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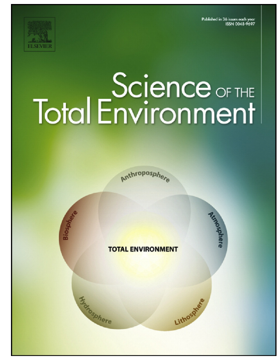

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Towards transparent valorization of food surplus, waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy

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Abstract

In this study, the key gaps of food waste prevention been addressed in the context of the emerging circular economy. First, current terminology related to food waste was reviewed and clarified, in particular, the terms food surplus, waste and losses. This work highlights why the clarity of these definitions is crucial for the sustainability of future food waste management systems, especially in the context of circular economy. Through a simple matrix, definitions are linked to the concepts of edibility and possibility of avoidance, leading to six distinct categories of food waste: i) edible, ii) naturally inedible (pits), iii) industrial residue, iv) inedible due to natural causes (pests), v) inedible due to ineffective management and vi) not accounted for. Category I encompasses surplus food only; category II-V food waste and category VI food losses. Based on this, an updated pyramid for food waste hierarchy is proposed, distinguishing surplus food and a new category for material recycling, in order to reflect the future food waste biorefineries in the circular bioeconomy. Nutrient and energy recovery are two separate categories and the terms recovery and recycling are clarified. Finally, a circular economy framework is presented for food surplus and waste, considering closing the loop throughout the whole food supply chain, in connection with the concept of strong and weak sustainability. This is presented along with a review of key EU policies related to food waste and examples of initiatives from the Member States.

Keywords: biorefinery, circular bioeconomy, food waste, minimization of residues, policy, strong sustainability

[1]Abbreviations

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AD Anaerobic digestion

1. Introduction

Food waste (FW) has been recognized as a global issue due to its environmental (UNEP, 2014), economic (Garrone et al., 2014), and social (Evans, 2011) impacts with global consequences, requiring a change in political actions (Evans et al., 2012; WRAP, 2013; IFPRI, 2016; EC, 2018; Searchinger et al., 2019). Food waste and losses mobilize a remarkable amount of natural resources. It consumes around 25% of all water used by agriculture each year (Searchinger et al., 2019); 23% of all cropland, equivalent to all cropland in Africa (Kummu et al., 2012); while it generates around 8% of annual global greenhouse gases (GHG) emissions (IPCC, 2019). The International Panel of Experts on Sustainable Food Systems (IPES) identified that 20% of the food produced in European Union (EU) is wasted with the cost of 143 billion euros annually, including wasted resources and environmental impacts (IPES, 2019). Half of all vegetable grown is lost or wasted before reaching the consumer (by mass; Henningsson et al., 2004). Social and ethical dilemma

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CAP Common Agricultural Policy

CE Circular Economy

EoL End-of-life

EPA Environmental Protection Agency

EWC European Waste Codes

FFV Fresh fruits and vegetables

FSC Food supply chain

FSWL Food surplus, waste and loss

FW Food waste

GHG global greenhouse gases

IFPRI International Food Policy Research Institute

SDG Sustainable Development Goal

WFD Waste Framework Directive

touches upon, among others, the undernourished of 815 million people (FAO, 2017) while excessive consumption in high-income countries leads to billions of tonnes of quality food thrown away (Kummu et al., 2012). Reynolds et al. (2015) estimated that 921,000 people, i.e. the equivalent of the whole population of Fiji in 2019, could be annually fed by all avoidable food waste in Australia.

In parallel, the growing need for energy and materials to supply the demands of a fast-growing and resource-intensive population is forcing a shift from a linear to a circular economy. Circular economy treats waste as a secondary resource (Ellen MacArthur Foundation, 2013). The EU has implemented an action plan for the Circular Economy, which includes also a commitment to meet the global Sustainable Development Goal (SDG) 12.3 to "halve per capita food waste at the retail and consumer level, and reducing food losses along production and supply chains (including post-harvest losses) by 2030" (Flanagan et al., 2018). Circular Economy is redefining the framework conditions for the waste management of food waste (and for other types of waste), creating new business opportunities. Food waste can be used to produce various biomaterials (Mirabella et al., 2014), bioenergy (Dahiya et al., 2018), as well as high-value products (Strati and Oreopoulou, 2014; Teigiserova et al., 2019).

Yet, being at the inflection point between the linear and circular paradigms it is important to ensure that any new management model for food prevention and food waste usage will be sustainable, i.e. stay within planetary boundary guardrails (Rockström et al., 2009; Steffen et al., 2015). Adopting the concept of strong sustainability for European bioeconomy instead of weak sustainability can be a crucial step in this endeavor.

However, there are several challenges towards food waste prevention and towards a sustainable food waste management system within the emerging circular bioeconomy. The first one considers the variable definitions of food waste, and therefore the possibility of developing coherent regulatory metrics for quantification (accounting). Actual global losses are an estimate (Parfitt et al., 2010). The existing data include high uncertainty (Corrado et al., 2019) and different scopes for measurements, making extrapolation and comparison of data very challenging.

The second challenge lies in a failure to distinguish food waste into appropriate categories that could be linked with a corresponding waste hierarchy. The current waste hierarchy is not properly distinguishing terminology in accordance with sustainable management. The terms used in the hierarchy do not have a clear scope and are often used as synonyms, such as "food loss" and "food surplus", "recycling" and "reuse", "recycling" and "recovery" (UNEP, 2014; Bernstad Saraiva Schott et al., 2013). A food waste hierarchy distinguishing food surplus and waste, but not clear end-of-life (EoL) pathways, was proposed by Papargyropoulou et al. (2014), while Garcia-Garcia et al. (2017) expanded EoL the most, but with no distinctions of surplus, waste and loss, and U.S. EPA classified industrial use in their hierarchy (Dou et al., 2016). Although there is an agreement on the prevention and avoidance of disposal, there is a continuing discussion and confusion in other EoL treatments. There is a need for clarification and harmonization combining feedstock specifics, surplus food, and food waste as a secondary resource and its EoL treatments. As waste hierarchy is used in policies, this lack of clarity can result in regulations that are not aligned, such as European marketing standards that lead to wastage of nutritious food that could have been prevented (Priefer et al., 2016).

In light of these issues, the goals of this article are as follows:

1. Summarize current food waste terminology and definitions and propose a clear-cutting categorization for the various types of food waste, losses and surpluses

2. Update the food waste hierarchy and link it to the categories of food waste developed in (1)
3. Introspect current policies and framework affecting food surplus and waste circular economy efforts in the European Union and their relation to strong and weak sustainability
4. Propose a framework for food waste management in a circular economy in the context of strong sustainability, complementing the existing one for non-organic waste

2. Definitions

2.1 Food waste according to regulation and science community

As many times pointed out, the definitions of food waste differ significantly in the literature and require harmonization in order to accomplish efficient quantification to assess the wastage of food (Hamilton et al., 2015; Thyberg and Tonjes, 2016; Xue et al., 2017; Hartikainen et al., 2018, EC, 2018). The difference in the definitions results in a wide range of food waste estimates (Bellemare et al., 2017) with limited comparability and usefulness in relation to measuring the distance to SDG 12.3. Several initiatives attempted to harmonize methodologies and definitions for FW, such as the FUSIONS quantification manual (Tostivint et al., 2016), the REFRESH project (Wunder et al., 2018), FLW (FLW, 2016) through its "FLW quantification ranking tool", and Champions 12.3, which includes monitoring indicators to achieve SDG 12.3 (Flanagan et al., 2018).

In Europe, definitions from European policies are considered vague and left to interpretation by the Member States in order to adapt them for national circumstances and priorities (HCWH Europe, 2017; EC, 2018a). To illustrate this lack of harmonization, a key EU directive, namely the Waste Framework Directive (WFD – 2008/98/EC) does not differentiate FW from other types of organic waste (such as garden waste) (European Parliament, 2008).

