A MESO-LEVEL WATER USE ASSESSMENT IN THE MEDITERRANEAN AGRICULTURE. MULTIPLE APPLICATIONS OF WATER FOOTPRINT FOR SOME TRADITIONAL CROPS

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Abstract

Currently, agriculture uses about 70-80% of global water resources and, in the Mediterranean area, it accounts for the high pressure of freshwater demand. This study provides a useful framework for the meso-level assessment of the Water Footprint (WF) in agriculture. Particularly, the WF methodology is used to quantify the water consumption and pollution of olives, grapes and tomatoes, traditional crops widespread both in the Apulia region, in Southern Italy, and in the Mediterranean area. Hence, from a meso-level assessment of the Water Footprint of Apulian agriculture, a general level of evaluation of the use of Mediterranean water resources was provided, estimating the Virtual Water (VW) too. Furthermore the climate change effects on the Water Footprint of the traditional crops identified were predicted, proposing some scenarios useful to reduce the grey component, which values for olives were evaluated by a sensitivity analysis. The results highlight that olives present the highest value of the WF and that grapes are the most affected by the variations according to the climate change scenarios, increasing over 200% of the green component and 77% of the blue one. Finally, a Circular Economy proposal, based on the reuse of the wastewater from a meso-scale perspective, highlights saving up to 70% of the water resource. The research questions proposed displayed the novelty of this paper, particularly as concerns the use of the Water Footprint analysis on a meso-level evaluation. Particularly, the new insights of this research addressed the needs of stakeholders in areas suffering from drought, such as the Mediterranean, to integrate and systematize a data-set of indicators to rationalize and plan water resource usage and safety in agriculture.

Keywords

Mediterranean agriculture; Water Footprint; Meso-Scale; Climate Change; Circular Economy

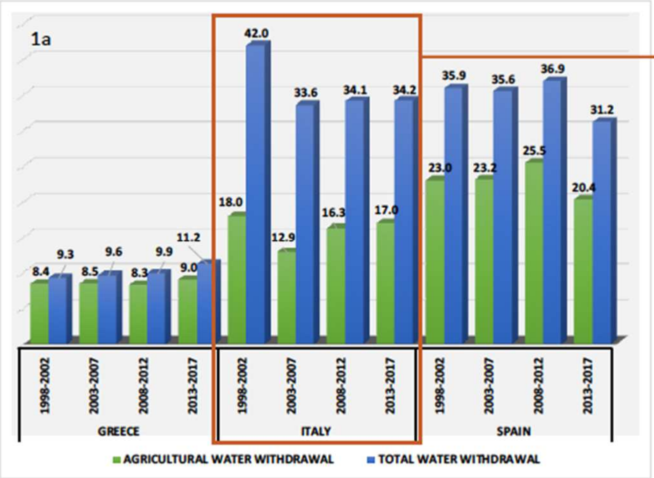
1. Introduction

Agriculture plays a fundamental role in food production to meet the needs of the constant growth of the world population, from 7.7 billion in 2020 to 9.7 billion estimated in 2050 according to the UN (2020). Consequently, the increasing food production generates further pressures on the agricultural system in terms of land, water and energy consumption, especially in the developing countries, so that the UN had included this issue among the Sustainable Development Goals (UN, 2015).

Currently, the global utilized agricultural area (UAA) amounts to 2.8E+09ha and the European one to 1.75E+08ha. About 71.5% of the European Union's UAA is located in seven Member States (Eurostat, 2018) that are France, Spain, Germany, Poland, Italy, Romania and the United Kingdom. Moreover, by 2030 the UUA is expected to increase over 15% for some Southern and South-Eastern European countries such as Portugal, Spain, France, Italy, Croatia, Greece and Romania (Eurostat, 2020a).

It should be emphasized that the agricultural sector of some Southern regions of the Euro-Mediterranean area already currently consumes 80% of water resources, while the rest of Europe uses only 44% (European Commission, 2017) and the world on average of 75% (Molden, 2017).

Particularly, the Mediterranean arid and semi-arid areas such as Italy, Spain and Greece (European Commission, 2018), which water issue was analysed in this study, need the assessment of the agricultural water consumption in order to implement approaches, e.g. Circular Economy (CE), to preserve the water resource and address the demand of water resources. A snapshot of these areas was made through the Figure 1a, which shows the agricultural water withdrawal and total water withdrawal in Greece, Italy and Spain, highlighting the high water withdrawal for agriculture. Particularly, in the period 1998-2017, Greece, which has 3.6E+06ha of utilized agricultural area (Eurostat, 2020b), presented the highest agricultural water withdrawal, between 80 and 90% of the total water withdrawal, whereas Spain, with 2.38E+07ha of utilized agricultural area (INĒ, 2020), uses at least 64% of total water withdrawal (AQUASTAT FAO, 2021) and Italy, which has 1.25 E+07ha of utilized agricultural area (ISTAT, 2019), almost 50% of total water withdrawal.



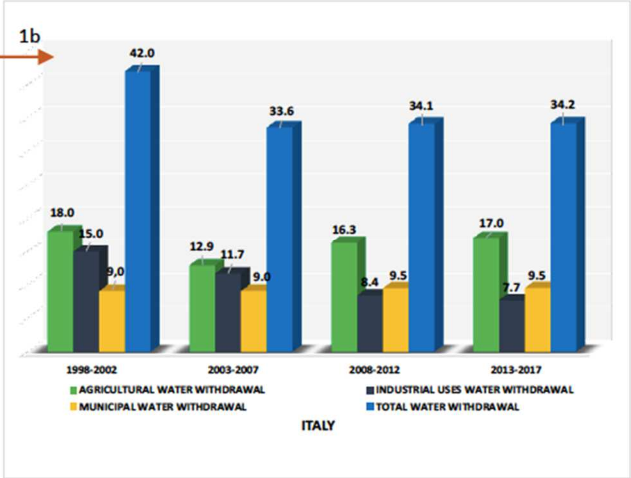


Fig.1a. Comparison between agricultural water withdrawal and total water withdrawal in Greece, Italy and Spain for the period 1998-2017 (Gm^3/year).
Fig.1b. Comparison between different use of agricultural water withdrawal in Italy for the period 1998-2017 (Gm^3/year).
Source: Authors' elaboration based on data given in AQUASTAT FAO (2021).

Furthermore, figure 1b underlines the decrease of total water withdrawal for the period 1998-2017 in Italy. Furthermore, the figure displays the higher water withdrawal for the agricultural sector than for the industrial sector (AQUASTAT FAO, 2021).

In this paper, we have undertaken a meso-level assessment of the water usage in order to reveal the interconnection between the micro and macro-level and address the Water Footprint reduction policies in the Mediterranean agriculture. The significance of the research on WF applications is also confirmed by Nouri et al. (2019), who underlined how the implementation of water-saving best practices in agriculture can reduce the WF of crop production and alleviate the blue water scarcity. Due to the different territorial characteristics, this analysis should be encouraged at meso-scale. For this reason, we focused on Apulia, in Southern Italy, a region characterized by Mediterranean area climate, drought phenomena and high agricultural economic vocation and assess the WF of traditional crops, such as olives, grapes, and tomatoes, widespread in the Apulia region and in the Mediterranean area. This research, providing multiple indicators and tools to be used at different territorial scales of analysis, contributes to a better understanding of the issue of sustainability of water supplies for agriculture. Therefore, starting from a meso-level assessment of Water Footprint based of Apulian agriculture, we provided a general level of evaluation of the use of water resources in the

Mediterranean area according to Cazcarro et al. (2016). The Virtual Water (VW), which is a further indicator to evaluate the water consumption of the crops, was estimated too.

The present analysis also predicted the climate change effects on the Water Footprint values of the traditional crops identified on the basis of Elbeltagi et al. (2020) and proposed some agricultural production scenarios, useful for reducing the value of the grey component.

In particular, the following research questions drove our analysis.

The evidence about the Mediterranean area significantly affected by climate change in the short and mid-term, leads us to investigate the influence of this event on the water footprint of some typical Mediterranean crops in the reference period 2030-2052 according to (IPPC, 2018). Hence, we hypothesized some scenarios according to Ahamadi et al. (2021), based on the climate change variations in the mid-term, to find confirmation about this research question.

Furthermore, we investigated the environmental impacts due to the use of fertilizers in agriculture based on Muratoglu (2020). As known, the present agricultural production is usually based on the intensive use of fertilizers, so it is useful to investigate the influence of this common agricultural practice on the grey component of the WF, specifically the nexus between the grey component and the leaching of fertilizers, nitrogen in particular.

Hence, we hypothesized that a reduction in nitrogen use improves the grey component value in the production of the olives: to address this research question we performed a sensitivity analysis.

These research questions improve the novelty of this paper, particularly as concerns the use of the Water Footprint analysis to rationalize and plan water resource usage and safety in agriculture, on a meso-level evaluation in the Mediterranean area.

