The Water-Food Nexus in Italy: A Virtual Water Perspective

# Chapter 13
# The Water-Food Nexus in Italy: A Virtual Water Perspective

**Francesco Laio, Stefania Tamea, and Marta Tuninetti**

**Abstract** Agriculture has a long-standing tradition over the Italian territory, and its geography is significantly heterogeneous across regions, due to different hydro-climatic conditions and local practices. This chapter examines the Italian water use in the agricultural sector by considering both the local water use and the reliance on external water resources occurring through the import of primary and derived commodities. The water assessment is carried out by means of the "water footprint" concept, which aims at quantifying the amount of water required for the production of a good, and the "virtual water trade", which tracks the exchange of water resources from producing countries, where water has been physically used, to consuming countries. In the first part of this chapter, the Italian virtual water balance is analysed considering the amount of water imported, exported and locally used for production. Overall, an increase of the virtual water import and a decline in the use of local water resources are observed: Italy relies on imported water resources for more about half of its food consumption. In the second part, the role of Italy in the international trade network is assessed. Results show that Italy is primarily a net importer of virtual water from other countries (e.g. France, Germany, Brazil, Indonesia), but, at the same time, it is also a net exporter towards the UK, the Mediterranean region, the USA and other minor countries. In the third part, the spatial variability of water use across Italy is explored, looking at the subregional spatial variability to highlight the production sites generating the largest water footprint.

## 13.1 Introduction

Food production is inextricably linked and reliant upon freshwater resources. In fact, the vast majority of global freshwater use (nearly 70% of the total withdrawal and around 90% of the total consumption) is devoted to the production of agricultural commodities, largely for human consumption (FAO 2011; Hoekstra and

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Mekonnen 2012). Water is thus a major factor controlling food availability. Rainfed agriculture, sustained by precipitation-recharged soil moisture (the so-called green water), covers 80% of the cultivated land worldwide. On the remaining 20% of cultivated land, irrigated agriculture provides 42% of global food production (FAO 2011). At present, nearly 30% of green water resources and only 10% of maximum available blue water (i.e. water withdrawal from surface- and groundwater bodies) are used (Oki and Kanae 2006). The total volume of blue water consumption from the agricultural, industrial and domestic sectors is 2000 $km^3 \cdot year^{-1}$ according to Wada and Bierkens (2014), and it is unevenly distributed worldwide, with the largest consumptions occurring in India, Pakistan, China, USA and Mexico.

In order to explore the nexus between food production and water consumption, Hoekstra and colleagues (e.g. Hoekstra et al. 2012) introduced the *water footprint* as an indicator of water use related to goods and services produced or consumed by an individual (or a country), separating green water from blue water. The notion of water footprint is tightly connected to that of virtual water content, which represents the amount of water that is conceptually embedded (though not physically present) in a traded good. The concept of virtual water content has been introduced by Allan (2003), who suggested that virtual water import, i.e. the water embedded in imported goods, was a mechanism that contributed to compensate for water shortage in the Middle East countries.

In light of the fact that agriculture is the major water-consuming sector, many studies have focused on water footprint of crops. In particular, they focused on the efficiency of water use, expressed by the crop water footprint (CWF) quantified as the volume of water evapotranspired during the growing season divided by the crop yield (Mekonnen and Hoekstra 2010; Hoekstra et al. 2012). In a framework where water resources suffer from increasing pressures from population growth, economic development and climate change, the international food trade is vital for food security (Hanjra and Qureshi 2010). Through the international trade of agricultural goods, water resources that are physically used in the country of production are "virtually" transferred to the country of consumption. Virtual water trade has often been recognized for its ability to improve physical and economic access to food commodities in water-scarce regions, allowing nations to save domestic water resources through the import of water-intensive products (Chapagain et al. 2006). Thus, food trade leads to a global redistribution of freshwater resources, although it is recognized that commodities are being traded, and not water.

This chapter focuses on the Italian consumption of water for agricultural production and on the prominent role of Italy in the global virtual water trade. The existing literature on these issues is very limited and includes the papers by Tamea et al. (2013), Antonelli and Greco (2014) and Santini and Rulli (2015). The chapter is organized as follows: Sect. 13.2 describes the virtual water balance of Italy, quantifying at the country scale the total amount of water expended for food production, the amount embedded in food consumed locally, and the amount of water virtually moved through the international food trade. Section 13.3 further specifies the international dimension of the problem, analysing the role of Italy in the international virtual water trade. Section 13.4 provides information on the water footprint of agricultural goods at high spatial resolution. Finally, in Sect. 13.5, some conclusions are drawn.

## 13.2 The Virtual Water Balance of Italy

The analysis starts with considering the volumes of virtual water embedded in the production, consumption and trade of Italy, with volumes obtained by aggregating across a large number of agricultural products.

