Water footprint of agriculture in Portugal

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Abstract

The sustainable management of water resources is increasingly challenging due not only to climate change but also to population growth. They both put pressure on water resources by increasing demand for the needs of a growing population.

Portugal is a country that has been subject to extreme weather events in the last years, with above average temperatures and very low rainfall values, making farming practice challenging under these conditions.

This dissertation studies the economic sector responsible for the largest volume of water consumption: agriculture. It focuses on the use of water in agricultural production of the main crops in Portugal, quantifying the total water footprint in its three components (green, blue and grey) in the year 2017 and comparing it with a normal climatological year (1971-2000).

Through the CROPWAT program, crop evapotranspiration, evapotranspiration of rainwater incorporated in crops and evapotranspiration of irrigation water, also incorporated in crops, were estimated for the five regions that were selected to represent Portugal, for the two mentioned periods.

Following the methodology proposed by Hoekstra *et al*. (2011), the total water footprints, as well as the distribution of green, blue and grey water by crop, water footprint of national consumption, virtual water content, water footprint per inhabitant, irrigation water needs and water productivity were estimated for the 15 groups of selected crops.

The obtained results are in line with the predicted when comparing the water consumption of the crops in the two periods, with the blue water footprint contributing more than the green to the total water footprint, a result that is even more noticeable in 2017. Regarding virtual water flows, a positive value was obtained, which means that Portugal is a virtual importer of virtual water.

***Keywords**: Water, Climate change, Water footprint, Agriculture.*

1 Introduction

Water is a key resource in the survival of all social and economic activities and functions of ecosystems, and its deterioration in quantity and quality is increasingly worrying. Climate change, combined with pollution and unsustainable water use, put pressure on water resources.

World population growth implies an increase in demand for water resources in order to satisfy the population water needs. Globally, the agricultural sector accounts for about 70% of total freshwater consumption, and in most developing countries this number reaches 90% (FAO, 2011).

The food needs of a growing population imply an increase in productivity in the agricultural sector, which is achieved through an increase in irrigated agriculture, which means a larger water consumption.

In 2002, Arjen Hoekstra presents the water footprint concept, an indicator of water use in relation with consumer goods. The water footprint of a product is the volume of freshwater used to produce the product, measured over the various steps of the production chain. Water use is measured in terms of water volumes consumed or polluted. Water consumption refers to water evaporated or incorporated into a product. The water footprint is a geographically explicit indicator that shows volumes of water use and pollution, but also the locations (Hoekstra, 2011).

The water footprint is divided in three components: green, blue and grey. The green component refers to the evaporation of rainwater in the growth of a crop, the blue component is relative to the evaporation of groundwater and surface water used in agricultural products and the grey component is the water that is needed to dilute polluted water from agricultural production until it reaches acceptable levels of water quality.

By quantifying the volumes of water incorporated in the products, it is possible to adapt the management of water resources and formulate more responsible strategies.

Objective

This study will essentially compare the water consumption between a drought year (2017) and an average year from a normal climatologic period (1971-2000) for a selected group of crops in terms of green, blue and grey water.

The comparison is made through the water footprint assessment of all the studied cultures, namely the internal and external water footprint of national consumption, water footprint *per capita* per year and the water footprint in each of the five considered regions.

Crop irrigation needs are also taken into account with the analysis of 2017 and an average year and, furthermore, the virtual water content is also calculated, as well as the virtual water flows.

2 Literature review

2.1 World and Portugal water use

2.1.1. World water resources situation

According to Dubreil (2006), the continuous growth of the world population causes an increase in water consumption in the various goods and services that society demands.

Approximately 30% of the world's economically accessible freshwater resources are exploited to meet the needs of the main sectors: domestic, industrial and agricultural.

Most of water use is performed by agriculture (70%), followed by industry (20%) and by domestic and commercial use (10%) (Cosgrove and Rijsberman, 2000). However, for developing countries, this distribution changes to 82% for agriculture, 10% for industry and 8% for domestic use; and in developed countries the industry is the largest consumer with 59%, followed by agriculture (30%), and domestic use with 11% (Pena, 2018).

2.1.2. Portugal water resources situation

Portugal has a type of atlantic-mediterranean climate, where precipitation is variable and irregular, with frequent and intense drought phenomena that can persist for several consecutive years (WWF, 2018).