A focus on the grey component was undertaken. This is the indicator of the so-called polluted water, which has not often been dealt with in scientific literature and whose reuse plays a key role in the conservation and sustainable use of the waste resource, especially in the driest areas, affected by a lower leaching power. Additionally, the different climatic conditions, crop yields and agricultural regulations differently affect the measurement of the grey component, especially at meso-level, making the comparisons difficult to be undertaken, as the literature highlighted (Chen et al., 2021). Consequently, this research provides new insights on this issue, as well as information and data that enabled useful comparisons.

Moreover, the framework provided allows us to measure the three components of WF, in order to analyze their specific role in the water use systems. This added further knowledge to scientific literature since other authors frequently focused on only one (Li et al., 2020) or two WF components (Novoa et al., 2019).

Finally, we provided the prospects of the Circular Economy in wastewater reuse in Apulia, in order to address the efficient management of water resources, involving their recycling and reuse and modelling circularity in the safe reuse of wastewater in agriculture (Voulvoulis, 2018).

2. Literature Review

We analyzed CE, WF and Climate Change topics in relation to the agricultural sector in a two-step analysis for quantifying and reviewing the scientific production of the last 35 years (Table 1).

2.1 Circular Economy (CE)

The transition to a CE encourages the agricultural sector to manage the imbalance between water supply and demand, for mapping consumption and promotes incentives for new approaches on natural resources, e.g. for water reuse (Voulvoulis, 2018).

Hovewer, among the still quite limited literature, Banin (1999) and Christou et al. (2017) highlighted the need for careful water treatment to ensure the long-term sustainability of irrigated agriculture based on wastewater. A solution has been proposed by Gallego-Schmid and Tarpani (2019): by the application of Life Cycle assessment (LCA) the wastewater treated in developed countries can be analyzed, to achieve hygiene objectives and health safety too.

Furthermore, in terms of the water management, the use of alternative water sources and the circular approach to reducing water consumption was encouraged (Brinzan et al., 2020).

Already in 2008, Lopez and Vurro highlighted that wastewater reuse and controlled management of reclamation consortia represented two key factors to partially resolve the problem of drought in Mediterranean areas. Hovewer, Palese et al. (2009) suggested the usefulness and the quality of wastewater for irrigating in environments characterized by drought problems, underlining that this reuse didn’t generate any parasites on plants.

In 2018, Ait-Mouheb et al. proposed an integrated approach model for the reuse of wastewater for irrigation in some Mediterranean countries. In line with the previous authors, we provided suggestions for designing a CE scenario based on the adoption of wastewater reuse strategies in agriculture. In particular, the new insights of this research addressed the needs of stakeholders in areas suffering from drought, such as the Mediterranean, to integrate and systematize a data-set of indicators to enable a reduction in the withdrawal of water resources similar to the Water Footprint, leading to a decrease of the stress of the consortium water sources.

2.2 Water Footprint (WF)

The WF concept was firstly introduced in 2002 by Hoekstra (Hoekstra and Chapagain, 2007), and according to Amicarelli et al. (2011, p. 428) “This material indicator translates human consumption into natural water resource use in m^3/y”.

Mekonnen and Hoekstra in 2011 quantified the green, blue and grey WF of global agricultural, using CROPWAT (CW) model by FAO (2018) and claimed that, at the global level, the blue component increases in the countries characterized by a high water scarcity. For these reasons the aforementioned research represented a fundamental methodological basis for our study.

Among the applications of the WF methodologies, some authors focused on the estimation of the consumption of the green and blue water for winter durum wheat grown in Southern Italy (Ventrella et al., 2015). Contrary, among the meso-scale analysis scales, a water-related strategy to support the different stakeholders in the agri-food industry it has been developed by (Papadimitriou et al., 2019). In the same year, using a combination of WF methodology and GIS (Geographic Information

Systems) tool, Casella et al. estimated the consumption of water used for some crops in a river basin in Apulia. Other authors presented a WF grey perspective for the determination of nitrate contamination in Apulia groundwater (Serio et al., 2018). Moreover, Pellegrini et al. (2016) proposed a comparative evaluation of the different agronomic systems of olive cultivation through the WF methodology. Nevertheless, on a general level, the first article focused on the application of the WF methodology was the study by Salmoral et al. (2010), which analyzes the production of olive oil in Spain in 1997-2008.

It must be pointed out that many scholars have analysed the application of a different method than the WF methodology, to evaluate the consumption of the water resource.

This is the Virtual Water approach that some scholars such as Van Oel et al. studied in 2009 in order to quantify the external WF of the Netherlands. Later, Yang et al. (2013) adopted a bottom-up/top-down approach for accounting the VW flows and WF in many economic sectors.

Recently, Sun et al. (2021) proposed a review of the status of Virtual Water application, finding a few studies concerning the VW accounting and flow analysis for aquatic products and agro-food processing.

2.3 Climate change

Climate change, vulnerability of water resources and water-energy-carbon nexus generated more complicated management of water resources (Lv et al., 2020). In general, water policies are needed to improve the allocation of water within the urban metabolic system against climate change. Some publications focusing on the impact of climate change in agriculture. Among these, Papadaskalopoulou et al. (2015) found that the several adaptation systems to satisfy water demand are not sufficient to guarantee this resource and Aleixandre-Tudo et al. (2019) focused on the resistance to drought as highlighted in their review.

Finally, Papadimitriou et al. (2019) confirmed that irrigated agriculture was impacted likewise by climate change, geographical characteristics, tourism activities, funding sources, population growth and environmental regulation.

As shown in Table 1 there are only 25 studies regarding the topic of the present research, of which the main ones concern the Mediterranean area. Given the shortage of this significant item, we fill the gap by providing an extended application of WF methodology building some dynamic scenarios, climate change based, to measure the variations occurring in the three components of WF. We proposed a replicable methodology as well, especially for the assessment of the grey component, which has not often been dealt with in the literature concerning the agri-food sector.

Furthermore, we provided a more realistic estimate of WF because it was based on measuring rain-fed crops, compared with those contained in previous studies, where the use of miscellaneous water supply and yield did not allow an analytical evaluation.

3. Materials and Methods

After analyzing the literature review associated with three main topics of this research (CE, WF and Climate Change) for agriculture at meso-level and found a lack of publication we have chosen to propose a multi-application of Water Footprint.

We use the Water Footprint (WF) methodology to quantify the direct and indirect water consumption and pollution (Hoekstra et al., 2011) in agriculture, particularly with reference to three traditional crops, those are olives, grapes and tomatoes, widespread in Apulia region and in the Mediterranean area.

The results by the assessment of the meso-level WF, were benchmarked with the water consumption of macro-scale: global and European, particularly in regard to Italy, Spain and Greece, that are among the main producing countries of tomatoes, olives and grapes. Additionally, we evaluated the variations of WF of the reference crops according to some scenarios, climate change impact-based, because, as identified by the Intergovernmental Panel on Climate Change (IPCC), the Mediterranean area is one of the regions in the world most affected by this effects (IPCC, 2007).

Some databases (AQUASTAT, Water Footprint Network, Irrigation Water Balance, Pluviometric Bulletins, Climatic Station and Meteorological database of Apulia Region) were queried for extrapolating useful information to build the data-set to be applied in the WF assessment. Furthermore, this study dealt with the WF estimate by combining data from the FAO Crop Water Productivity Model with updated data of hydrological indicators and land soil data through a downscaling approach as suggested by Cantelaube et al. (2012).

Moreover, we measured, based on the Penman-Monteith method, the three components of WF to analyze their role in the water use systems.

3.1 Materials

As follows, data on the climatic situation and agricultural production of the Apulia Region were listed.

3.1.1. Study area

Apulia region, located in Southern Italy, covers an area of 1.95E+04km^2 bordering the Adriatic and Ionian seas respectively along the east and southeast coasts and has 4,029 millions of inhabitants. It is characterized by a territory, which is flat for 53%, hilly for 45.5%, mountainous only for 1.5%. The greatest part of the territory (79%) is used for agriculture (only 24% of this percentage is irrigated) (Lopez and Vurro, 2008), 13% is covered by forestry and semi-natural environments (CORINE Programme, 2000) and 8% is used for other purposes. Water bodies cover slightly more than 1% of the territory including both natural lakes and artificial storage dams (Ladisa et al., 2012). Currently, in Apulia, the intensive agriculture is practised, especially for the production of tomatoes and olives. This kind of agriculture uses considerable quantities of chemical products for the defence and fertilization of crops, conversely, integrated agriculture provides for a reduction of the quantities of fertilizers, such as nitrogen, phosphorus and potassium. Integrated agriculture is based on agricultural specifications, issued by the regional public administration under EU regulation, to jointly combine

Table 1

Main papers according to the topic enquires on Science Direct and Web of Science from 14 November to 18 January 2021 for the period 1985-2020.