### *13.2.1 Virtual Water Volumes*

The assessment of virtual water is based on the FaoStat dataset of the Food and Agriculture Organization (FAO 2018), which provides complete information about the national production and trade of agricultural goods in the period 1961–2013. The goods here considered include crops, processed crops, livestock primary and processed, and live animals, for a total of 208 produced goods and 272 traded goods. The number of produced goods is smaller because it refers only to primary products, as summing primary and derived goods would lead to double count the water needed to produce them. Care is used in avoiding the double counting of primary crops used as feed and of animal goods, produced from animals grown with the same crops. To do so, a feed ratio, *f*, i.e. the ratio between feed and total supply, of each category of goods is derived from the Food Balance Sheet of Italy (FAO 2018). After associating such ratio to each good in the category, the production of each good is reduced multiplying by (1-*f*), thus neglecting the fraction of goods being used as feed.

Production and trade data are converted into equivalent virtual water volumes according to the virtual water content (VWC) per unit weight of the good. The virtual water content is computed starting from the public dataset WaterStat (Mekonnen and Hoekstra 2010) which provides the VWC of a large number of goods, differentiated by the country of production and averaged over the period 1996–2005. The dataset accounts for rain-fed and irrigated areas in each country and returns a weighted mean across the whole national production. A simple but robust method, the Fast-Track method (Tuninetti et al. 2017), is then applied to obtain the time-varying virtual water content from 1961 to 2013. The method assumes that the temporal variability of VWC is entirely defined by the variability of agricultural crop yield, and it has been verified in Tuninetti et al. (2017). The time-varying VWC is applied to all crop-based goods (about 75%), while the remaining goods are left with a VWC constant in time and equal to the national WaterStat data. The virtual water considered in the present analysis is green, i.e. soil water originating from precipitation, and blue, i.e. water withdrawn from surface or groundwater and provided to crops as irrigation. Unless differently specified, the sum of green and blue virtual water is considered. Where the blue virtual water is considered alone, the

VWC of each product is obtained from the total VWC multiplied by the ratio of blue to total VWC, as available in the WaterStat dataset (Mekonnen and Hoekstra 2010) and kept constant in time.

The volume of each produced and exported good is multiplied by the VWC of the good in Italy, year by year, assuming that the country mainly exports locally produced goods. The volume of each imported good is multiplied by the world average VWC of trade of such good, as the origin of imported goods could not be defined across the whole period. Indeed, the origin of imported goods can only be derived for the period 1986–2013 thanks to the availability of detailed trade matrixes from the FaoStat database (see Sect. 13.3). The world average VWC is computed year by year as a mean of all national time-varying VWC of the good weighted by the country exports. Finally, the virtual water volumes are summed across all goods to obtain the total volumes of virtual water embedded in the import, export and production of Italy.

### *13.2.2 Virtual Water Balance in Time (1961–2013)*

A simple balance is applied to compute the virtual water embedded in the consumption of agricultural goods *C*, as:

$$C = P + I - E, \tag{13.1}$$

where *I* is import, *E* is export and *P* is production; stock variations are neglected, and supply is assumed to be entirely consumed, thus encompassing in this term also seed, waste and other uses. The temporal evolution of the virtual water balance of Italy, with reference to the sum of green and blue water, is shown in Fig. 13.1 with the positive (*P*, *I*) and negative (*E*, *C*) terms of the balance represented on the positive and negative axes, respectively.

The calculations show that in 2013, the last year analysed, Italy imported 71 $km^3$ of virtual water (31 $km^3$ in 1961) and exported 24 $km^3$ (4 $km^3$ in 1961), while it used 66 $km^3$ for agricultural production (70 $km^3$ in 1961) and 113 $km^3$ for consumption (97 $km^3$ in 1961). VW import increased markedly in the first decade, and then it reduced its pace with some oscillations and started a more regular increase after the mid-1980s, concluding with a decade of limited increase. The overall trend of Italian import is positive and in good agreement with the increase of global virtual water trade, and it appears to have only temporarily suffered from the global crisis in 2008. VW export has constantly increased across the whole time period, at a regular pace of 0.4 $km^3$/year and very large percentage increases, as also highlighted in previous studies about Italy (Tamea et al. 2013; Antonelli and Greco 2014).

The VW embedded in agricultural production of Italy had non-monotonic variations in the considered period, with a total increment of about 10 $km^3$ in the first two decades and a comparable decline started around the year 2000. Such decline follows the decrease of agricultural area in Italy, which dropped from 20.7 million hectares in 1961 down to 13.6 in 2013, with a harsh decline of arable land in particular, which lost almost 50% of its surface (FAO 2018). The marked increase of

