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Water scarcity and consumer behavior: an analysis of diet-related water footprint

Enrica Nadia Frola, Alessia Cavaliere, Elisa De Marchi, Felice D'Alessandro, Alessandro Benfenati, Giacomo Aletti and Alessandro Banterle

Department of Environmental Science and Policy, University of Milan, Milan, Italy

Research Paper

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Corresponding author:
Elisa De Marchi;
Email: elisa.demarchi@unimi.it

Abstract

Within the framework of an increasing water scarcity, fostered by the climate change, in this study we investigate the environmental impact associated with current food consumption by means of the Water footprint indicator focusing on the case of Italy. For the analysis of the real food consumption and its impact, we selected the Mediterranean diet as a benchmark, since previous evidence shows that Italians are shifting their dietary habits away from the traditional Mediterranean Diet in favor of dietary patterns rich in animal-based products, especially meat. To promote more sustainable food choices, we applied a Sustainable Diet Model to analyze alternative diets that can reduce the Water footprint associated with food consumption. The results of the analysis show that by adopting slight changes in the consumption of certain categories of foods, it is possible to reduce the Water footprint of diets. The findings of this research are useful for supporting policies for the promotion of sustainable food consumption that would lead to a reduction in the exploitation of a scarce resource such as water, improving the allocation of this resource and achieving the objectives of the 2030 Agenda.

Introduction

Global freshwater resources are limited, and the efficient and sustainable management of water is a critical concern for the planet's future. Agriculture depletes considerable amounts of freshwater, accounting for 70% of its use (FAO, 2017). Over 2 billion people are already living in a situation of severe water stress; population growth, urbanization, changing diets, and the need for increased agricultural production are all contributing factors that pose additional pressure on water resources (UN, 2018). Climate change is expected to intensify both extreme events linked to water, like floods and droughts, and water scarcity issues, worsening the situation at worldwide level.

Recent data point to an increasing frequency of extreme climatic events, especially droughts, in the Mediterranean region (Ali et al., 2022). These events, may lead to a decline in crop yields (Semenov et al., 2014; Senapati et al., 2018).

Italy is not exempt from such events. For instance, in 2022, Italy experienced a severe drought due to insufficient winter precipitation, particularly in the Po River region (Toreti et al., 2022). Additionally, the Italian population ranks among the top countries globally in terms of per capita water consumption and wastage of water (The European House—Ambrosetti, 2021). Furthermore, previous studies have indicated that the gradual shift away from the Mediterranean Diet (MD) toward diets rich in animal products is already leading to increased environmental impacts, including heightened water usage (Capone et al., 2013).

In such context, addressing climate change and finding solutions to limit water consumption is crucial to ensure water security. Diets with low environmental impact can play a significant role in diminishing the stress on water resources.

The impacts of diets on the environment have been largely investigated in recent years, generally by means of the Carbon footprint (CF) indicator. For instance, a vast literature demonstrates that the production and consumption of food are significant contributors to greenhouse gas (GHG) emissions (Notarnicola et al., 2017), especially concerning animal-based products. Cutting on animal-based foods consumption and substituting them with alternative foods would reduce the GHG emissions associated with diets (van de Kamp et al., 2018). However, environmental externalities extend beyond atmospheric pollution and include significant impacts on water consumption (Ritchie and Roser, 2020). This aspect is of growing interest.

The literature supports the idea that the Water footprint (WF) of animal products is higher than the one of plant-based foods (Mekonnen and Hoekstra, 2012; Hoekstra, 2014). Reducing animal-based food consumption, in particular red meat, would lead to a reduction in resource use and contribute to an overall reduction of the environmental impact caused by dietary choices (Ridoutt, Hendrie and Noakes, 2017). Moreover, decreasing the intake of meat products could prove beneficial in lowering the risks of cardiovascular diseases and some types of cancer (González et al., 2020).

Embracing sustainable eating habits can contribute to enhancing environmental sustainability while ensuring that nutritional sufficiency is maintained (Cavaliere, De Marchi and Banterle, 2018). In 2015, FAO acknowledged the MD as a model of a sustainable diet. Indeed, it has been demonstrated to have a preventive effects against obesity, diabetes, and various other diseases (Katz and Meller, 2014), while having low environmental impacts (Vanham, Hoekstra and Bidoglio, 2013). This is due to the modest consumption of animal-based foods in favor of a higher consumption of plant-based ones, such as cereals, fruits, and vegetables. There are slight variations in the MD among the Mediterranean countries. Such differences concern the type of foods consumed, which slightly change from one country to another because of cultural and religious traditions, the types of available crops, as well as climatic factors (Noah and Truswell, 2001).

Previous evidence suggests that in Mediterranean countries, including Italy, there is a trend of moving away from the MD model (FAO, 2015) in favor of diets that are more abundant in animal-based foods. As previous literature has shown, this transition is associated with an increased environmental impact. For instance, the study conducted by Cavaliere et al. (2023) examined food consumption patterns in Italy and showed that elevated consumption of animal-based products is associated with higher environmental impacts. This shift in dietary preferences is also expected to have negative impacts on water usage, given that animal products are known for being high-water intensive (Mekonnen and Hoekstra, 2012; Hoekstra, 2014). However, the latter aspect has been scarcely investigated.

This study has two primary objectives: (i) to expand the existing research in this field by presenting new evidence concerning diet-related WF, and (ii) to propose potential alternative dietary patterns that could help mitigate the strain on water resources, always ensuring that consumers receive adequate nutrition.

Literature background

WF indicator

The concept of 'virtual water' originated in the early 1990s and was first introduced by Tony Allan (Allan, 1993, 1994). It referred to the amount of water 'virtually' embedded in a product. However, it wasn't until the early 2000s that the WF indicator was introduced. Hoekstra and Hung (2002) defined the WF as '*the cumulative virtual water content of all goods and services consumed by one individual or by the individuals of one country*.' This definition, along with the calculation methodology, underwent further refinement and expansion by Hoekstra et al. (2011) and by Hoekstra (2012).