A recent study by the International Food Policy Research Institute (IFPRI) highlights the urgency for common definitions throughout the whole food supply chain (FSC) including pre-harvest losses (IFPRI, 2016). Among others, the distinction between agricultural waste and food waste needs to be clearer, as to how exactly these wastes differ and in this respect how to refine definitions to eliminate their overlap. As stated in the widely used definition of the landmark EU-funded project FUSIONS, pre-harvest waste (including "not mature" crops and dead animals) does not count as food waste, meaning that all pre-harvest waste is quantified as agricultural waste (Östergren et al., 2014).

Yet, animals and fish can be consumed before they reach maturity for the market they are intended. Hartikainen et al. (2018) argue that these should be counted as food waste as they can be slaughtered at any stage of maturity and used for food (i.e. introduced in the FSC). The study also argues that the inedible part should not be included in the food waste definition. One rationale for this is that only edible parts of food can be considered for prevention and redistribution to malnourished. However, there is no universal standard of what is edible and what is not. Distinguishing inedibility and edibility is rather subjective and differs not only from country to country but, also by consumer's preference. For example, dishes prepared from chicken feet are consumed in Asian regions while in European countries it is generally considered inedible. Within the same region, kiwi peels may be eaten by some individuals while being considered inedible by others. The common terminology should support both social and environmental goals, distinguishing edible, which is meant for prevention and redistribution to malnourished, and inedible for further EoL valorization, such as animal feed or bio-based products.

2.2 Clarifying terminology

A variety of terms have been used to describe waste in connection to food, in particular, the terms “food loss”, “food waste”, and “surplus food”. The most common definition of these three main terms and their connection to the FSC are represented in Table 1. Here, five stages of the FSC are distinguished: agricultural production, post-harvest activities, processing and manufacturing, retail and wholesale, consumption and services. Agricultural production consists of pre-harvest primary production, which is usually excluded from food waste, as only post-harvest activities are included.

Food loss often refers to the post-harvest and processing stage (FAO, 2011; Thyberg and Tonjes, 2016), but sometimes includes food loss at any stage of the FSC that is still suitable for human consumption, albeit unmarketable for aesthetic reasons (Kantor et al., 1997). It can refer to an unintentional loss in quality or quantity. However, the term “food waste and loss” is often used as one category, therefore leading to overlapping (FAO, 2014; Girotto et al., 2015). The definition of food loss has major implications, as the term is used in policies. Notably, the EU Common Agricultural Policy (CAP) argues that only food loss, and not FW, is generated during primary production (European Court of Auditors, 2016). This implies that any food items wasted at the pre-harvest/agricultural stage would be part of food loss with no FW reported, while “food waste and losses” would be reported at the other stages.

Surplus food represents the leftover edible food fit for human consumption. It can often refer to the retail and consumption stages of the FSC (Garrone et al., 2014), but also to overproduction at the agricultural e.g. primary production stage (Papargyropoulou et al., 2014). Parts of the surplus food and food loss become food waste either due to naturally inedible parts or to unconsumed parts that degrade (Papargyropoulou et al., 2014).

Institutions and scientific communities use the terms food "surplus", "loss" and "waste" presented in Table 1 to form boundaries and scope for research methodologies and accounting, as presented in Table 2. Different boundaries for the terms and definitions of food waste lead to results that are very challenging to compare or use to feed action plans or specific interventions.

From this point onwards, the acronym FSWL will be used to represent the overall food surplus, losses and waste (for which the single term "food waste" is often used).

Here, this work proposes that surplus food only encompasses the nutritional surplus of food fit for human consumption, to reflect that people are inclined to eat leftovers, but less likely to eat what is considered "waste". Even though surplus food is originating primarily after the agricultural stage, there are cases when food can be consumed prior to post-harvest activities, such as consumption of not-mature animal mentioned by Hartikainen et al. (2018). Food waste is then food that cannot be expected to be eaten by humans, due to either natural inedibility or inedibility due to the management of food, throughout whole FSC as proposed in IFPRI (2016) and Bellemare et al. (2017). In this context, and in the perspective of complete material flow assessments, food loss should only refer to the streams that are truly lost, i.e. inexplicable, whether because "not accounted for" or disappearing from the accounting. Examples include the discrepancies of the FW stream when transporting food items (reported outputs not matching the initial inputs). *(INSERT TABLE 1 and 2 HERE)*

3. Clarifying and updating hierarchy for food surplus, waste and loss

3.1 Expanding the levels of the waste hierarchy

The waste hierarchy is built upon strategies introduced in the 1970s by the European Parliament's Directive on Waste (European Parliament Council, 1975) and the European

Commission's Second Environment Action Program (European Commission, 1977), later refined into the waste hierarchy in the EU's legislation (European Parliament Council, 1989). The waste hierarchy provides a guide to choose the most environmentally-efficient EoL treatment (European Parliament Council, 2008). Since the hierarchy is a very general way for prioritization of EoL treatment, actors and institutions can interpret its meaning in different ways to achieve their goals, which is mainly a consequence of the unspecific terms used in the hierarchy. For instance, feeding to animals can belong to the reuse and recycling category, and bio-based products can belong to both recycling and recovery (UNEP, 2014; Bernstad Saraiva Schott et al., 2013). Moreover, EUROSTAT states "the only reasonable treatment of biowaste is composting or anaerobic digestion" (EU Open Data Portal, 2019). This assumption points towards a lack of databases for sharing waste information and technologies. Adopting a separated waste hierarchy for FSWL is perceived as promising to increase the efficiency of prevention and reuse (European Of Court Auditors, 2016; Wunder et al., 2018), but has not been adopted by the new Waste Framework Directive (Official Journal of the European Union, 2018).

As for the waste hierarchy, prevention is found on top of the FSWL pyramid. This means that the greatest efforts are to be placed on keeping edible food edible. Prevention can be achieved via various pathways at the source either through better logistics and management tools (production, processing and retail level), or targeting consumer's education, behavior, and consumption habits (consumer level) (Papargyropoulou et al., 2014; Garrone et al., 2014). In particular, these efforts are to be targeted first and foremost on the most resource-intensive and polluting food items, in particular, red meat and dairy products (Hedenus et al., 2014; Stoll-Kleemann and O'Riordan, 2015; Searchinger et al., 2019). In other words, it weights more to prevent e.g. beef to reach the FSWL management chain than preventing e.g. vegetables to reach the FSWL.

The second level represents reuse for human consumption. Surplus food is the only fraction that can be directly reused for human consumption and is often part of the prevention strategies or studies (Mourad, 2016; Garrone et al., 2014). Due to food's highly degradable nature, reuse of surplus food is tied to strict safety and hygiene norms, which can limit the quantity of reused food and by consequence increase FW (Priefer et al., 2016).

As the animal feed sector has its own food safety rules, it is a distinct reuse category, coming after reuse for humans for obvious ethical reasons. In this perspective, the vision is that surplus food is reused exclusively for humans, while food waste may be re-used by animals (and never by humans). The safety precautions for reusing food waste for animal feed needs to ensure prevention of incidents, such as Bovine spongiform encephalopathy (BSE) and foot and mouth disease (FMD) (Tomley and Shirley, 2009; Henningsson et al., 2004). The European Commission has recently published the Guidelines for FW to animal feed (EC, 2018b), with a restriction on the reuse of the meat waste and its residues. If this fraction would be heat-treated it could be used for feeding omnivorous non-ruminants (Wunder et al., 2018) increasing considerably the amount of animal feed available. Heat-treatment can be expensive and if not incentivized, the application of other cheaper technologies will be prioritized by the industry, such as incentivized biomass to energy (Wunder et al., 2018). The latter is often a consequence of targets to reach high shares of overall renewable energy (in Europe: 20% by 2020 and 32% by 2030) (European Council, 2018).

Moving down the hierarchy, "recovery" and "recycling" are often used interchangeably even though they are two separate categories. For example, anaerobic digestion (AD) is sometimes included in recovery (as energy recovery in Braguglia et al., 2018) and other times in recycling (UNEP, 2014). As AD involves not only biogas but also digestate production, it is considered by the EU waste legislation as a recycling valorization (EC, 2018a). Redistribution of food is sometimes referred to as "recovery" (Garrone et al., 2014), while FW used as animal feed can be counted as "recycling" (Mourad, 2016).

