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Abstract

Reducing food losses and waste (FLW) has been identified as an essential means of increasing food security, while reducing pressure on natural resources. To assess the reliability of future strategies to reduce and manage FLW along the food supply chain (FSC), not only their quantification but also the 'qualification' in both economic and nutritional terms must be considered. The methodology proposed in this work allows to quantify FLW at the distinct stages of the FSC (agricultural production, postharvest and storage, processing, distribution, households and extradomestic consumption). In addition, economic and nutritional FLW are estimated. A Nutritional Food Losses and Waste Footprint (NFLWF) index is proposed to assess and balance the variables described. This index is used to define food recovery strategies focused on those food categories and stages of the FSC with lesser efficiency. NFLWF distinguished between food losses (FL) and food waste (FW) depending on the scope of the analysis. The former provides information to producers, while the latter creates awareness among consumers. Furthermore, the potential for FLW reduction is estimated through the quantification of avoidable and unavoidable FLW. Our study is focused on the Mediterranean region, in particular on Spain. Almost 30% of the national food production is estimated to be lost or wasted. Vegetables, fruits and meat result the food categories less efficient. Agricultural production is the main responsible of FLW generation, followed by households. Each Spanish citizen is estimated to throw away around 180€ per year, while a 77% could be saved.

Keywords	Food losses; food waste; food security; material flow analysis; reduction potential
Taxonomy	Food Security, Flow Analysis, Food Waste

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HIGHLIGHTS

- Material flow analysis of Spanish food losses and waste (FLW) was conducted
- Estimation of FLW along the supply chain in weight, economic and nutritional terms
- Each Spanish citizen throw away around 90 kg per year, estimated at 180 euros
- More than half of FLW could be prevented: 37 million extra people could be fed
- Nutritional Food Losses and Waste Footprint index proposed as decision-making tool

First steps to a Sustainable Food Production and Consumption in Spain: Estimating Potential Food Waste Reduction

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ABSTRACT

Reducing food losses and waste (FLW) has been identified as an essential means of increasing food security, while reducing pressure on natural resources. To assess the reliability of future strategies to reduce and manage FLW along the food supply chain (FSC), not only their quantification but also the 'qualification' in both economic and nutritional terms must be considered. The methodology proposed in this work allows to quantify FLW at the distinct stages of the FSC (agricultural production, postharvest and storage, processing, distribution, households and extradomestic consumption). In addition, economic and nutritional FLW are estimated. A Nutritional Food Losses and Waste Footprint (NFLWF) index is proposed to assess and balance the variables described. This index is used to define food recovery strategies focused on those food categories and stages of the FSC with lesser efficiency. NFLWF distinguished between food losses (FL) and food waste (FW) depending on the scope of the analysis. The former provides information to producers, while the latter creates awareness among consumers. Furthermore, the potential for FLW reduction is estimated through the quantification of avoidable and unavoidable FLW.

Our study is focused on the Mediterranean region, in particular on Spain. Almost 30% of the national food production is estimated to be lost or wasted. Vegetables, fruits and meat result the food categories less efficient. Agricultural production is the main responsible of FLW generation, followed by households. Each Spanish citizen is estimated to throw away around 180€ per year, while a 77% could be saved.

Keywords: Food losses, food waste, food security, material flow analysis, reduction potential

1. Introduction

Increasing awareness is being worldwide addressed in recent years to food security. According to the Food and Agriculture Organization of the United Nations (FAO) food security is a matter of availability, access, utilization and stability; and exists 'when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life'. Feeding the world's population sustainably is a major challenge of our society and has been stated as one of the key priorities for development cooperation by the 2010 EU policy framework on food security (EC, 2010). However, the exploitation of natural resources to meet humanity's demand for food is among the major causes of environmental degradation. In particular, food systems have been estimated to be responsible for 20-30% of the anthropogenic greenhouse gas emissions, being the agricultural stage the largest emitter (Garnett, 2011, Vermeulen et al., 2012). Moreover, in a global context of increasing population, it has been estimated that a 60% rise in agricultural production will be required by 2050 to satisfy population's nutritional needs (Alexandratos and Bruinsma, 2012). Therefore, improving the food supply chain (FSC) efficiency has been identified as an essential means to enhance food security, while reducing pressure on natural resources (Chaboud and Daviron, 2017). Different approaches have been proposed to meet these objectives such as improving the agricultural production systems, changing diets and implementing demand-side measures, and the reduction of food waste (Alexander et al., 2017). The latter is one of the main Sustainable Development Goals (SDG) adopted by the United Nations Member States in September 2015, according to which food waste at the retail and consumer level should be halved by 2030 and food losses along the FSC should be reduced. The pathways to achieve this target are being addressed by AgroCycle project (€8 million, 8 EU countries and China), which will deliver a blueprint for achieving sustainable agri-food waste valorisation.

Many studies have assessed the food losses and waste along the FSC. The study of Gustavsson et al. (2011) carried out by FAO is the most highly cited work. According to this report, around a third of all food produced globally for human consumption is lost or wasted; 1.3 billion tons per year (Gustavsson et al., 2011). Moreover, they estimated that the food wasted in industrialised regions is around 12 times higher than in developing countries. Loss rates for different world regions, FSC stage and commodity group were defined. A similar approach was followed by Kummu et al. (2012), which estimated that the nutritional energy lost would be enough to feed around 1.9 billion people and that approximately half of the losses in the FSC could be prevented. At European level, the FUSIONS EU project estimated at 88 million tons and 143 billion euros the food losses and waste (Stenmarck et al., 2016). This study is based on a previous 'preparatory study on food waste across the EU 27 Member States' (Monier et al., 2010), which estimated the losses over all stages of the food value chain except agricultural production at 180 kg/cap/a; based on the Eurostat database, literature data, stakeholder consultations, and assumptions.

Although global and regional studies are very useful to provide significant data, they fail to describe individual singularities. For example, despite being usually highlighted as a good example of balanced diet, the Mediterranean region has reached a level of environmental degradation that requires immediate action (UNEP, 2010). Scarce natural resources and increasing environmental impacts are the main reasons. Additionally, it has been found out that the majority of the Mediterranean countries rely on the biocapacity of foreign countries to satisfy their population's demand for food (Galli et al., 2017). However, national data for this region are often not available or lack for sufficient quality (Monier et al, 2010, Stenmarck et al., 2016). This is the reason why studies at national level are an up-coming trend in the literature (Caronna, 2011, Beretta et al., 2013, Halloran et al., 2014).

Moreover, although food losses and waste have been quantified in terms of weight, nutritional and economic losses are rarely addressed. Only some partial approaches have been found in the literature and they do not explore the nature of this relationship. For example, Buzby and Hyman (2012) estimated the total amount and monetary value of food loss in the United States. Kummu et al. (2012) quantified the global food losses in terms of energy (kcal). Alexander et al. (2017) studied the global wet and dry mass food lost and the nutritional content of these losses in terms of energy and proteins. Therefore, this work assumes there is essential that future strategies to reduce food losses and waste (FLW) along the food supply chain consider not only their quantification but also their 'qualification' in both nutritional and economic terms. This work proposes a standardised methodology to calculate the Nutritional Food Losses and Waste Footprint (NFLWF) index that assesses and balances the amount generated and the nutritional and economic value of FLW. The quantity variable is directly related to the environmental dimension, which refers to the unnecessary pressure on natural resources caused by avoidable food production and wastage, as well as environmental impacts caused by the whole food system (Fig. 1). The nutritional variable refers to the food losses and waste in terms of nutritional content, which is directly related to the availability and access dimensions of food security and safety. Finally, in terms of economic impacts, reducing food losses and waste would help all of the stakeholders to save money, especially to consumers, although it could involve transfer mechanisms and trade-off for other stakeholders (Chaboud and Daviron, 2017). The main idea is to define a measurable nutritional-economic efficiency of FLW along the FSC, to further guide the definition of food recovery strategies focused on those categories and stages of the supply chain with lesser efficiency. NFLWF distinguished between food losses (FL) and food waste (FW) depending on the supply chain step. Our study is focused on the Mediterranean region, in particular on Spain, where although numerous initiatives have been implemented at national and sub-national levels ('More food, less waste', 'Save Food', 'Food responsible consumption') there is still a significant gap regarding FSC losses and waste.