The current WF indicator comprises three key components, as defined by Hoekstra et al. (2011):

1. **Blue Water**, this component represents the quantity of water consumed during the production of a good or service. The water consumed can either be evaporated or incorporated into a product and may or may not return to the catchment area (such as seas, lakes, rivers) from which it was initially obtained.
2. **Green Water**, encompasses the amount of water from rainfall that is either retained in the soil or temporarily remains on the surface of the soil or vegetation. Over time, a portion of this precipitation undergoes evaporation or transpiration through plants.
3. **Grey Water**, is associated with the contamination of freshwater caused by the production processes. More specifically, it symbolizes the quantity of water required to disperse pollutants that originate from the manufacturing of particular products throughout their entire supply chain, ensuring that the water quality adheres to established standards.

The concept of WF is less popular among consumers compared to the CF (Guenther, Saunders and Tait, 2012), which has become more and more widespread thanks to the implementation of carbon labels on various food products since 2006 (Liu, Wang and Su, 2016). Consequently, there are promising opportunities for scientific research to delve deeper into and explore the role of WF of diets, which is a relatively new area of investigation (Tamea, Antonelli and Vallino, 2021a; Vanham et al., 2021).

Literature background: diet-related WF

Several studies have investigated the environmental implications of dietary choices using various approaches and indicators, such as GHGs emissions, land use, energy consumption, resource depletion, and water utilization (for instance, Rosi et al., 2017; Bahn, EL Labban and Hwalla, 2019; Athare, Pradhan and Kropp, 2020; Benvenuti, De Santis and Cacchione, 2021).

In a recent study by Cavaliere et al. (2023), the environmental impact of the Italian diet was assessed in terms of both CF and Ecological footprint. Their findings revealed that shifts in dietary patterns toward diets richer in meat products led to increased diet-related environmental impacts.

To date, only a limited number of studies have explored the environmental consequences of food consumption solely from the perspective of WF, and these studies are relatively recent (Capone et al., 2013; Vanham, Hoekstra and Bidoglio, 2013; Vanham et al., 2021; Tamea, Antonelli and Vallino, 2021a). Therefore, our objective is to contribute to the existing literature in this field, aiming to address the main limitations of previous studies and expand knowledge in the field.

Capone et al. (2013) and Vanham, Hoekstra and Bidoglio (2013) both conducted investigations into the WF associated with food consumption and dietary patterns. Specifically, Capone et al. (2013) focused their analysis on evaluating the WF of the Italian dietary pattern, utilizing consumption data from the Italian Food Consumption Survey 2005–2006. They compared the WF of the Italian diet with those of North American and Scandinavian diets. Additionally, they estimated the WF of a recommended diet proposed by the Italian Institute of Food Science at La Sapienza University in 2006, which adheres to MD guidelines. Their findings indicated that the WF of the Italian diet was 69.9% higher when compared to the MD. However, they did not provide alternative diets to improve the current situation.

Vanham, Hoekstra and Bidoglio (2013) explored alternative dietary scenarios aimed at reducing the WF. In their study, they examined the WF of food consumption in the EU28 (the authors included EU27 + Croatia, who became a EU member on 1 July 2013) for the period from 1996 to 2005. They proposed three alternative diets: a healthy diet, a vegetarian diet, and a combination diet. Their findings revealed that the consumption of animal

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products, particularly red meat and milk, contributed significantly to a high WF. It is worth noting that Vanham, Hoekstra and Bidoglio (2013) based their analysis on an average diet across all EU28 countries. However, dietary preferences and habits vary significantly from one country to another, influenced by factors such as culture, traditions, climate, and more.

In a subsequent study, Vanham et al. (2021) expanded upon their earlier research by assessing the WF in Mediterranean countries, including Algeria, Egypt, France, Greece, Italy, Morocco, Spain, Tunisia, and Turkey. They compared the WF of the real diets in these countries with the MD and with the EAT-Lancet one. Their findings revealed that, in most of the countries studied, real food consumption resulted in a higher WF compared to the MD, except for Tunisia and Algeria, where the opposite trend was observed. Finally, Tamea, Antonelli and Vallino (2021a) conducted a study on WF and virtual water trade associated with agricultural production in Italy. Virtual water refers to the water necessary for the production of an item and it is also known as 'embedded water' or 'exogenous water', as defined by Hoekstra in 2003. The study points out that virtual water trade implies a dependency on goods produced in other countries, resulting in vulnerability to external crises, externalized costs, and water management issues. What distinguishes this study is the use of an innovative database called CWASI, developed by Tamea et al. (2021b). This database represents an improvement over the WaterStat database since it distinguishes between the WF of production and the WF of the supply side, with the latter encompassing the concept of virtual water trade, i.e., the water 'imported' through products. Additionally, the CWASI database is updated to the year 2016, providing more recent data compared to WaterStat, which provided average WF values only up to the year 2005.

Materials and methods

To obtain a comprehensive understanding of food consumption patterns in Italy, we examined real food consumption data spanning a 16-years period. After analyzing such trend data, we narrowed our focus to the most recent available data (year 2021) to estimate the WF associated with the real Italian diet (RID). Subsequently, we compared the WF of RID with that of the Italian Mediterranean diet (IMD). In Appendix A it is possible to see the standard portions of each food category in the IMD. Lastly, adopting the approach employed in Cavaliere et al. (2023), we developed three alternative dietary scenarios that could minimize WF and provide adequate nutrition to consumers. Detailed descriptions of each of these methodological steps are provided in the following subsections.

