84(3): 241-260.

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. Food Policy, 44, 272-284.

Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, A.E., & Hertwich, E.G. (2012). Carbon, land, and water footprint accounts for the European Union: consumption, production, and displacements through international trade. Environmental Science & Technology, 46 (20), 10883–10891. http://dx.doi.org/10.1021/es301949t.

Toscano, P., Genesio, L., Crisci, A., Vaccari, F. P., Ferrari, E., La Cava, P., & Gioli, B. (2015). Empirical modelling of regional and national durum wheat quality. Agricultural and Forest Meteorology, 204, 67-78.

Vrain, E., & Lovett, A. (2016). The roles of farm advisors in the uptake of measures for themitigation of diffuse water pollution. Land Use Policy, 54, 413–422.

Weidema, B. P., Thrane, M., Christensen, P., Schmidt, J., & Løkke, S. (2008). Carbon footprint. A Catalyst for Life Cycle Assessment?. Journal of Industrial Ecology, *12*(1), 3-6.

Xu, F., Baob, X.H., Li, H., Kwan, M.P., & Huang, X. (2016). Land use policy and spatiotemporal changes in the water area of anarid region. Land Use Policy, 54, 366–377.

Zubelzu, S., Álvarez, R., & Hernández, A. (2015). Methodology to calculate the carbon footprint of household land use in the urban planning stage. Land Use Policy, 48, 223–235.