International Food Research Journal 27(6): 988 - 1000 (December 2020)

Journal homepage: *http://www.ifrj.upm.edu.my*

Review

Environmental implications of global food loss and waste with a glimpse on the Mediterranean region

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Article history

Received: 8 October 2019
Received in revised form: 5 March 2020
Accepted: 18 August 2020

Keywords

climate change, food production, land use, sustainability, water footprint

Abstract

Food loss and waste (FLW) is one of the most critical challenges humanity faces in the Anthropocene era, with major environmental impacts both at the local and global levels. FLW is related to two direct environmental impacts, (i) depletion of resources used to produce food that is wasted, and (ii) negative impacts on the environment, including climate change. Indirect impacts of FLW include ecosystem disruption, deforestation, and biodiversity loss, as well as water pollution and land degradation due to useless intensification of production through high application rates of fertilisers and pesticides. The current food production systems in the Mediterranean area face four main environmental challenges: land degradation, water scarcity, climate change, and biodiversity loss; but published research in scholarly literature is limited. The per capita ecological footprint has increased in the Mediterranean countries over the last decades while biocapacity has decreased, thus increasing the ecological debt of the region. Mediterranean countries are also large contributors of around 4.4 Gt CO_2 eq. per annum of the carbon footprint of food wastage, which contributes to greenhouse gas emissions and climate change. Considering water footprint, a conservative percentage of 30% of water wastage occurs when food is wasted by the Mediterranean people. To address the FLW challenge, Mediterranean countries must adopt and implement systematically monitored strategies for FLW prevention or reduction. In this context, (i) current knowledge and available technologies (e.g., infrastructure in storage and transport) must be exploited, (ii) development of novel technology must be supported, and (iii) market reforms must be implemented. Concurrently, awareness-raising campaigns and productive recycling of surplus food are required for reducing FLW by consumers and the food service sector.

Introduction

Natural resources, such as soil, water, and biodiversity are facing serious threats in several parts of the world, with particularly acute pressure in the Mediterranean region (Galli *et al.,* 2017). The development of unsustainable farming systems coupled with the vulnerability of Mediterranean ecosystems have led to serious problems such as soil erosion (Smetanová *et al.,* 2019), soil degradation (Karamesouti *et al.,* 2015), changes in vegetation and natural plant cover (Malatesta *et al.,* 2019), underground water over-exploitation (Gemitzi and Lakshmi, 2017) and contamination (Pace and Vella, 2019), and food security problems (Lacirignola *et al.,* 2014). Protection of the natural environment including water resources, air quality and climate, soil, and species biodiversity, along with cultural and landscape heritage as well as traditional knowledge, should receive attention (UNEP/MAP, 2005). Concerning water resources protection, methods for improving the performance of wastewater treatment with dominance of the populations of autotrophic microbial community in the activated sludge could be exploited (Sepehri and Sarrafzadeh, 2018). Several cases of environmental degradation have reached high levels in the Mediterranean region, a fact calling for continuous alertness and prompt response (UNEP, 2010; UNEP/MAP, 2016). The current food production systems and product utilisation patterns in the

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Mediterranean area face four main environmental challenges that have to be properly addressed: land degradation, water scarcity, climate change, and biodiversity loss, as current patterns of food consumption imply high ecological footprint (Lacirignola *et al.,* 2014).

Food loss and waste (FLW) describes the decrease in food for human consumption in various stages of the food supply chain, beginning from production up to final household consumption (FAO, 2011a; 2019), as depicted in Figure 1. Almost one-third of food products is lost or wasted globally, which amounts to about 1.3 billion tonnes per annum (Vilariño *et al.,* 2017). The greatest losses are associated with livestock production, while losses of harvested crops are also substantial, with 44.0% of crop dry matter (36.9% of energy and 50.1% of protein) lost prior to human consumption (Alexander *et al.,* 2017).

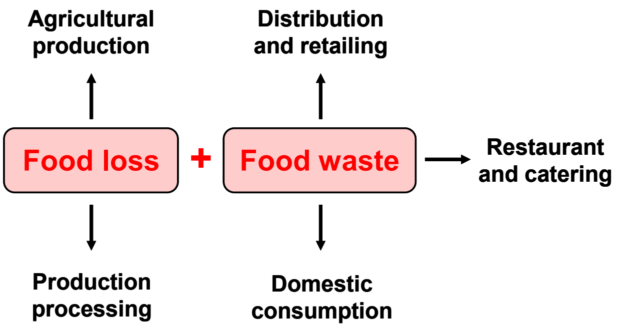

Figure 1. Food is lost or wasted throughout the supply chain.