Trends in food consumption in Italy and analysis of WF

For the analysis of food consumption trends in Italy we used the data of the periodical household surveys provided by the Italian Institute of Statistics (ISTAT). We analyzed data of available years over a time span of 16-years, specifically: 2005; 2009; 2013; 2017; 2021. Data provided by the survey were representative of the Italian population, with a sample ranging between N = 45,000 and N = 50,000 (with the only exception of year 2013, when the sample was N = 20,275).

The ISTAT survey gathered information on food consumption by utilizing various questions about how often individuals consumed 14 primary food categories:

- bread, pasta and rice;
- potatoes;
- fruits;
- leaf vegetables;
- vegetables;
- red meat;
- white meat;
- fish;
- pulses;
- milk;
- cheese;
- cured meat;
- sweets;
- snacks.

The survey did not include data on individual consumption of beverages, olive oil, and eggs. As such, the estimated average calorie intake of RID is approximately 1600 kcal day^{-1}, which is a bit lower compared to the recommended daily calorie intake of the IMD (around 2000 kcal day^{-1}) For the sake of comparison, we kept the calorie intake constant at 1600 kcal day^{-1} in all diet scenarios.

Participants in the survey were requested to disclose their eating habits in terms of how often they consumed various foods, using a semantic scale ranging from 'more than once a day' (= 1) to 'never' (= 5). The consumption frequencies were then switched into weekly portion sizes, measured in grams that subsequently let us calculate the individual weekly diet.

After analyzing variations in food consumption of the specific food categories across the considered years, we focused on the most recent consumption data (2021) and estimated the WF of the RID. The latter was calculated by multiplying the unit water footprint (uWF, i.e., the quantity of water needed to produce a unit amount of the product) by the daily individual consumption (in grams) of that food. The same approach was adopted to calculate the WF of the IMD. The WF of the RID was then compared to the one of the IMD to evaluate differences and the factors influencing them.

The WF data—the CWASI database and the WF of fish

The first and most widely used WF database, named WaterStat, has been created by the Water Footprint Network (Mekonnen and Hoekstra, 2010a, 2010b). The WaterStat database encompasses average uWF measurements for both the green and blue water components spanning from 1996 to 2005. These measurements are available for a variety of agrifood products, originating from both crops and animals, including both primary and processed goods. The uWF, expressed in m^3 t^{-1} or, equivalently, in L kg^{-1}, quantifies the volume of water needed to produce a specific quantity of products.

Tamea et al. (2021b) improved this database within the CWASI—Coping with water scarcity in a globalized world—project (project funded by the European Research Council (ERC-2014-CoG, project 647473) and led by Prof. F. Laio from Politecnico of Turin, Italy), the one from which we retrieved the WF data for the present study. The novelty of the CWASI database is represented by a differentiation between the production and supply side of annual values of uWF of primary and processed crops.

The uWF of production (uWFp) pertains to crop products that are cultivated locally, and it refers to factors such as evapotranspiration and crop yield. These values are estimated on an annual basis, beginning from 1961 to 2016, and are available for a total of $N = 255$ countries.

The uWF of supply (uWFs) represents the domestic provision of primary and processed crops, originating from both local production and international trade. These figures are calculated as an average value between the quantities of local production and imports from the year 1986 to 2016 (see Tamea et al., 2021b for a comprehensive review).

The CWASI database kept the WaterStat values for uWF of animal-based foods, with no temporal variation.

For the purpose of our analysis, we used data of uWF of supply both for crop and animal-based products. This choice has been made since the supply data better represent human consumption, which is the focus of this research. We used data of uWFs of crops of the year 2016, the most recent available.

For the assessment of the WF of fish we used the study from Pahlow et al. (2015), like previous studies (see for instance Vanham et al., 2021), since the WF of fish is not included either in the WaterStat database or in the CWASI one. The motivation is that computing the WF of marine fish like any other agrifood products, meaning calculating it as proportion between the average worldwide ocean evaporation and the total amount of caught fish (Fereres et al., 2017), would return an unreasonably high value, besides being devoid of significance, given the fact that ocean evaporation (a component of the calculation) is a process that would occur anyway (Fereres et al., 2017). Nonetheless, it is possible to approximate the WF of aquaculture fish by assessing the amount of water used and polluted during the production of their food. This methodology mirrors the approach used for determining the WF of various other animal products.

We considered the blue and green WF values of aquaculture fish referred to the year 2008 from Pahlow et al. (2015).

The Sustainable Diet Model and alternative dietary scenarios

To examine different dietary options that can reduce the WF while maintaining nutritional adequacy, we employed a modified version of the sustainable diet model (SDM), originally developed by Cavaliere et al. (2023).

By adapting the formula, the SDM solves the following problem:

$$\arg \min_{\substack{m_i \leq x_i \leq M_i, \\ \sum_{i=1}^{14} k_i x_i = K}} \omega_w \sum_{i=1}^{14} \frac{w_i x_i}{1\left[\dfrac{\text{liter}}{\text{pers} \cdot \text{day}}\right]} + \beta \sum_{i=1}^{14} \left(\frac{x_i - p_i}{p_i}\right)^2 \quad (1)$$

In equation (1), the vector $x_i = (x_1, x_2, \ldots, x_{14})$ is the weekly consumption, measured in grams, of all 14 food categories included in the analysis. The values m_i and M_i represent the lower and upper bounds for the range of intake for each food category. The variable K is the total weekly caloric intake of the diet and it is constant. The variable k_i represents calories of each specific food category and it can vary depending on the chosen diet model being tested.

The variable w_i is the WF associated with the weekly consumption of each food category. The first term, $\sum_{i=1}^{14} w_i x_i$ equals the total WF of the diet.