Therefore, nutrient and energy recovery are to be in two separate categories for the reason that these are two distinct services with foreseen differentiated importance in the future. Especially in the context of safe operating space, where biogeochemical flow boundary of nitrogen cycle has been already surpassed (Rockström et al., 2009), and the concerns about the depletion of phosphate rock (Van Vuuren et al., 2010). The specific case is anaerobic digestion (AD) of food waste, which provides both fertilizer (as degassed biomass e.g. digestate) and energy (as methane or storable hydrocarbon), and therefore can fit either of the categories. Here, the intended service of AD (energy or nutrient), i.e. the one that justifies why AD takes place, should be the one determining to which category AD belongs (for the case considered). As the digestate represents a large portion of the material output, about 80% of incoming biomass (Pehme et al., 2017; Hamelin et al., 2014), it is considered primarily as nutrient recovery if applied as fertilizer. If fertilizer is not applied due to various reason, such as local regulation then AD belongs to energy recovery. Further, food waste is regarded as a secondary material resource for the economy, just as plastic, glass or metal scraps. This means that e.g. "recycling" refers to material recycling that does not involve complete degradation as is the case of energy and nutrient recovery. In doing so, recycling then targets products that can be re-introduced into the economy, taking into account economic value, such as market price. Including the economic value into the hierarchy has been urged by a number of economists (Rasmussen et al., 2005; Papargyropoulou et al., 2014). Thus, recycling considers higher-value products, such as bio-based chemicals and products that range around 1-50,000 USD/kg (Teigiserova et al., 2019), but excludes fertilizer, compost and other land application valorization with lower economic value and/or market size. In a nutshell, surplus food is prevented first, followed by reuse for human consumption (reuse-H), while food waste is considered for reuse for animal feed (reuse-A), to be prioritized over the material recycling, followed by the nutrient recovery, and finally used for the energy recovery, with the disposal avoided. These suggestions are represented as a revised food waste (and surplus) pyramid in Figure 1. *(INSERT Figure 1 HERE)*

3.2 Categorization of food surplus, waste and losses

Depending on the ambient conditions and food's nature some parts of the food are bound to become a waste. However, there is a difference between natural inedibility of food, such as bones and pits, and inedibility as a consequence of food degradation, such as rotten food. Both cannot be expected to be eaten by humans, but while the first one cannot be avoided, the second one can be avoided to some extent, making it partly avoidable.

Table 1 provided a clarified overview of the terminology used for FSWL, its use in earlier studies in Table 2. Using these definitions further, a matrix is developed, Table 3, connecting FSWL to the concepts of edibility and avoidance. This allows categorizing of FSWL according to six useful and distinct categories. Category I encompasses all edible food that is fit for human consumption; hence the surplus food. Category II cannot be avoided due to foods natural inedibility. Category III, on the other hand, can be minimized by process-optimization, though it also cannot be avoided fully. Categories IV and V cover cases where inedibility cannot be avoided completely, due to food's high perishability (category V) or due to unpredicted conditions (damages by weather or pests; category IV). Especially when transporting or dealing with large quantities, some of the food is bound to be damaged. Such waste can include mold formation due to inappropriate storage, defects from handling, etc. Further, category V is differentiating the situations where the lack of resources (poor functioning of the FSC) prevents efficient management to those where inefficient management is due to negligence. The former are the situations where the actors cannot easily make a direct change, due to the unavailability of appropriate infrastructure, cold storage, institutional and legal frameworks, etc. (mostly, but not exclusively, associated with monetary resources). The latter situation represents cases where actors have all the resources to implement changes, but edible food has been spoiled, damaged, or left uneaten after preparation. Finally, the last category (VI) belongs to previously discussed loss or “amounts not accounted for”. *(INSERT Table 3 HERE)*

Surplus food can be decreased on each level of the FSC (Dahiya et al., 2018) and thus prevented (Figure 1), while food waste cannot. At the consumer stage, “partly avoidable” food waste can be defined on the basis of consumer habits, such as bread crumbs or potato peels that are naturally edible and therefore it is considered as surplus food. On the retail stage of the FSC, surplus food is often not re-distributed in time due to transportation and distribution costs, despite the best prevention efforts. In fact, most food items need to be reused immediately, but the distribution usually waits until the quantity of food is high enough to cover the costs/generate a profit (Buzby et al., 2014). Therefore, when prevention fails, surplus food (category I) becomes food waste (category V).

The inedible fraction of food (categories II-V) represents a big potential for material recycling, which can be seen from the increased interest from the scientific community on industrial use of food waste as a secondary resource input for biorefineries (Mirabella et al., 2014; Galanakis, 2012). Material recycling is unlikely to happen for consumer mixed waste as these streams are would require heavy processing to extract higher value products. In the perspective of material recycling, avoidable and partly avoidable waste is thus interesting due to large quantities of homogeneous waste that can be used as a secondary resource. According to the hierarchy presented in Figure 1, material recycling should be considered as a preferred treatment for food waste when it cannot be used for animal feed. Hence, developing strategies for recovering streams from unavoidable (category II and III) and partly unavoidable (category IV and V) food waste could generate economic and environmental benefits as these streams are always present. For instance, in the unforeseen event of a storm or a frost, large amounts of category IV waste could be generated which could feed existing material recycling facilities. The use of category V waste for material recycling appears less plausible, though not to be excluded the moment large quantities are generated. In some cases, partly avoidable FW may be reduced upon intensifying short value chains (Kneafsey et al., 2013; Michalopoulos, 2018), as exemplified in the Horizon 2020 project DECISIVE (DECISIVE, 2019).

4. Ensuring regenerative circular bioeconomy for FSWL

4.1 Importance of strong sustainability for the target goals and decision-making

Re-introducing and re-circulating streams through the economy also referred to as closing the material & resource flow loop, is generally perceived as sustainable. Yet, there is a need to differentiate weak and strong sustainability, and to anticipate externalities in the future circular economy (Pizzol et al., 2014; Lopes et al., 2011).

Sustainability science and industrial ecology often distinguish between natural, human, and manufactured capital, and a large body of work have studied their interrelations (Weisz et al., 2015). In a nutshell, manufactured capital represents material goods, services, or infrastructure beyond those found directly in nature, while natural capital encompasses natural resources and ecosystem services. Alongside these terms, sustainability science also distinguishes between strong and weak sustainability. Weak sustainability (WS) sees natural and manufactured capital as substitutable, strong sustainability (SS) sees them as complementary and highlights the need to conserve critical natural capital (Pelenc and Ballet, 2015; Ang and Van Passel, 2012).

Prevention and environmental impacts are difficult to translate into economic measures as opposed to direct economic savings. Therefore, regulatory instruments are needed to enforce the changes towards strong sustainability to ensure strong sustainable development, restoration and conservation of natural resources by staying inside the ecological ceiling of a safe operating space for humanity (MEA, 2006; Rockström et al., 2009; EU, 2018, Decision No 1386/2013/EU; European Parliament, 2013). One example of such regulatory instruments is the use of taxes and subsidies as proposed by The Lancet Commission (2019) and IPCC (2019). Specific examples of measures affected by these taxes and subsidies include: sustainable cultivation of crops and their inclusion into healthy diets; subsidies for purchase of suboptimal (such as misshaped vegetable) food or its sale in separate category in shops for lower prices (Aschemann-Witzel et al., 2015); donations of food for food banks (Searchinger et al., 2019), and general prioritization of restorative business models; and payment for ecosystem services (IPCC, 2019).