The Mediterranean region is directly concerned with the problem of FLW (Capone *et al.,* 2016; Abiad and Meho, 2018; Berjan *et al.,* 2019). The situation is alarming particularly in the southern part of the Mediterranean region that hugely depends on food imports (FAO, 2015a; COMCEC, 2017; Berjan *et al.,* 2018). In light of the scarce resource base of the region and the low food productivity, high food losses are not only uneconomical but also ecologically detrimental, and threatening to the food security (FAO, 2015a; 2015b; 2019). An action plan on Sustainable Consumption and Production (SCP) for the Mediterranean area, which was the first plan for the promotion of SCP in the region, was approved in Athens, Greece in February 2016. Priority areas of this plan were related to agriculture and food production, and included promotion of sound practices in food production and processing, along with the use of innovation and technology achievements and limiting waste of resources. The SCP plan targets prevention at the level of source, recovery, and recycling of resources hierarchically (UNEP/MAP, 2015).

The impact of the global FLW on the environment and natural resources is massive (Hudson and Messa, 2015; Roux *et al.,* 2018; Scherhaufer *et al.,* 2018; TEEB, 2018; Usubiaga *et al.,* 2018; Wunderlich and Martinez, 2018; Willett *et al.,* 2019). However, no study has ever examined the effects of global FLW from an environmental perspective. As FLW matters for sustainability, four different components, i.e., carbon footprint, water footprint, land occupation or degradation impact, and biodiversity impact were used by FAO (2013a) to assess the environmental footprint of FLW. These components are considered in the present paper, too. In recent years, the issues of FLW and their consequences for food security and for the environment of an increasingly growing population have been considered with apprehension by governmental and non-governmental organisations. The importance of this issue as a major ethical dilemma lies in the fact that more than 925 million people all over the world continue to suffer from undernourishment (Abiad and Meho, 2018).

Studies on FLW have generated positive change, but further in-depth studies are necessary to give the FLW debate more weight and credibility (Chaboud and Daviron, 2017). Our main objective in this paper was thus to provide a qualitative and quantitative overview of the main environmental implications and impacts of FLW with a spotlight especially on the Mediterranean area.

Research methodology

A systematic literature review was conducted to identify relevant publications on the topic. Published papers on FLW were identified through searching common databases such as Web of Science, SCOPUS, and Google Scholar. Keywords for searching and selecting relevant publications were selected based on the main words pertaining to our topic to reach the most relevant articles. Therefore, the main keywords used to search and select articles were the phrases ‘food loss and waste’ and ‘Mediterranean’. An attempt was made to focus on material published in peer-reviewed journals, written in English language, without restrictions on the publication date. To increase accuracy in selection, additional search was also attempted in the databases of the major international publishing houses (Taylor and Francis, Elsevier, Springer, Wiley, and Hindawi). Due to shortage of publications in this category (i.e., papers in peer-reviewed academic journals), we extended our search to the so-called grey literature, using the same keywords. Publications without full-text were excluded from our analysis. Also, information from other sources of minor importance that were difficult to access was not included in the database. Possible omissions that might have occurred from this search were overcome by checking thoroughly the references of each selected publication to ensure that any papers that were omitted or any other data of vital importance were finally included in the database. Based on methodology and specific focus, the selected publications were grouped into different categories. From this pool, all publications have undergone further analysis if they assessed, discussed, or pointed out to FLW.

Food loss and waste in the Mediterranean region: an overview

The Mediterranean region covers a total land of 854 million ha, of which only 118 million ha are convenient for food production. Land degradation in terms of soil erosion, soil salinisation, soil compaction, loss of organic matter, coastal littoralisation (i.e., the development of economic activity in coastal areas due to urban growth, industrial activities, tourism, and irrigation) are serious in several areas of Mediterranean countries (Zdruli *et al.,* 2007; 2016). In the European Union (EU), Mediterranean countries indicates the agricultural land averages 0.30 ha per capita and 11.4 ha per agricultural worker, while in Middle East and North Africa countries, the respective values are 0.25 ha per capita and 1.9 ha per agricultural worker, indicating significantly less available land for agricultural production in these countries. Moreover, the region-wide arable land was estimated to drop from 0.48 ha per capita in 1961 to 0.21 ha per capita in 2020 (Zdruli, 2014). Recent data show that many Mediterranean countries were already below 0.21 ha per capita in 2016 (Table 1). The most critical situations were recorded in Montenegro, Palestine, Lebanon, Malta, Egypt, and Cyprus.