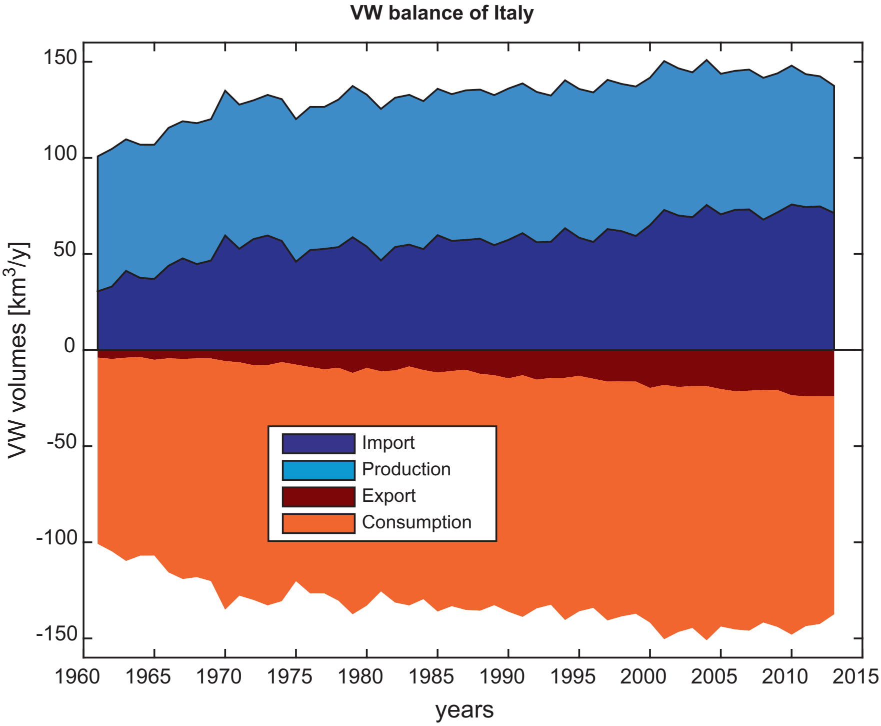


**Fig. 13.1** The (green plus blue) virtual water balance of Italy with time-varying CWF

virtual water imports and the decline in the use of local water resources lead to a situation (in 2013) in which VW import overtook the VW of local production. This implies that Italy relies on imported (virtual) water for more than half of its water balance pertaining agricultural products, placing the country in a position of strong dependency on international trade and on external water resources. The VW dependency may reflect into a vulnerability of the country if a crisis would occur worldwide or in trade partner countries, as they could reduce the food (and embedded water) exported to Italy, reducing the country supply.

The virtual water embedded in the national consumption, as obtained from Eq. (13.1) and shown in Fig. 13.1, increased markedly in the first 15 years of analysis, nourished by the increase in both local production and import. A long phase of stagnation follows, with some fluctuations dictated by the variability of imports, likely compensated by the dynamics of national food stocks that are here embedded in consumption. It is worth relating the virtual water embedded in national consumption to the country population (data taken from the same data source: FAO 2018) and look at the per-capita virtual water balance.

Figure 13.2 shows that trends in all VW balance terms are confirmed, indicating their predominance over the population trend in Italy and highlighting that all increases occurred at a more-than-proportional rate with population. Per capita VW consumption has been relatively constant in time in the last decades, with an average

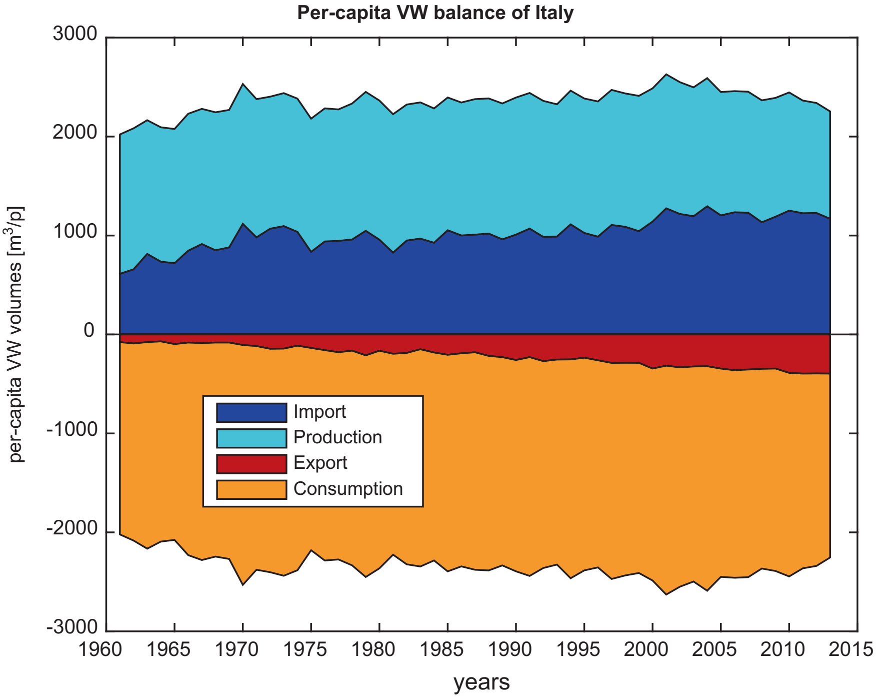


**Fig. 13.2** The per-capita (green plus blue) virtual water balance of Italy

equal to 2100 $m^3$/p/year (about 5800 litres/p/day), compared with a VW embedded in agricultural production of about 1300 $m^3$/p/year (about 3600 litres/p/day). The difference between the two terms is provided by trade, in particular by the difference between per-capita VW import and VW export, whose averages equal about 1000 $m^3$/p/year and 200 $m^3$/p/year, respectively.