Section	Year	Topic	Methodology	Area	Keywords	Journal	Authors
Circular Economy	1999	Wastewater	Review	Mediterranean Region	Wastewater reuse, chemistry, irrigated agriculture	Proceeding of Conference on Water in the Mediterranean Area	Banin
	2008	WW treatment in agriculture	Analysis of regional master plan	Apulia Region	Water footprint, Consumption, Virtual water, Indicators, Water use, efficiency, External water dependency	Proceeding of Conference on Integrated Concepts for Reuse of Upgraded Wastewater	Lopez and Vurro
	2009	Wastewater in agriculture	Annual hygienic impact assessments	Southern Italy	Olea europaea L, Faecal indicators, Health hazards, Agricultural recycling, Wastewater reuse	Agriculture Ecosystems and Environment	Palese et al.
	2017	CE and irrigation	Review	Global	Antibiotics, Accumulation, Human health risks, Antibiotic-resistance, genes, Uptake, Reclaimed wastewater irrigation	Water Research	Christou et al.
	2018	CE and water management	Review	Mediterranean	Wastewater reuse, Irrigation in agriculture, Environmental impacts, Sanitary and environmental impacts, Systemic approach, Integrated treatment systems	Regional Environment Change	Ait-Mouheb et al.
	2018	Transition to CE	Review	Global	Circular economy, Wastewater treatment and reuse, Water scarcity	Current Opinion in Environmental Science and Health	Voulvoulis
	2019	Wastewater	Review	China and India	LCA, Eutrophication, Sanitation, Environmental impacts, Sludge, Sustainability	Water Research	Gallego-Schmid and Tarpani
	2020	CE and alternative water resource	System of returnable guarantee	Romania	Agriculture, wastewater, permits, circular economy	Sustainability	Brinzan et al.
	2021	VW and Climate Change	Review	Global	Virtual water, Research status, Quantification, Impact assessment, Limitations	Agricultural Water Management	Sun et al.
Water Footprint	2006	VW and pollution	CW Model	Global	Cotton consumption, Water footprint, Green water, Blue water, Virtual water, Water pollution	Ecological Economics	Chapagain et al.
	2007	WF and VW	Virtual Water Flow	Global	Water footprint, Consumption, Virtual water, Indicators, Water use efficiency, External water dependency.	Water Resources Management	Hoekstra and Chapagain
	2009	WF and VW	WF internal and external	Netherlands	Virtual-water, External water footprint, Water scarcity, Netherlands	Ecological Economics	Van Oel et al.
	2010	WF	CW Model	Spain	Water Footprint, Virtual Water, Olive oil sector, Spain	Papeles de Agua virtual	Salmoral et al.
	2011	WF indicator	WF internal and external, CW Model	Italy	WF, Water Footprint, physical indicators, sustainability, environmental management system	International Journal of Sustainable Economy	Amicarelli et al.
	2011	WF and water scarcity	Based on Hoekstra et al. (2011)	Global	Water Footprint, crops, derived crops	Hydrology and Earth System Sciences	Mekonnen and Hoekstra
	2013	WF and VW	Bottom-up and top down approach	Global	Scarcity, Virtual Water, Water Footprint	Current Opinion in Environmental Sustainability	Yang et al.
	2015	WF (blue and green component)	Model DSSAT CERES-Wheat	Southern Italy	Irrigation, water productivity, model simulation, climate change	Italian Journal of Agrometeorology	Ventrella et al.
	2016	WF	Based on Hoekstra et al. (2011)	Apulia Region	Olive oil sector, Freshwater consumption, Water footprint assessment, Blue water, Irrigation.	Journal of Cleaner Production	Pellegrini et al.
	2018	WF	Grey component	Southern	Nitrate contamination, Agricultural land use, Grey water footprint, Environmental pollution, Human health.	Science of the Total Environment	Serio et al.
	2018	WF	GIS and CW	Apulia Region	Candelaro river, Food Agriculture Organization, Land use map, Reuse, Virtual water content, Water management	Sustainable Production and Consumption	Casella et al.
	2019	Wastewater	Review	China and India	LCA, Eutrophication, Sanitation, Environmental impacts, Sludge, Sustainability	Water Research	Gallego-Schmid and Tarpani
Climate Change	2015	Climate change and water availability	Review	Cyprus	Climate change, Adaptation, Water resources, Supply Demand Cyprus	Resources, Conservation and Recycling	Papadaskalopoulou et al.
	2019	WF and Climate Change	Drivers-Pressures-State-Impact-Response framework	Malta	Abstraction, groundwater, policy, soil, water resources	Outlook on Agriculture	Papadimitriou et al.
	2019	Climate change and water availability	Review	Global	Bibliometrics, scientific journals, scientific research, water-use efficiency	Journal of Agricultural Science	Aleixandre-Tudo et al.
	2020	CE and water management	Review	China	Climate change, Urban metabolism, Water management, Synergy management, Water-energy-carbon nexus	Resources, Conservation and Recycling	Lv et al.

the protection of the natural environment and technical-economic needs. The area identified for the WF application of this study is affected by a moderate rainfall and extends for 3.8E+03km^2.

3.1.2. Climatic data

The studied area covers a large domain and different climate conditions typically of the Mediterranean area. The twenty weather stations observed, located over the Apulia region, represent the different climatic condition according to the Köppen-Geiger classification (Yan and Mohammadian, 2020), dominated by Cs climate classification, namely Mediterranean climate with hot summers, representing the characteristic temperate weather of the Mediterranean area. Then, this region has a semi-arid Mediterranean climate with hot and dry summer and mild and rainy winter seasons. In the greatest part of it, annual precipitation varies between 450 and 550 mm. As Ladisa et al. (2012) highlighted, Apulian hydrological regimes are irregular and torrential, with high flow rates during the rainy season and very scarce in summer.

The climatic data of Apulia allowed the WF calculation. A data set of monthly climatic information for 2018 was obtained by consulting the Pluviometric Bulletins published by the Civil Protection of the Regione Puglia (2019), considering a sample of twenty weather stations, as above.

It must be pointed out that the maximum temperatures are recorded mainly from June to August and in these months most of the sample stations detect few quantities of rainfall. This combined effect creates drought problems especially in agriculture. In the period from October to January the peak of rainfall was recorded.

The dataset consisted of the maximum (M) and minimum (m) temperature, relative humidity (RH), wind velocity (ws) and rainfall (R). The monthly values were used to compute the annual average of values for all parameters, as shown in Figure 2.

The average sunshine hours per month are included from 9 hours minimum in January to 15 hours maximum in June and July.

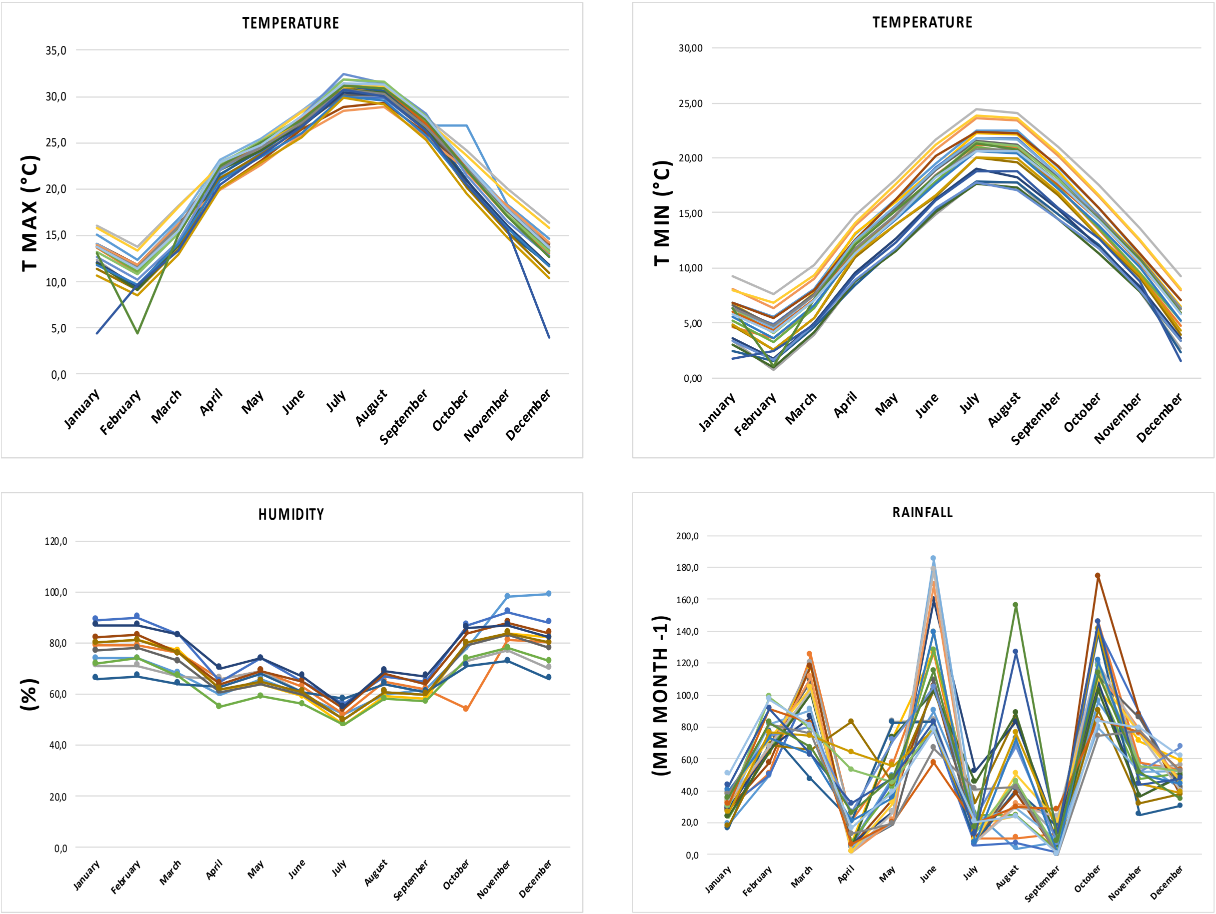


Fig.2. Data extrapolated from the climatic station of Regione Puglia (2019): Maximum temperature (a); Minimum temperature (b); Humidity (c) and Rainfall (d).
Source: Authors' elaboration based on data given in Regione Puglia (2019).