In the north of the country precipitation is higher, and the temperatures are lower, and in the south the situation is reverse, with summers with high temperatures and winters where precipitation in less intense. Hence, the greatest impact on water availability/needs ratio occurs precisely in the summer, when water availability is slow, but needs are high, particularly regarding irrigation needs in agricultural sector.

Figure 1 - Temperature and precipitation in Portugal (1931-2017) (IPMA, 2017)

According to IPMA's annual climate report (2017), 2017 was a year classified as extremely dry and extremely hot, being the second warmest year since 1931, with an average air temperature of 16.33 ° C, and with a total annual precipitation value of 541.3 mm, being the 3rd lowest value since 1931.

2.1.3. Agriculture sector in Portugal

According to PNUEA (2012), Portugal started the 21st century with an annual water demand estimated in 7.5 Mm^3 in the three sectors: urban, industrial and agricultural, with the last one being responsible for the largest consumer (more than 80%).

Due to the climate, precipitation variation in Portugal makes irrigation a necessity and a condition of success for agriculture, and more than half of the agricultural holdings depend on water for agriculture, and irrigation accounts for 60% of national production (AGROTEC, 2018).

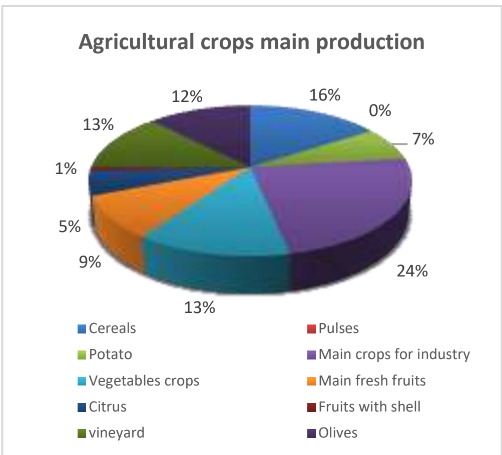


Figure 2 - Production of the main agricultural crops in 2017 (INE, 2017).

According to Figure 2, in 2017, crops for industry production including tomato, sunflower, tobacco, beet and hops were the main national vegetable productions, responsible for 24% of agricultural production. Followed by cereal production, with 16%, and vegetables and vineyards production, both with 13% of the total production.

2.2 Water footprint and virtual water

2.2.1 Water footprint

The concept of water footprint was introduced in 2002 by A.Y. Hoekstra and emerges as an indicator that assesses the amount of fresh water used, both directly and indirectly, by a consumer or product, being a measure in terms of volume of consumption and pollution of water (Hoekstra *et al.*, 2011).

The water footprint allows us to understand the relationship between the amount of water used in a process or product and the environmental impact resulting from the consumption of this water.

The water footprint has three components: green, blue and grey. According to the author Hoekstra *et al.* (2011), the blue water footprint of a product is an indicator of fresh, surface or underground water consumption along its production chain, and is directly related to the variables of the hydrological cycle. The consumption of blue water refers to the loss of water that is in a river basin, considered as a loss when it evaporates, returns to another basin or the sea or is incorporated into a product.

The green water footprint refers to the volume of water which precipitates and is stored in the soil or is temporarily on the surface thereof or on the vegetation and does not undergo leakage or seepage into the soil, then being part of precipitation or undergoing evaporation or being used in plants. That is, the green water footprint is the volume of rainwater consumed during a given process, being relevant for agriculture since it corresponds to the total rainfall water that undergoes evapotranspiration plus the water incorporated in harvested agricultural products.

The grey water footprint refers to the degree of pollution and is defined as the volume of fresh water needed to assimilate the pollutant load, from natural concentrations and environmental quality standards of water.

2.2.2 Virtual water content

Virtual water was a concept formulated to quantify the water incorporated in the products. It was introduced by John Allen in 1998 and it’s defined as water incorporated in commodities, that is, water involved in the production process of any industrial or agricultural good, also accounting for water used in manufacturing and transportation (Hoekstra and Chapagain, 2007).

3 Methodology

3.1 CROPWAT program

The methodology used in this dissertation is based on the methodology of the Water Footprint Assessment Manual (Hoekstra *et al.,* 2011).