### *13.2.3 The Blue Virtual Water Balance*

Previous results refer to the sum of green and blue virtual water. Here only blue virtual water is considered, including the water volumes provided as irrigation to satisfy the evaporative demand of crops plus the indirect use of blue water embedded in animal products plus the volumes for processing the agricultural goods. Volumes are obtained as mentioned above (Sect. 13.2.1), i.e. by multiplying the production and trade quantities of each good by the time-varying total (green plus blue) VWC and by the ratio of blue to total VWC, as given in the WaterStat dataset (Mekonnen and Hoekstra 2010). The blue VW of national consumption is obtained as in Eq. (13.1), and the four terms (positive *P*, *I* and negative *E*, *C*) are shown in Fig. 13.3.

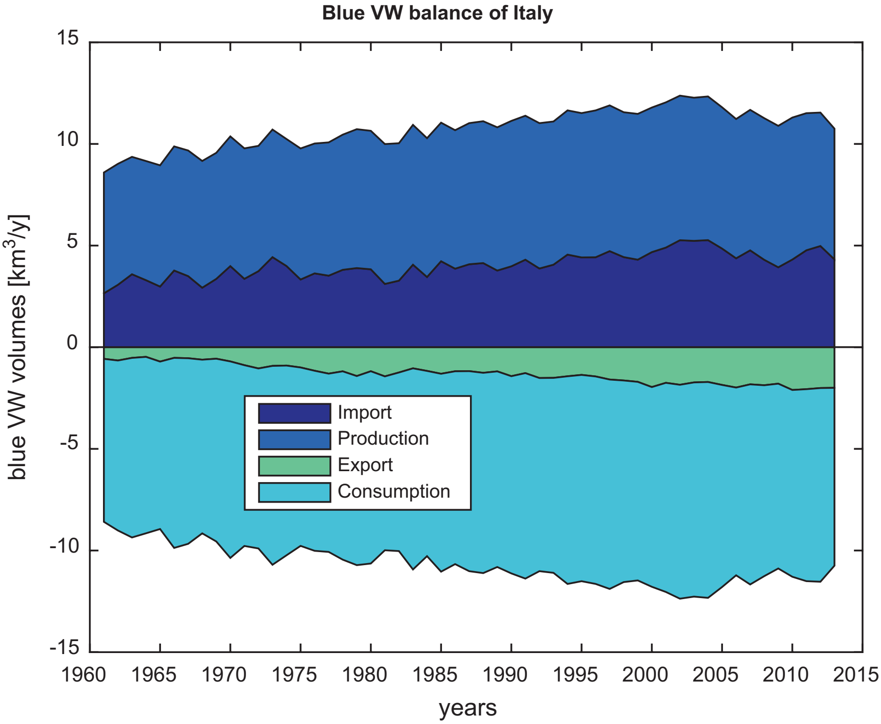


**Fig. 13.3** The blue virtual water balance of Italy

In Italy in 2013, the blue VW embedded in trade was 4.3 $km^3$ and 2.0 $km^3$ for import and export, respectively, while the agricultural production and the national consumption required 6.4 $km^3$ and 8.7 $km^3$ of blue water. All terms have been increasing in time, at least until year 2000. The blue VW import increased markedly, with larger fluctuations in the first decade; the absence of a rate change after the 1970s (as seen for the total VW import) indicates that in such period Italy increased the share of blue water in its imports. The blue VW import shows oscillations around a constant value after year 2000, in line with the import of total VW. The blue VW export increased steadily throughout the whole period. The blue VW embedded in agricultural production has grown until the early 1990s and then stagnated and started decreasing in the last decade.

In order to correctly interpret the above data about the blue VW of national production and compare them with the results in Sect. 13.4, it must be noticed that the present analysis includes a large number of agricultural goods and animal products. In large part, the computed blue VWC refers to the optimal volume needed to satisfy an evaporative demand, and therefore it results in significantly lower than the agricultural water withdrawals reported in national and international reports. Withdrawals can be converted into effective irrigation by irrigation efficiencies. Accordingly, the values in Fig. 13.3 are compatible, for example, with the Sixth

Italian Census of Agriculture (ISTAT 2010) which indicates a volume of agricultural water withdrawals of 11.1 km$^3$ (in 2010) or with the AquaStat database of FAO (FAO 2018), which indicates a volume of agricultural water withdrawals of Italy of 12.9 km$^3$ (in 2007). Other values from the AquaStat database, such as 25.6 km$^3$ in 1970, are probably justified by the much lower irrigation efficiency at that time, in particular in relation to rice cultivations.