The ecological footprint of consumption per capita has increased in the period 1961 - 2007, while the biocapacity has decreased, and this has thus augmented the ecological deficit in Mediterranean countries (Ewing *et al.,* 2010). The cropland ecological footprint is the most important component of the ecological footprint (Ewing *et al.,* 2010; Galli *et al.,* 2017). The ecological footprint of an average resident of the Mediterranean region was approximately 3.0 global ha (gha) in 2010 (Galli and Lacirignola, 2015), a bit higher than that of the average world resident (2.7 gha). For residents of the Mediterranean region, a biocapacity of 1.2 gha per capita was reported, which is slightly below the world average of 1.7 gha per capita (Borucke *et al.,* 2013). The food sector is a crucial factor for the ecological footprint in the Mediterranean region (Galli *et al.,* 2017), reaching about 35% of the total footprint (Galli and Halle, 2014).

Table 1. Arable land (hectares per person) in Mediterranean countries.

Mediterranean country	Most recent year	Most recent value
Albania	2016	0.22
Algeria	2016	0.18
Bosnia and Herzegovina	2016	0.30
Croatia	2016	0.21
Cyprus	2016	0.07
Egypt	2016	0.03
France	2016	0.27
Greece	2016	0.20
Italy	2016	0.11
Lebanon	2016	0.02
Libya	2016	0.26
Malta	2016	0.02
Montenegro	2016	0.01
Morocco	2016	0.23
Palestine (West Bank and Gaza)	2016	0.01
Slovenia	2016	0.09
Spain	2016	0.27
Syria	2016	0.27
Tunisia	2016	0.26
Turkey	2016	0.26

Source: World Bank (2020) based on FAO's data.

The issue of water scarcity is a crucial problem in the development of the Mediterranean area and a major limiting factor of the agricultural production (Scardigno *et al.,* 2017). The availability of water has shown a steadily declining trend in the region since the late 1950s. Therefore, water resources in several parts of the Mediterranean region are limited and unevenly distributed. On average, only 3% of the global water resources is received by the Mediterranean region (UNEP/MAP-Plan Bleu, 2009), while about half of the 'water scarce' world population (i.e., less than 1,000 m^3 per capita per annum) lives in the southern Mediterranean areas (CIHEAM, 2008). Furthermore, a decrease of 20% has been predicted in surface water availability by 2070 to 2099 due to climate change (Mariotti *et al.,* 2008). Increased pressure will be put on the agricultural sector that consumes the largest volume of water in the Mediterranean region, accounting for 64% of the overall demand in the period 2005 - 2010 (Molden *et al.,* 2013). Increasing food demand will also affect volumes of irrigation water. Products like meat, milk, and wheat represent a great proportion of FLW (more than a half) in

Mediterranean countries (Lacirignola *et al.,* 2014).

The Mediterranean area is considered a region where climate change is estimated to affect the environment and related human activities. Furthermore, many countries in the region are increasingly dependent on food imports and thus exposed to food price volatility (CIHEAM, 2014). There is high intensity of resource use in most Mediterranean countries and this high intensity is further getting worse by FLW (Lacirignola *et al.,* 2014). All these evidences stress the importance of efficient use of resources in the Mediterranean area, and the key role of reducing FLW is in improving the use efficiency of natural resources, thereby preserving ecosystems (CIHEAM, 2014; Lacirignola, 2015).

Carbon footprint, energy losses, and greenhouse gas (GHG) emissions

Every product generates CO_2 throughout its life cycle, and therefore, has a carbon footprint that weighs heavily on climate change. The energy from fossil fuel is the driving force of food production systems. For example, petroleum is used in almost every aspect of food production, including seedbed preparation, mechanised planting and harvesting, land irrigation, production of fertilisers, as well as cooling and transportation of products. On the other hand, methane is emitted when food is discarded in a landfill and decomposes anaerobically (FAO, 2013a). Thus, FLW contributes to GHG emissions, occurring from the degradation of wasted food in a landfill and forms the embedded emissions related with food production, processing, transport, and retailing (Garnett, 2008; Venkat, 2011). In addition, organic waste, including FLW, is an important source of methane when material is sent to landfill. Decomposition of organic material is a major contributor to GHG emissions, which causes global warming. The United Kingdom's Waste and Resources Action Programme (WRAP) concluded that each tonne of avoidable FLW generates 4.5 tonnes of CO_2 eq. emissions (WRAP, 2011). The largest component of wasted materials sent to landfills at a global level is food, which is also the main source of landfill gas. Especially, landfill gas represents about 17% of methane emissions in the USA (FAO, 2013a).