The term $\beta \sum_{i=1}^{14} ((x_i\text{-}p_i)/p_i)^2$ quantifies people's resistance to modify their dietary patterns when substantial variations are involved, such as the complete removal of specific food categories from the diet. Higher values for β indicate that people have a low acceptability of new dietary patterns, while low β means a greater willingness to alter the diets.

Therefore, the solution to equation (1) seeks to find best dietary solution that minimizes both the total WF and the deviation from the RID. In this equation, the parameter β is set to different values: 0.2 for the mainly animal-based diet, 0.6 for the mainly plant-based diet, and 1 for the exclusively plant-based diet.

The mainly animal-based diet is built upon the Atlantic Diet (AD) guidelines. The AD is the traditional dietary pattern of Portugal and Galicia (Vaz Velho, Pinheiro and Rodrigues, 2016) and it is considered a variation of the IMD, offering similar health advantages, especially on preventing cardiovascular diseases (Oliveira, Lopes and Rodriguez-Artalejo, 2010; Guallar-Castillón et al., 2013). It differs from the IMD for its higher intake of fish, red meat, milk, cheese, and potatoes, as observed in the findings of García-Gómez et al. (2022). This diet is included in the study, as it is quite similar to the IMD and people may shift to such dietary model with relatively low efforts, while contributing to reduce diet-related environmental impacts. For the AD, we assume the parameter $\beta = 0.2$, meaning a low resistance in changing the eating habits.

The mainly plant-based diet is based on the EAT-Lancet diet. Introduced in 2019 by the EAT–Lancet Commission, the EAT-Lancet diet is regarded as an exemplary model of a sustainable diet. This diet, as outlined by Willett et al. (2019), is not only health-conscious but also environmentally sustainable, playing a pivotal role in reshaping the global food systems while staying within the limits of planetary boundaries (Steffen et al., 2015). The EAT-Lancet is a primarily plant-based diet, which also allows for a moderate consumption of meat and dairy products. It shares similarities with the IMD but incorporates a higher quantity of fruits and vegetables, whose consumption is low in the RID.

For the EAT-Lancet diet we assume a greater resistance to changing dietary habits toward a predominantly plant-based diet ($\beta = 0.6$). This suggests that people are assumed to be less inclined to adopt such dietary changes, reflecting the challenges associated with transitioning to a diet that places a greater emphasis on plant-based foods, such as social, religious, cultural, neophobic, and economic obstacles (Abe-Inge et al., 2024).

Moreover, we assess the WF for an exclusively plant-based diet. This choice aligns with prior research findings indicating that predominantly or entirely plant-based diets, such as vegetarian and vegan diets, exhibit minimal environmental impact, as supported by studies like those conducted by Hallström, Carlsson-Kanyama and Börjesson. (2015), Chai et al. (2019), and Cavaliere et al. (2023).

The exclusively plant-based diet avoids all animal-based foods, thus red meat, white meat, cured meat, fish, milk and cheese. We increase the minimum amount (in terms of grams per day) of pulses in order to compensate for nutritional lack of proteins deriving from the complete exclusion of animal-based products. Nevertheless, it's important to acknowledge that adopting a vegan diet may lead to nutritional inadequacies, and nutritional integration may be necessary to address the absence of nutrients like vitamin B12, essential fatty acids, and calcium (Alles et al., 2019; Schupbach et al., 2017; Jeitler et al., 2022). Our study prioritises optimizing the WF of the diets, addressing nutritional concerns is not the main focus. For the plant-based diet, we set $\beta = 1$.

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Results

Trends in food consumption in Italy and WF comparison: RID vs IMD

Data show that food consumption in Italy has remained overall constant over time (see Appendix B for the weekly intake of each food category over time). In detail, the analysis shows slight increases in the consumption of white meat (+2.37%), leaf vegetables (+4.77%), and vegetables (+6.78%). Larger increases can be noticed in the consumption of fish (+9.96%), pulses (+13.94%), and snacks (+18.73%). On the other hand, we notice decreases in the consumption of the following food categories: sweets (−2.41%); cured meat (−4.04%); potatoes (−6.62%); cheese (−8.06%); red meat (−8.44%); fruits (−10.67%); bread, pasta, and rice (−13.87%); and milk (−21.40%). Figure 1 shows the positive and negative variations of changes in food consumption in Italy over the 2005–2021 period. Despite the decreasing consumption trend of certain animal-based food categories over the past years, especially cheese, red meat, and milk, which have a greater impact in terms of water consumption (Mekonnen and Hoekstra, 2012; Hoekstra, 2014), the WF of the RID is still 95.96% higher than that of the IMD (Table 1). This is because the Italian population consumes quantities of animal products that largely exceed the amount recommended in the IMD. In 2021, red meat consumption in Italy (+381 g week $^{-1}$ compared to the MD) was the major contributor to WF (Fig. 2), associated with a uWF value equals to 18.65 L g^{-1}.

As a result, the WF of red meat category of the RID is equal to 1228.95 L person^{-1} day^{-1} (+476.61% higher than the one of the IMD). The second most impactful food in terms of WF is represented by the sweets, whose current consumption is + 215 g week^{-1} compared to the IMD recommended portion (50 g week^{-1}). The WF of sweets is equal to 686.06 L person^{-1} day^{-1} (+434.46% higher than the one of the IMD). The other most impactful food categories in the RID are: cheese, which has a WF equals to 284.63 L person^{-1} day^{-1} (+63.76% with respect to the IMD); fish, with a WF of 138.07 L person^{-1} day^{-1} (+90.92% with respect to the IMD); cured meat, which has a WF equals to 130.85 L person^{-1} day^{-1} (+460.24% with respect to the IMD); and white meat, with a WF of 116.11 L person^{-1} day^{-1} (+115.36% with respect to the IMD). On the other hand, we found an opposite situation for certain food categories which have a low uWF and whose weekly consumption in the RID is lower than that of the IMD. As a consequence, the WF of these food categories is lower than it would be in the IMD. This is the case of milk (57.09 L person^{-1} day^{-1}, −72.49% with respect to the IMD); it is the same for vegetables, with a WF of 49.82 L person^{-1} day^{-1} (−59.19% with respect to the one of the IMD); leafy vegetables, with a WF equals to 10.54 L person^{-1} day^{-1} (−56.15% with respect to the one of the IMD); fruits (WF of 102.76 L person^{-1} day^{-1}, −50.97% with respect to the WF of the recommended IMD portion); bread, pasta, and rice (143.30 L person^{-1} day^{-1}, −37.93% with respect to the IMD); and pulses (98.79 L person^{-1} day^{-1}, −3.24% with respect to the IMD).