3.1.3. Crops

Apulian territory hosts about 17% of the Italian farms. From 1990 to 2015, farms recorded a reduction of 32% on regional level and 92% on national level (ISTAT, 2020). Apulian agriculture is characterized by a variety of products as shown in Table 2.

In the period 2016-2020 (ISTAT, 2021), many crops have had significant production changes: sunflower (+48.1%), watermelon (+25.7%) and almond (+24.8%), whereas tomato (-18.2%), olive (-8.7%) and onion (-2.6%).

Table 2
Crops production in Apulia (tons) (2016-2020) based on data given in ISTAT (2020, 2021).

Crops	2016	2017	2018	2019	2020	Average Production	Δ% (2016-2020)
Almond	2,24E+04	2,75E+01	2,72E+01	2,95E+01	2,79E+01	2,69E+01	+24.8
Clementine	1,43E+04	1,24E+02	1,23E+02	1,24E+02	1,46E+02	1,32E+02	+1.8
Grape	2,03E+06	1,94E+06	2,12E+06	2,10E+06	2,01E+06	2,04E+06	-1.2
Nectarine	2,06E+04	2,13E+01	2,15E+01	2,13E+01	2,17E+01	2,13E+01	+5.4
Olive	7,59E+04	9,07E+02	5,74E+02	7,75E+02	6,93E+02	7,41E+02	-8.7
Onion	4,12E+04	4,11E+01	3,97E+01	4,17E+01	4,01E+01	4,07E+01	-2.6
Sunflower	2,52E+03	3,72E+00	3,87E+00	3,73E+00	3,74E+00	3,52E+00	+48.1
Tomato	1,93E+06	1,74E+06	1,66E+06	1,62E+06	1,58E+06	1,71E+06	18.2
Watermelon	7,89E+03	8,96E+01	7,17E+01	9,92E+01	9,91E+01	8,77E+01	+25.7

Among the most important Mediterranean agricultural products, we focused on tomato, grape and olive crops in rainfed open-rain (Tab. 2).

The planting period considered and the harvest date of each crop are presented in Table 3, based on the information from CW by FAO (2018) and literature by Casella et al. (2019). The yield was expressed in t/ha as reported by Mekonnen and Hoekstra (2011) and it was specifically divided into rain fed and irrigated, as Table 3 shows. For the regional yield we considered data by Tarantino and Disciglio (2009). In particular, the yields of tomato were based on Giuliani et al. (2016), whereas those of olives on Pellegrini et al. (2016), grapes on Intrigliolo et al. (2012).

3.2 Methods

3.2.1. Water Footprint (WF)

It must be pointed out that the WFs of the three crops have been assessed at meso-level. Then, these results were compared to the macro level WFs, according to data gathered from the Water Footprint Network tool (2020).

It was used the WF indicator of Hoekstra et al. (2011) according to the equations (1):

$$\textit{Water Footprint} = \textit{Blue Water} + \textit{Green Water} + \textit{Grey Water} \tag{1}$$

Specifically, the blue water represents the water from surface or underground resources that can evaporate or incorporated into a crop, alternatively taken from a basin of water and returned either in another or at a different time. The green water derives from water from rainfall, water stored in the ground which then evaporates, transpires or is incorporated by plants. The grey water is the amount of fresh water needed to assimilate pollutants to meet specific water quality standards. This component considers the pollution of a freshwater source, caused directly or indirectly through the runoff or leaching from the soil, impermeable surfaces, or other widespread sources.

In this analysis the blue, green and grey components were elaborated for the three crops to quantifying the total water footprint, which is the sum of these components.

This study was carried out in accordance with ISO 14046:2014 (ISO/TC 207/SC5, 2014) and by the use of 1 ton of product, e.g. 1 ton (t) of tomato, as the functional unit.

The green water footprint (WF_{green}, m^3/t) (Eq. 2) were calculated by dividing the green Crop Water Utilization (CWU_{green}, m^3/ha) by the crop yield (Y, t/ha). Alongside, the blue water footprint (WF_{blue}, m^3/t) (Eq. 2) were calculated by dividing the blue Crop Water Utilization (CWU_{green}, m^3/ha) by the crop yield (Y, t/ha) (Eq. 3). For the grey water footprint (WF_{grey}, m^3/t) we used the equation (4) according to Hoekstra et al. (2011). Thus, the total WF refers to the sum of the green, blue and grey WF according to the equation (1).

$$WF_{green}=CWU_{green}/Y \tag{2}$$

$$WF_{blue}=CWU_{blue}/Y \tag{3}$$

$$WFgrey = \frac{L}{Cmax-Cnat} \tag{4}$$

Where L is the pollutant load, C_{max} is the maximum acceptable concentration (mass/volume), C_{nat} is the natural concentration of the receiving body (mass/volume).

CWU_{green} and CWU_{blue} (m^3/ha) were calculated (Eq. n. 5) from the accumulated corresponding actual crop evapotranspiration (ETc, mm/day), according to the equations (6) and (7):

$$CWU = CWR\frac{P}{Y} \tag{5}$$

$$CWR = 10 * \Sigma_{d=1}^{lg} ETc \tag{6}$$

Where CWR is the Crop Water Requirement (m^3/ha), P the production (t) and Y the yield (t/ha).

$$ET_c=K_c * ET_0 \tag{7}$$

K_c is the crop coefficient correlated to the characteristic of the crops and ET_0 is the reference evapotranspiration calculated in relation to the climatic condition.

In order to calculate ET_c, CW 8.0 model (2018), a software developed by FAO for the calculation of crop water requirements and irrigation based on soil, climate and crop data, was used. Additionally, it allowed us to evaluate different crop performance in rainwater and respect to climate change.

Some scientific studies had used CW to quantify the WF indicator of crops and derived crop products and to analyse the VW and evapotranspiration. Among these publications, the first article by Chapagain et al. (2006) has presented a VW analysis of cotton consumption through the use of CW.

The inventory of climatic data, as mentioned in the sub-section 3.2 (Fig. 2), was used in CW to elaborate ET_0 according to the equation *Monthly* ET_o *Penman-Monteith.*

ETc (Eq. 8) was calculated using the approach of the dual crop coefficient and forecasting of the rain events on the Kc value (Tab. 3), as reported in Allen et al. (1998):

$$ET_c = (K_{cb} + K_e) \times ET_0 \tag{8}$$

$$K_c = K_{cb} + K_e \tag{9}$$

Where K_{cb} is the basal crop coefficient and K_e the soil coefficient.

Table 3

Crop data, planting/harvesting period, yield and Kc value.

Crops	**Planting Period**	**Harvesting Period**	**Yield (t/ha)** ***rain fed***	**Yield (t/ha)** ***irrigated***	**Kc_{in}**	**Kc_{mid}**	**Kc_{total}**
Tomato	April 2018	August 2018	45.5	82.8	0.60	1.15	0.80
Grape	April 2018	October 2018	8.30	16.3	0.30	0.70	0.45
Olive	March 2018	November 2018	2.50	10.0	0.65	0.70	0.70

Source: Authors' elaboration based on data given in Casella et al. (2019).

The crop coefficient (K_{cb}) estimated in the study area was extracted from Allen et al. (1998) and (Tab. 3) and the soil data (K_e) from Batjes (1997) for the maximum soil moisture values and from Allen et al. (1998) for the maximum rooting depth values, both used in the CW per crop analyzed.

The Kc values (Eq. 9) were used for the CW calculation of ET_c using monthly climatic data and soil data.

Therefore, the CWU (green and blue) and then the WF (green and blue) for each crop identified were calculated.

However, in order to calculate the WFgrey (Eq. 10) we used the equation (4):

$$WFgrey = \frac{\frac{(\alpha * AR)}{Cmax - Cnat}}{Y} \tag{10}$$

Where α is the fraction of leaching, AR the rate of application of chemicals to the field per hectare (kg/ha) based on regulations of the Apulia region (BURP, 2020), C_{max} the maximum acceptable concentration (kg/m^3) based on legislation (European Council, 1991b), C_{nat} the value of 0 as suggested by Hoekstra et al. (2011) and Y the yield production (t/ha).

According to a recently assumption by Hoekstra et al. (2011), for the calculation of the WF grey we referred to nitrogen fertilizers, assuming a leaching rate of 10% (α). Moreover, for C_{max} value we referred at European maximum permissible concentration of nitrogen equal to 11.3 mg/L.