Kummu et al. (2012) argued that around 20% of the total use of water, cropland and fertilizers are used to produce surplus food ending as food waste, which could have been avoided upon adopting environmental and socially responsible business models according to the strong sustainability principles. Effective (or strongly sustainable) application of SDG 12.3 on surplus food prevention would imply a need for policy regulations that incentivize the implementation of upcycling technologies ensuring that the exchanges between the technosphere and the natural environment lead to healthy ecosystems. This touches upon SDG 3.9 that calls for a reduction in the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination. The vision is that the implementation of upcycling technologies needs an integrated plan for eliminating micro-pollutants and their recirculation or concentration back to the technosphere. Conservation of healthy soil ecosystems (e.g. SDG target 2.4) is needed to avoid externalities on human health connected to the micro-pollutants exposure, such as heavy-metals (Thomsen et al., 2012; Pizzol et al., 2014).

Yet, to be more than a mere concept, SS needs to be measured, which in turns requires metrics and indicators. The European Union plans to develop indicators for measuring resource efficiency in the circular economy, including food waste (EC, 2018a; EC, 2018b). To this end, the conventional use of current EU's waste codes (EWC) by the Member States is not sufficient, as it does not captures separate categories and classification of FW and therefore must be expanded and updated to improve FW data in EU's Member States. Further support in decision-making was suggested by the Commission as a way to monitor the progress of Circular Economy by means of ten indicators divided into four thematic areas: Production and Consumption; Waste management; Secondary raw materials; and Competitiveness and Innovation (Eurostat, 2019). All four areas can help to address FSWL and monitor its use as a secondary resource. For instance, the thematic area Secondary raw materials consist of three indicators that can help integrate FW into CE: 1) Contribution of recycled materials to raw materials demand, 2) Circular material use rate, 3) Trade-in recyclable raw material.

4.2 Ensuring strong sustainability in EU's legislation

In the EU, until very recently, FSWL as a policy issue was not explicitly defined and therefore neither properly addressed (Blakeney, 2019; European Of Court Auditors, 2016). The Landfill Directive is a driver for putting the waste hierarchy forward, while the Waste Framework Directive is the cornerstone of the Circular Economy. The largest step in recognizing the food waste issue was the adoption of a key non-legislative act, namely the Roadmap for a resource-efficient Europe in 2011, which established that "by 2020 […] the disposal of edible food waste should have been halved in the EU" (EC, 2011); now expressed in the SDG 2030 target 12.3 for the whole world. More recently, the Circular Economy Package included legislative proposals on food waste (EC, 2018a), as part of mobilizing the actions for the reduction of FSWL and its use as a secondary resource. While the Circular

Economy Policy Package (EC, 2015) aims to close material loops through the recycling and reuse of products, the Bioeconomy Strategy (EC, 2018a) is a research and innovation vision aimed at enhancing the exploitation of biomaterials while restoring natural resources and ecosystem health. It has recently been suggested to combine these two strategies into the concept of "Circular Bioeconomy" (EEA, 2018). A circular bioeconomy would address ecosystem health-restoring resource flows, biodiversity aspects and nutrient cycles, local FSC and biorefineries to diversify income and contribute to the substitution of emission-intensive fossil-based production systems by biobased chemicals, ingredients and products (EEA, 2018). The European Commission intends to implement authorization procedures for over a hundred of safe recycling processes including food contact materials to ensure food safety and reduce food waste (EC, 2018c). Table 4 provides examples of frameworks and policies that have taken steps towards strong sustainability when it comes to FSWL throughout the FSC. A more detailed overview of policies that touch upon FSWL has been provided by the EU project REFRESH (Wunder et al., 2018), focusing on SDG 12.3. *(INSERT Table 4 HERE)*

Furthermore, while many of the currently used quantifications are proxy from the project FUSIONS (data from 2014 and older), there are some quantification estimates from Portugal (Medeiros and Swatuk, 2013), Italy (available in Italian, Garrone et al., 2012), France (available in French; Garot, 2014), and Hungary (Bori, 2018), and the estimates using 2010 values from Eurobarometer (European Parliament News, 2017). This highlights the need for more recent quantifications at national level, especially in light of the prevention efforts. Even though the generation of food waste is predicted to rise, prevention can be efficient in decreasing food waste, as proven by the example of the United Kingdom (Searchinger et al., 2019; Lipinski et al. 2013). There are several examples of governmental initiatives in EU-28 to decrease FSWL, see Table 5. Italian legislation focuses on food donation throughout the whole FSC (González-Vaqué et al., 2017). Denmark (Danish Veterianry and Food Administration, 2017), Belgium (EESC, 2014) and France (Chrisafis, 2016) concentrate on retail level, even though French legislation supports battle against food waste overall with "Loi N. 2016-138 du 11 fevrier 2016 relative a la lutte contre le gaspillage alimentaire" (González-Vaqué et al., 2017). Several states, such as Germany, Portugal, and Hungary, support tax deduction on food donation (EESC, 2014).

(INSERT Table 5 HERE)

4.3 Proposal of circular economy pathways

Expanding commonly used figure for the circular economy (see Figure 6 in Ellen MacArthur Foundation, 2013), which is coherent for materials like electric and electronic waste (WEEE), closing the loop for FSWL engages all levels of FSC. Figure 2, represents the summary of possible circular pathways within the FSC. It distinguishes inedible and edible fractions for EoL options, in accordance with the updated food waste hierarchy (Figure 1). The pre-condition for edible streams to enter the framework of Figure 2 is that prevention of becoming food surplus failed. Edible surplus food is proposed for the reuse mostly at the consumption & service stage (food banks), retail stage (when food is diverted directly from retailers to the secondary retailer such as Wefood in Denmark (Wefood, 2019)), but also at the consumption and service stage (redistribution of leftovers from catering and restaurants). Inedible food waste that can be used for animal feed may stem from the agricultural production, post-activities, or processing & manufacturing stage as illustrated on the right-hand side by dotted lines. All other inedible streams are generated and recirculated at all stages of the FSC, where recirculation options involving material recycling (yellow flows) have precedence over those going straight to nutrient and energy recovery (orange flows). For instance, large quantities of mango peels from mango processing can be used as semolina for pasta (Ajila et al., 2010). Tomato processing waste can be used for carotenoids production, a colorant that extends the shelf-life of food and has many health benefits (Strati and Oreopoulou, 2014).

The vision of Figure 2 is to illustrate how the various stages of the FSC can generate and use FSWL, and how it can be linked to the food waste hierarchy proposed in Figure 1 and the notion of edibility. It should also be highlighted that although the inedible streams can be used for material recycling within the FSC as illustrated in Figure 2, they can also be used for materials outside the FSC, e.g. as bioplastics (Teigiserova et al., 2019), shoes (Piñatex™ in Ramchandani and Coste-Maniere, 2018), or chemicals (Mika et al., 2018). *(INSERT Figure 2 HERE)*

In order to prevent eventual rebound effects, i.e. not to encourage any additional generation of FSWL as input to feedstock-dependent biorefineries (left side of Figure 2), there is a need to establish distinct degrees of priorities for inedible streams, for which the FSWL categories are very useful. The priorities are illustrated in Figure 3. The vision is to ensure that additional FSWL generation is prevented, therefore the partly avoidable food waste streams (inedibility due to natural conditions or poor management; categories IV-V) are found at the bottom (priority 3). Streams, such as those stemming from dairy and red meat production represent the lowest priority (priority 4). The rationale is the same as explained for prevention in the food waste pyramid (Figure 1), namely to target the most resource-intensive and polluting food items like those for which preventing rebound effects is the most important. Waste coming from processing industry (category II, such as rice husks, and category III) may be more interesting for biorefineries, given the potential volumes and uniform streams it can generate, hence it is proposed as priority 1 and 2. The vision is that priority 2 and 3 streams enter biorefineries only after enforcing optimization efforts to minimize their generation in the first place. *(INSERT Figure 3 HERE)*

5. Discussion

5.1 Limitations

5.1.1 The challenge of measuring FSWL

Our work introduced several new terms to make it easier to deal with food waste in the upcoming era of the circular economy. Yet, the boundaries of wording clarification and concepts categorization must also meet those of quantification when it comes to implementing concrete policies and evaluate their efficiency.