To summarize, it can be noticed how the biggest contributor in terms of WF of the RID are animal-based foods, namely red meat, cheese, fish, cured meat, and white meat, accounting for more than 80% of the total WF of the RID (Fig. 3).

WF of alternative dieatry scenarios

As for the SDM, we use the following procedure. Firstly, we assign the maximum and minimum values (M_i and m_i) of food intake to each of the 14 categories. The M_i and m_i values are expressed in grams per day and have been identified starting from the guidelines of the IMD (CREA, 2018). We then establish the β value for each diet as explained in the Materials and Methods section.

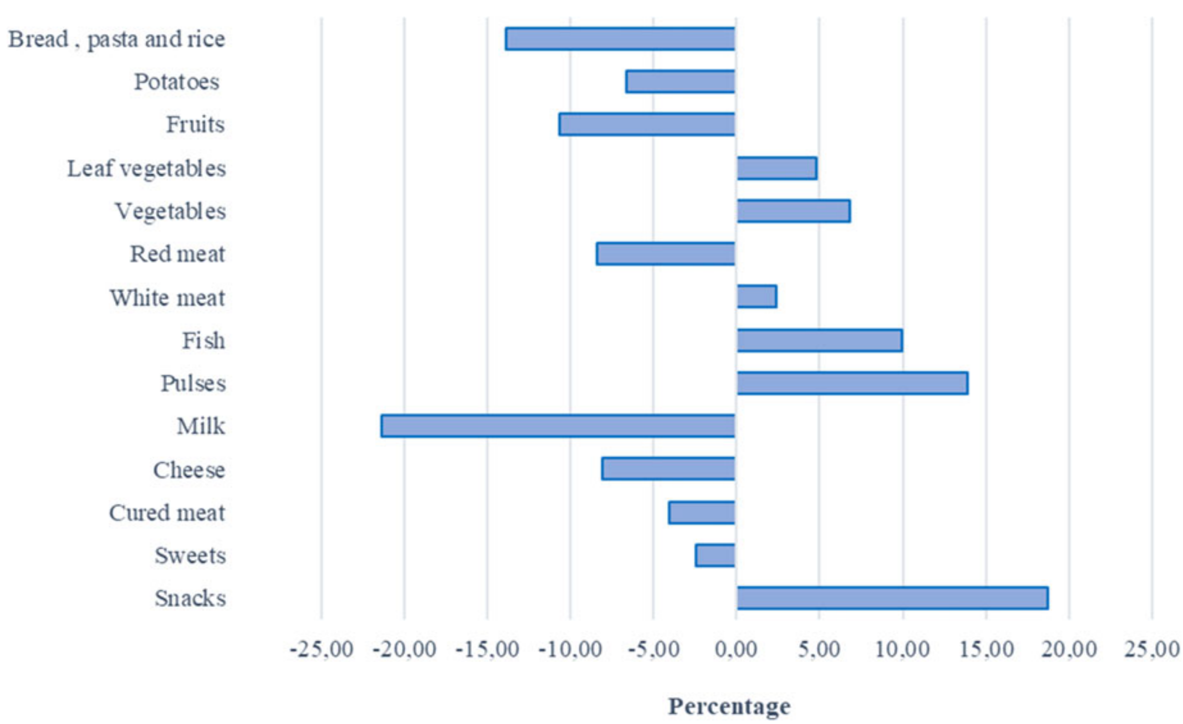

Figure 1. Changes in real food consumption in Italy from 2005 to 2021.

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Table 1. Water Footprint by food categories respectively for the Real Italian Diet and the Italian Mediterranean Diet

Food	uWF l g^{-1}	WF RID 2021 (L $person^{-1}$ day^{-1})	WF IMD (L $person^{-1}$ day^{-1})	Δ
Bread, pasta, and rice	0.98	143.30	230.87	−37.93
Potatoes	0.12	9.72	5.58	74.19
Fruits	0.49	102.76	209.60	−50.97
Leafy vegetables	0.15	10.54	24.03	−56.15
Vegetables	0.31	49.82	122.09	−59.19
Red meat	18.65	1228.95	213.13	476.61
White meat	2.36	116.11	53.91	115.36
Fish	1.81	138.07	72.32	90.92
Pulses	1.49	98.79	102.10	−3.24
Milk	0.69	57.09	207.54	−72.49
Cheese	3.38	284.63	173.81	63.76
Cured meat	6.59	130.85	23.36	460.24
Sweets	18.12	686.06	128.37	434.46
Snacks	2.11	20.05	3.36	496.42
Total		**3076.76**	**1570.07**	**95.96**

By solving the SDM as described, we obtain the WF values respectively for (i) the mainly animal-based, (ii) the mainly plant-based, and (iii) the exclusively plant-based diets (Fig. 4).

The mainly and exclusively plant-based diets have a substantially lower environmental impact in terms of WF with respect to both the RID and the IMD.