The software used in this assessment was CROPWAT 8.0, a program developed by FAO Department of Soil and Water Resources for Windows that uses the Penman-Monteith method to calculate crop evapotranspiration. This methodology requires as inputs the maximum and minimum monthly temperatures (°C), number of hours of sun (h), wind speed (m/s) and relative humidity (%), latitude, longitude and altitude. The program uses climate and precipitation data from CLIMWAT, which is a FAO climate database. The output given by the model is solar radiation ($MJ/m^2/day$) and ET_0 reference evapotranspiration (mm/day).

The green and blue evapotranspiration during the crop growth period are estimated through the results obtained with the CROPWAT model:

- The crop water needs during the growth period under certain climatic conditions;

- The effective precipitation during the same period;

- The irrigation needs.

3.2 Study area

The information of the cultivated area (ha) and production (ton) of each crop was available by NUTS II in the Agricultural Statistics of 2017.

Figura 3 - NUTS II and the meteorological stations choosen for each region (PORDATA, 2017).

For each of the 5 NUTS II, a meteorological station was selected to extract the climatic parameters to be inserted in CROPWAT program. The selected stations are represented in Figure 4.

The temperature and precipitation data for 2017 were taken from IPMA, and for a climatological normal year calculation, the average values of the period 1971-2001, were taken from the CLIMWAT database. This climatic data was after inserted in CROPWAT program.

The study group consists in 15 agricultural crops, including wheat, corn, rice, oats, barley, beans, potatoes, tomatoes, sunflowers, apples, oranges, kiwi, almonds, olives and wine grapes.

3.3 Agricultural water use

Crops water requirements

Crop water requirements (CWR, m^3/ha), were calculated applying a factor 10 to the evapotranspiration (mm) obtained from CROPWAT for each crop:

$$\begin{cases} CWR = 10 \times ET_c & (1) \\ ET_c = k_c \times ET_0 & (2) \end{cases}$$

Where ET_c (mm) is the crop evapotranspiration, k_c (-) is the crop coeficiente that incorporates crop characteristics and and averaged effects of evaporation from the soil; ET_0 is the reference evapotranspiration.

Virtual water content

The virtual water content (VWC, m^3/ton) of a crop is divided into 3 components: green (VWC_{green}, m^3/ton), blue (VWC_{blue}, m^3/ton), and grey (VWC_{grey}, m^3/ton):

$$\mathbf{VWC = VWC_{green} + VWC_{blue} + VWC_{grey}} \quad (3)$$

The three components are determined as it follows:

$$\begin{cases} \mathbf{VWC_{green}} = \dfrac{\mathbf{CWR_{green}}}{\mathbf{Y}} & (4) \\ \mathbf{VWC_{blue}} = \dfrac{\mathbf{CWR_{blue}}}{\mathbf{Y}} & (5) \\ \mathbf{VWC_{grey}} = \dfrac{\mathbf{CWR_{grey}}}{\mathbf{Y}} & (6) \end{cases}$$

In the three previous equations, *Y* (ton/ha) is the productivity of each crop, which is found by dividing the production (ton) by the cultivated area (ha).

Water footprint

Agricultural water footprint (PH, m^3/ton) is defined as the volume of water used to produce one ton of crop, and it's also divided into three components:

$$\mathbf{WF} = \boldsymbol{WF}_{\mathbf{green}} + \boldsymbol{WF}_{\mathbf{blue}} + \boldsymbol{WF}_{\mathbf{grey}} \quad (8)$$

The three components are calculated using the following equations:

(9)

(10)

$$\begin{cases} \boldsymbol{WF}_{\mathbf{green}} = \dfrac{\boldsymbol{Eff.Rain}}{\mathbf{Y}} \\ \boldsymbol{WF}_{\mathbf{blue}} = \dfrac{\boldsymbol{Irr.Req.}}{\mathbf{Y}} \\ \boldsymbol{WF}_{\mathbf{grey}} = \dfrac{(\boldsymbol{\alpha} \times \boldsymbol{Apl} \times \boldsymbol{A})/(\boldsymbol{C}_{\boldsymbol{m}\acute{a}\boldsymbol{x}} - \boldsymbol{C}_{\boldsymbol{nat}})}{\boldsymbol{P}} \end{cases} \quad (11)$$

In equations (9) and (10), the effective rain and irrigation requirement estimated by the program in mm are converted to m^3/ha applying the factor 10.