Almost one third of the total food quantity that is annually wasted throughout the world contributes about 6 to 10% of the human-generated GHG emissions (Vermeulen *et al.,* 2012). According to Kummu *et al.* (2012), the amount of global FLW in 2009 entailed about 3,300 - 5,600 million metric tonnes of CO2 eq. emissions. The global carbon footprint of FLW in 2007 has been estimated at 3.3 giga tonnes (Gt) of CO_2 eq., not counting land use change. This value is translated to more than double of the total volume of GHG emissions pertaining to all road transportation in the USA in 2010 (1.5 Gt of CO_2 eq) (FAO, 2013a). Another figure reaches to 3.6 Gt CO_2 eq (FAO, 2011b), which does not include the 0.8 Gt CO_2 eq from managed organic soils and deforestation. Therefore, the total carbon footprint of FLW is about 4.4 Gt CO_2 eq per annum, including land use change. Between 1961 and 2011, the annual amount of FLW by mass grew by a factor of three, from 540 Mt to 1.6 Gt; as associated production-phase GHG emissions were more than tripled (from 680 Mt to 2.2 Gt CO2 eq.). A 44% increase in global average per capita FLW emissions was also identified, from 225 kg CO_2 eq. in 1961 to 323 kg CO_2 eq in 2011 (Porter *et al.,* 2016). Thus, FLW contributes to climate change (FAO *et al.,* 2018; 2019), accounting for about 8% of the annual global GHG emissions (FAO, 2015c). To put this in perspective, FLW would appear third, after USA and China, and before India and Russia, when integrated into a ranking of top emitter-countries worldwide (WRI, 2012; FAO, 2013a; 2015c) (Figure 2). The carbon footprint attributed to FLW in North Africa, and Western and Central Asia region (including southern and eastern Mediterranean countries) is predicted at 200 million tonnes per annum or 6% of the global total carbon footprint of FLW (FAO, 2013a). In Europe, 186 Mt CO_2 eq., 1.7 Mt SO_2 eq, and 0.7 Mt PO_4 eq. can be attributed to food waste, representing 15 to 16% of the total impact of the entire food supply chain (Scherhaufer *et al.,* 2018). In Greece, it was estimated that approximately 100 kg of food waste per person is generated per annum, of which approximately 30 kg per person is avoidable (Abeliotis *et al.,* 2015). Moreover, the calculations of

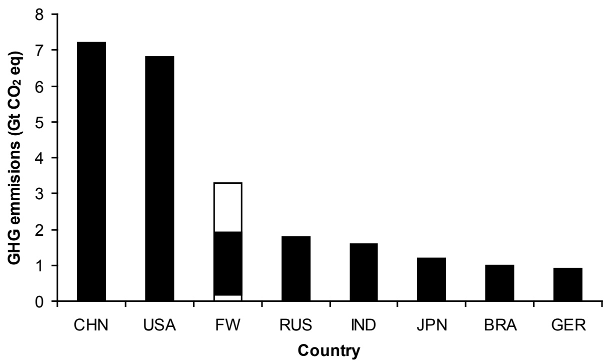

Figure 2. GHG emissions from food waste (FW) as compared with GHG emissions from selected countries. CHN: China; RUS: Russia; IND: India; JPN: Japan; BRA: Brazil; and GER: Germany (FAO, 2013a).

the same study revealed that emissions of 5672.5 Gg of CO_2 eq. are associated with food waste in Greece (Abeliotis *et al.,* 2015).

Cereals, meat, and vegetables are the major contributors to global carbon footprint of FLW. About 33% of the total carbon footprint is due to products of animal origin, but with a volume contribution of only 15% to the total FLW volume, indicating a high 'carbon intensity' (i.e., amount of GHG emissions per kg of product) (FAO, 2013a). The overall results indicate that for most of the impact categories, the foods with the highest environmental burden are meat products (beef, pork, and poultry) and dairy products (cheese, milk, and butter) (Notarnicola *et al.,* 2017). Although meat is a rather low contributor to global FLW with reference to volume (less than 5% of the total FLW), it greatly affects climate change, sharing more than one-fifth of the carbon footprint of the total FLW. This effect can be attributed to the multiple sources of emissions during meat production, i.e., the emissions from meat production, the emissions from feed provision, and the emissions from manure use. Therefore, to reduce GHG emissions related to FLW, important commodities, such as meat and cereals, should be targeted (FAO, 2015c). Emissions of biogenic GHG such as methane (CH_4) and nitrous oxide (N_2O), a common characteristic of all food products, also play a key role in carbon footprints (FAO, 2013a). CH_4 and N_2O are very powerful GHGs (IPCC, 2007).