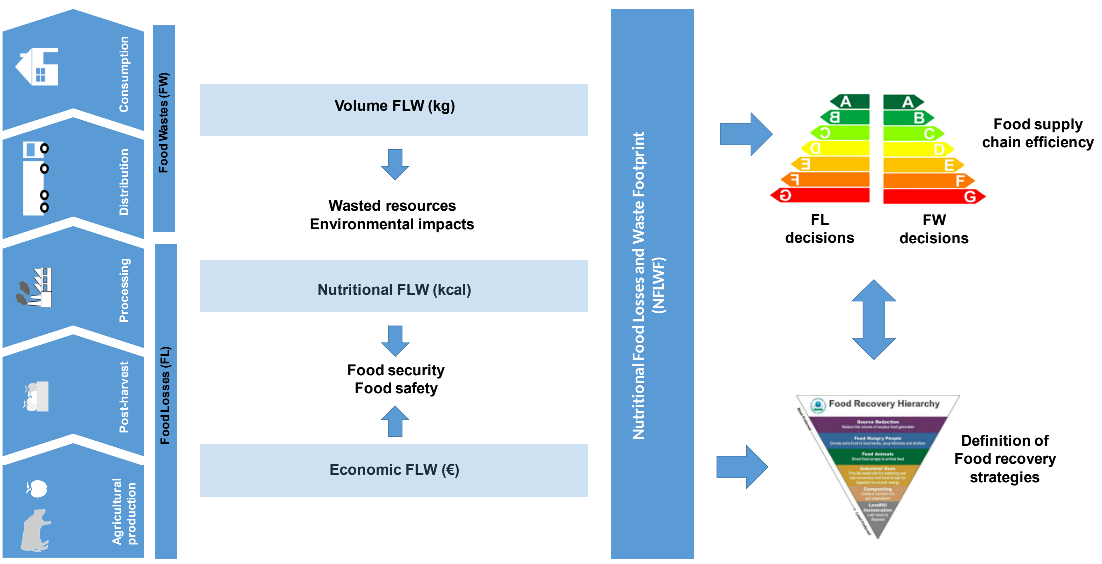

Fig. 1 Conceptual diagram of this work

2. Methodology

2.1 Definitions

Different definitions, measures and indicators have been reported in the literature in recent years, owing to the increasing awareness in facing the food waste management problem. To avoid confusion and make our results comparable to other studies, we have adopted technical criteria widely agreed with the scientific community.

In this study, we distinguished between FL and FW within the different steps of the FSC. According to FAO, FL refer to a decrease in food quantity or quality in the early stages of the food supply chain, reducing the amount of food suitable for human consumption. This concept refers to losses in the production, postharvest and storage and processing of products. On the other hand, FW refers to later steps of the FSC, i.e. distribution and consumption (Gustavsson et al., 2013). Generally, FL or spoilage relates to system that require investment in infrastructure, while FW relates more to behavioural issues (Papargyropoulou et al., 2014). These definitions are in line with other studies (Parfitt et al., 2010, Kummu et al., 2012, Gustavsson et al., 2013). Furthermore, the term 'wastage' encompasses both food loss and food waste, which are also referred as FLW (FAO, 2013). Recently, it has been suggested that 'food loss 'encompasses both FL and FW and is thus equivalent to food wastage (Corrado et al., 2017). However, we prefer to maintain the conventional definitions.

Furthermore, the distinction between 'avoidable' and 'unavoidable' FLW is done. Avoidable FLW is the amount of food thrown away because it is no longer wanted or has been allowed to go past its 'best before' or 'expiration' date. This term refers to food parts considered edible by the vast majority of people (Corrado et al., 2017). Unavoidable FLW are food parts which are not and have not been edible under normal circumstances (e.g. egg shell, apple core, banana skin, and animal bones). This distinction can be subjective because what is considered edible depends on several factors such as culture, religion, social norms and personal preferences. In addition to that, harvesting, storage, transportation and processing losses that are not avoidable with best available technologies and reasonable extra costs can also be considered as unavoidable (Beretta et al., 2013). Despite this, it can reveal how unnecessary is food waste and highlight the potential for food waste prevention.

2.2 Material Flow Analysis (MFA)

MFA quantifies the mass/resources flow, loss in a system, and also facilitates in data reconciliation in a well-defined space and time (Padeyanda et al., 2016). An MFA can also be used for developing indicators to assess resource efficiency and sustainable development (Sakai et al., 2017), such is the case of this work. Fig. 2 outlines the material flow model used for quantifying the food losses and waste throughout the supply value chain.

For this purpose, the most representative commodities products in terms of mass, nutritional and economic value are first selected for the specific country or region under study. Then, a food balance sheet (FBS) is constructed to determine the total domestic supply (DS). The FBS shows the patterns of a country's food supply during a specific period of time (Ju et al., 2017). The term 'domestic supply' refers to the total amount of food available to be used in a spatial unit under study after production losses, imports, exports and stock variation have been considered. The methodology of FAO (2001) is used to estimate the DS, as indicated in Eq. (1):

$$DS_i = \sum supply\ elements_i = Prod_i + Imp_i + Stock_i - Exp_i \tag{1}$$

Where $Prod_i$ refers to the country's food production in a specify year for food category *i*. It represents the first stage of the FSC, namely agricultural production (j=1). Imp_i and Exp_i describe the importation and exportation quantities. $Stock_i$ refers to the stock availability of commodity *i* for the year under study.

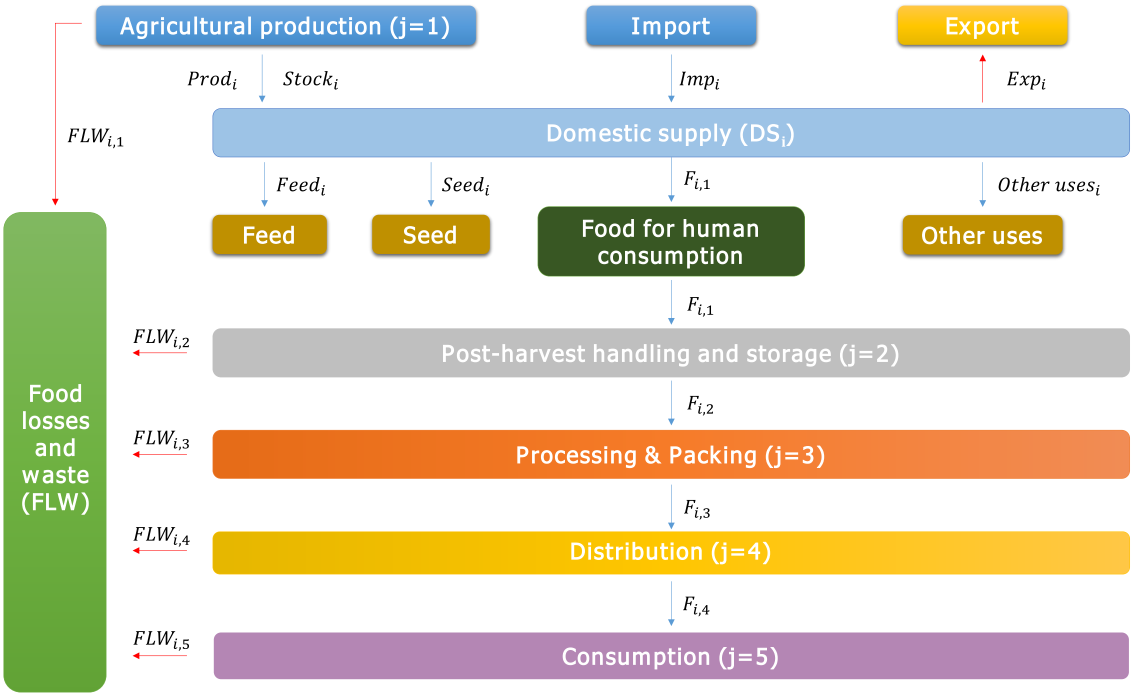

Fig. 2 Material flow analysis model.

Once the domestic supply is estimated, food available for human consumption is determined using Eq. (2):

$$F_{i,1} = DS_i - \sum utilisation\ elements_i = DS_i - (Feed_i + Seed_i + other\ uses_i) \tag{2}$$

Where $F_{i,1}$ represents all forms of the food category *i* available for human consumption after withdrawing the utilization elements feed, seed and other utilities from the domestic supply quantity (FAO, 2001). $Feed_i$ describes the amount of commodity used for animal feed. $Seed_i$ is the amount of commodity used for reproductive purposes, e.g. seed, planting, fish for bait. *Other* $uses_i$ refers to the quantities of commodities used for other non-food purposes, e.g. wheat for bio-energy production.

The volume of FLW for each commodity group is calculated differently depending on the FSC stage. For example, agricultural production losses are estimated as having occurred before the production volume is derived, while postharvest and storage losses are calculated as a percentage of the reported production value. The rest of food losses and waste are determined as a function of the food quantity entering the corresponding stage. Consequently, the total volume of FLW for each commodity group throughout the FSC is quantified using Eq. (3-4):

$$FLW_i = \sum_{j=1}^{j=5} FLW_{i,j} = \left(\frac{\alpha_{i,1}}{1-\alpha_{i,1}} + \alpha_{i,2}\right) \cdot Prod_i + \sum_{j=3}^{j=5} \alpha_{i,j} \cdot F_{i,j-1} \tag{3}$$

$$F_{i,j} = F_{i,j-1} - FLW_{i,j} \qquad \forall j \in [2,5] \tag{4}$$

Where $\alpha_{i,j}$ is the percentage of food losses and waste generated in each j stage for food category i; $F_{i,j}$ is the food available for human consumption of category i leaving the supply chain sector j (j=2, postharvest handling and storage; j=3 processing and packaging; j=4 distribution; j=5, consumption).