The grey water footprint (equation 10) is calculated by multiplying the fraction of leaching pollutant (α) by nitrogen application rate (*App*, kg/ha) and the cultivated area (*A*, m^2), then dividing by the difference between the maximum acceptable concentration ($C_{máx}$, kg/m^3) and the natural concentration (C_{nat}, kg/m^3) of the pollutant, that in this study was considered 0.1 mg/l and not zero, as proposed by Hoekstra *et al*., 2011.

The productivity *(Y)* of each crop is calculated by dividing the production (ton) by the cultivated area (ha).

Water footprint of national consumption

The water footprint of national consumption (PH_{cn}, m^3/ano) has two components: domestic water footprint of national consumption ($PH_{i,cn}$, m^3/ano) and external water footprint of national consumption ($PH_{e\ cn}$, m^3/ano):

$$\mathbf{PH_{cn} = PH_{i,cn} + PH_{e,cn}} \quad \mathbf{(12)}$$

The internal water footprint of national consumption ($PH_{i,\ cn}$, m^3/ano) is defined as the volume of national water resources to produce goods and services consumed by the national population, and is calculated by the difference between the water footprint of the country (m^3/ano) which is equal to the total volume of water used by each crop (CWU_{total}), and the volume of virtual water exports (V_e, m^3/ano):

$$\mathbf{PH_{i,cn} = CWU_{total} - V_e} \quad \mathbf{(13)}$$

The external water footprint of national consumption ($PH_{e,\ cn}$, m^3/ano) is defined as the volume of water resources used in the exporting countries to produce goods and services that are consumed in the country concerned, ie equal to the volume of water virtual imported (V_i, m^3/ano):

$$PH_e = V_i \tag{14}$$

The net water import (V_i, m^3/ano) and the net water export (V_e m^3/ano) of virtual water of a given crop are calculated as follows:

$$\begin{cases} V_i = Imp \times PH_{mg} & (15) \\ V_e = Exp \times PH^* & (16) \end{cases}$$

Imp is the import, in tons, of a given crop, and PH_{mg} refers to the water footprint of the exporting country's crop, which were taken from the mean global water footprint of Mekonnem and Hoekstra (2011) report.

Exp is the export, in tons, of a given crop, and *PH** is the average water footprint of a crop exported from Portugal, calculated according to the following equation:

$$PH_c^* = \frac{P \times PH + (Imp \times PH_{mg})}{P + Imp} \tag{17}$$

P is the production agricultural production (ton) and PH is the water footprint of the crop produced in Portugal (m^3/ton);

Water footprint per inhabitant

The agricultural water footprint per inhabitant per year is obtained dividing the total water footprint (PH_{total}, m^3/ano) by the total population of the country:

$$PH_{per\ capita} = \frac{PH_{total}}{População} \tag{18}$$

4 Results

3.4 Total water footprint

Figure 5 shows that the water footprint values for each crop are identical in both years. Comparing the total water footprints of all crops, the values obtained for 2017 and a normal climatological year are 830 m^3/ton and 891 m^3/ton respectively.

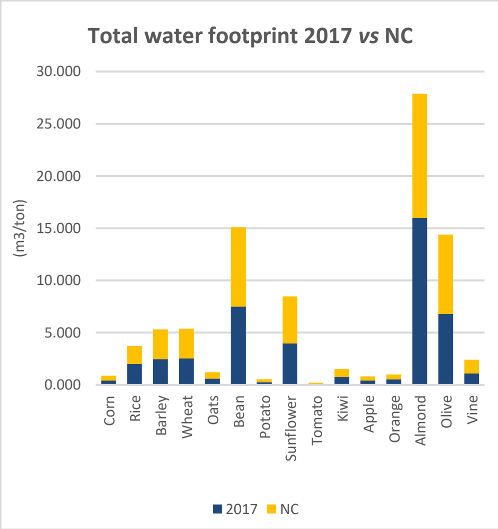


Figura 3 - Comparison of the total water footprint of each crop in percentage in the year 2017 and in a normal climatological year.