3.2.2. Virtual Water (VW)

As suggested by Wichelns (2011), public policies regarding the distribution of water resources, in agriculture or in international trade should jointly consider VW and WF indicators.

For this reason we proposed another methodology to assess the water consumption at the national level of the selected crops. This application is based on the VW trade concept, introduced by Allan in 1993 and then involved several scholars (see Tab. 1 in § *Literature Review*). The VW trade evaluation allows to highlight the balance between export and import of crops water content (Eq. 11) and is expressed in m^3/kg.

$$VWT = WF * TV \tag{11}$$

Where VWT is the virtual water trade volume of an agricultural product (m^3), WF is the water footprint in m^3/kg, TV is the trade volume of an agricultural product (kg).

Hence, it occurs in some nations to save scarce domestic water resources by importing water-intensive products and exporting goods that require less water. On the other hand, water-rich countries can profit by exporting water-intensive products (Mekonnen and Hoekstra, 2010).

To estimate VW flow, we used a global hydrological model of CW, specifying the VW source through the green water and blue water of the WF, in line with the global hydrological cycle.

The VW trade was quantified as difference between export and import values, using crop products data of FAOSTAT. Finally, the VW trade was calculated for tomatoes, olives and grapes. The same calculations were undertaken for Italy, Spain and Greece in order to make a comparison among the results.

3.3.3. Climate Change scenarios

Climate change is a well-known phenomenon that causes global temperatures to rise, alters precipitation patterns and also affects the availability of water resources (IPCC, 2018).

Therefore an extended application of WF to the climate change scenario as proposed by Zhang et al. (2015) could provide some insights on the issue of using water in a sustainable way.

According to the 2018 IPCC Report, from 2030 to 2052, we expect a temperature increase of 1.5°C (medium confidence) to 2°C (high confidence). In order to assess this impact on water resources, we applied a dynamic climate change model to the WF results at meso-scale.

Therefore, we filled the average temperature and the rain data in CW, according to Berg et al. (2013), who argued that more precipitation is expected due to global warming.

We have hypothesized six climate change scenarios applied to the area considered for the reference period 2030-2052:

1) $R_{1.5}$: increase of 1.5°C;

2) $E_{1.5}$: increase of 1.5°C;

3) R_2: increase of 2°C;

4) E_2: increase of 2°C;

5) $R_{2(13.33)}$: increase of 2°C;

6) $E_{2(13.33)}$: increase of 2°C.

We have built the first four scenarios by an increase of 10 mm of rainfall on the basis of the IPPC Report (2018) suggestions. Also, the scenarios $R_{2(13.33)}$ and $E_{2(13.33)}$ were based on our assumption of a proportional increase of rainfall to 13.33 mm and an increase of 2°C. We indicated the first letter of above scenarios with R, that is Real and E, that is Estimated: they referred to the hours of sunshine considered, particularly the real hours are indicated in Regione Puglia (2019) and the estimated hours proposed by CW. These hours of sunshine are different each month and include the hours from sunrise to sunset. Hence, the increase of rainfall was applied in the wettest months, from October to January.

4. Results

4.1 Water Footprint

In order to provide a macro-scale of investigation of the Water Footprint of tomatoes, olives and grapes (Tab. 4), we queried the interactive tool of the Water Footprint Network Toll (2020).

Globally, China has the highest value of Water Footprint for tomatoes, whereas Spain has it for olives and grapes. For olives, Croatia and Egypt present the highest rate of the green component (98.75% and 77.78%).

As mentioned in the important study by Mekonnen and Hoekstra (2011), at global level, the blue component increases where there is high water scarcity, as displayed by Table 4, above all in Mediterranean countries, such as Egypt for tomato and olive and Greece for grape.

Table 4
Water Footprint Total (m^3/year) and composition of the different Water Footprint components of main global producers countries for tomato, olive and grape (2019) based on data given in Water Footprint Network tool (2020).

	Tomato	WF				**Olive**	WF				**Grape**	WF			
		Total	Green	Blue	Grey		Total	Green	Blue	Grey		Total	Green	Blue	Grey
		m^3	%				m^3	%				m^3	%		
1	China	6,50E+03	64.62	1.02	34.36	Spain	1,40E+04	78.57	19.29	2.14	Spain	6,40E+03	68.75	12.50	18.75
2	India	1,70E+03	54.12	25.29	20.59	Tunisia	7,50E+03	96.00	3.60	0.40	Italy	4,20E+03	76.19	6.67	17.14
3	Egypt	1,60E+03	10.00	61.25	28.75	Italy	6,20E+03	92.06	6.67	1.27	France	3,70E+03	97.30	0.59	2.11
4	USA	1,40E+03	25.00	60.00	15.00	Greece	3,60E+03	86.11	13.89	0.00	USA	2,50E+03	29.20	52.00	18.80
5	Iran	1,20E+03	12.50	83.33	4.17	Turkey	3,20E+03	84.38	10.63	4.99	Turkey	2,30E+03	82.61	0.00	17.39
6	Turkey	1,20E+03	42.50	40.83	16.67	Morocco	3,00E+03	70.00	27.67	2.33	China	2,10E+03	66.67	0.00	33.33
7	Italy	7,06E+02	59.50	28.17	12.33	Syria	2,70E+03	62.96	29.63	7.41	Portugal	1,10E+03	90.91	4.09	5.00
8	Russian F.	6,02E+02	86.67	12.50	0.83	Portugal	2,00E+03	98.20	1.75	0.05	Argentina	1,10E+03	37.27	53.64	9.09
9	Mexico	5,00E+02	32.00	46.00	22.00	Algeria	1,10E+03	75.83	20.00	4.17	Romania	1,00E+03	95.00	1.10	3.90
10	Ukraine	4,70E+02	76.60	7.45	15.95	Libya	1,10E+03	40.00	57.27	2.73	Iran	1,00E+03	83.00	0.02	16.98
11	Iraq	4,50E+02	26.67	60.00	13.33	Egypt	5,40E+02	16.48	77.78	5.74	Australia	7,70E+02	46.75	25.97	27.28
12	Indonesia	3,54E+02	83.33	1.47	15.20	Jordan	3,50E+02	57.14	34.29	8.57	Greece	6,40E+02	59.38	23.49	17.13
13	Spain	3,18E+02	40.63	27.81	31.56	Lebanon	3,50E+02	60.00	39.93	0.07	S. Africa	6,40E+02	51.56	37.50	10.94
14	Brazil	3,00E+02	73.33	20.67	6.00	Palestine	3,40E+02	94.12	5.85	0.03	Moldova	6,30E+02	96.83	1.90	1.27
15	Cuba	3,00E+02	46.67	13.67	39.66	Argentina	2,80E+02	60.71	38.75	0.54	Chile	5,40E+02	70.37	1.15	28.48
16	Nigeria	2,10E+02	80.95	17.62	1.43	Albania	1,90E+02	94.74	3.42	1.84	Ukraine	4,90E+02	85.71	0.07	14.22
17	Romania	1,90E+02	89.47	10.00	0.53	Israel	1,10E+02	64.55	30.00	5.45	Bulgaria	4,80E+02	97.92	0.35	1.73
18	Greece	1,70E+02	48.82	26.47	24.71	USA	1,10E+02	43.64	52.73	3.63	Hungary	4,50E+02	84.44	0.05	15.51
19	Algeria	1,64E+02	62.50	35.63	1.87	France	1,00E+02	88.00	5.50	6.50	Germany	4,10E+02	95.12	0.00	4.88
20	Cameron	1,30E+02	92.31	3.92	3.77	Croatia	8,00E+01	98.75	0.04	1.21	India	3,80E+02	92.11	0.00	7.89

Globally (Fig. 3) the major component of Water Footprint is represented by the green water for olives (82%), followed by that of grapes (70%) and tomatoes (51%), whereas, the lowest value of WF is associated with the grey component, which is only 1.5% for olives, 14.4% for grapes and 19.6% for tomatoes.

From the comparative analysis at Mediterranean level (Fig.3) of Italy, Greece and Spain, it must be noted that Italy presents the highest value of both total Water Footprint and green component (59.50%), Spain the highest value of the grey component (31.56%), whereas Greece has the lowest value of total Water Footprint for tomatoes, olives and grapes and the grey component equal to zero for olives. Nevertheless, Italy, Greece and Spain have a similar value of the blue component (27.47-28.17%).

Comparing these crops on the Italian scale, olives present the highest value of the green component (92.06%), whereas tomatoes the highest value of the blue component (28.17%) and grapes the highest value of the grey component (17.14%). Overall, at national level, olives present the highest value of Water Footprint, followed by tomatoes and grapes. On the contrary, on a regional scale, grapes present the highest value of Water Footprint, followed by olive and tomato (Fig. 4).