Up till now, consistently with the famous adage "you cannot manage what cannot be measured", most studies have focused on quantifiable recycling and recovery strategies (Eriksson et al., 2015; Vea et al., 2018; Galanakis, 2012). The complexity of quantifying prevention, the top priority policy-wise, has already been acknowledged. In fact, it has been highlighted as the least measurable among the waste hierarchy treatments (Mourad, 2016). Prevention from the primary production to the retail can be achieved by more efficient management. However, the consumer stage is particularly challenging to influence and measure as it involves many factors that interact together. These factors include economic motives, social drivers and cultural pressure as well as individual preferences. While economic reasons, e.g. saving money, are a driving force for behavioral change (Thyberg and Tonjes, 2016), socio-psychological motivations, such as conservatism, misinformation and bureaucratic resistance, can represent up to 40% of difficulties for waste prevention (Henningsson et al., 2004). Economic factors are further influenced by geographic, cultural, political and personal reasons linked to food waste generation (Thyberg and Tonjes, 2016), with different countries having different waste generation patterns. This being said, Searchinger et al. (2019) highlighted different generic easy-to-operate strategies for prevention, such as smaller portion sizes in restaurants at a different price, and avoiding misleading “sell by” dates in retail stores, as already practised in the United Kingdom (Lipinksi et al., 2013).

Distinguishing the terms proposed in Table 3 can be a challenging task, mainly surplus food, and partly avoidable food. As surplus food refers to edible food this varies per region as well as per individual preference. Each country and region have their own eating habits and partly avoidable food waste can largely vary.

Therefore, countries should aim to make a list of inedible items considered inedible by the majority in order to improve the quantifications of the waste. For instance, by engaging experts and performing questionnaires for consumer preference. This should be parallel with developing an understanding of where and why FSWL occurs as highlighted by Searchinger et al. (2019). Generally, being non-digestible by humans is a valid criteria for inedibility, such as pits and bones, but there are food items that are known to be eaten by some while not-eaten by others (such as mentioned chicken feet and kiwi peels). If incentives should be established to reduce this stream at the consumer level, clear boundaries at the management scale (local, regional) would need to be established, along with clear measurement metrics.

Quantifications of the consumers waste can sometimes be based on consumer’s data such as diaries, weighting, source separation and similar, therefore consumers understanding of the definitions is important. Using the term surplus food with the clarification of how it differs from food waste is highly relevant to increase the reuse by humans (Garrone et al., 2014). According to the results of the study by Papargyropoulou et al. (2014), the distinction between “surplus food” and “food waste” is also an important food security issue. Food loss, on the other hand, was here defined by its intrinsic characteristic of never been measured. By using very efficient quantification methods food loss is ideally zero, with all surplus food redistributed and reused, and all food waste reused for animal feed, material recycling, or nutrient and energy recovery.

5.1.2 Interpreting the proposed frameworks for multi-valuable output processes

Proposed FSWL hierarchy (Figure 1), updated circular economy model (Figure 2), and prioritization for the use of FW in CE (Figure 3) are guidance tools, and as often the case with such tools, generic rules covering all cases are almost impossible to establish. While material recycling primes over nutrient and energy recovery, in practice, exceptions should be allowed. With a proper evaluation to confirm the "exception" status, other options might be more environmental. FSWL is not independent of the developments happening in the other sectors of society and should not be considered in silo. This can especially be the case when cascading production takes place and multiple outputs challenge the priorities presented in our proposed FSWL hierarchy (Figure 1). For instance, a certain food waste stream may be driven to AD as a result of increasing investments into renewable gas triggered by other streams, although energy recovery comes at the bottom of the FSWL pyramid. Such case is not necessarily to proscribe, especially taking into account that it also generates a digestate that can be refined into e.g. biopesticides (Cerda et al., 2019; here considered as material recycling). The gas may similarly be refined into platform molecules for e.g. the chemical sector. Another example of multi-functional EoL technologies generating environmentally-valuable co-products can include those where biochar (Elkhalifa et al., 2019) and/or activated carbon (Zhao et al., 2018) are generated, such as pyrolysis. The activated carbon and biochar can uptake heavy metals, thereby improving the regenerative nature and health of the soil. According to IPCC (2019), certain biochars can be used not only for carbon sequestration, but also to improve water holding capacity and nutrient use efficiency in soil, and even increase the yield (in tropics). However, any management strategies for FSWL would need to be evaluated by tools such as life cycle assessment to prove their environmental performance when compared to the alternative treatments, within a specific context.

5.1.3 Food waste categories

Some streams may be seen as classifiable into more than one of the categories presented in Table 3. For instance, orange peels stemming from juice production could belong to categories II and III at the same time. But peels being inherently inedible belong to category II. This could pose problems in an accounting context and would require further categorization principles. For instance, it could be decided to classify unavoidable food waste streams into category II first, and then category III (processing). Additional work could also consider combining these categories with the stages of the FSC in a step-wise decision tree for classifying FSWL.

5.2 Time dimension: short value chains for FSWL management

As FSWL is highly degradable, short management cycles are of tremendous importance, particularly in the context of a warmer climate (IPCC, 2019). Food waste processed immediately, for any EoL, could be considered as minimization of low-quality waste generation (Figure 2). Short FSWL management cycles, in fact, prevent the degradation of the content in the unavoidable and partly unavoidable waste (category II-IV in Table 3) to be re-introduced as the new materials in the case of recycling FW. In the short chains, the costs for transportation, treatment of waste, costs of raw material, energy need and others costs are furthermore generally decreased (Chertow, 2000). Short management cycles of FSWL are likely to be favored in industrial symbiosis or decentralized systems where geographic proximity allows immediate use of the waste fraction (EU, 2018). Examples are presented in (Short et al., 2014), among others. On the prevention side, Searchinger et al. (2019) propose to establish additional local food banks combined with third-party scheduled retrieval services making re-distribution shorter and easier from farms and retail stores to food banks. Internet apps informing food banks of the availability of surplus food in near-real time do exist (Lipinski et al., 2016) and can further enhance the efficiency of this prevention strategy.

5.3 Perspectives

Our analysis of selected European framework and policies showed that steps towards SS have been taken, but need further refining to achieve SS in the European law. For instance, decreasing waste of animal origin needs improved legislation on its reuse (European Council, 2009), while CE derived fertilizer needs stronger limits for heavy metal content to ensure healthy soil systems (European Parliament, 2017; European Parliament, 2019). EU-wide initiatives, such as the circular economy indicators mentioned in Table 4 (Eurostat 2019) and initiatives mentioned in Table 5, are helping to promote FSWL prevention, reuse, recycling and recovery on each stage of the FSC.

Further, there is an issue with the meaning of the word prevention. The Waste Framework Directive defines prevention as “measures taken before a substance, material or product has become waste, that reduces (a) the quantity of waste, including through the reuse of products or the extension of the life span of products (b) the adverse impacts of the generated waste on the environment and human health…” (European Parliament, 2008). Strictly applying this official definition implies that using FW directly in the short-chains (e.g. in the industrial symbiosis) can be counted as prevention, i.e. preventing “waste” usable for applications at the top of the hierarchy pyramid to become waste of lower quality for use at the bottom of the pyramid. A distinction between the two types of prevention (of becoming FSWL in the first place, and becoming food waste of lower quality than already is) could be the topic for more exploration. As highlighted throughout this study, definitions need to be very clear and transparent in order to support the strong sustainable circular economy.

The suggested clarified food waste hierarchy and closed-loop framework, as well as our proposed categories of food, are seen as important stepping stones towards sustainable management of FSWL. These categories can provide business and policy decision support on how to reach the SDG 12.3 2030 target and further transition towards the circular economy. It can be further used by policy-makers and managers to prioritize the efforts, and analyze the trends and efficiency of the circular economy in Europe for food waste.