The average carbon intensity varies depending on different products wasted in each region. Higher values of carbon intensity are recorded in North America than in Europe, probably because the share of meat in FLW is higher. However, much lower values of carbon intensity are recorded in Sub-Saharan Africa, probably because of the high share (more than 50%) of starchy roots (commodities with low carbon intensity). The carbon intensity in industrialised Asia (e.g., Japan and South Korea) is high due to the carbon footprint of wasted cereals, most notably rice. In addition, rice is an important contributor to carbon intensity in South and Southeast Asia (FAO, 2013a). The consumption phase accounts for the highest carbon footprint of FLW (37% of total). The carbon footprint of FLW at the consumption phase also includes the energy used when the food was grown, stored, processed, and distributed (FAO, 2013a). Moreover, FLW is the waste of energy (Hall *et al.,* 2009).

FLW results in almost 170 Mt of CO_2 eq. per annum in the EU27 (EC, 2010). This figure represents approximately 3% of the total emissions of EU27 in 2008, and is comparable with the total GHG emissions of Romania or Netherlands in 2008 (EC, 2014). The average total emissions of each tonne were estimated at 1.9 tonnes CO_2 eq. with the life cycle analysis. The total food waste in Mediterranean countries of the EU27 is shown in Figure 3. Food loss and waste is projected to climb to as much as 126 million tonnes (from 90 million tonnes) by 2020 due to population growth, which will increase GHG emissions to about 240 million tonnes (EC, 2010). Another study by WWF (2013) examined the environmental impact of FLW in Italy. Food waste-related GHG emissions amounted to 14.3 million tonnes of CO_2 eq. in 2012 (WWF, 2013).

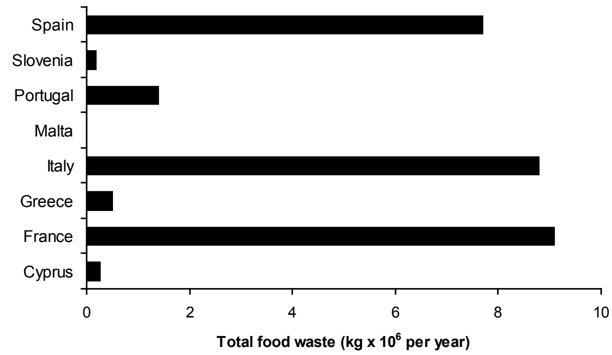

Figure 3. Total food waste (FW) from Mediterranean countries of the EU27 (EC, 2014).

The environmental impacts of food production show that minimising FLW is a high priority. Limiting the amount of food required for consumption by minimising waste could alleviate adverse effects such as land use change, biodiversity loss, and CO_2 emissions associated with agriculture (Schott *et al.,* 2013). A more efficient food chain would minimise adverse effects on required resources and GHG emissions through adoption of waste reduction measures (GO-Science, 2011). Moreover, reducing post-harvest losses could be an important climate mitigation strategy, considering that post-harvest handling reductions are feasible particularly in developing countries (FAO, 2015c).

Water footprint

The water footprint is related to water consumption. Over 90% of the world water footprint is associated with the consumption of food products (Hoekstra and Mekonnen, 2012). The water footprint refers to the suitability of fresh water in volumes of water consumed or polluted. This footprint can be divided into three main parts: green, blue, and grey (Figure 4). These parts provide a picture of water use by depicting the source of water consumed and the volume of fresh water required for the assimilation of pollutants (Hoekstra *et al.,* 2011). Blue water is the freshwater (surface and groundwater) used in agriculture. This category is stored in lakes, groundwater streams, glaciers, and snow. Green water is the soil moisture from precipitation, used by plants via transpiration. This category is a part of the evapotranspiration flux in the hydrologic cycle. Finally, grey water footprint describes the amount of water required to dilute pollutants.

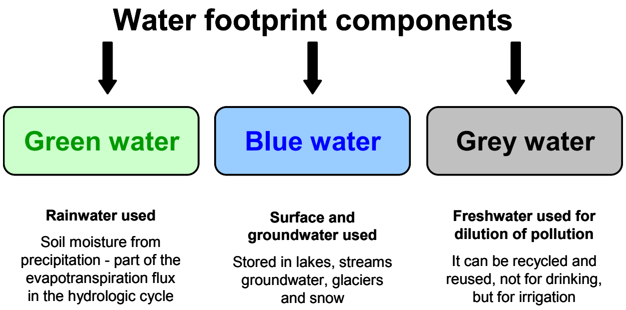

Figure 4. Water footprint components.