## 13.3 Italy Within the Virtual Water Trade Network

### *13.3.1 Materials and Method*

This section analyses the role of Italy in the international trade of agricultural commodities, including both crops and animal products, for 272 traded goods, under the perspective of virtual water. The virtual water trade (VWT) network for year 2013 (the most recent and reliable year) is reconstructed by means of the trade data provided by the FAO database and using the virtual water content detailed in Sect. 13.2.1.

Detailed trade data are available for each commodity, as metric tons exchanged per year, since 1986 (only cumulative export and import are reported in the Food Balance Sheets starting from 1961) as declared by the trading countries. Starting from these data, for each product a bilateral trade matrix, **F**, is constructed whose elements $F_{i,j}$ represent the trade flow from country $i$ to country $j$. When divergent declarations exist from the exporter and importer countries, the flow is chosen from the country with higher reliability.

The trade matrix **F** is then converted into a VWT matrix (**VW**) by using the virtual water content of the commodity in the exporting country, assuming that countries export locally produced goods. When a country does export a given commodity, but it is not a producer itself of that commodity, this country is assigned the VWC of the closest producing country, with the assumption of similarities in the water use efficiency. Hence, the virtual water flow ($VW_{i,j}$) from country $i$ to country $j$ reads

$$VW_{i,j} = F_{i,j} \cdot VWC_i \tag{13.2}$$

and it is expressed in cubic metres of water per year. Each country has a typical *VWC* for each crop and each year, as specified in Sect. 13.2. For each link (e.g. the import from Brazil to Italy), the virtual water volume is finally summed up over all traded food items, thus building up the network of all countries trading virtual water with Italy.

It is worth noting that using a detailed trade matrix to compute the virtual water flows allows one to obtain a more accurate estimates of the flows. In fact, in this case also the import flows are associated with the VWC of the origin country, rather than assigning them a world-average value as done in Sect. 13.2.2.

### 13.3.2 Results

Italy is one major global importer of virtual water, but it also has a relevant role in food (and thus, virtual water) export. As previously shown, Italy is a net virtual water importer, thus intensively relying on external water resources. In 2013, the VW volume imported (55 $km^3$) exceeds of more than two times the VW volume exported (24 $km^3$). The fact that the imported VW volume shown here is smaller than the value (71 $km^3$) obtained in Sect. 13.2.2, using globally averaged VWC, suggests that Italy tends to import from countries that exhibit lower VWC (i.e. higher water use efficiency) than the global average. Over 60% of the Italian export is directed towards ten major countries, most of which localized in Europe (the USA is the only exception); nearly 60% of the Italian import comes from just ten major countries, four of which are outside the European territory (Fig. 13.4). Germany and France are the most important European partners: they import 6 $km^3$ of virtual water from Italy (30% of the total Italian export) and export 11 km3 of virtual water towards the Italian territory (20% of the total Italian import). Rice, macaroni and cheese of cow milk are the most important products in terms of virtual water behind the Italy-France flow; rice, chocolate and cheese of cow milk are the most important products behind the Italy-Germany flow. Italy imports a consistent volume of virtual water from Germany (5.6 $km^3$) mostly because of the import of pork meat, coffee and chocolate. Italy also relies on a similar amount of water coming from Indonesia

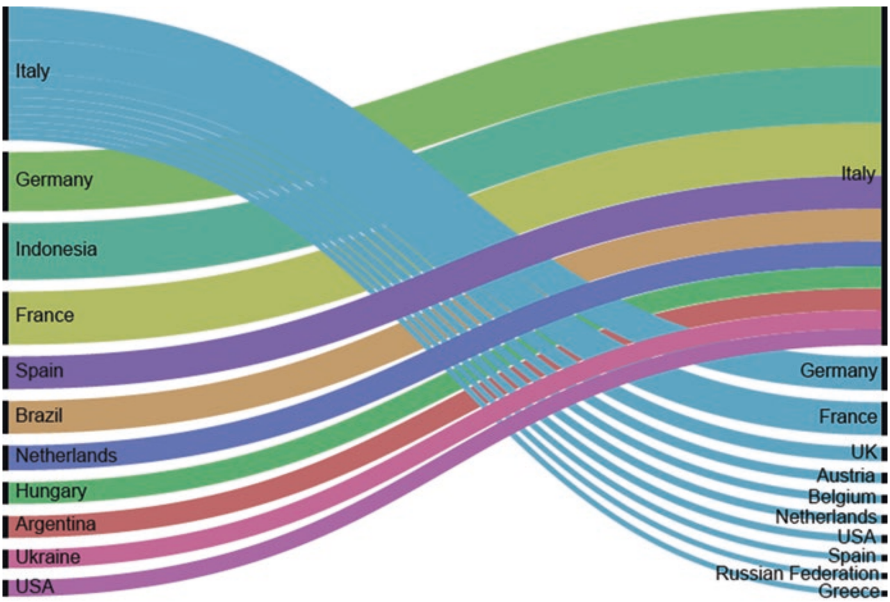


**Fig. 13.4** Top-ten virtual water flows departing from and reaching Italy in 2013

through the import of palm oil and coffee. It imports other foreign water resources from Brazil (3.1 $km^3$), Argentina (2.1 $km^3$) and the USA (1.6 $km^3$).