6. Conclusion

This article has summarized, categorized and clarified the common definitions and terms for food waste (here referred to as food surpluses, waste and losses; FSWL). The term “food loss” is proposed to only refer to “not accounted for”, “surplus food” to all edible food fit for human consumption and the rest belonging to “food waste”. Introducing the term surplus food into the waste hierarchy has been stressed out as important for prevention and reuse of food for human consumption.

Three useful tools that can improve quantification methods have been introduced 1) Category matrix for FSWL 2) Updated food waste hierarchy and 3) Circular economy framework for FSWL. Linking edibility and degree of possible avoidance resulted in six categories for food, which can be used to measure FSWL more efficiently and contribute to knowledge on unavoidability/edibility of the waste at each part of the FSC. The levels of the food waste hierarchy have been expanded by material recycling due to economic potential of unavoidable food waste, with nutrient and energy recovery as separate categories due to importance of addressing nitrogen flows and other nutrients. These clarified EoL treatments can support faster intervention, which is critical for highly perishable wastage. In strong sustainability context, the prioritization framework for the use of FSWL into biorefineries was introduced. This article stressed-out that emission intensity of food waste prevention or used for biorefineries should also be considered. CE framework can improve and uncover valorization of food waste in the supply chain, with many examples showcasing closed-loop pathways included.

Proper implementation of transparent FSWL valorization needs to be supported by policies. Even though steps towards SS have been taken, mostly by launching of the Circular Economy framework and to some extent the Bioeconomy Strategy, policies need to be harmonized towards the common goal of prevention and EoL according to the FSWL hierarchy. Implementation of the proposed tools can help to harmonize objectives of reduction and regulation of FSWL in policies.

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Figure 1 and 2 are to be 2-column fitting image. Figure 3 can be 1.5-column fitted.

Caption in chronological order.

Figure 1 Updated hierarchy for food surplus and waste proposed herein building on terminology from major European and national projects (UNEP, 2014; WRAP, 2013; FUSIONS : Östergren et al., 2014; WRI, 2016). *FFV fresh fruits and vegetables

Figure 2 Circular economy framework proposed herein for FSWL in the food supply chain (FSC). The figure is color-matched to the food waste hierarchy of Figure 1. FFV: fresh fruits and vegetables. Dotted lines: inedible for humans but edible by animals. Only recycling within the FSC is explicitly shown, but recycling may also occur for non-food applications. The pre-condition for edible streams to enter this framework is that prevention of becoming food surplus failed.

Figure 3 Ranking proposed to prioritize which inedible food waste stream to use in future food waste biorefineries. Linked to categories presented in Table 3.

Table 1 Overview of the most commonly used terminology and connection to the FSC. [1]FSC food supply chain [2]FFV fresh fruit and vegetable

Term	Commonly used definition	Scope in FSC[1]	Example
Food loss (FAO 2014; IFPRI 2016)	The unintentional decrease in edible food quantity or quality before consumption, including postharvest losses.	Production, post-harvest and processing	-Edible crops left in the field -Food damaged due to poor transportation from factory to retailer
Food waste (Östergren et al., 2014; IFPRI 2016)	Food originally produced for human consumption that was discarded or was not consumed by humans. Including still edible food that is deliberately discarded.	Whole FSC, but primarily retail, and consumer stage (including services)	-Plate waste -Food spoiled due to poor storage in retail or households
Surplus food (Garrone et al., 2014; Mourad, 2016)	The edible food produced, manufactured, retailed or served that has not been consumed by humans (mainly due to socio-economic reasons), including food produced beyond nutritional needs.	Whole FSC, but primarily retail and consumer stage	-Overproduction of food during production -retail waste such as FFV[2], canned goods

Table 2 Overview of the most common definitional framework of food waste. [1]AD anaerobic digestion [2]EoL end-of-life

	The definitional framework of food waste	Scope	Example
FAO (2014)	"The decrease in quantity or quality of food" and waste "has been left to spoil or expire as a result of negligence by the actor (predominantly, but not exclusively, the final consumer)"	Included: Edible Excluded: inedible, intended for feed	-Excluded: not edible (bones, cooking oil or coffee grains…) -Included: rotten fruits
FUSIONS (Östergren et al., 2014)	Food and inedible parts of food removed (lost or diverted) from the food supply chain. Waste that can be disposed or recovered by "composting, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea"	Included: Edible and inedible Excluded: Not mature; intended for non-food uses (feed or industrial use)	- Excluded: unripe green tomatoes that cannot be expected to be eaten by human - Citrus peels for biomaterial/chemicals - Included: citrus peels for AD[1]
FLW Protocol (FLW, 2016)	Food and its inedible parts removed from the FSC, for the following EoL[2]: bio-based materials, biochemical processing, anaerobic digestion, composting, controlled combustion, land application, landfill, not harvested/plowed in, discard/refuse/little and sewer/wastewater treatment	Included: Edible and inedible Excluded: intended for non-food uses (energy, feed or industrial use)	-Excluded: leaves/stem of crops left on the field -Included: peels and pits for the production of biochemicals
IFPRI (2016)	"Potential food loss and waste", i.e. food loss+ food waste+ potential food loss, including pre-harvest stage: Crops lost before harvest to pests and disease or left in the field, crops lost due to poor harvesting techniques or sharp price drops, or food that was not produced because of a lack of appropriate agricultural inputs	Included: the whole plant, from primary production to consumption, including pre-harvest	-Excluded: crops not intended for human consumption -Included: all pre-harvest waste including leaves/stems
Bellemare et al. (2017)	"Food waste" is the difference between the amount of food produced and the sum of all food employed in any kind of productive use, whether it is food or non-food"	Whole plants and animals produced for food	- Leaves and stems left on the field after harvest
Hartikainen et al. (2018)	Only edible parts are food waste, for animals taken at any stage of their maturity, for the crops from post-harvest onwards	Included: Edible parts Excluded: Inedible parts	- Included: animals died before reaching their maturity -Excluded: bones, pits, leaves

Table 3 Categorization of FSWL in connection with edibility and possibility of avoidance

<table>
<tr><td>Edible</td><td colspan="2">Inedible</td><td rowspan="2">Other</td></tr>
<tr><td>Avoidable</td><td>Unavoidable</td><td>Partly Avoidable</td></tr>
<tr><td rowspan="2">I. All edible food</td><td>II. Naturally inedible (ex. bones, pits, leaves)</td><td>IV. Became inedible due to natural causes (crops damaged due weather)</td><td rowspan="2">VI. Not accounted for</td></tr>
<tr><td>III. Processing waste residues
(ex. apple pomace, tea leaves)</td><td>V. Became inedible due to inefficient management
a. poor functioning of the FSC (lack of proper refrigeration, inadequate infrastructure, etc.)
b. avoidable negligence</td></tr>
<tr><td>Surplus food</td><td colspan="2">Food waste</td><td>Food loss</td></tr>
</table>

Table 4 Overview of key frameworks and policies throughout the FSC at the European level, highlighting a specific element of these that relate to weak and strong sustainability. [1]AD anaerobic digestion [2]Cadmium