The agricultural sector already uses 70% of the global freshwater withdrawal, and any high production rate will likely mean more water use. This resource is estimated to be a key constraint to global food security, and when food is wasted, water is squandered (FAO, 2013a). FLW causes depletion of over a quarter of the used freshwater resources (Lundqvist *et al.,* 2008). The blue water footprint concerning agricultural production in 2007 was about 250 km^3 (FAO, 2013a), which is 3.6 times as great as the total consumption in the USA (Mekonnen and Hoekstra, 2011). Minimising FLW can reduce water needs. For example, a FLW decrease by 50% at a global level would allow recovering 1,350 km^3 of water per annum (FAO, 2012).

Cereals and fruits contribute significantly to the blue water footprint of FLW with 52 and 18% of total FLW, respectively, but with contributions to total FLW of 26 and 16%, respectively. However, starchy roots contribute only 2% to the water footprint, representing 19% of the total FLW (FAO, 2013a). Generally, animal products show a greater water footprint per tonne of product than crops. The greatest contribution of animal products to the observed water footprint comes from the animal feed, whereas the drinking water of animals only accounts for a rather small share. Moreover, three parameters affect the water footprint of animals: feed origin, feed composition, and animal feed conversion efficiency (FAO, 2013a).

Comparing regional FLW and water scarcity gives a view of the ineffective pressure of FLW on the water resource. In this context, the industrialised Asia and the southern and south-eastern Asian regions significantly contribute to water scarcity through FLW. However, a direct link between water scarcity and FLW volumes is not so obvious. For example, most of North Africa and West and Central Asia have arid or semi-arid climates, so these regions are expected to have the largest share of water-scarce surfaces. However, the North African and West and Central Asian regions have a relatively minor share of FLW in relation to water scarcity in the region (FAO, 2013a).

The issue of FLW has important environmental impacts especially in southern and eastern Mediterranean countries, given the scarce natural resource base, especially water, and the high demand for agriculture production. An estimation of FAO (2013b) showed the blue water footprint of FLW to be 42 km^3 per annum in North Africa and West and Central Asia (including southern and eastern Mediterranean countries). This figure outpaces water loss of any other region with reference to water loss per capita (Kummu *et al.,* 2012). In particular, cereal production has a great contribution to the blue water footprint (FAO, 2013a).

In Mediterranean countries, about 90% of the water footprint comes from the consumption of food products. The values of water footprint range from 61.8% in Serbia to 97.7% in Tunisia (Capone *et al.,* 2014). Water amounts ranging from 294 m^3 per capita (in Palestine) to 706 m^3 per capita (in Portugal) are wasted each year by Mediterranean residents (Capone *et al.,* 2014); considering the water footprint of food products (Mekonnen and Hoekstra, 2011), a conservative percentage of FLW of 30% (FAO, 2011a), and also inferring that the same amount of water is wasted every time food is wasted (WWF, 2013).

A study conducted by WWF (2013) showed that 706 million m^3 of water was related to food waste concerning meat, crop commodities, and milk by Italian consumers in 2012. It should be noted that the contribution to water waste may largely vary among food categories, e.g., 43% of water waste in the above study was due to the waste of meat products, whereas 4% was associated with the waste of milk and dairy products. Capone *et al.* (2014) estimated that 600 L of water is wasted per capita, namely 2,400,000 m^3 per day in the whole Apulia region in south-eastern Italy (i.e., 876,000,000 m^3 per annum). This corresponds to the water volume used yearly for irrigation in the whole region.

Reducing FLW will reduce water

requirements in agriculture (Lundqvist et al., 2008), thereby alleviating the related environmental impact (Nellemann *et al.,* 2009). Therefore, initiatives contributing to reduction of FLW will affect freshwater resource availability (Ridoutt *et al.,* 2009).

Land occupation and degradation

Food loss and waste is also a waste of land resources (Wirsenius *et al.,* 2010; FAO, 2013a; TEEB, 2018). The land is a limited natural resource base with a number of competing uses (e.g., arable fields, pastures, managed woods, urban settings, buildings, and roads). A view on the loss of this resource requires land occupation assessment (Mattila *et al.,* 2012). The McKinsey Global Institute (MGI, 2011) ranked reducing FLW in the top three measures that will contribute to the improved productivity of global resources. This report pointed out that reducing FLW in developed countries by 30% would save roughly 40 million ha of cropland. Moreover, intensive farming diminishes soil fertility. Therefore, wasting about one-third of the food production at a global level signifies an intensive pressure on soil. In turn, the reduction of soil quality brings further use of synthetic inputs (e.g., fertilisers) that cause pollution. Consequently, a great part of arable lands can be lost (FAO, 2013a).