In fact, the mainly plant-based diet has a WF equals to 1131.38 L $person^{-1}$ day^{-1}, which corresponds to −63.21% with respect to the WF of the RID and −27.91% with respect to impact of the IMD. The exclusively plant-based diet improves the WF related to food consumption even more: with a WF of 729.34 L $person^{-1}$ day^{-1}, it represents the least impactful diet.

On the other hand, the mainly animal-based diet, which includes moderate amount of meat products, has a WF of 1885.92 L $person^{-1}$ day^{-1}, which represents a reduction of −38.70% with respect to the WF of the RID, but is + 21.12% higher than the one of the IMD.

Discussion

The analysis of food consumption in Italy from 2005 to 2021 reveals that the current consumption of red meat is approximately four times higher compared to the recommended intake of the IMD, which is 100 grams $week^{-1}$ per capita.

Vegetable consumption, instead, is relatively low, at around 1100 grams $week^{-1}$ per capita, compared to the recommended portion in the IMD, which is 2800 grams $week^{-1}$ per capita. Consequently, the overall WF of the RID is very high.

This aligns with previous research demonstrating that animal-based foods are the primary contributors to diet-related WF, as highlighted by studies by Hoekstra (2012) and Gerbens-Leenes, Mekonnen and Hoekstra (2013). Through the SDM, we show that a reduction in WF can be obtained with modest changes in consumption habits, which could be easily acceptable for consumers to undertake. Transitioning to a dietary pattern akin to

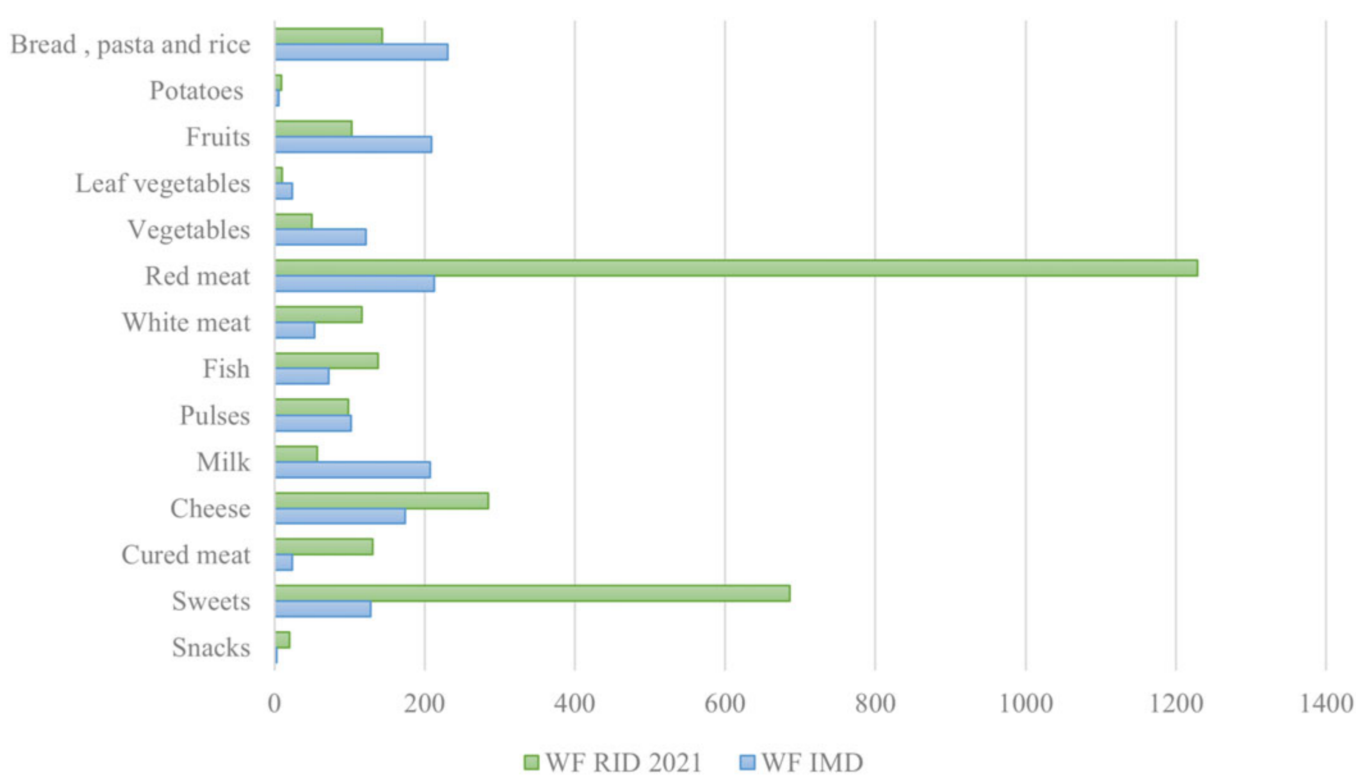

Figure 2. Graphic representation of the WF of the RID *vs* the WF of the IMD for each food category (L $person^{-1}$ day^{-1}).