The resulting assessment at meso-level is displayed in Figure 4 and highlights that the grey component of tomatoes was the highest (81.35%) in comparison to the green (5.11%) and blue ones (13.54%). For olives too, the major component is represented by the grey component (89%) while the blue and green component was over 5% each. The similar result occurred for grapes, with a grey component of 93%, while green accounts for 5% and blue 2%. These results are in line with the Apulian water footprint calculated by Russo (2020), particularly for tomatoes, whereas the Water Footprint of grapes is consistent with the green component only and the Water Footprint of olives for the blue and grey components. Going into more detail, Russo (2020) quantified for tomatoes the highest value (78.3%) for the grey and the lowest one (6%) for the green components; for olives, the highest (86.3%) for the grey and the lowest value for the blue components (5%). Lastly, for grapes, the grey water was the highest (89.4%) and the green water the lowest (3.6%).

In conclusion, at meso-level, olives were seen to have the major impact by 3.90E+04m^3/ha in terms of Water Footprint total, grapes by 3.50E+04m^3/ha and tomatoes by 2,20E+04m^3/ha followed.

4.2 Virtual Water Assessment

By the comparison of Virtual Water trade values in 2018 of increasingly exporting countries (Duarte et al., 2021) such as Italy, Spain and Greece (Tab. 5), it was highlighted that Italian grapes present the highest value of Virtual Water, exporting more than 4,65E+05 tons. Spanish tomatoes have the highest value of Virtual Water, exporting more than 8,13E+05 tons. Lastly, olives were largely exported from Greece and for this Virtual Water value is the highest of the three countries.

Table 5
Virtual Water Trade for Italy, Spain and Greece (2018).

2018	**Italy**			**Spain**			**Greece**		
	Import (tons)	Export (tons)	Virtual Water (m^3)	Import (tons)	Export (tons)	Virtual Water (m^3)	Import (tons)	Export (tons)	Virtual Water (m^3)
Tomato	1,30E+05	7,93E+04	-5,12E+05	1,69E+05	8,14E+05	6,57E+06	2,93E+04	3,77E+04	8,57E+04
Olive	9,30E+03	2,02E+03	-1,87E+06	9,47E+03	1,69E+04	-1,91E+06	5,87E+02	4,28E+03	9,48E+05
Grape	1,96E+04	4,65E+05	1,45E+07	6,41E+04	1,76E+05	3,64E+06	1,26E+03	6,77E+04	2,17E+06

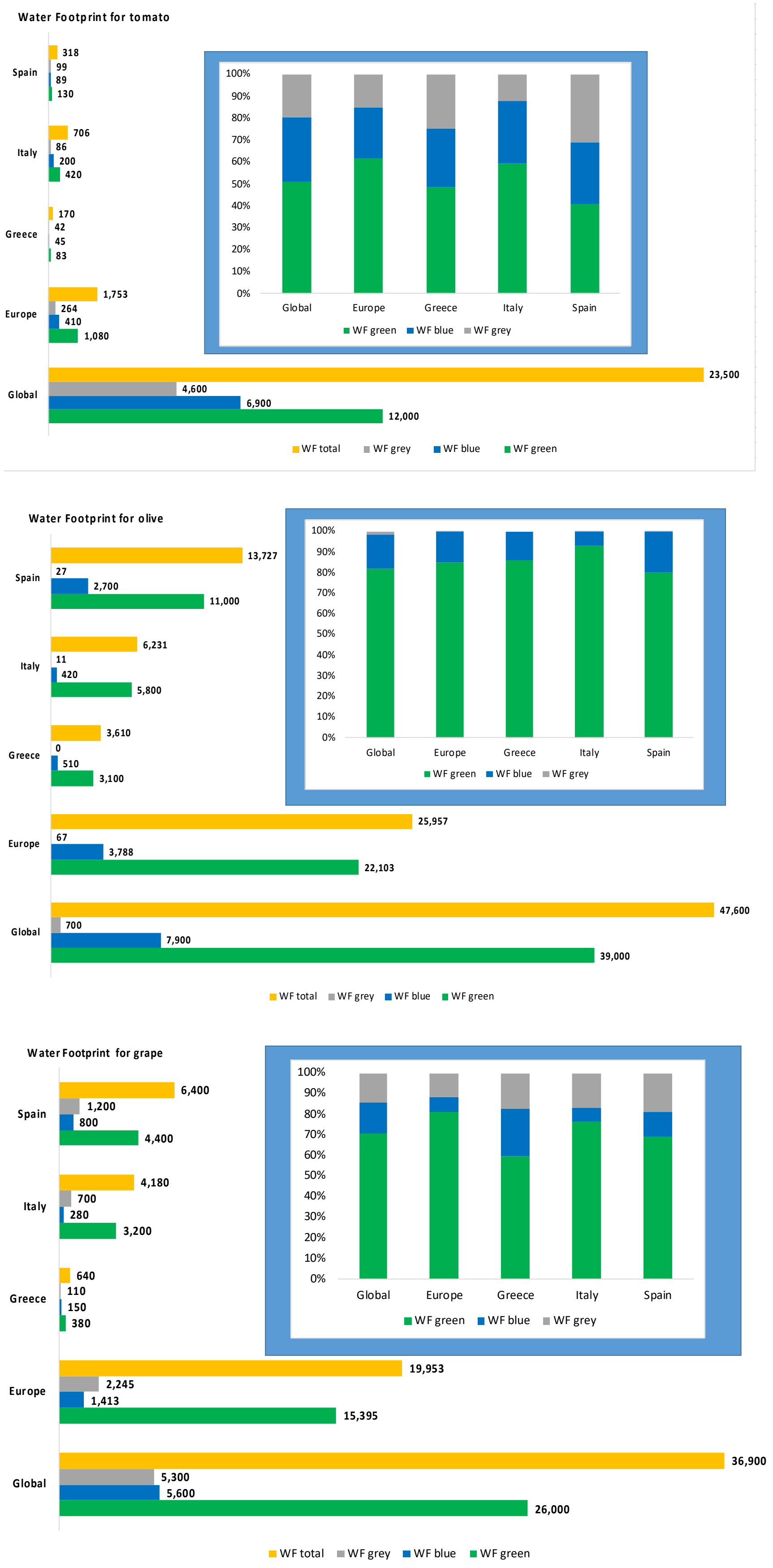


Fig.3. Comparison of Water Footprint for tomato, olive and grape, among different value scales (Mm^3/year). Authors' elaboration on data given in Water Footprint Network Tool, 2020.

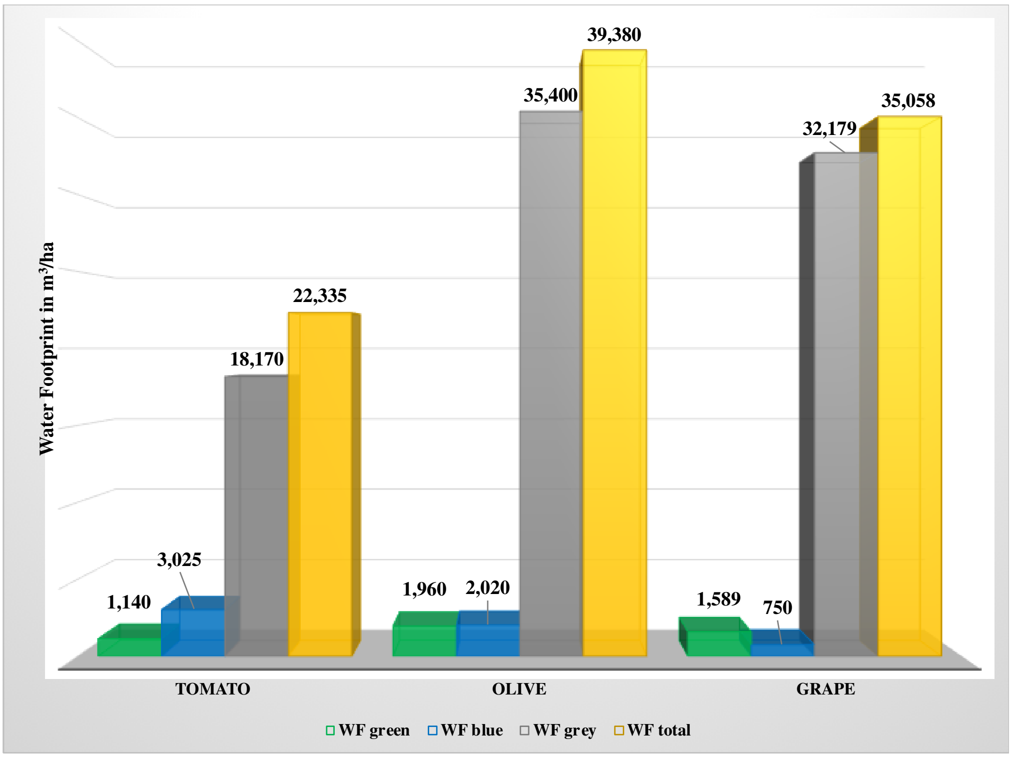


Fig. 4. Assessment of Water Footprint (m^3/ha) for tomato, olive and grape at meso-level.

4.3 Climate Change scenarios

Applying the assumptions of the climate change impact-based scenarios, it has been noted that the total Water Footprint was the highest in the fifth scenario for tomatoes, olives and grapes, conversely, it was the lowest in the fourth scenario (Tab. 6).