Selected policy frameworks and regulations influencing whole food supply chain		
Policy	**Weak (WS) and Strong Sustainability (SS)**	**Reference**
Landfill Directive (1999/31/EC)	WS Accepts continued production systems aligned with the concept of the linear economy.	The Council of the European Union (1999)
	SS Economic and normative measures for banning and decommissioning of landfills. The requirement of zero biowaste disposed of at landfills.	
Waste Framework Directive (WFD – 2008/98/EC)	WS Do not differentiate FW from other types of organic waste	European Parliament (2008)
	SS Driver of the use of FW as a secondary resource	
Circular economy 2015 and Bioeconomy Packages 2018	WS Link with chemicals legislation and non-toxic materials is weak	EEA (2018); EC (2018a); (EC, 2015)
	SS Cover the entire product life cycle from production to waste management and the market for secondary raw materials. Includes the protection of the environment and human health, from the bioconcentration risk of chemicals. Elimination of legacy substances.	
Circular Economy Indicators	WS *Waste management* does not quantify food waste amounts nor types. Recycling of biowaste accounts for composting and AD[1] plants.	Eurostat (2019)
	SS *Waste management* includes six indicators measuring recycling rates of different types of waste of which one may potentially become of relevance to FW. *Competitiveness and Innovation* include an indicator on patents related to recycling and secondary raw materials; only SS if it provides an alternative to the fossil driven industry, not a constant growth which drives waste generation (for companies to stay competitive with fossil alternative).	
CE Fertilizer Directive	WS Cd[2] limit of 60 mg/kg P_2O_5 (now 60), with limitis of 40 mg/kg P_2O_5 planned in 6 years, and 20 mg/kg P_2O_5 in 16 years. Hazard to human health as it accumulates in agricultural crops, which even the 40 mg/kg limit will scarcely prevent due to very long persistence of Cd.	Römkens et al. (2018); Rietra et al. (2017); European Parliament (2017); European Parliament (2019)
	SS Biowaste derived fertilizers impact investment in Cd removal technologies due to the voluntary option for 'low cadmium' labelled fertilizers (content ≤ 20 mg Cd/kg phosphorus)	
Food safety and hygiene rules	WS EU prohibits food donation of certain items close to or already past its "use by" or "best before" dates. Restriction on the reuse of the waste of animal origin	European Court of Auditors (2016); EC (2018b); (European Council, 2009)
	SS Ensuring health and safety	
Agricultural production, Post-harvest activities, Processing and Retail		
European marketing standards	WS: Contributes to the partly avoidable waste by setting specific aesthetic criteria thus discarding nutritiously unspoiled food.	Priefer et al. (2016)
	SS: Education of consumers, revoking of aesthetic criteria	
Unfair trading practices (UTPs)	WS: informal contracts, which may lead to the last minute order cancellation or alteration by buyers, supply and demand imbalances, poor information sharing, and other factors	(Fałkowski et al., 2017)
	SS More comprehensive approach for business-to-business relationships. In effect from April 2021	European Council (2019)
Agricultural production, Post-harvest activities and Processing		
Common Agricultural Policy (CAP)	WS design of rural development and current definitions of food waste and loss	Wunder et al. (2018); IPES (2019)
	SS next Common Agricultural Policy (CAP) is envisaged to promote the reduction and valorization of FW within the EU Member States. Information activities (agricultural practices to reduce harvesting losses), investment in physical assets (improving storage conditions or in better quality farm equipment)	

Retail, and Consumption stage		
Food Labelling	WS Different regulations across MS are restraint in the trading. Uncertainties for mark dates and labels in the EU Regulation 1169/2011 on the provision of Food Information to Consumers (FIC). Not-highly-perishable food can be interpreted by business operators. SS Efforts in educating consumers and business operators on the difference between "best before" and "use by" terminologies for food products	European Council (2011); Mahy and Conte-Salinas (2016); Wunder et al. (2018)

Table 5 Overview of governmental prevention initiatives and food waste in the EU

Country	FW numbers per annum	Prevention initiative	Reference
United Kingdom	Total: 9.9 million tonnes Household: 4.67 million tonnes in 2012 (excluding sewer and home compost) 236 kg/per capita	- nation-wide initiative, reduced overall FSWL by 14% in five years (2007-2013) and 21% reduction at the household level - public relation efforts, updated guidance on food labels, food storage tips printed on carrier bags, revised marketing for promoting perishable goods	Stenmarck et al. (2016); WRAP (2013); European Parliament News (2017); Searchinger et al. (2019); Lipinski et al. (2013)
Denmark	Total: 0.9 million tonnes Household: 462 thousand tonnes 146 kg/per capita	- decrease food waste at the retail level (supermarket and hypermarkets) - donation is tax-deductible with the limit of DKK 14,800 if the company in question is listed as an endorsed association by the Danish Tax Authorities	Stenmarck et al. (2016); European Parliament News (2017); Danish Veterianry and Food Administration (2017); EESC (2014)
Germany	Total: 10 million tonnes Household: 5 million tonnes 149 kg/per capita	- "Too good for the bin!" initiative, whole FSC - no VAT on donation or a symbolic rate - Donations are tax-deductible until 20% of corporate income or 0.4% of revenue plus wages and salaries - goods past their 'best before' date are allowed to be donated to charities or other social organizations	Stenmarck et al. (2016); European Parliament News (2017); EESC (2014)
France	Total: 5.4-9.6 million tonnes Household: 2.2-3.5 million tonnes 136 kg/per capita	- food producers, processors and distributors, consumers and associations must assume responsibility and take action. - supermarkets with an area larger than 400 m2 are obliged to establish contracts for giving away the edible food to charity, else they are fined 3750 euros.	Garot (2014); European Parliament News (2017); González-Vaqué et al. (2017); Chrisafis (2016)
Italy	Total: 5.5 million tonnes Household: 2.5 million tonnes 179 kg/per capita	- food business operators may donate surplus food - donations to particular entities are deductible up to 10% of their taxable income, but up to 70,000€ per year - foods with labelling irregularities can be donated if displaying the date of expiration and ingredients - not fit for human consumption may be given away to be used as animal feed, for composting	Garrone et al. (2012); European Parliament News (2017); González-Vaqué et al. (2017); EESC (2014)
Portugal	Total: 1 million tonnes Household: 324 thousand tonnes 132 kg/per capita	- no VAT for food donation to specific entities (e.g., the State and non-profit organizations) - food donations may be deductible from the taxable income basis plus 20%, 30% or 40% depending on the type of the institution, with the limit of the 8/1000 of the turnover	Medeiros and Swatuk (2013); European Parliament News (2017); EESC (2014)
Hungary	Total: 2 million tons Household: and retail 760 thousand tons 175 kg/per capita	- no VAT is applicable to charitable donations - 20% can be deducted from the corporate tax base, 50% if donated to the Hungarian Disaster Fund or Hungarian Cultural Fund. An additional 20% can be deducted in case of long term	Bori (2018); European Parliament News (2017) ; EESC, (2014)

		donation agreement of at least 3 years	

Conflict of interest

The authors acknowledge that there is no conflict of interest.

Highlights for Teigiserova, Hamelin and Thomsen. Towards transparent valorization of food surplus, waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy

- Unclear definitions and frameworks for food waste prevent efficient minimization
- Six categories distinguishing edibility and level of avoidance were created
- Waste hierarchy expanded by material recycling and nutrient recovery
- Framework to close the loop of food waste in the supply chain included
- Three tools for harmonized and simplified food quantification and management