2.3 Nutritional Food Losses and Waste Footprint (NFLWF)

The quantification of FLW have been recognised as a necessary step to identify how much, why and where FLW occur (Fusions, 2014). On the other hand, improving FLW assessment methodologies has been remarked as crucial for overcoming the methodological weaknesses and to increase transparency (Chaboud, 2017). According to this and in line with the FAO definition of FLW, our starting hypothesis is the conviction that future strategies to reduce FLW along the food supply chain must take into account not only the quantification but also the 'qualification' in both economic and nutritional terms. In particular, the need of a single score that relates the amount of FLW, their economic value and the related nutritional content is posed. We then proposed the Nutritional Food Losses and Waste Footprint (NFLWF) as an indicator to assess the efficiency of the food system along the supply chain, encompassing the measure of the economic and nutritional intensity of the FLW. In order to provide significance to the results and help in the decision-making process, this indicator distinguishes between FL and FW leading to two separate indexes: Nutritional Food Losses Footprint (NFLF) and Nutritional Food Waste Footprint (NFWF), respectively. NFLF can be used to analyse infrastructural decisions in the earlier FSC stages, while the NFWF is aimed at creating awareness among consumers.

This study proposes a standardised methodology to calculate the NFLWF index. Fig. 3 describes the 3-steps methodology approach followed in this work. First, a MFA is required to quantify the food supply and losses/waste produced along the supply chain. Then, economic and nutritional assessments are conducted to qualify the efficiency of the FSC. Finally, NFLWF identifies those food categories with greater nutritional and economic wastage intensity.

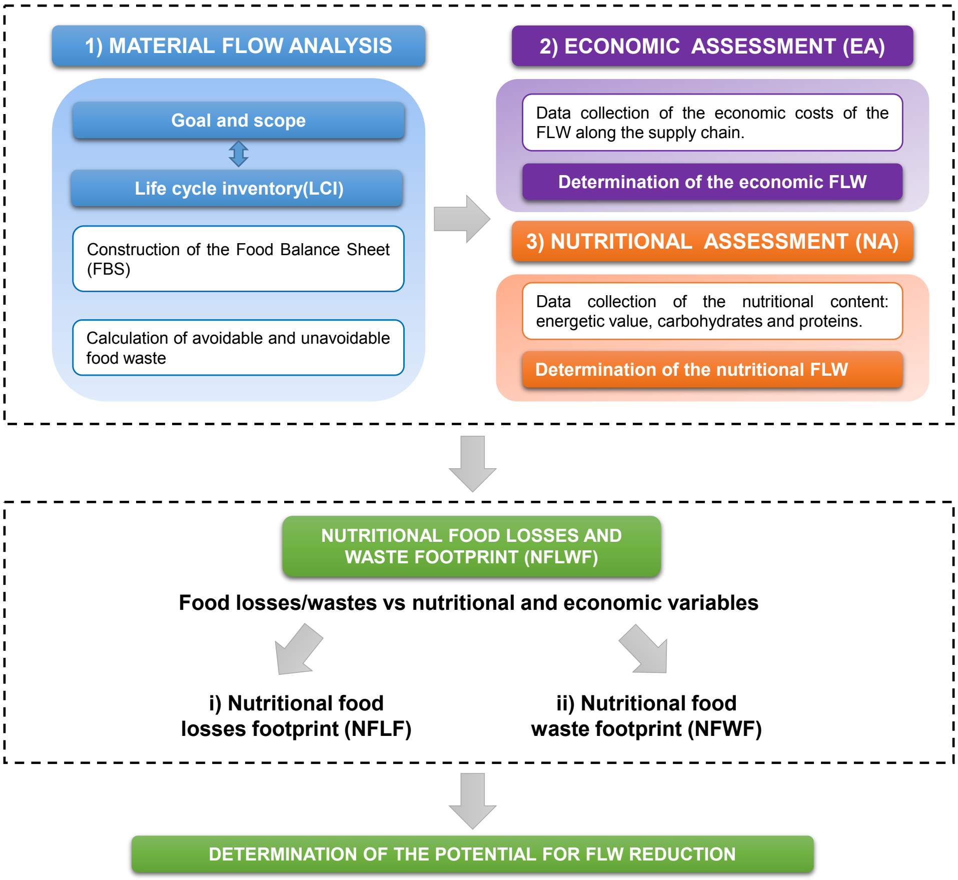

Fig. 3 Methodological approach proposed for the determination of the Nutritional food losses and waste footprint (NFLWF)

To estimate the NFLWF, it is first necessary to determine the economic food losses and waste (EFLW) as described in Eq. (4).

$$EFLW_i = \sum_j EFLW_{i,j} = \sum_j FLW_{i,j} V_{i,j} \tag{5}$$

Where $EFLW_{i,j}$ represents the economic food losses and waste of food category i in the supply stage j and $V_{i,j}$ their corresponding economic value.

Furthermore, the nutritional food losses and waste (NFLW) are also estimated (Eq. 5).

$$NFLW_i = \sum_j NFLW_{i,j} = \sum_j FLW_{i,j} NC_{i,j} \tag{6}$$

Where $NFLW_{i,j}$ represents the food losses and waste of food category i in the supply stage j and NC_k their corresponding nutritional content (k=1, kcal; k=2, proteins, k=3, carbohydrates).

Finally, a Nutritional Food Losses and Waste Footprint (NFLWF) is developed, which consists of an eco-label rating system based on the descriptive weighting of the economic and nutritional losses and waste and the mass quantity of these losses/waste. This footprint, comprises two different indicators: NFLF and NFWF addressed to FL and FW, respectively. Each footprint, depending on the FSC stage for which it is defined, can be used for decision-making of producers, consumers and/or other stake-holders.

2.4 Determination of the NFLWF for the FL and FW in the Spanish framework

2.4.1 Goal and scope

The main goal of this work is to develop a standardized methodology to calculate the Nutritional Food Losses and Waste Footprint (NFLWF) to guide FL and FW strategies along the FSC in a specific region. A further goal of this study is to provide an analysis of the FSC efficiency in the Mediterranean region, in particular, in Spain. Therefore, our assessment involves three main steps: first, the FL and FW are estimated in terms of weight, economic and nutritional value based on a material flow analysis (MFA). Secondly, the Nutritional Food Waste Footprint (NFWF) indicator is developed to evaluate the significance of those food losses and waste. Finally, the potential for FLW reduction is determined along the FSC by the estimation of avoidable and unavoidable FLW.

The functional unit selected for this work is defined as the supply of food for a Spanish citizen in the year 2015 in terms of food categories (Muñoz et al., 2010).

The system boundaries of this study comprise the entire supply chain, i.e. from agricultural production to the consumer. The definition of the supply chain stages is based on Gustavsson et al. (2011): agricultural production, postharvest and storage, industrial processing, distribution (i.e. retail/wholesale) and consumption. The consumption stage was divided into households consumption and related extradomestic consumption. The latter was estimated as 22% of the total consumption, based on the reported data from the Spanish Ministry of Agriculture, Fishery, Food and Enviroment (MAPAMA, 2012). Owing to the lack of data, same consumption and waste generation patterns were assumed for both households and extradomestic stages. Our study does not consider losses and waste of food directed to animal feed, seed and other uses. Food waste in other countries, resulting from the production of food imported for consumption in Spain, was included in the analysis, assuming the FLW rates to be equal to production in Spain. Food waste resulting from the production of food for export was not included (Beretta et al., 2013).

A basket of products was selected based on the consumption data reported by MAPAMA (2015a). These food commodities were classified according to eleven categories following FAOSTAT classification: cereals, sugar, vegetable oils, vegetables, fruits, pulses, roots & tubers, dairy, eggs, fish & seafood, meat & animal fat. Alcoholic beverages have been excluded from the analysis. These categories are assessed within the framework of four different diets: vegetarian, pescetarian, mediterranean, omnivorous diets. More data regarding the food commodities considered are available in table S1 of the supporting material (SM).

2.4.2 FLW calculation

A FBS is constructed following the methodology previously described. The domestic supply estimated includes the total production, but the assessment of the FL and FW only considers the fraction of the total production directed to human food. Spanish production of primary food commodities was sourced from Eurostat (2015a, 2015b, 2015c, 2015d). International trade was also sourced from Eurostat (2015e), considering both importation and exportation quantities. Finally, national stock data were obtained from FAOSTAT database (FAO, 2013) and assumed similar to the food availability in 2013, which are the most updated data at present. The relative percentages reported in FAOSTAT datasheets (FAO, 2013) were used to estimate the part of the total production intended for human consumption, as well as the fractions addressed to the rest of utilisation elements. The resulting FBS is available in the supplementary material (see table S2, SM).

For each FSC stage, the FLW weight percentages reported by FAO for the European region (Gustavsson et al., 2013) were used to quantify the volumes of food losses and waste for each commodity group separately using the estimated FBS, except for postharvest losses when there are data available for Spain in the FAOSTAT Balance sheets. These percentages were adapted to the Spanish region when possible (MAPAMA, 2013a, 2013b) and are described in table S3 in the SM.

2.4.3 Economic FLW calculation

Prices at origin, wholesale and consumer level were obtained from the Spanish Ministry of Economy and Competitiveness (MINECO, 2015) and the MAPAMA (2015b) (see Table S5 in the SM). Same costs were assumed for FL at agricultural production and postharvest stages. Regarding processing stage, economic value of production reported by Eurostat were used when consistent data where available. Otherwise, wholesale prices were used for processing and distribution stages. It was assumed that food service establishments and related extradomestic services can buy their food for lower prices than private households. A 5% volume discount was considered (Beretta et al., 2013).