Tomatoes displayed an increase in the green component by 37.80% in the fifth and sixth scenario, whereas the blue component increased by more than 21.1% in the fifth scenario and decreased by 21.06% in the second scenario. Olives presented a major increase by 50.26% in the fifth and sixth scenarios in terms of the green component of Water Footprint. The blue component increased by more than 21.14% in the fifth scenario, while it decreased by 20.40% in the second one.

Of all the crops, the rise in temperature values has generated the biggest increase for grapes in terms both of the green and the blue components. In particular, the green component has been affected by an increase of 218.7% in the last two scenarios and the blue one increased more by 77.33% in the fifth scenario.

Table 6
Comparison between real and climate change scenarios (m^3/ha) at meso-level.

			Scenario					
		Real	**$R_{1.5}$ (1)**	**$E_{1.5}$ (2)**	**R_2 (3)**	**E_2 (4)**	**$R_{2(13.33)}$ (5)**	**$E_{2(13.33)}$ (6)**
Tomato	WFgreen	1,14E+03	1,14E+03	1,18E+03	1,18E+03	1,18E+03	1,57E+03	1,57E+03
	WFblue	3,03E+03	3,22E+03	2,39E+03	2,75E+03	2,04E+03	3,66E+03	2,72E+03
	WFgrey	1,82E+04	1,82E+04	1,82E+04	1,82E+04	1,82E+04	1,82E+04	1,82E+04
	TOT	2,23E+04	2,25E+04	2,17E+04	2,21E+04	2,14E+04	2,34E+04	2,25E+04
Olive	WFgreen	1,96E+03	2,21E+03	2,21E+03	2,21E+03	2,21E+03	2,95E+03	2,95E+03
	WFblue	2,02E+03	2,16E+03	1,61E+03	1,84E+03	1,37E+03	2,45E+03	1,83E+03
	WFgrey	3,54E+04	3,54E+04	3,54E+04	3,54E+04	3,54E+04	3,54E+04	3,54E+04
	TOT	3,94E+04	3,98E+04	3,92E+04	3,94E+04	3,90E+04	4,08E+04	4,02E+04
Grape	WFgreen	1,59E+03	3,80E+03	3,80E+03	3,80E+03	3,80E+03	5,07E+03	5,07E+03
	WFblue	7,50E+02	1,18E+03	8,69E+02	9,98E+02	7,35E+02	1,33E+03	9,80E+02
	WFgrey	3,27E+04	3,27E+04	3,27E+04	3,27E+04	3,27E+04	3,27E+04	3,27E+04
	TOT	3,51E+04	3,77E+04	3,74E+04	3,75E+04	3,73E+04	3,91E+04	3,88E+04

In all scenarios, the grey component of Water Footprint did not register any variations because the increases of rainfall and temperature only affect the green and blue components and this issue represents a limit for these scenarios. Nevertheless, the Water Footprint grey continues to display a higher value than other components.

5. Discussion

It has to be stressed that there is a discrepancy of Water Footprint components on the national scale (Water Footprint Network Toll, 2020) in comparison to meso-level assessed in this research, confirmed by Russo (2020) too. At a national level the largest component is the green one, conversely the grey shows the highest value at meso-level in Apulia. Indeed, as suggested also by Zotou and Tsihrintzis (2017) in their study on the Water Footprint of some crops in a Hellenic area, if a value of the natural concentration of pollutants higher than zero is used, the yield value decreases, therefore a very high value of the grey component occurs. Additionally, having analyzed the cultivation of crops in rainfed open-rain, these present a higher grey component of Water Footprint than that of irrigated systems. In Spain, Chico et al. (2010) calculated a grey component for tomatoes equal to 84% of the total Water Footprint. Lastly, as stated by Jarmain et al. (2020) in their report on the sustainable table and grape wine production in South Africa, in order to obtain more accurate soil leaching fractions for different crops and pollution levels, further research is also needed to investigate the impact of water purification and other strategies to decrease the grey component value of Water Footprint.

Due to the significance of a higher value of the grey component of Water Footprint compared with the other two components values, we have undertaken a sensitivity analysis for this component in section 6.

The results of applying the Virtual Water trade methodology confirmed the importance of this indicator. By means of this methodology, it is possible to quantify the virtual weight that each traded agri-food product can reach. It is a valid tool, in particular, for countries that use the absence of imports to make up for their own water resources or to highlight the export of products with a high rate of water consumption by countries with a great lack of water.

These innovative assessments through the climate change scenarios are useful to evaluate the planting and harvesting period of some crops and the variations in the use of water resources with respect to the increase in temperature and rainfall.

Nevertheless, as Abbade (2020) highlighted in order to reduce land use and water scarcity due to agriculture, environmental impacts must be reduced and sustainable practices must be boosted in the Mediterranean and globally.

The present framework of assessing the Water Footprint and the variations associated with climate change provides a model for bottom-up approaches to be applied in the production of water-intensive goods, as Haida et al. (2019) suggested. For this reason, the implementation of water resource management measures in high-consumption sectors, such as agriculture, must involve primarily local stakeholders, integrate numerous policy areas such as regional departments and apply bottom-up processes.

In addition, a constant exchange of knowledge in the agricultural sector can support more water-efficient management, combining environmental benefits for both society and farmers (Levidow et al., 2014).

Our study gives evidence of the significant linkage between meso and macro levels, providing multiple indicators to measure, assess and compare the water availability. This kind of observation is useful for predicting alternative scenarios of availability and use of water resources in territories by different scales, but sharing similar climate conditions, yields and edaphoclimatic characteristics.

6. Sensitivity analysis

Nowadays, agri-food players mostly practice intensive agriculture in order to meet the demand for certain agricultural products, increasing the use of fertilizers and producing significant impacts on the environment. Thus, in order to investigate if the higher value of the grey component was associated with the leaching of fertilizers, we undertook a sensitivity analysis of WF for olives.

It has to be highlighted that Nemecek et al. (2015) considered that the proper management of some fertilizers, such as nitrogen, would improve the condition of the fields, saving the demand for non-renewable energy resources, reducing the global warming potential, acidification and eutrophication. Hence, considering the reduction of the nitrogen quantity an important measure to be applied according to the integrated agriculture standard, we verified the incidence of this fertilizer on water consumption at meso-scale by the use of the WF grey indicator. Through a sensitivity analysis, we quantified the grey component in two different scenarios: a) high production and b) low production, according to the standard values provided by the Apulia Region (BURP, 2020) for integrated production. The assumptions to quantify the grey component of olive crops based on the equation (10) were as follows:

a. high production scenario: yield between 6-10 t/ha and 120 kg/ha of nitrogen;

b. low production scenario, yield between 3-5 t/ha and 70 kg/ha of nitrogen.

Generally, in order to reduce the impact of fertilizers, recommendations were made to reduce α (the % of leaching) for olives: α was equal to 0.017 t/ha in standard level production (Hoekstra et al., 2011), above quantified, whereas in scenario a) it decreased to 0.012 t/ha and in scenario b) to 0.007 t/ha.

The resulting grey WF, equal to 3,19E+01 m^3/ha (minimum value), of the high production scenario, is lower by 10% compared to our analysis based on a standard level equal to 3,54E+01 m^3/ha. On the contrary, the grey component increased in the low production scenario to 3,72E+01 m^3/ha (maximum value), higher by 5% compared to the standard level, above quantified.

The results highlighted that the increase in the yield production of olives and fertilizer use can reduce the nitrogen release into the freshwater resources and decrease the grey water pollution, as recently highlighted by Muratoglu (2020) too. This balanced approach occurred in the high production scenario, although it depends on the high freshwater amount used, so our hypothesis is not confirmed. This sensitivity analysis proposed can be replicated both per crop and for the other components of WF (green and blue), by varying the type and the rate of the fertilizers or other factors too. Generally, this method of evaluation can be managed and replicated by stakeholders and farmers, as suggested by Pattara et al. (2016).

7. Prospects of CE in the wastewater reuse in Apulia

Based on a Circular Economy approach, we provide new insights on the reuse of wastewater in agriculture to be adopted in water management especially in semi-arid areas such as Apulia.

The reuse of treated wastewater could be a sustainable key practice of the water management policy resources in agriculture, moving from a linear to a circular consumption paradigm. In fact, the wastewater reuse practice addresses a double aim: to guarantee the sustainability of water uses, mainly in agriculture (D'Agostino et al., 2014) and address the decrease in available resources also due to climate change (Vergine et al., 2015).

Some scholars (e.g. Saliba et al., 2018) identified a high level of acceptance of wastewater reuse among Apulian stakeholders. However, most farmers choose occasional and non-habitual use. It emerged that the fundamental path to be activated must involve training the stakeholders and informing them of the enhancement of wastewater reuse within a full water management policy.

7.1 *Legislative framework*

From the legislative standpoint there are two national laws: the D.Lgs n.152/99 and n.185/03 (GU, 2000, 2003), which set up the quality standards for agricultural water reuse.