According to Kummu *et al.* (2012), the amount of cropland used to grow lost and wasted food is about the size of Mexico. FAO (2013b) evaluated the land surface (including cropland and grassland) occupied by the food that is produced, but then wasted. In 2007, the total amount of FLW globally occupied about 1.4 billion ha, namely 28% of the global agricultural land area. This figure is comparable to the land area of the largest countries, where land surface devoted to food production that is wasted is second to the total land area of the Russian Federation. This value also represents a larger land area than that covered by Canada and India together. Meat and milk, with 78% of the total surface, are the main contributors to land occupation of FLW, whereas their respective contribution to total FLW is 11%.

Land losses due to FLW are also severe in North Africa and West and Central Asia (including southern and eastern Mediterranean countries). These losses exceed 360 million ha, greater than other regions. Such land losses can be due to livestock feeding on non-arable grasslands for the production of meat and milk and also to the low productivity of livestock as a result of low productivity of grasslands (FAO, 2013a). In Italy, the ecological footprint of fruits and vegetables wasted in stores is almost 400 million m^2 of cropland, namely 3.7 m^2 for each kg of fruit and vegetables wasted. For the wasted meat, the ecological footprint is 83 million m^2 or 38 m^2 per kg wasted (Segré and Falasconi, 2011).

According to FAO (2013a), land use waste indicators are inadequate for describing all land-related environmental impacts. Indeed, land use waste indicators do not address the issue of land use change, accounting for the impact of deforestation, urbanisation, and soil sealing. Also, they do not consider impacts on soil quality and productive capacity (FAO, 2013a). This phenomenon, called land degradation, is a global issue of concern. The issue of land degradation is defined by the FAO Land Degradation Assessment in Drylands (FAO/LADA) model as the reduction of land capacity to provide ecosystem goods and services, such as maintaining hydrological cycles, cleaning water and air, and regulating climate over a time period (FAO, 2011c).

Other environmental impacts of FLW

Natural landscapes and their ecosystem services are also adversely affected by the resources that go into producing lost and wasted food (Lipinski *et al.,* 2013; TEEB, 2018; Willett *et al.,* 2019). In fact, waste of food determines many other negative environmental impacts and externalities. These are linked with the impacts of agricultural production. In this respect, the impacts of agricultural inputs (fertilisers and pesticides) overuse/waste, especially on underground and surface water resources, can be cited, as well as deforestation, biodiversity loss, and ecosystems disturbance.

A total of 28 million tonnes of fertilisers are used per annum to grow the lost and wasted food at a global level (Kummu *et al.,* 2012). Fertiliser consumption, especially nitrogenous ones, is high in Mediterranean countries (Lacirignola *et al.,* 2014). The intensive use of nitrogen fertilisers jeopardises environmental sustainability of current food consumption systems in the Mediterranean region. According to WWF (2013), 143 thousand tonnes of nitrogen is used to produce food that is wasted by Italian consumers, plus 85.8 thousand tonnes of nitrogen wasted throughout the supply chain. Estimating the impacts on biodiversity at a global level is difficult, though FWL compounds the disadvantages of intensive monocropping and agriculture expansion into wild areas, which both contribute to biodiversity loss (Stuart, 2009; FAO, 2013a). Globally, FLW may represent more than 20% of biodiversity pressure (EC, 2014). In particular, the wasted food is a major factor contributing to biodiversity loss through soil over-exploitation, habitat change, environmental pollution, and climate change. A total area of 9.7 million ha is deforested for producing food each year, partly driven by inefficiency in global food production. This figure compares to 74% of total annual deforestation. Furthermore, FLW is responsible for the expansion of agriculture into wild areas and high fishing intensity that over-exploit forests and marine habitats. This situation entails serious disruption of species habitats and loss of wildlife, including the extinction of several species (FAO, 2013a).

Importance of addressing the problem of FLW

Reducing FLW is an essential action for reducing the environmental impact of the current food production systems (Foley *et al.,* 2011; HLPE, 2011; 2014; FAO, 2012; UNEP, 2012a; 2012b; FAO, 2013a; 2013b; 2017; Lipinski *et al.,* 2013; Gorski *et al.,* 2017; Chaboud and Daviron, 2017; TEEB, 2018; Willett *et al.,* 2019) and for increasing the efficiency of the food chain (Kummu *et al.,* 2012; HLPE, 2014; Spiker *et al.,* 2017). FLW causes two direct environmental impacts: depletion of resources available for food production and adverse effects on the environment, including GHG emissions (FAO, 2013a; 2013b; HLPE, 2014). The pollution of surface and groundwater by high use of nitrogenous fertilisers is a main indirect environmental impact. Negative consequences of FLW also include biodiversity loss imposed by intensive monocropping and agriculture expansion into wild areas (FAO, 2013a).