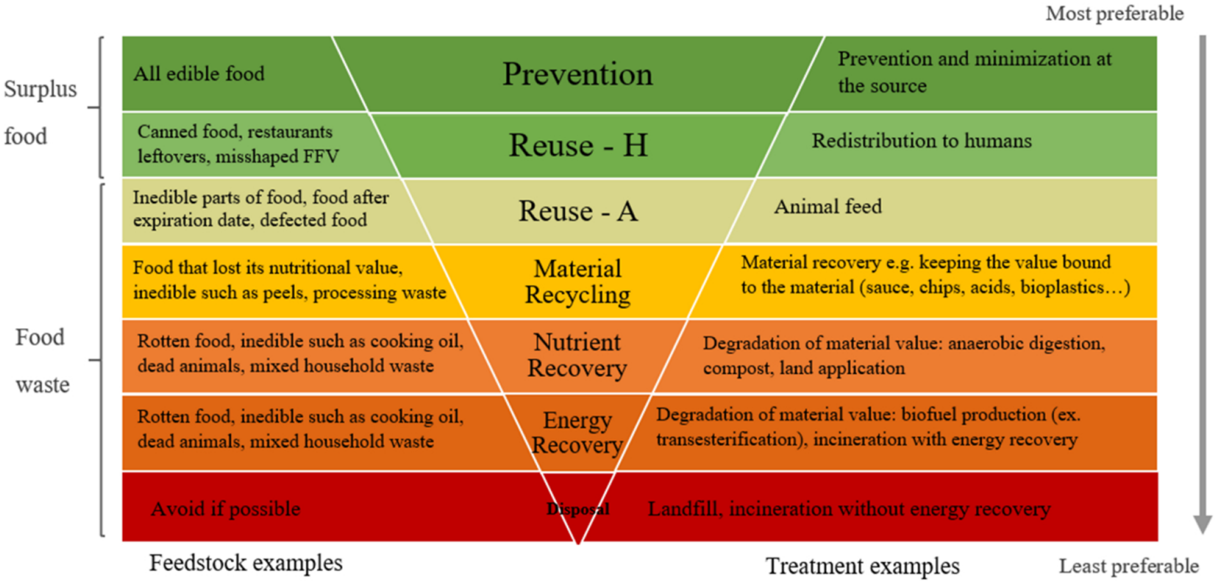
Most preferable
Surplus food
All edible food
Prevention
Prevention and minimization at the source
Canned food, restaurants leftovers, misshaped FFV
Reuse - H
Redistribution to humans
Inedible parts of food, food after expiration date, defected food
Reuse - A
Animal feed
Food waste
Food that lost its nutritional value, inedible such as peels, processing waste
Material Recycling
Material recovery e.g. keeping the value bound to the material (sauce, chips, acids, bioplastics…)
Rotten food, inedible such as cooking oil, dead animals, mixed household waste
Nutrient Recovery
Degradation of material value: anaerobic digestion, compost, land application
Rotten food, inedible such as cooking oil, dead animals, mixed household waste
Energy Recovery
Degradation of material value: biofuel production (ex. transesterification), incineration with energy recovery
Avoid if possible
Disposal
Landfill, incineration without energy recovery
Feedstock examples
Treatment examples
Least preferable

Figure 1

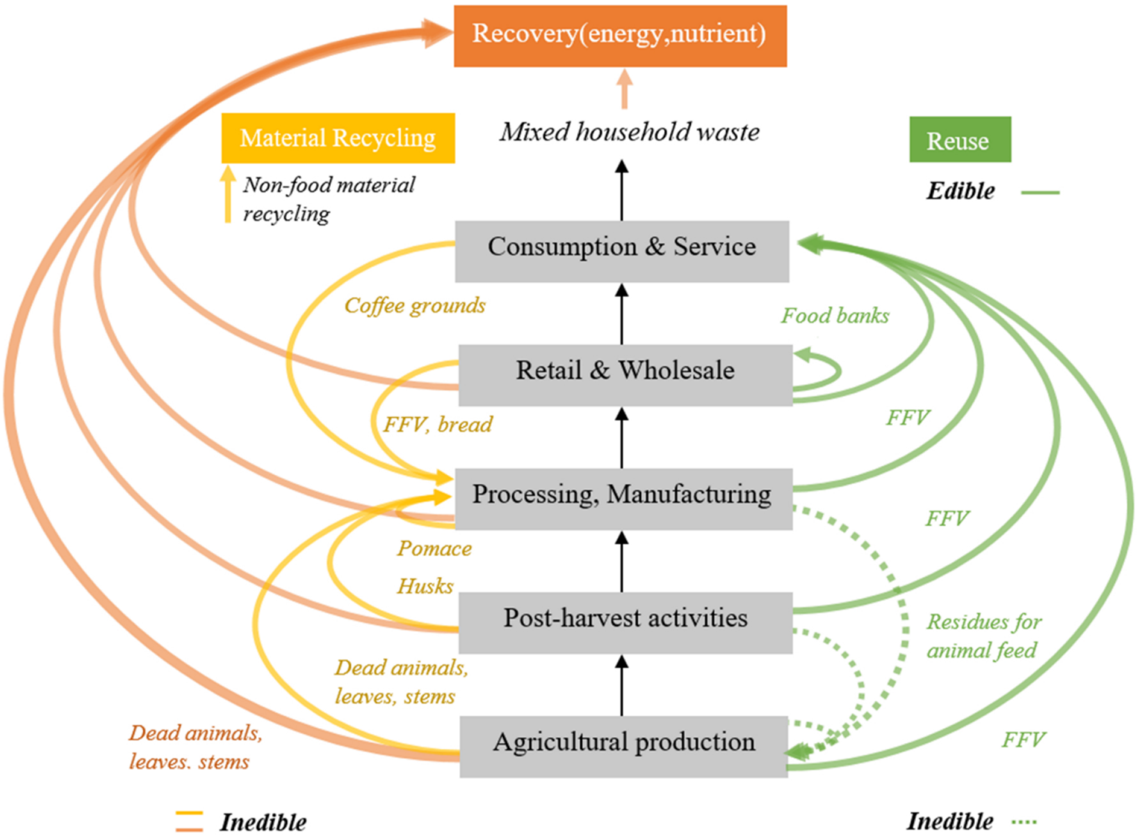
Recovery(energy,nutrient)
Material Recycling
Mixed household waste
Reuse
Non-food material recycling
Edible
Consumption & Service
Coffee grounds
Food banks
Retail & Wholesale
FFV, bread
FFV
Processing, Manufacturing
FFV
Pomace
Husks
Post-harvest activities
Residues for animal feed
Dead animals, leaves, stems
Agricultural production
Dead animals, leaves. stems
FFV
Inedible
Inedible

Figure 2

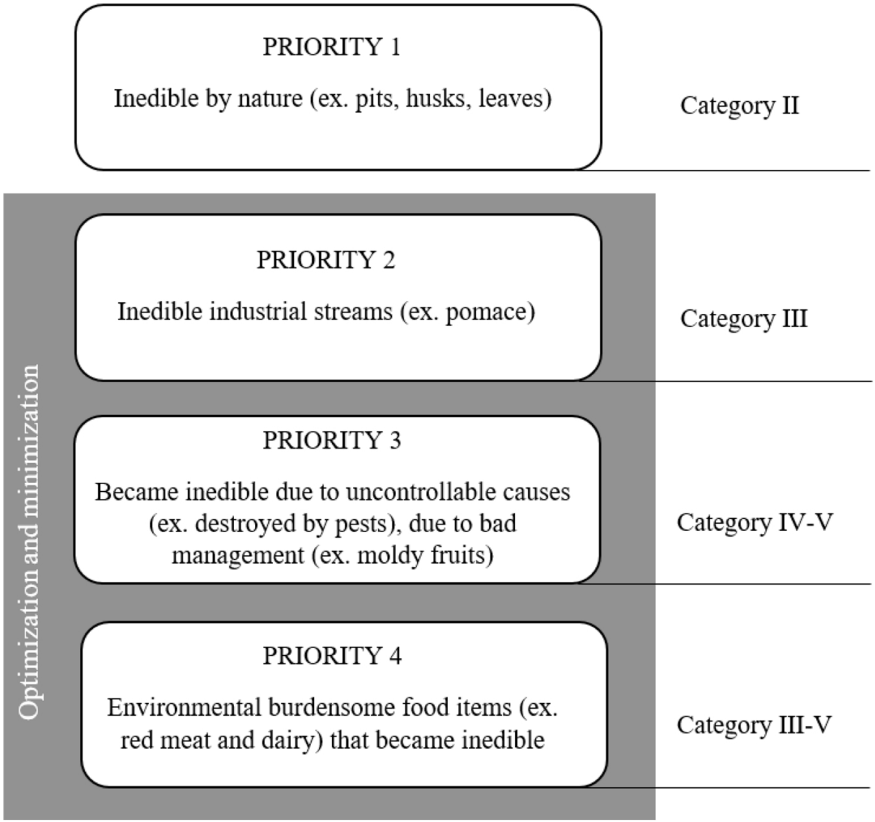
PRIORITY 1
Inedible by nature (ex. pits, husks, leaves)
Category II
Optimization and minimization
PRIORITY 2
Inedible industrial streams (ex. pomace)
Category III
PRIORITY 3
Became inedible due to uncontrollable causes (ex. destroyed by pests), due to bad management (ex. moldy fruits)
Category IV-V
PRIORITY 4
Environmental burdensome food items (ex. red meat and dairy) that became inedible
Category III-V

Figure 3