2.4.4 Nutritional FLW calculation

Diet is an important determinant of human health (Tilman and Clark, 2014). Food commodities can be classified according to the diet where they are present: vegetarian, pescetarian, mediterranean and omnivorous diet. The diets have different compositions. A vegetarian diet includes cereals, roots and tubers, sugar, vegetable oils, vegetables, fruits, pulses, dairy and eggs. A pescetarian diet is a vegetarian diet that includes fish and seafood. A mediterranean diet is similar to the pescetarian, but includes moderate amounts of meat. Omnivorous diets consider all food groups.

In addition to the diet classification, food commodities can be characterised according to their nutritional content. Proteins, carbohydrates and caloric content of the food commodities were sourced from the Spanish Bedca database (2017) and are outlined in Table S6 in the SM.

2.4.5 Avoidable and unavoidable FLW calculation

Although inedibility food content is the most usual criteria followed for determining unavoidable FLW, the boundary between edible and inedible food is often subjective. This is due to its related variability over time and among different countries and cultures (Chavoud and Daviron, 2017).

In this work, the definition of Beretta et al. (2013) for unavoidable FLW and the methodology proposed by Kummu et al. (2012) are followed. In this sense, a minimum scenario is defined to quantify the potential for FLW reduction. This scenario assumes that for each FSC stage, the lowest loss and waste percentages reported by Gustavsson et al. (2013) in any region can also be achieved in Spain. The minimum FLW are then identified with the unavoidable FLW (see Table S7 in the SM).

3. Results and discussion

3.1 Material flow analysis results

Fig. 4 shows the material flow analysis to meet the Spanish food demand in 2015. The first column indicates the material balance to estimate the domestic supply. Since statistical production values do not account for the losses occurred during this stage, it can be assumed that the real production flow is the sum of the production reported and the production losses. Both have been then included in the graphic as independent flows. The net domestic supply after considering agricultural production losses, imports, exports and stock variation is 78,653 Mton per year. From this, 27,896 Mton (35%) are used for animal feed and 5,830 Mton (8%) are employed for seed and other non-food uses such as oil for oil production and wheat for bio-energy. The material balance also reveal that only 57% of the net domestic supply is addressed to human consumption. However, just 43% is finally ingested as shown in the third column, while the rest is lost or waste.

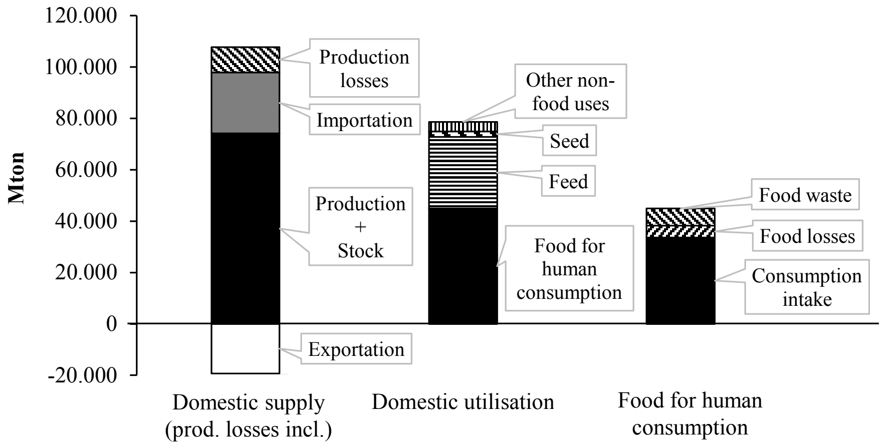

Fig. 4 Results of the material flow analysis of the food produced to meet the Spanish demand.

3.2 Food losses and waste quantification

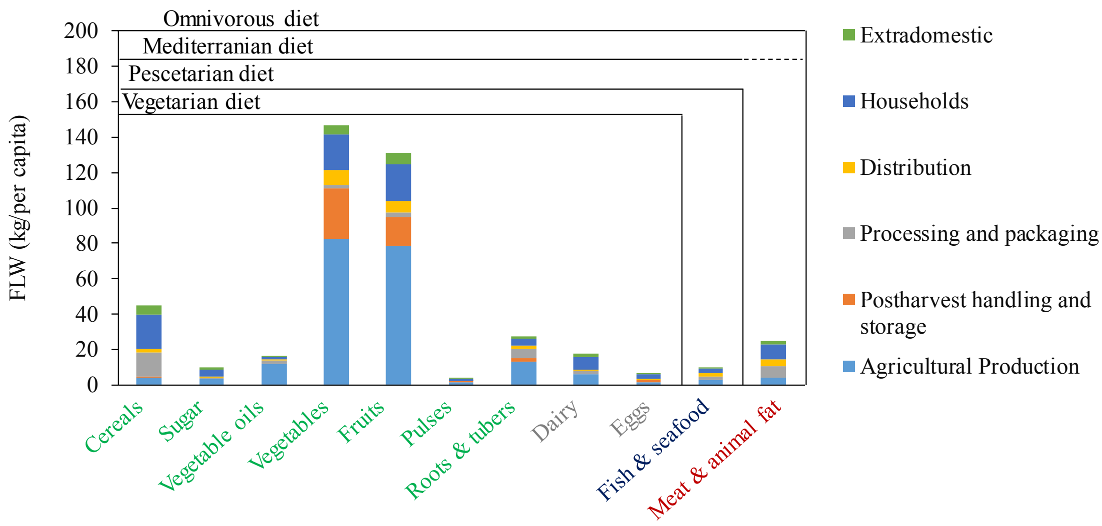

Fig. 5 Food losses and waste of the different food categories throughout the supply chain. Values expressed in kilograms per capita.

The FLW analysis reveals that vegetables and fruits are the food categories most affected by the inefficiencies in the FSC. Their FLW were estimated at 147 and 131 kg·pc·y^{-1}, respectively, which account for more than 60% of the total Spanish FLW. They are followed by far by cereals category, whose contribution to the total FLW is around 10%. Consequently, no significant difference is observed in mass waste generation among the different diets studied, since the majority of the losses and waste are shared by fruits and vegetables, which are present in every diet.

Agricultural production and postharvest stages are the main steps contributing to the FLW, amounting to 60% for the food categories under study. This contribution is more significant for fruits and vegetables (74%), owing to climatic conditions, diseases and pests (MAPAMA, 2013a). On the other hand, inefficiencies in manual and technical harvesting, unsatisfied quality standards and mismatch between offer and demand cause fruits and vegetables losses in both harvest and postharvest.

After agricultural production and postharvest, household consumption is the second main hotspot for food wastage (21%). The quantity of food annually wasted in households was estimated at 91 kg per person. Almost half of this waste is due to fruits and vegetables, which are highly perishable. Secondi et al. (2015) suggested that food waste in this stage is the result of multiple factors relating to various aspects rather than the outcome of a single behaviour. The education level, sorting practices, the extent of urbanisation and concern were some of the variables proved to be associated to individuals' behaviour. Conversely, FLW in the service sector results three times lower (25 kg·pc^{-1}·y^{-1}) than at households.

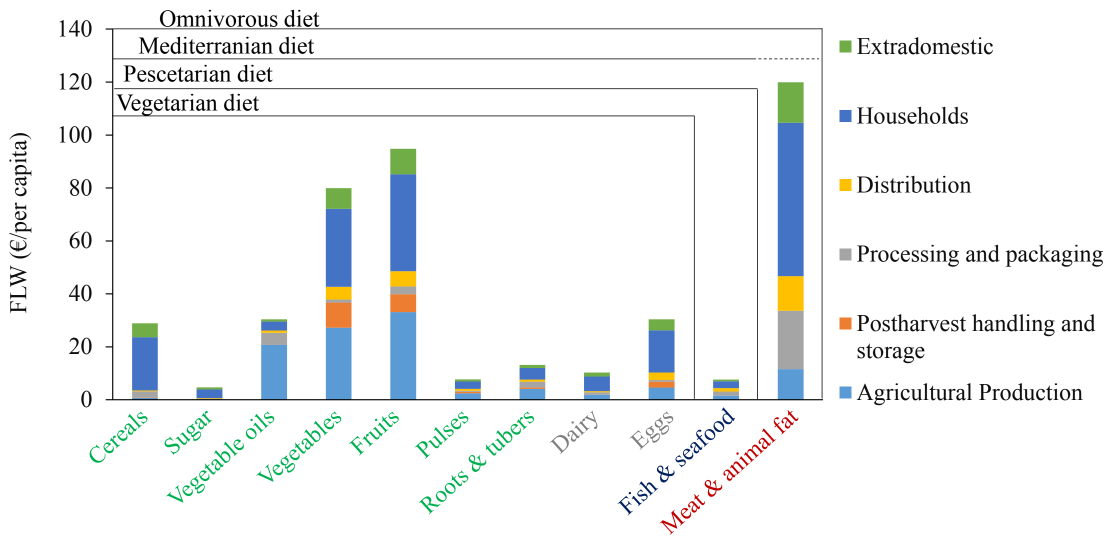

Fig. 6 Food losses and waste of the different food categories throughout the supply chain. Values expressed in euros per capita.