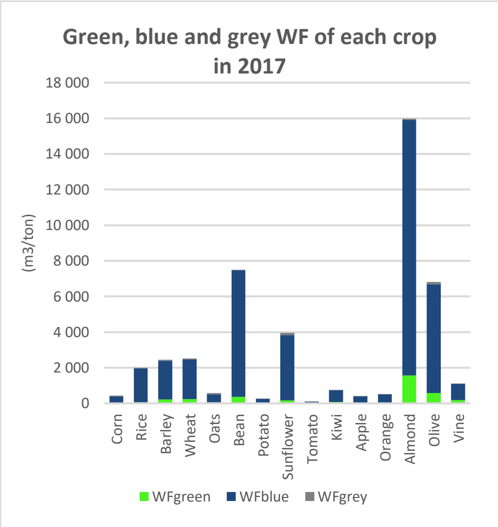
3.5 Green, blue and grey water footprint distribution of all crops

The graphs of Figure 6, which represents the value of green, blue and grey water footprints in the total water footprint, for 2017 and for a normal climatological year respectively, shows the disparity between the results obtained for green and blue water footprints between the two periods.

In 2017, the blue water footprint was superior to green water footprint in all crops without exception. Climatic conditions in that year, with extreme heat and drought, meant that, in order to meet the water requirements of the plants, the amount of irrigation water increased, since rainwater was insufficient, which led to a higher consumption of blue water in relation to green water.

In a normal climatological year, the differences between the contribution of the green and blue water footprints are not so pronounced. Nevertheless, it is evident that the blue water footprint represents a considerably weight in the total water footprint of the cultures. Exceptions for grape, almond and apple crops, where the contributions of rainwater and irrigation water are balanced.

About the grey water footprint, it is verified that this one had a bigger expression in the contribution of the total water footprint in the oats and corn crops, contributing with about 10% of the total. It should be noted that the values of the grey water footprint are the same in both time periods, as it was considered the same rate of application of fertilizer.



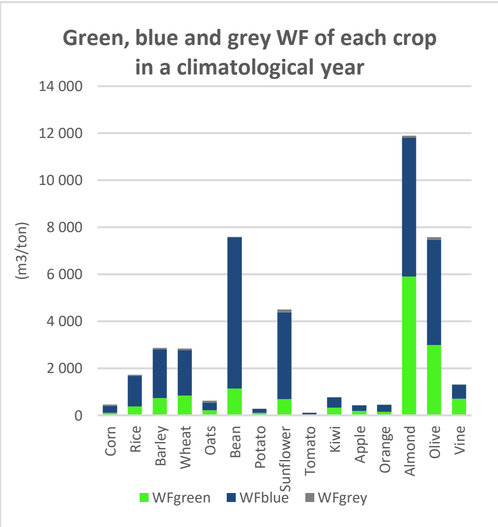


Figura 4 - Green, blue and grey water footprint by crop, for the year 2017 and a normal climatological year respectively.

3.6 Internal and External WF

Figure 7 shows the water footprint of national consumption of the selected crops in 2017. The crops responsible for a larger external water footprint were wheat, corn and sunflower, and the ones responsible for a higher internal water footprint were olive, corn and almond.
The volume of water consumed by the inhabitants of Portugal of the crops (water footprint of national consumption), was 16.4 km^3 in 2017.

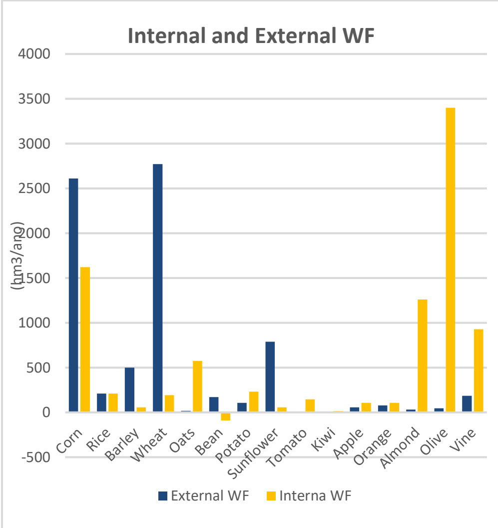


Figure 5 - Internal and external water footprint of national consumption

3.7 Water footprint per inhabitant per year

Water footprint per inhabitant per year is portrayed in Figure 8. The crop with the highest footprint in both study periods was corn, with 410 m^3/inhabitant/year in 2017 and 277 m^3/inhabitant/year in a normal climatological year.