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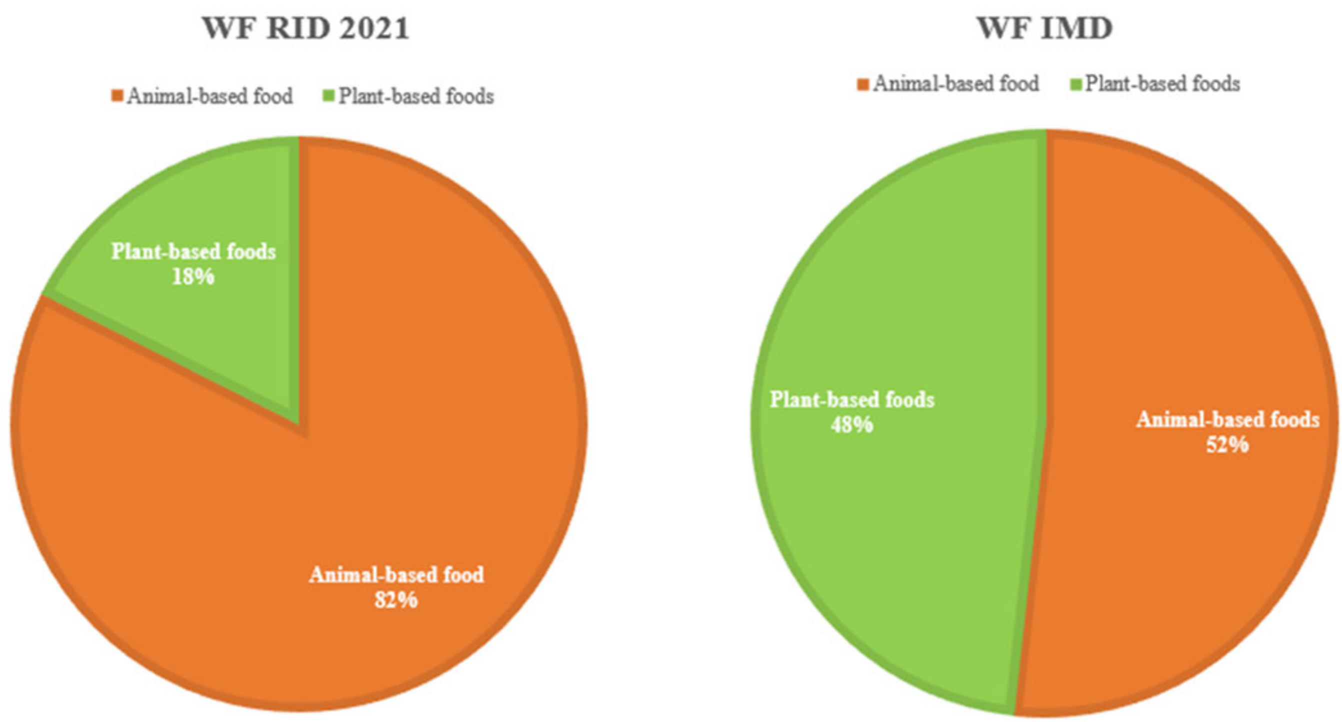

Figure 3. Pie charts of the contribution of animal-based foods and plant-based ones to the WF of the RID 2021 and of the IMD (L person^{-1} day^{-1}).

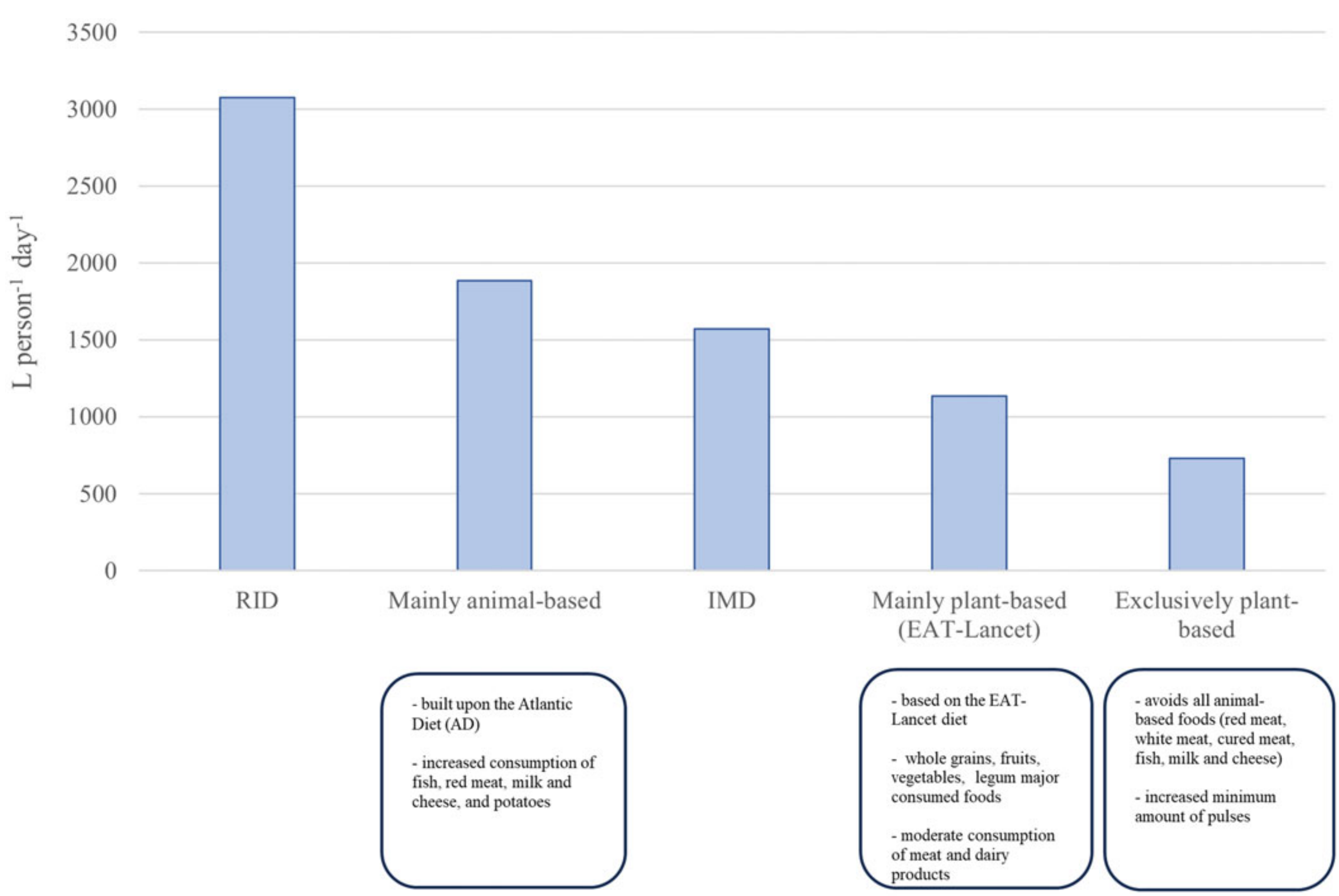

Figure 4. Bar charts of the WF of all dietary patterns.