A few years earlier, article 12 of Directive 271/1991 (European Council, 1991a) invited member countries to "reuse, whenever deemed appropriate, the treated wastewater and to dispose of it with minimum environmental impact". Subsequently, Italy implemented this directive and the Apulia region provided for the recycling and reuse of treated water, through legislative and regulatory measures, among which Regional Law 27/2008 (BURP, 2008) and Regional Regulations n. 8 and n. 12 of 2012 (BURP, 2012a, 2012b).

Therefore, the reuse of wastewater, as indicated by these latter regulations, could have many purposes, particularly environmental ones (restoration and water balancing of humid areas), irrigation (of crops for the production of food for human and animal consumption; for public gardens), urban (cleaning of the road surface or supply for urban toilets), industrial (for firefighting, cleaning and industrial thermal cycles).

Finally, the latest European directive recently published (2020/741) encompasses, among other measures, the requirements of refined water quality (European Parliament, 2020).

7.2 Estimation of wastewater savings

Taking into account that a city with 100,000 inhabitants drains, yearly, an average of 7E+06m^3 of water into the sewer (Regione Puglia, 2016), Apulia, with roughly 4 million inhabitants, generates more than 2.82E+08m^3 per year. Currently, the minimum rate of purified wastewater to be used amounts to only 5% of the total equal to 1.4E+08m^3, but if all purifiers installed were operating for irrigation purposes, the yearly maximum availability of wastewater refined increases to 1.16E+08m^3 (Zotti, 2020) and the rate of utilization to 41% of the total.

Furthermore, taking into account that consortia supply 1.66E+08m^3/year of water resources (BII, 2015), the reuse of wastewater for irrigation purposes could reduce this demand by 70% and also save considerable economic resources for farmers, estimated to about 7 million euros per year (Regione Puglia, 2016).

At a general level, the reuse of treated and purified wastewater for irrigation also allows farmers to save the rate of chemical fertilizers. Already thirty years ago, FAO (1992) highlighted that the discharges have an important content of nutrients, including up to 50 mg/L of nitrogen, 10 mg/L of phosphorus and 30 mg/L of potassium useful for agricultural land.

It must be stressed the issue of COVID-19 transmission which could also potentially be linked to water and wastewater. Therefore, even in the reuse of wastewater in agriculture, the risks associated with the COVID-19 pandemic must be taken into account (Kataky et al., 2021).

Given that olive crops cover a large part of the agricultural area with the highest incidence of water withdrawal from consortia (BII, 2015), among the crops investigated, a Circular Economy strategy based on wastewater reuse could reduce water stress and Water Footprint values too.

8. Conclusions, limitations and future implications

WF is an environmental indicator for assessing the impact of large water use in the agricultural sector, taking into account the interactions between climate change (internal conditions) and stakeholders behaviours (external conditions), identifying the best sustainable conditions at a macro level too.

Based on the obtained results, the following conclusions can be drawn:

- At meso-level, olives present the highest WF total value, grapes and tomatoes followed.
- Grapes are more affected by climate change than the other crops. It has been stressed that climatic changes generated some variations for the green and blue WF, conversely keeping constant the grey one, which remains the highest among the three components.
- The edaphoclimatic characteristics as well as the natural factors are the aspects that mainly affect the performance of each crop and its WF.
- On the meso-scale in particular, recovering data about agricultural practices is not straightforward, as they are not yet effectively systematized.

It also must be pointed out that the adoption by farmers of the high production scenario of integrated agriculture can reduce the grey WF of up to 10% compared to the standard production. Therefore, the novelty of this study also concerns the design of a method to reduce the impact of fertilizers (e.g nitrogen) and reuse the water resource in the CE approach.

This framework is useful indeed when drawing up the CE standards for better management of the crops with higher WF values and implementation of bottom-up approaches among stakeholders.

- The circular systems to be implemented in the Apulian agricultural for the reuse of wastewater would allow a reduction in the water stress conditions of the aquifer up to even more than 70%, a more controlled supply from the consortia and an increase in the sustainability of energy costs.

Some limitations of our analysis concern the comparisons between different areas of investigation, due to the great variability of data which lead to the great variability of WF values of the different countries. Moreover, in the climate change scenarios, the variables which can affect the results are numerous, although we limited the use to a few of them. Nevertheless, at the EU level by 2030, we would be aiming to halve the percentage of untreated water. In addition, this research proposes a clear answer to UN 12-SDG (Sustainable Consumption and Production), as the agri-food sector is part of the human activity that can be improved to achieve a more sustainable and cleaner future for the planet.

Finally, this paper also provides a tool to increase the knowledge of the effects of climate change on the water resource and a useful framework to compare the amount of this resource among the Mediterranean agricultural systems at meso and macro scales.

Future research will furtherly enlarge the sample of crops investigated and the variables of the climate change involved, dealing with dynamic methods of analysis.

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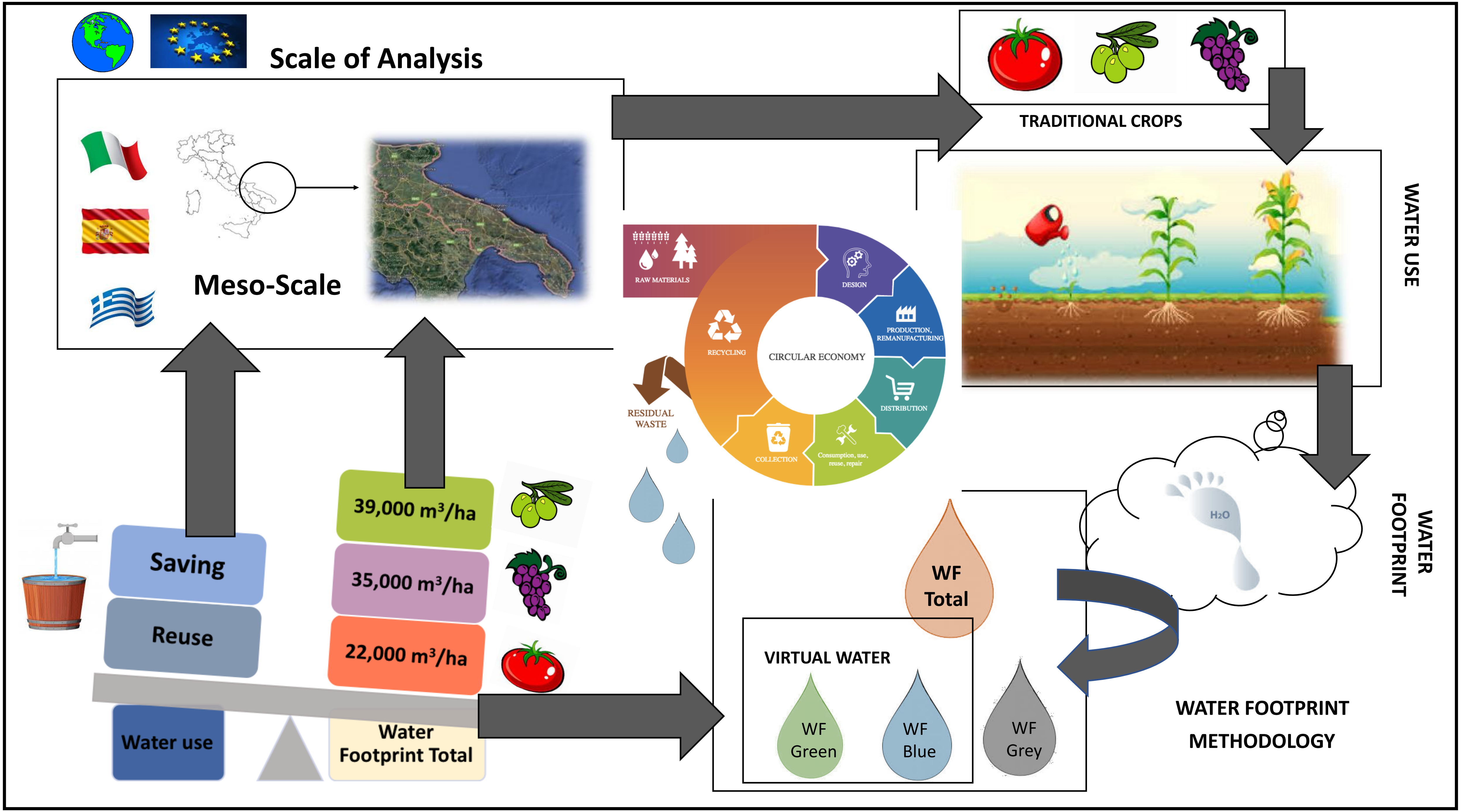
Scale of Analysis
Meso-Scale
TRADITIONAL CROPS
WATER USE
RAW MATERIALS
DESIGN
PRODUCTION, REMANUFACTURING
DISTRIBUTION
Consumption, use, reuse, repair
COLLECTION
RECYCLING
CIRCULAR ECONOMY
RESIDUAL WASTE
H2O
WATER FOOTPRINT
WF Total
VIRTUAL WATER
WF Green
WF Blue
WF Grey
WATER FOOTPRINT METHODOLOGY
Saving
Reuse
Water use
39,000 m³/ha
35,000 m³/ha
22,000 m³/ha
Water Footprint Total