## 13.4 High-Resolution Crop Water Footprint

All of the analyses performed in the previous sections pertained with aggregated data over the country. This section considers higher-resolution data to investigate the spatial variability of the water footprint of agricultural production within the Italian territory. Since the analysis focuses only on crops, the term "crop water footprint" is used here in place of the virtual water content per unit weight of crop.

### *13.4.1 Crops Under Consideration*

Twenty different crop-based commodities are considered, which are largely cultivated across the Italian territory. The gross production of these products is 58 million tons in 2010 according to the statistics for ISTAT (2018), and it corresponds to more than 90% of the total Italian agricultural production. Moreover, these crops are central in the human diet covering 83% of the total food energy intake required by the typical Italian diet (FAO 2018, Food Balance Sheet) and also because some of these products are important components of the feed for livestock (e.g. maize).

### *13.4.2 Materials and Methods*

The Italian water footprint of crop production is obtained with a detailed assessment that considers the following products: wheat, rye, barley, oats, rice, grain maize, sorghum, other cereals, tuberous plants, dried pulses, roots and bulbs, stalks, salads, fruits, oleifera seeds, sugar beet, fresh fruit, citrus fruit, grapes, olives. For each crop, the analysis evaluates (i) the crop water footprint (*CWF*) as a function of the crop actual yield and its evapotranspiration demand and (ii) the total water footprint (*WF*) generated by the crop production, which equals the product between the *CWF* and the production of a given year. Each assessment is accomplished both for green and for blue water resources, in order to explore the different dependencies of crop species on irrigation water.

The *CWF* value is evaluated for each crop at a spatial resolution of 5 by 5 arc minutes, corresponding to areas of about 7 by 7 km at the Italian latitude, although the input data present different spatial resolutions, which have required some preliminary elaborations. *CWF* estimates are referred to year 2010, which allows us to present the most updated assessment of the Italian WF given that studies are generally centred on the period 1996–2005 due to data availability at the global scale (e.g. Mekonnen and Hoekstra 2010; Tuninetti et al. 2015). *CWF* is defined in each pixel as the ratio between the water evapotranspired by the crop during the growing season, $ET_a$ (mm), and the crop actual yield, $Y_a$ (ton/ha), as

$$CWF = \frac{10 \cdot ET_a}{Y_a} \tag{13.3}$$

where the factor 10 converts the evapotranspired water height expressed in mm into a water volume per land surface expressed in m$^3$/ha.

The total water evapotranspired by the crop in a single growing season, $ET_a$, is obtained by summing up over the length of the growing period the daily actual evapotranspiration, $ET_{a,j}$ ($j$ is the day). The length of the growing period is delimited by the planting and harvesting dates taken from the dataset MIRCA2000 provided by Portmann et al. (2010). This dataset distinguishes between rain-fed and irrigated production and provides the month in which the growing period starts and ends at 5 by 5 arc minute resolution, considering multi-cropping practices, for year 2000. The planting and harvesting dates are set in the middle of the month due to lack of more precise information. Despite some adjustments in the planting and harvesting dates of each crop may have occurred between 2000 and 2010, the growing seasons have been considered to remain the same of year 2000. Given that some products are missing in the MIRCA2000 dataset, associations are made arbitrarily between the missing products and the most similar classes available in the dataset (namely, maize for grain maize, other cereals; others annual for oats, roots and bulbs, stalks leaves and inflorescences, salad, fruits; potatoes for tuberous plants; soybeans for oleifera seeds; others perennial for fresh fruit, total olives).

Daily $ET_{a,j}$ is calculated following the approach proposed by Allen et al. (1998), namely,

$$ET_{a,j} = k_{c,j} ET_{0,j} k_{s,j} \tag{13.4}$$

where $k_{c,j}$ is the daily crop coefficient, $ET_{0,j}$ is the daily reference evapotranspiration from a hypothetical well-watered grass surface with fixed crop height, albedo and canopy resistance and $k_{s,j}$ is the daily water stress coefficient depending on the available soil water content, with a value between 0 (maximum water stress) and 1 (no water stress).

The crop coefficient depends on crop characteristics and, to a limited extent, on climate. It is influenced by crop height, albedo, canopy resistance and evaporation from bare soil. During the growing period, $k_{c,j}$ varies with a characteristic shape divided into four growing stages (I, initial phase; II, development stage; III, mid-season; IV, late season). The crop coefficients and the proportional length of each growing stage have been derived from Chapagain et al. (2006) and are specific for 10 different climatic regions.