In 2017, the crops with the highest water footprint per inhabitant, after corn, were olive and wheat, while in a normal year were wheat and sunflower. The crops with a lower water footprint per inhabitant were kiwi, beans and tomato.

The water footprint per capita in 2017 of all the studied crops obtained a total average value of 1590 m^3/hab/year and 794 m^3/hab/year in a normal climatological year, considering the same number of inhabitants (year 2016).

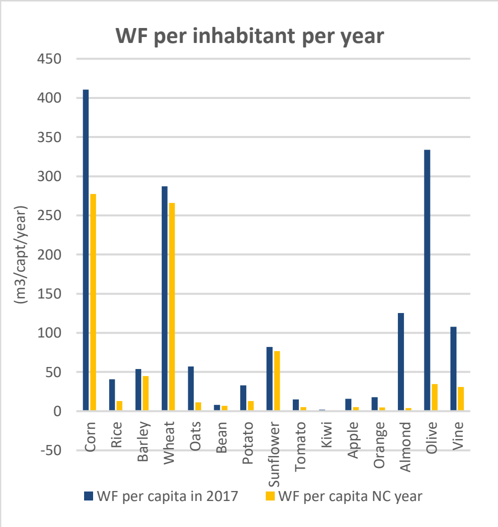


Figura 6 - Water footprint of agricultural crops, per inhabitant, in the year 2017 and in a normal year.

3.8 Virtual water content

Figure 8 represents the virtual water content of all crops considered during 2017. Through the portrayed graph it can be said that almond has the highest virtual water content when compared with the other crops (28 739 m^3/ton), followed by beans and olives.

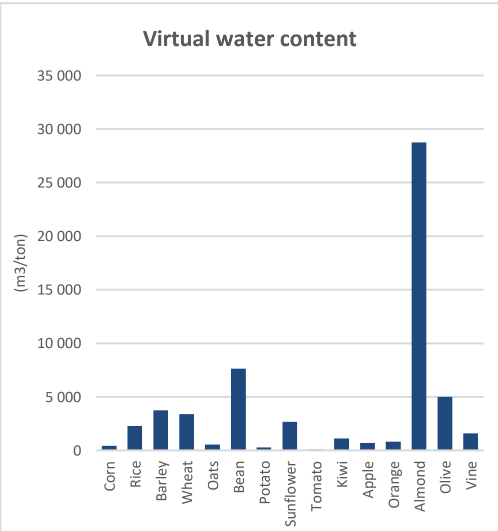


Figura 7 - Virtual water content in 2017

The total virtual water content in green water was 68 m^3/ton, 754 m^3/ ton in blue water content and 28 m^3/ton in grey water content, which together obtained the total virtual water content of 850 m^3/ton in 2017.

4 Discussion

The total water footprint of the same crop in 2017 (830 m^3/ton) and in a normal year (891 m^3/ton) are similar. For some crops, the water footprint in 2017 was higher than in a normal year due to the different climatic variables of the study periods, such as crop evapotranspiration in 2017 being higher due to higher average air temperatures and/or lower relative humidity.

In a normal climatological year, green water footprint was, in general, inferior to the blue one. However, in some cultures and in certain regions, the inverse happened. In winter months, North and Center (NUTS II) have higher precipitation values than the other regions, hence, green water footprint was superior to the blue water footprint.

The average total grey water footprint was 36 m^3/ton for both years, since the same fertilizer application rate was considered, as well as the same productivity values. It is noteworthy that only nitrogen fertilizer was considered, and that other fertilizers, pesticides and herbicides did not take part into the calculation of the grey water footprint. The cultures whose grey water footprint contributed to a greater weight in the total water footprint were beans and corn.

The water footprint by region was also calculated, with Alentejo region obtaining the highest value and Lisbon obtaining the lowest for both of the 2 years compared along this report.

Concerning the total water footprint in 2017 of the 15 crops, the one responsible for a greater consumption of water was almond, with a total water footprint of 15 976 m^3/ton, followed by bean and olive, respectively with 7500 m^3/ton and 6805 m^3/ton.