According to Fig. 6, the described pattern is reversed when the economic value of FLW is assessed. Meat and animal fat category emerges as the largest contributor to economic wastage, representing a 28% (120 $€ \cdot pc^{-1} \cdot y^{-1}$) of the total FLW. It is followed by fruits and vegetables categories, which share 22% and 19%, respectively. Therefore, it can be concluded that those diets including meat on the menu such as mediterranean and omnivorous, involve higher economic FLW than those avoiding this category, such as vegetarian and pescetarian diets.

Regarding the FSC stages, it can be observed that the closer to the consumer the FLW are generated, the more expensive they become. Consequently, household consumption emerges as the main hotspot of economic food waste, accounting for nearly 45% of the total economic wastage. Our analysis estimates that each Spanish citizen throw away around 180€ of food per year, which is below the European average estimated at c.a. 195€ (Stenmarck et al., 2015). According to HISPACOOP (2013), half of this wastage could be avoided with an adequate purchasing and storage planning. Improper preparation, lack of awareness about the difference between expiration and preferential consumption dates and portion size acquired in the supermarkets are other reason for food waste generation in households.

On the other hand, agricultural production becomes the second main hotspot of the economic FLW (25%), again due to vegetables and fruits wastage. Therefore, our results suggest that economic food losses at the beginning of the supply chain are not as significant as at the consumption stages. This could be the reason why no substantial improvement actions are being addressed to the early stages of the FSC.

3.3 Nutritional assessment of the FLW

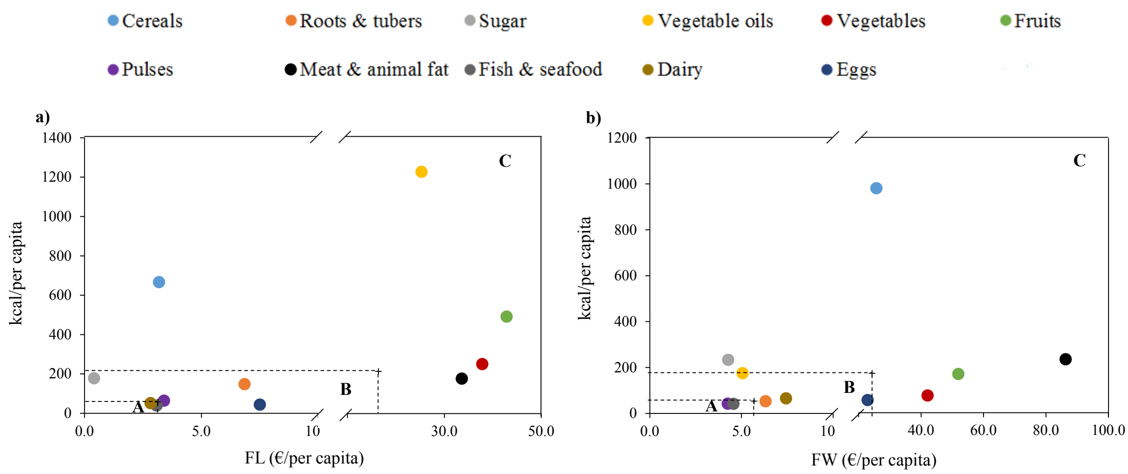

Fig. 7 Energy content of a) food losses (FL) and b) food waste (FW) for the different food categories throughout the supply chain versus their related economic value. Values expressed in kcal per capita.

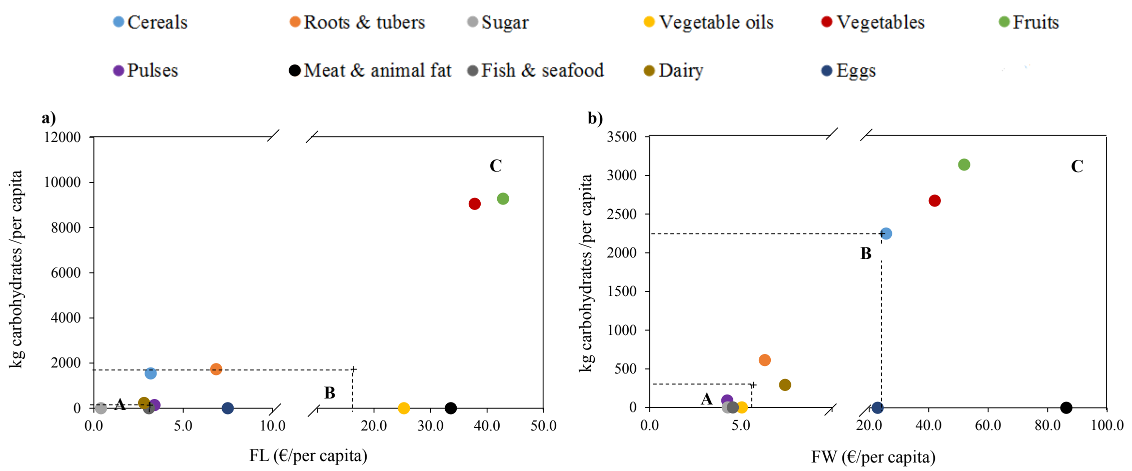

Fig. 8 Protein composition of a) food losses (FL) and b) food waste (FW) for the different food categories throughout the supply chain versus their related economic value. Values expressed in kilograms of proteins per capita.

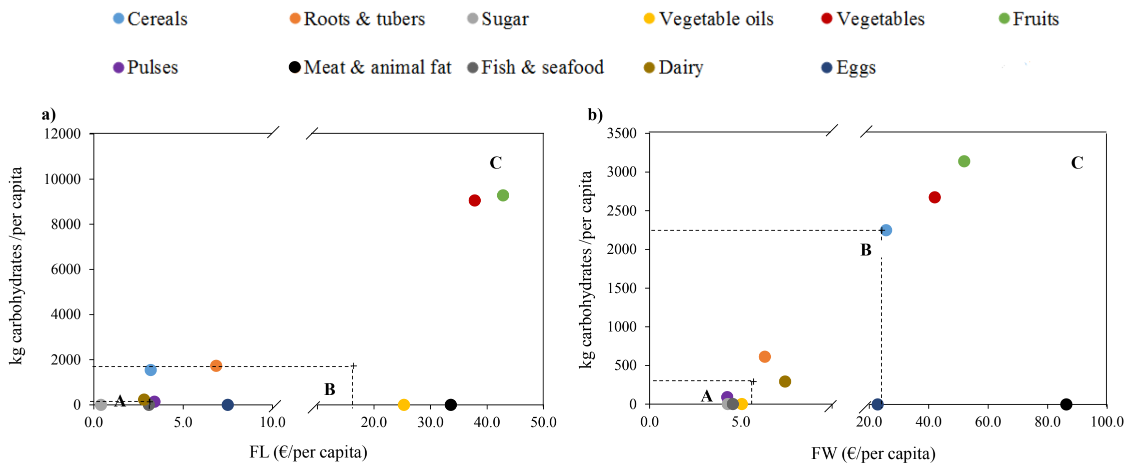

Fig. 9 Carbohydrates composition of a) food losses (FL) and b) food waste (FW) for the different food categories throughout the supply chain versus their related economic value. Values expressed in kilograms of carbohydrates per capita.

Figures 7-9 compare the nutritional content of the FLW for the different food categories to their economic value. FL and FW are disaggregated to distinguish between producers' and consumers' decision-making. Three different NC indicators are assessed: i) energy content (kcal), ii) proteins and iii) carbohydrates. A rating letter is used to sort the different food categories according to the intensity of the nutritional-economic wastage. "A" is for the food categories with less nutritional-economic FLW intensity, while "C" is for those with higher intensity. For example, sugar category show the best rating in terms of energy losses (Fig. 7a). Conversely, its rating is deteriorated to "C", when the energy waste is assessed. On the other hand, the classification of a food category can vary among the different nutritional features. Such is the case of cereals category, which gets "C" for energy losses and "B" for protein and carbohydrate losses. To simplify the decision-making, the rating method scales from "AAA" to "CCC" to be finally translated into global "A" and global "C". This constitutes the Nutritional Food Losses Footprint (NFLF) and the Nutritional Food Waste Footprint (NFWF).

As outlined in Fig. 10, meat, fruits, vegetables and vegetable oils present the worst NFLF (C), since the largest nutritional and economic losses at the beginning of the FSC are attributed to these commodities. As was previously observed, this is essentially due to the losses generated in agricultural production. Therefore, mitigation strategies should be focused to this stage for these categories. The exception is meat category, for which the largest economic and nutritional losses are produced in processing and packaging stage. A better rating (B^-) is observed for cereals, whose NFLF is deteriorated owing to the energy losses, respectively. On the other hand, the best NFLF is observed for dairy and sugar (A), which show the largest nutritional-economic efficiency between agricultural production and distribution stages.