Monthly $ET_0$ data at 10 by 10 arc minute resolution are given by New et al. (2002) as a long-term average over 1961–1990. These data are converted to 5 by 5 arc minute data by subdividing each grid cell into four square elements and assigning them the correspondent 10 by 10 values. Daily $ET_{0,j}$ values are determined through a linear interpolation of the monthly $ET_0$ data and attributing the monthly value to the middle of the month.

The water stress coefficient typical of the cell varies along the growing period depending on the total available water content (*TAWC*) and the readily available water content in the root zone (*RAWC*). Specifically, *RAWC* is the portion of *TAWC* that the crop can actually use. These variables vary along the growing season depending on the rooting depth, which is different from crop to crop and is generally deeper under rain-fed conditions. The values of rooting depths and the fraction of *TAWC* that can be actually used by the plants have been derived from Allen et al. (1998). Coefficients $k_{s,j}$ are computed under rain-fed and irrigated conditions. In each cell, the presence of rain-fed and/or irrigated conditions is established based on the MIRCA2000 dataset, which gives the crop-specific area cultivated in year 2000 and the proportion of the total area that is cultivated under rain-fed or irrigated conditions. Hence, the provincial cropland available from the ISTAT dataset are firstly disaggregated at the $5' \times 5'$ cells according to the MIRCA2000 spatial distribution. Then, the total areas are split into rain-fed and irrigated areas using the mentioned proportions.

For irrigated production, the crop is assumed to transpire at full rate, i.e. irrigation is provided to compensate for the difference between potential (crop) and actual evapotranspiration. Hence, $k_{s,j}$ is equal to 1 throughout the growth period. For rain-fed production, $k_{s,j}$ depends on the daily soil water balance, and whenever water from precipitation is not sufficient for an optimal evapotranspiration, the crop goes stressed, and $k_{s,j}$ becomes lower than 1. The water balance is based on the 30 arc second maps of the available water content given by the Harmonized World Soil Database and the 10 arc minute maps of monthly precipitation given by New et al. (2002).

Since the daily $k_{s,j}$ is different in the two production types, as well as the $ET_{0,j}$ (i.e. the growing period can have different planting dates in rain-fed and irrigated conditions), the $ET_{a,j}$ (green and blue) is different in the two production types. In the case of rain-fed crops, the green component is equal to the total volume of evapotranspiration. In the case of irrigated crops, the blue component is equal to the volume of irrigation water provided to the crop, and the green component is the difference between the total evapotranspiration and the blue component. The overall evapotranspiration of green and blue water from the cell is obtained by the weighted mean of the green and blue evapotranspiration in rain-fed and irrigated conditions. Further details on the computation of the water stress coefficient can be found in Tuninetti et al. (2015).

Crop yields data for year 2010 have been calculated using the ISTAT data about production and cultivated area available at the province level for each study commodity: i.e. yield is the ratio between production and harvested area, and it is expressed as ton per hectare. In this study, yield is assumed as constant across each province due to the lack of more detailed data, thus assigning to each pixel the yield value of the relative province. Gridded production, which is required to evaluate the total WF, is obtained as the product between the gridded yield and the distributed area.

### 13.4.3 Results

Figure 13.5 shows the Italian water footprint associated with the production of 20 study products for year 2010. The overall Italian WF was 31 $km^3$ (green plus blue water), of which 11% (3.5 $km^3$) came from surface- and groundwater bodies to fill the irrigation demand along the growing season. The WF shown here is smaller than that shown in Fig. 13.1 is due to the different sets of products considered in the present analysis, which leaves out all animal-based and other minor plant-based products.

The Italian water footprint varies considerably across the territory due to different climatic conditions, soil properties and cultivated crops. The total WF (Fig. 13.5a) varies between 0.5 $hm^3$ and 40 $hm^3$ in a single cell. The cells with the largest WF values are found in Puglia where some gridded values exceed 50 $hm^3$. These large values, and the spatial heterogeneity in general, are determined not only by the annual potential evapotranspiration (which of course increases with decreasing latitude), but also by the extension of the cultivated area within the cell, and by the duration of the growing season for the cultivated crops, with permanent crops