Water footprint values were compared with Mekonnem and Hoekstra (2011) study and, indeed, calculated values of most crops are similar to the global water footprint values available in the mentioned study. The exception occurs in almond, corn and oats crops, which is mainly due to the productivity values calculated, that differ from the average global values used, as well as the conditions of soil, temperature, precipitation and irrigation techniques ranging in the different regions of the world.

Irrigation requirements were also compared between a normal year and 2017. Once again, the results were as expected and, due to the values of blue water footprint being higher than green water footprint, irrigation requirements were higher in 2017 for all crops. These results were compared with the values from the DGADR (2018) concerning reference water allocation and, from the 15 crops, the mean difference is ± 17%, with the largest differences to be observed for olives, almonds and oranges.

The water footprint of national consumption, for crops consumed by the inhabitants of our country, in 2017, was 16.4 km^3, and the crops with the highest water footprint of the national consumption were corn, wheat and olive.

Regarding virtual water content, the obtained average value considering all the studied crops was 850 m^3/ton. Grey water contributed with 3%, green water with 8% and blue water contributed with 89% for the total distribution of virtual water content.

Analyzing virtual water flows, namely the import and export of virtual water in 2017, the total values of 7.6 km^3 and 1 km^3, respectively, were obtained. The crops with the largest volume of imports of virtual water were wheat, corn and sunflower, and those with the highest virtual volume of exported water were olive, rice and almond. A virtual water balance was also made for 2017, obtaining a positive value of 6.6 km^3, which means a net inflow of virtual water coming from other countries.

Water productivity calculated for each crop has a total value of 1205 tons for each cubic hectometer of water consumed. The culture with a higher water footprint was the almond and therefore, this is the crop with a lower water productivity, and so, it was the crop that presented the lowest production per volume of water consumed. On the other hand, the crop that obtained a higher value of productivity was tomato, since it was the one that presented a smaller water footprint, meaning that it was the culture where a high production by volume of water consumed was observed.

The value of the water footprint per inhabitant in 2017 was 1590 m^3/ hab /year, which is slightly lower, but within the same order of magnitude as in the study by Chapagain and Hoekstra (2004) of 1855 m^3/inhabitant/year. It is important to note that this water footprint only considers the 15 crops studied.

When comparing water footprint per capita for agriculture in the other Mediterranean countries, Portugal has the lowest water footprint, with Greece in first place, with a water footprint of 2083 m^3/inhabitant/year, Spain with 1922 m^3/inhabitant /year and Italy with 1868 m^3/ inhabitant /year.

It should be noted that all the calculations and results presented in this report do not represent all agricultural production in Portugal, since the study presents approximately 64% of the total agricultural production (ton) and 32% of the utilized agricultural area (ha), according to IEAA data (2016).

5 Conclusions

Climate change manifests itself in the Mediterranean countries through higher average temperatures and decreased precipitation, which are unfavorable for agricultural production causing a decrease in productivity and an increase in irrigation needs.

The present analysis demonstrates that the use of water in irrigation for agricultural sector is not a problem in an average climatological year, but the same doesn't happen in a dry year. High temperatures and low rainfall in 2017 increased significantly evapotranspiration rates and, consequently, water needs of crops. Thus, to meet agricultural crops water needs, blue water consumption increased through irrigation, and therefore, blue water footprint was superior to the green water consumption.

There are four main factors that determine the water footprints per capita of the countries: the average volume consumption per inhabitant, usually related to the country's income; the consumption habits of the inhabitants; climate, which affects evaporation rates; and agricultural practices. Portugal has the highest water footprint per inhabitant in Europe when it comes to the agricultural sector, and is only surpassed by the other Mediterranean countries, Greece, Spain and Italy. One of the reasons why those are the European countries with the greatest water footprints is that their location in the Mediterranean region makes them subject to a particular climate with high evapotranspiration rates, since they are more exposed to solar radiation than the other European countries. (WWF, 2018).

The water use sustainability is independent of the geographical context and the reduction of the water footprint is necessary both in regions of water scarcity and in regions of water abundance. In the first case, the ideal will be to prioritize the problem resolution at local level, reducing the pressure on water resources. In regions where fresh water is abundant, the water footprint must also be reduced, because although it does not solve problems of water scarcity at the local level, it contributes to global water sustainability**.**

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