Regarding distribution and consumption stages, the worst NFWF is again observed for meat, fruits, vegetables and vegetable oils (Fig. 10b). On the other hand, the classification is reversed for other categories such as dairy and sugar. This is mainly due to the increase in the price of these commodities at consumption stage with regard to their price at origin, especially for sugary products. Conversely, pulses and roots and tubers categories improve their nutritional-economic efficiency, changing from B to A and B^+, respectively.

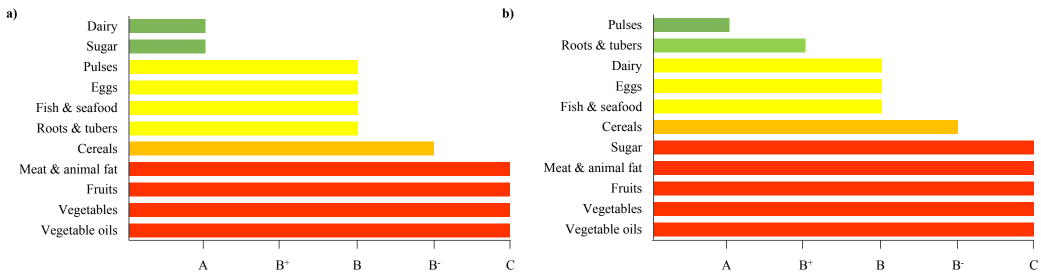

Fig. 10 a) Nutritional Food Losses Footprint (NFLF) and b) Nutritional Food Waste Footprint (NFWF).

3.4 Determination of the potential for FLW reduction

The results for the avoidable and unavoidable food losses and waste are described in Figs. 11-12. As shown, around half of the FL generated from agricultural production to processing could be prevented (56%) compared to the existing situation (Fig. 11a). Again, results suggest that agricultural production is the stage where most improvements can be achieved, since this process is responsible for 77% of the avoidable losses (Fig. 11b). Conversely, the minimum efforts are required in processing and packaging, since this stage only generates 8% of the avoidable losses. Furthermore, Fig. 11a shows how the unavoidability of the losses increases as the food moves through the supply chain, increasing from agricultural production (39%) to processing (63%), which highlights the improvement potential of the first FSC stage. As shown in Fig. 12a, pulses exhibit the highest potential for improvement in FSC efficiency (82%), followed by vegetables (67%). On the other hand, meat and dairy present the largest FSC efficiency since they exhibit the lowest potential percentages of reduction (14 and 19%, respectively).

In terms of FW, the potential for improvement is increased to 75% (Fig. 11a), being the majority of avoidable waste produced in households (76%, Fig. 11c). Extradomestic consumption and distribution stages are by contrast, much less contributing to FW (21 and 3%, respectively). Therefore, the target of the European Parliament of halving food waste by 2030 could be achieved if efforts are essentially addressed to consumers. Regarding food categories, dairy emerges as the commodity with higher potential for improvement (92%), followed by pulses (90%) and cereals (88%). Conversely, meat and fish are the categories less wasted, showing both a 58% potential reduction.

Regarding economic FLW, the potential reduction percentages are similar to those described (Table 1). Results suggest that a 48% percentage of the economic losses could be prevented, while 77% of the economic food waste could be saved. The largest potential for improvement lies in household consumption, where around 160€ per inhabitant and year could be saved.

In nutritional terms, it can be remarked, that almost 1700 kcal per citizen are wasted per year. Assuming 2100 kcal/cap/day as the amount of daily kilocalories needed for an average person to lead a healthy life (Kummu et al., 2012), this would be enough to feed around 37 million citizens.

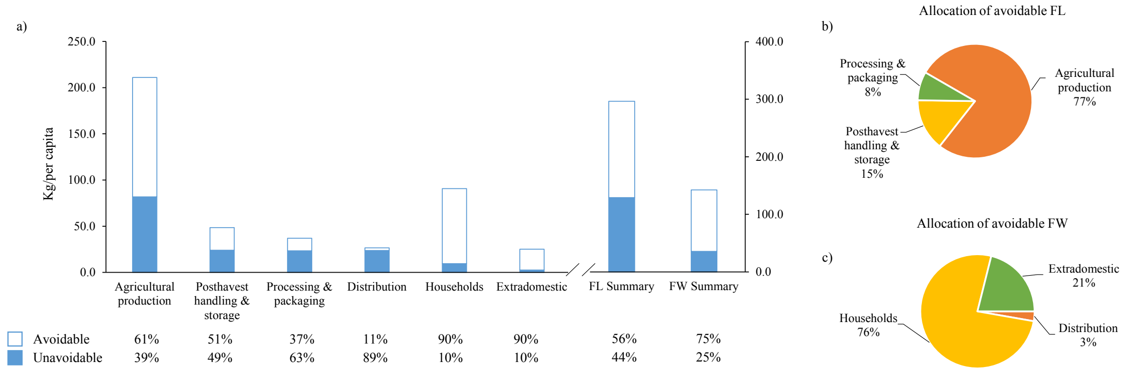

Fig. 11 Results for the potential FLW reduction across the food supply chain. FL refers to agricultural production, postharvest and processing together. FW refers to distribution, households and extradomestic consumption. A: Contribution of the avoidable losses at each stage of the food supply chain. Results are expressed in both kg per capita and percentage over the stage. B: Allocation of avoidable FL. C: Allocation of avoidable FW.

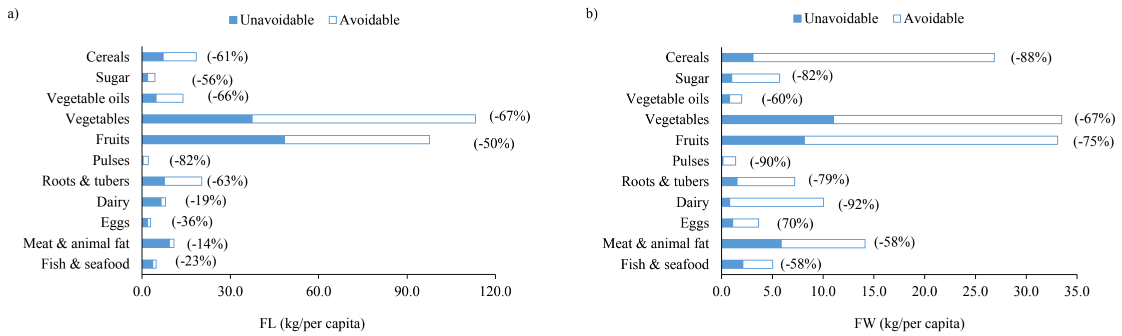

Fig. 12 Results for the potential FL (a) and FW (b) reduction for the different food categories under study. Negative percentages represent the potential reduction that can be achieved for each food commodity owing to avoidable FLW.

Table 1 Results for the potential FL and FW reduction in economic and nutritional terms. Baseline scenario refers to Spain in 2015.

	FL		FW	
	Baseline	**Min. scenario**	**Baseline**	**Min. scenario**
€/per capita	167	87 (-48%)	261	60 (-77%)
kcal/per capita	3,348	1,412 (-58%)	2,110	441 (-79%)
proteins/per capita	4,147	2,024 (-51%)	2,604	818 (-69%)
carbohydrates/per capita	21,968	9,049 (-59%)	9,064	2,075 (-77%)

3.5 Strategies for FLW management

Traditionally, waste management strategies have been defined according to the waste hierarchy, which stablishes a set of priorities for reducing and dealing with waste generation. However, the waste hierarchy have been criticised for being primarily focused on delivering the best environmental option over social and economic factors. Furthermore, food waste is a complex flow, for which specific guidelines are required. Some food recovery strategies have already been proposed, such as the Moerman ladder in the Netherlands (Waarts et al., 2011), the Food Recovery Hierarchy in the United States (USEPA, 2014), and the Food Waste Pyramid in the United Kingdom (Feeding the 5000, 2014). They all prioritise prevention, since the waste management options include downcycling and loss of the intended product (Eriksson et al., 2015).

Our proposal comprises a double pyramid, which combines the FLW management hierarchy to the NFLWF pyramid, as a graphical tool to communicate to Spanish producers and consumers which are the main efforts required and to which food categories should be addressed (Fig. 13). On the left, the classic upside-down pyramid that interprets and applies the waste hierarchy in the context of food waste, ranging the strategies from most to least favourable. The NFLWF pyramid, placed complementary to the former, shows the food categories with higher NFLWF on the top and those with greater nutritional-economic efficiency on the bottom. This approach highlights the importance of considering not only the environmental aspects but also the nutritional and economic perspectives when proposing FLW management strategies.