Various studies have underlined that FLW reduction is indispensable for reducing the environmental impacts of food systems (Lipinski *et al.,* 2013; Alexander *et al.,* 2017; TEEB, 2018; Usubiaga *et al.,* 2018; El Bilali *et al.,* 2019; El Bilali, 2020), thus preserving ability to sustain future increase in the global demand for food. Wasting food means losing precious natural resources, human resources (employees of the food chain or agricultural workforce), financial resources (capital invested in agriculture), and a great amount of energy (used in production and transportation of food) (FAO, 2011a; Fox and Fimeche, 2013). Moreover, recent studies have examined the environmental impact of FLW by estimating the levels of GHG emissions (carbon footprint) (WRAP, 2011; Dorward, 2012; Eriksson *et al.,* 2015), water footprint (Ridoutt *et al.,* 2010; WRAP, 2011; Kummu *et al.,* 2012; Chapagain and James, 2013; Vanham and Bidoglio, 2013; Vanham *et al.,* 2015), nitrogen pollution (Grizzetti *et al.,* 2013), and land use (Wirsenius *et al.,* 2010; Kummu *et al.,* 2012; Galli *et al.,* 2017).

Food and drink waste involve major environmental consequences at global and local levels. The long journey of food products requires resources and labour, and produces GHG emissions. Water, energy, and resources consumed throughout a product's life cycle are lost when this product is wasted. Therefore, these losses must be also considered (BCFN, 2012). The environmental impact of food production (e.g., land, water, and energy) varies largely depending on the place and the way of production (Foster *et al.,* 2006; HLPE, 2014) as well as on the stage where the loss or waste occurs, especially for energy (Winkworth-Smith *et al.,* 2015). Product wastage at a later stage of the supply chain brings about a higher environmental cost than its wastage at an earlier stage (FAO, 2013a). At the level of consumer, FLW has a greater impact on the environment than a similar mass of post-harvest loss, as energy has been consumed in processing, packaging, and transport (MGI, 2011).

The present review provides a qualitative and quantitative overview of the main environmental implications and the impacts of FLW with a spotlight especially on the Mediterranean area. So far, studies on FLW have generated positive change, but further in-depth studies are necessary to give the FLW debate more weight and credibility (Chaboud and Daviron, 2017). This is particularly applicable for the Mediterranean area for which research and knowledge sharing to identify what is wasted, what the consequences are, and how to avoid, prevent, and/or reduce them are lacking. Research integration and synthesis as compiled in the present review provides an overview of the main environmental implications and impacts of FLW, and it can be a benchmark for future research that will offer policy tools to help reducing FLW at all stages along the food supply chain. In combination with knowledge-sharing platforms that can facilitate dissemination of attained findings, information provided in this work can enable effective implementation of newly developed guidelines for FLW reduction through capacity building and awareness raising campaigns.

Conclusion

Wasting food is unsustainable, not only economically, but also environmentally. Moreover, FLW further reduces the efficiency of the food chain.

Therefore, measures of waste reduction will alleviate the impact on resources used and minimise GHG emissions, thereby rendering the food chain more efficient. The elimination of FLW along the food chain should be highly considered by Mediterranean policies and be included in the research plans related to the agri-food sector. Reducing FLW is an essential element contributing to broader improvement of the Mediterranean food systems. Moreover, minimisation of FLW is an important prerequisite for achieving environmental sustainability, i.e., sustainable management of natural resources as well as mitigation of climate change. Action in that direction is imperative, especially for a resource-constrained region such as the Mediterranean. Therefore, a composite and integrated approach dealing simultaneously with behaviour, lifestyle, food policy, food chain management, and physical capital (e.g., infrastructures and cold chain) is highly needed to offset the negative impacts of this global issue. This is a particularly high priority in the Mediterranean region, which is characterised by fragile ecosystems and scarce natural resources. Mediterranean countries must adopt and implement strategies for FLW prevention or reduction that are systematically monitored and assessed. To this end, strategic plans that incorporate vertically and horizontally coordinated dimensions relevant to FLW reduction should be designed for the food and agricultural sector. In this context, all activities should be well coordinated to achieve sustainable results. Using current knowledge and available technologies and infrastructure in storage and transport, investing in novel technology, and reforming markets can contribute to FLW reduction. Furthermore, awareness-raising campaigns and productive redistribution of surplus food are required to reduce waste by consumers and the food service sector. In all cases, it is essential to adopt, implement, and spread best practices in food production and consumption.

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