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the AD, which involves higher consumption of animal-based foods compared to the IMD, would still represent an improvement relative to the RID. This finding is consistent with previous studies (Esteve-Llorens et al., 2019; González-García et al., 2020). More substantial reductions in WF can be attained following the IMD recommendations or other primarily plant-based dietary patterns, such as the EAT-Lancet diet, which allows only moderate meat consumption (Kassem, Rudbeck Jepsen and Salhofer, 2021). Completely avoiding all animal-based products can bring additional environmental benefits (Rosi et al., 2017; Castañé and Antón, 2017), although such drastic changes may face challenges in gaining widespread consumer acceptance.

In addition to the results presented, this paper makes a unique contribution to the field by expanding the literature concerning the environmental consequences of food consumption from the perspective of WF. Compared to previous studies (such as Capone et al., 2013; Vanham, Hoekstra and Bidoglio, 2013), our study relies on recent real consumption data in Italy and proposes alternative dietary scenarios tailored for the Italian case, taking into account the level of resistance that individuals might encounter in changing their dietary habits.

Despite these results, it is important to acknowledge that this study has some caveats. First, our analysis relies on self-reported food consumption data and the food intake calculation is based on the conversion of frequencies into standard portion sizes of each food. However, the data do not allow for controlling that respondents' real consumption correspond to such portion sizes. Food Frequency Surveys have some limitations (Wild et al., 2001). In fact, people often struggle to accurately discern both frequencies and the quantities of the foods that they consume (Shim, Oh and Kim, 2014). This may lead to potential over- or underestimation of food consumption and their related environmental impact. Second, the uWF values for each food category are derived from an average calculation of uWF values for specific food products selected from the CWASI database. As a result, the estimated WF of diets may have some slight bias, as different products within the same food category (e.g., fruits) may have different uWF values. This also occurs, for example, in the assessment of the CF of food consumption. Indeed, even within the same food category, different products can have significantly different GHG emissions, as demonstrated by Hallström, Carlsson-Kanyama and Börjesson (2015) and Tilman and Clark (2014). For these reasons, the use of an average category value may not accurately represent individual product differences.

Conclusion

The results presented in this article show that the RID does not align with the IMD recommendations. Specifically, the high animal-based food consumption (especially of meat), is responsible for high WF. Improvements in terms of WF can be achieved by partially or completely eliminating animal-based foods, as demonstrated in the cases of exclusively or mainly plant-based diets. However, shifting toward vegetarian or vegan diet might be challenging for consumers. Alternative diets, such as mainly animal-based' diets with reduced portions of these products could represent an advantage in terms of WF reduction and might be more easily adopted by the population.

These results offer novel insights for guiding policies aimed at promoting sustainable food consumption. Indeed, adopting diets with low environmental impact can help diminishing the stress on water resources, especially in a context of increasing water scarcity, exacerbated by climate change. The Mediterranean basin is likely to become severely affected by extreme climatic events in the next future. These aspects stresses the importance of tackling the WF of current food habits in Mediterranean countries, as well as the intent to find alternative diets to reduce the impact of the RID in terms of WF.

Designing policies to foster the adoption of sustainable food consumption can significantly contribute to reducing the WF of diets, aligning with the objectives of the Agenda 2030. To facilitate the shift towards more sustainable choices, increasing consumer awareness about the WF of food can be crucial. The implementation of informative campaigns and the introduction of specific labels signaling the WF of food products can guide consumers in making informed decisions when selecting among different food options.

Future research could focus on individual consumption data to obtain a more precise understanding of the environmental impact of each individual's dietary choices and identify tailored solutions to reduce their impact.

Competing interests. None.

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Appendix

Appendix A. Standard IMD portions for each food category

Food	IMD (g week^{-1})
Bread, pasta, and rice	1652.00
Potatoes	320.00
Fruits	3024.00
Leafy vegetables	1120.00
Vegetables	2800.00
Red meat	80.00
White meat	160.00
Fish	280.00
Pulses	480.00
Milk	2100.00
Cheese	360.00
Cured meat	24.80
Sweets	49.60
Snacks	11.16

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Appendix B. Trend of food consumption of each food category over the period 2005–2021

Food	2005 g week^{-1}	2009 g week^{-1}	2013 g week^{-1}	2017 g week^{-1}	2021 g week^{-1}
Bread, pasta, and rice	1190.55	1146.64	1095.76	1061.95	1025.37
Potatoes	596.88	585.97	580.93	563.37	557.40
Fruits	1659.70	1609.08	1547.45	1557.74	1482.64
Leafy vegetables	468.79	477.54	475.14	503.89	491.15
Vegetables	1070.16	1100.00	1092.21	1170.00	1142.72
Red meat	503.80	510.27	476.31	460.44	461.29
White meat	336.58	346.71	343.00	338.57	344.57
Fish	486.13	489.95	472.28	500.12	534.57
Pulses	407.64	405.03	425.19	463.43	464.47
Milk	735.00	715.14	694.97	612.66	577.68
Cheese	641.21	617.54	605.95	576.85	589.53
Cured meat	144.80	146.34	139.39	135.28	138.94
Sweets	271.64	266.64	254.48	266.14	265.09
Snacks	56.06	60.27	59.75	61.00	66.56

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