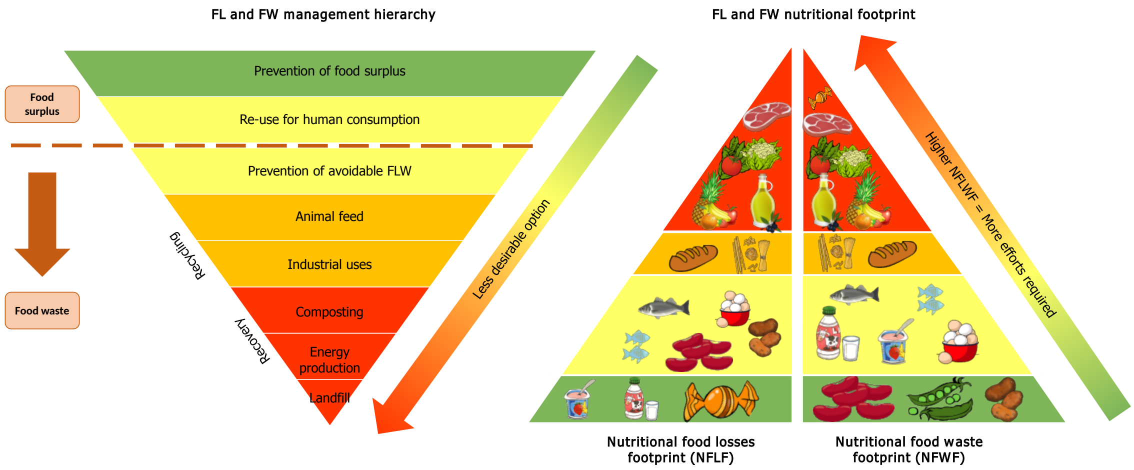

Fig. 13 Food losses and food waste management strategies

As shown in Figure 13, two different levels are first distinguished in the FLW management pyramid based on Papargyropoulou et al. (2014) approach: food surplus and food waste. Surplus food is the edible food that is produced, manufactured, retailed or served but for various reasons is not sold to or consumed by the intended customer (Garrone et al., 2014). The management of surplus food has been highlighted as a critical element to mitigate food insecurity. Strategies associated to its management can be divided into prevention and re-use techniques. The most favourable option is prevention and refers to reducing food surplus by not producing un-necessary food and building awareness regarding sustainable production and consumption. Once prevention via is depleted, donation can prevent food surplus from becoming waste. However, this strategy is essentially eligible for unsellable but not inedible food at supermarkets and post-harvest stage. Regarding the latter, Lee et al. (2017) remark the high uncertainty in both the supply of food (quantity and time) and the supply of labour (volunteer gleaners). It is necessary to develop a regulation framework and introduce strategies that boost and facilitate the donation with the consequent associated social benefits.

The instant food becomes unfit for human consumption it becomes food waste. Then, prevention is again recommended for avoidable waste. For FL, prevention strategies include improving agricultural infrastructure, technological skills and more efficient storage, transport and distribution techniques. Sheahan and Barret (2017) criticise that most FL reduction strategies are posed after harvest, although the compounding effects of pests and deterioration are accumulated before harvest. They suggest cultivar selection and development as one of the most important means of mitigating losses, i.e. investing in high-yielding varieties with long post-harvest lives. For FW, such strategies should consider the improvement of food labelling, better consumer planning when shopping and preparing food, as well as technological improvements in packaging and improving shelf life for perishable foods. Once prevention via is exhausted, recycling strategies are recommended. Recycling into animal feed is the most desirable and then, when no food can be made from food waste, the next best option is to process it into feedstock for industrial processes (e.g. bio-plastics). After recycling via is depleted, recovery strategies are recommended. Some examples are the production of fertiliser through composting, the production of biogas and digestate from anaerobic digestion or the recovery of energy from incineration. Finally, disposal would be the least desirable option.

Since the food biosecurity requirements increase the higher the level in the waste hierarchy, Eriksson et al. (2015) states that there is a decreasing likelihood that the whole waste flow will be suitable for the same type of waste management. There is a need of subdividing the food waste stream, instead of treating it in its entirety. As results suggest, fruits, vegetables, vegetable oils and meat are the food categories with higher NFLF and NFWF and thus require a greater emphasis. Based on the hierarchy previously described, they primarily would need a reduction in their production. This would avoid the destruction of fruits and vegetables, which is often carried out to prevent price falling when there is overproduction (Waarts et al., 2011). On the other hand, fruit and vegetable losses could be avoided by improving agriculture and harvesting techniques or revising marketing standards for fruits and vegetables to increase the sale of these products with deviant shapes, colours or sizes, which are edible but nowadays unsellable. Once prevention via is exhausted, recycling is the next option. As observed in Fig. 13, feeding is the most desirable option. However, FL and FW from animal origin are a potential source of risks to public and animal health and their use is highly restricted (EC, 2009). For example, the use of meat wastes in ruminants (cattle, goat and sheep) diets is banned in the EU because of concerns about Bovine Spongiform Encephalopathy (BSE), a disease that does not affect pigs, poultry, or fish (Salemdeeb et al., 2017). Therefore, animal FLW should be collected separately from those of vegetative origin. After industrial processing, some animal wastes can be valorised into gelatin, protein concentrates, pharmaceuticals and consmetics or bio-based materials (Jayathilakan et al., 2012). These uses are essentially eligible for processing and distribution stages, since food waste generated in the consumption stage is generally of low quality. Otherwise, recovering strategies are the best option. Composting kills pathogens, converts nitrogen from unstable ammonia to stable organic forms, reduces the volume of waste and generates a fertiliser. Anaerobic digestion is also a good choice for stabilization of organic waste owing to the production of biogas and digestate, wich can also be applied restrictedly as fertiliser. Finally, landfilling of organic waste is illegal and then is the last favourable option. It should be highlighted that food categories placed at the bottom of the NFLWF pyramid do not necessarily imply landfilling strategies, but less influence on the efforts pursued.

3.6 Comparison to other studies

The first study on food waste considering Spanish country was conducted by Monier et al. (2010). It estimated that around 7.7 million tons of food were wasted in Spain in 2006, excluding agricultural production and postharvest stages. This is well in line with our estimation for 2015 excluding the same stages (8.3 million tons). Gustavsson et al. (2011) and Kummu et al. (2012) calculated that around a third of the total food production in terms of weight is lost or wasted across the FSC. These findings agree with our study, which estimates that FLW constitutes nearly 30% of the Spanish food production. Estimates of FUSIONS project (Stenmarck et al., 2016) for EU-28 in each FSC stage are also well in line with ours: 33 vs 37 kg/per capita for processing, 21 vs 25 kg/per capita for food service and 92 vs 91 kg/per person for households. The largest disagreement is observed in the first stage of the FSC, namely 'primary production' in FUSIONS project, whose estimation is 15 times lower than ours for agricultural production and postharvest stages together. The reason of such difference lies in the timing and scope of food waste definition.

Following the approach of Monier et al. (2010), the results of this study have been compared to the generation of animal and vegetal waste in Spain; despite animal and vegetal wastes may, in some instances, include some green wastes besides food waste (Eurostat, 2015f). Slurry and manure were excluded from the analysis. Per capita calculation used Eurostat data for 2014, since it is the year for which the most recent Eurostat data is available. In particular, we found that for the sector 'Manufacture of food products; beverages and tobacco products', data agree with our results for the processing stage: 37 vs 37 kg per capita. Conversely, underestimations were found for the rest of stages (i.e. 21 and 19 kg/per capita for agriculture and other sectors, respectively). Limitations in the reliability of Eurostat data were already remarked by Monier et al. (2010), due to the lack of clarity on the definition and methodology for collecting and calculating food waste and lack of information for some sectors.

Finally, Kummu et al. (2012) estimated that approximately half of the FSC losses could be avoided compared to the current situation, lying the largest potential for improvement in agricultural production and consumptions stages as stated in this work. In particular, consumption waste could be reduced by 63% in Europe, while a 75% potential improvement is estimated in this work for FW.

3.7 Limitations of the study

The most significant source of uncertainty in this work is due to the loss and waste percentages used for the calculations. Data used from Gustavsson et al. (2013) are for Europe region and differences among countries are not considered. These percentages have been updated using Spanish studies when possible, although the majority of them have been considered of insufficient quality given the differences in methodologies and FLW definitions. Nevertheless, data from Gustavsson et al. (2013) are the best currently available and considered a good reference for this work.

This study assumes that there is no discrepancy between domestic supply and domestic utilisation (sold production + imports – exports) and, consequently, all goods sold and all imports are consumed, following FAOSTAT approach. However, we have observed a significant gap between the statistical data of production sold in the industry and consumption data according to MAPAMA (2015a). This can be due to the methodological differences behind these studies: they use different product classifications, external trade records movement of goods across borders and it does not distinguish imports and exports involving sales from other flows. Furthermore, the surveys have different thresholds for the minimum size of enterprise that can be surveyed while only 12,000 household consumers are surveyed by MAPAMA recording their daily purchases. Besides, the estimates of this work are considered trustworthy based on the previous comparison and validation with other studies.

Furthermore, it must be remarked that a proportion of food losses and specially food waste are directed to other uses, such as feed, seed or biofuel production. Therefore, although the majority of FLW are unfit for human consumption, a share of them are recycled instead of being lost or wasted.

Finally, the described minimum scenario is an idealisation of the minimum FLW achieved in other regions as stated by Kummu et al. (2012). These loss and waste rates could be unfeasible in the country under study owing to geographical differences or economic, political, and social factors. For example, reducing FLW in the FSC could involve transfer mechanisms and trade-off for other stakeholders, being inefficient in economic terms (Chaboud and Daviron, 2017). On the other hand, avoidable food waste may differ from one country to another, based on cultural, religious, and personal preferences related to what is considered edible. Political and regulatory framework may also constrain the potential to reduce FLW (Kummu et al., 2012).