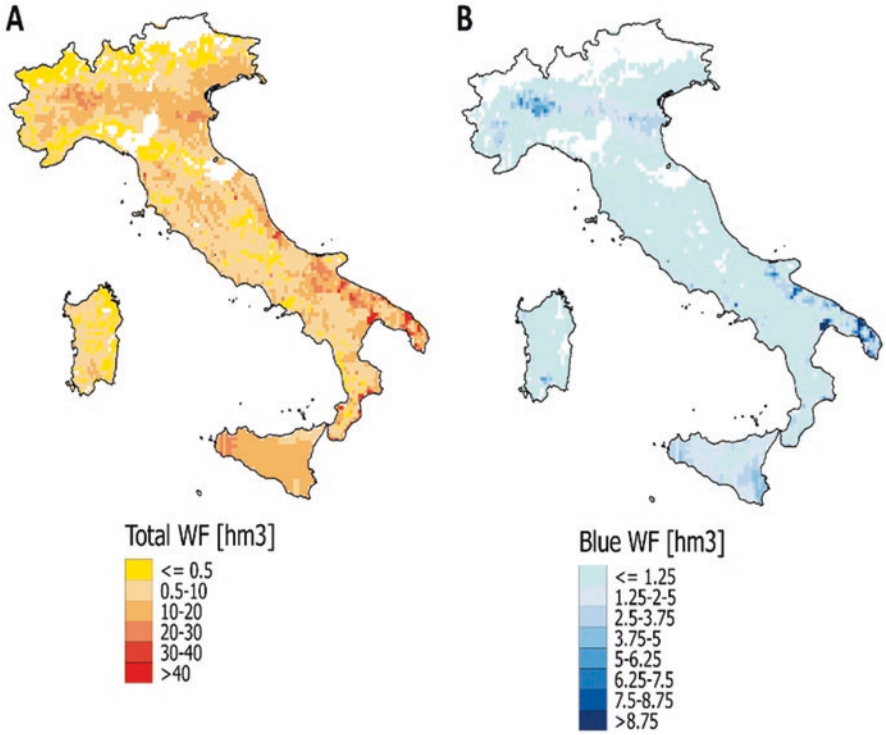


**Fig. 13.5** The Italian water footprint at 5′×5′ resolution referred to year 2010: blue plus green water footprint (**a**), blue water footprint (**b**)

**Table 13.1** Gross irrigation volumes (or withdrawals) associated with the Italian production of 20 study crops. Average efficiencies are taken from Howell (2003); system prevalence is given by the ISTAT (2010, Table 2.39)

| | Surface irrigation | Submerged irrigation | Irrigation sprinkler | Drip irrigation | Others | Total |
|---|---|---|---|---|---|---|
| Average efficiency [%] | 40 | 14 | 75 | 90 | 53.5 | |
| System prevalence [%] | 27.2 | 34.8 | 26.8 | 9.6 | 1.5 | |
| Irrigation volume [$km^3$] (this study) | 2.6 | 8.4 | 1.2 | 0.4 | 0.1 | **12.7** |

leading to larger footprints than temporary crops. The blue WF (Fig. 13.5b) also shows a significant variability with the largest WFs in Piemonte and Puglia, either in sites where rice is cultivated or in places where reliance on irrigation is stronger due to scarce precipitation and intensive agriculture.

It is quite interesting to notice that some areas, for example a large part of the Tuscany and Lazio regions, are characterized by a strong spatial heterogeneity in the water use, with high and low consumptions in nearby cells (Fig. 13.5a). This testifies of a landscape where agricultural activities were, in year 2010, interspersed with other economic activities, contrasting with other areas (e.g. Plain of Po river, Apulia) devoted to intensive agriculture practices.

The blue WF of crop production refers to the net irrigation water requirement; thus it refers to the amount of water that is actually evapotranspired by the crops. The net irrigation requirement rarely coincides with the total volume of water that needs to be withdrawn from surface- or groundwater bodies, namely, the gross irrigation requirement. This amount is generally larger due to the inefficiencies that characterize the water transportation and irrigation systems. In Table 13.1 the gross irrigation volumes required by the Italian agricultural production of the 20 study crops are summarized. These values have been obtained by allocating the total blue WF to the different irrigation systems according to the system prevalence given by the ISTAT database for year 2010. Accordingly, 27.2% of the Italian agriculture relies on surface irrigation, 34.8% relies on submerged irrigation (86% is used for rice production), 26.8% relies on irrigation sprinkler, and 9.6% relies on drip irrigation. The total blue WF is then divided by the characteristic efficiency of the irrigation systems, i.e. surface, submerged, sprinkler and drip irrigation, as provided by Howell (2003). The estimated gross irrigation volume is around 12.7 $km^3$ of surface water plus groundwater, which is nearly four times the consumptive blue water use (i.e. blue WF). The estimated gross irrigation volume compares well with the ISTAT estimate, which is around 11.1 $km^3$, and differs from it by only a 10%.

## 13.5 Concluding Remarks

Water used for food production represents a large share of the total amount of water consumed by human beings. In this chapter, the water footprint of over 200 agricultural goods in Italy has been quantified to measure the total water use for food production, as well as the total amount of virtual water imported to or exported from Italy. For 20 food items, the analysis has been extended to consider a higher spatial resolution (grid cells covering about 50 $km^2$). The obtained results depict a situation where most of the water footprint is in the form of green water, with the cultivation of only few food items (e.g. rice and maize) being dependent on relevant amounts of irrigation water. Also spatially, regions of Italy where the blue water footprint is high are limited to few agriculture-intensive areas. In general, the country relies markedly on foreign water resources to meet its water-for-food needs. The external water footprint of the Italian consumption is especially large both in nearby country as France and Germany and in faraway countries like Indonesia and Brazil. Globalization of water resources through the virtual water trade is thus already a reality for Italy.

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