4. Conclusion

This work estimates the food losses and waste (FLW) in Spain through the food supply chain (FSC) in mass, economic and nutritional terms. Results suggest the importance of reducing FLW, as almost 30% of the national food production is lost or waste along the FSC. Half of this losses are generated in the agricultural production step, being vegetables and fruits the main responsible of this amount. Household consumption is the second main hotspot for food wastage, accounting for 20% of the FLW. Each Spanish citizen is estimated to thrown away 90 kg of food per year, thus awareness campaigns and effort actions should be addressed to this stage.

In fact, when economic wastage is assessed, household consumption becomes the highest contributor (45%), being meat the main food category wasted in economic terms. Our findings emphasise that economic food losses at the beginning of the supply chain are not as significant as at the consumption stages. This can be the reason why no substantial improvement actions are being addressed to agricultural production and harvesting stages, especially for fruits and vegetables categories.

Our study also develops a methodology that balances both nutritional and economic variables to facilitate the decision-making process for the proper food waste management. A Nutritional Food Losses and Waste Footprint (NFLWF) is developed, which distinguishes between food losses (NFLF) and food waste (NFWF). The former is addressed to identify those food categories which require efforts at the beginning of the supply chain, especially in production stage. The later refers to the consumption step and it can serve as a label to create awareness among consumers.

In particular, Spanish country, which is characterised by a Mediterranean diet, requires the development of strategies for fruits, vegetables and meat, which are the food categories with higher NFLWF regarding both FL and FW. This work suggests that efforts should be addressed to food categories with higher NFLWF, for which specific-oriented strategies are required. The

Furthermore, we estimate the potential for FLW reduction through the quantification of avoidable and unavoidable FLW. Our results suggest that around half of the FL generated from agricultural production to processing could be prevented (56%) compared to the existing situation. This percentage is increased to 75% for FW. In economic terms, it means that 160€ per citizen could be saved per year. Finally, it is estimated that around 37 million extra people could be fed if FW are reduced.

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SUPPLEMENTARY MATERIAL

Contents

Section S1- Food categories

Table S1 Food commodities included in the study

Food category	Commodities included
Cereals	Wheat, rice, maize, others
Roots & tubers	Potatoes
Sugar	Sugar
Vegetable oils	Sunflowerseed oil, palm oil, olive oil, others
Vegetables	Tomatoes, onions, other
Fruits	Oranges and mandarines, grapes (excluding wine), apples, others
Pulses	Beans, peas, others
Meat & animal fat	Bovine meat, mutton and goat meat, pigmeat, poultry meat
Fish & seafood	Fish and seafood
Dairy	Milk, cheese, butter
Eggs	Eggs

Section S2- Food losses and waste calculations

Table S2 Food balance sheet (FBS) for Spain in 2015 All values in 1000 tonnes.

	Domestic supply					Domestic utilisation				
	Prod	Import	Stock	Export	Total	Food[(1)]	Feed	Seed	Losses[(2)]	Oth. Use
Cereals	19861	14313	-37	1021	33117	6583	23957	1782	197	599
Roots & tubers	2284	685	113	287	2795	2188	102	77	102	325
Sugar	512	1368	-53	195	1632	1619	0	0	0	13
Vegetable oils	3840	1822	-601	1262	3800	1941	0	0	0	1858
Vegetables	14123	1061	78	5520	9742	7523	484	0	1735	0
Fruits	16201	1623	-56	7907	9861	8507	11	0	858	485
Pulses	503	221	30	21	733	316	317	62	38	0
Meat & animal fat	6053	389	0	1636	4806	4806	0	0	0	0
Fish, Seafood	1191	1627	6	1062	1762	1686	75	0	0	1
Dairy	8104	593	0	199	8498	6318	1689	0	0	492
Eggs	2040	30	13	176	1907	1725	3	138	41	0

(1) Includes also the amount of the commodity available for human consumption as part of mixed processed food products, containing different types of commodities.

(2) Refers to the amounts of commodity lost during handling, storage and transport between production and distribution, i.e. postharvest and storage stage. Losses occurring during the pre-harvest and harvesting stages are excluded from this table.

Table S3 Food losses and waste percentages for each food category as a percentage of what enters in each supply chain stage. Unless stated otherwise, percentages are obtained from Gustavsson et al. (2013) for Europe region.

	Agricultural production	**Postharvest handling & storage[2]**	**Processing & packaging[3]**		**Distribution**		**Consumption**	
			Milling	**Proc.**	**Fresh**	**Proc.**	**Fresh**	**Proc.**
Cereals (%)	4.60	1.0	1.80[4]	10.00	2.00	2.00	25.00	25.00
Roots & tubers (%)	26.05[1]	4.5		14.70[4]	7.00	3.00	17.00	12.00
Sugar (%)	24.98[1]	0.00		2.00	10.00	2.00	19.00	15.00
Vegetable oils (%)	21.86[1]	0.00		5.00	1.00	1.00	4.00	4.00
Vegetables (%)	26.05[1]	12.3		2.00	10.00	2.00	19.00	15.00
Fruits (%)	20.77[1]	5.30		2.00	10.00	2.00	19.00	15.00
Pulses (%)	24.98[1]	7.5		5.00	10.00	2.00	19.00	15.00
Meat (%)	3.20	0.00		6.30[3]	4.00	4.00	11.00	11.00
Fish & seafood (%)	9.40	0.00		6.00	9.00	5.00	11.00	10.00
Dairy (%)	3.50	0.00		1.20	0.50	0.50	7.00	7.00
Eggs (%)	4.00	2.03		0.50	2.00	2.00	8.00	8.00

(1) Extracted from MAPAMA (2013a) for Spain.

(2) Postharvest handling & storage percentages were estimated from the FAO Food Balance Sheets for Spain in 2013 (FAO, 2015) and assumed to be maintained for 2015.

(3) Conversion factors were used to determine the average proportion of commodities used fresh: roots & tubers, 27%; vegetables, fruits and pulses, 40%; fish & seafood, 4% (Gustavsson et al., 2011).

(4) Extracted from MAPAMA (2013b) for Spain.

Allocation factors were used to determine the part of the agricultural product intended to human consumption in the estimation of agricultural and postharvest losses. These factors were calculated from Table S2. For food categories not reported in Table S4, allocation factor equal to unity were assumed.

Table S4 Allocation factors

	Cereals	**Roots & tubers**	**Vegetable oils**	**Vegetables**	**Fruits**	**Pulses**
Allocation factor	0.20	0.78	0.51	0.77	0.86	0.43

Section S3- Economic FLW calculation

Table S5 Prices at origin, wholesale and consumer level for the food categories under study

	Production (€/kg)	Wholesale (€/kg)	Retail (€/kg)
Cereals	0.2	0.2	1.0
Roots & tubers	0.3	0.4	1.0
Sugar	0.0	0.4	0.8
Vegetable oils	1.8	2.2	2.7
Vegetables	0.3	0.6	1.5
Fruit	0.4	1.0	1.7
Pulses	1.6	2.0	3.5
Meat & animal fat	2.7	3.4	7.2
Fish & seafood	0.6	0.7	1.0
Dairy	0.3	0.6	0.8
Eggs	2.5	3.8	7.0

Section S4- Nutritional FLC calculation

Table S6 Proteins, carbohydrates and energetic content for the food categories under study

	Proteins (%)	**Carbohydrates (%)**	**Kcal (per 100 g)**
Cereals	10	84	362
Roots & tubers	12	85	73
Sugar	0	0	408
Vegetable Oils	0	0	887
Vegetables	18	80	22
Fruits	4	95	51
Pulses	29	65	303
Meat	50	0	164
Fish & seafood	89	0	83
Dairy	19	29	65
Eggs	34	0	150

Section S5- Avoidable and unavoidable FLW calculation

Table S7 Unavoidable food losses and waste percentages for each food category as a percentage of what enters in each supply chain stage.

	Agricultural production	Postharvest handling & storage(2)	Processing & packaging(3)		Distribution		Consumption	
			Milling	Proc.	Fresh	Proc.	Fresh	Proc.
Cereals (%)	2.00	1.0	0.50	3.50	2.00	2.00	1.00	1.00
Roots & tubers (%)	6.00	4.5		**10.00**	3.00	2.00	2.00	1.00
Sugar (%)	10.00	0.00		2.00	8.00	2.00	5.00	1.00
Vegetable oils (%)	6.00			5.00	1.00	1.00	1.00	1.00
Vegetables (%)	6.00	0.00		5.00	1.00	1.00	1.00	1.00
Fruits (%)	10.00	4.00		2.00	8.00	2.00	5.00	1.00
Pulses (%)	10.00	4.00		2.00	8.00	2.00	5.00	1.00
Meat (%)	6.00	0.00		2.00	1.00	1.00	1.00	1.00
Fish & seafood (%)	3.10	0.00		5.00	4.00	4.00	2.00	2.00
Dairy (%)	5.70	0.00		6.00	9.00	5.00	2.00	1.00
Eggs (%)	3.50	0.00		0.10	0.50	0.50	0.10	0.10

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