H2020 MSCA-RISE-2018

ProCEedS Project

Promoting **C**ircular **E**conomy in th**e** Foo**d** **S**upply Chain

D1.1
An overview of Circular Economy best practices in the context of food supply chains

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Project Information

Acronym: ProCEedS
Title: Promoting Circular Economy in the Food Supply Chain
Coordinator: The University of Sheffield
Grant Number: 823967
Programme: H2020 MSCA-RISE-2018
Start: 1 September 2019
Duration: 3 years
Website: http://proceeds-rise.eu/

Consortium:

The University of Sheffield (USFD)
Universitá degli Studi di Napoli Parthenope (UPN)
South East European Research Centre (SEERC)
Uniwersytet Lodzki (Ulodz)
Instituto Nacional de Tecnologia Agropecuaria (INTA)
Solagri Societa' Cooperativa (SOLAGRI)
Nefeloudis Food Additives (TN)
Fundacja Rozwoju Przedsiebiorczzosci (FRP)
Proteg Spa (PROTEG)
Agrilogistica Srl (AGRIT)
Regather Limited (RGT)

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Deliverable

Number: D1.1
Title: An overview of Circular Economy best practices in the context of food supply chains
Lead beneficiary: Universitá degli Studi di Napoli Parthenope (UPN)
Work package: WP1 – Performance Evaluation of Circular Food Supply Chains
Dissemination level: Public
Nature: Report (RE)
Due date: 30th November 2020
Submission date: 30th November 2020
Contributors: Meletios Bimpizas (USFD), Andrea Genovese (USFD), Maddalena Ripa (UPN), Remo Santagata (UPN), Sergio Ulgiati (UPN)

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Table of Contents

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Executive summary

The process of industrialisation signified not only a technical and economic transition but also a socio-metabolic one with distinct biophysical characteristics. Mass urbanisation, globalisation, maximalist free-trade policy, and economic growth fetishism culminated into the modern materialistic society where individuals comprise particles of mass, yet unequal, wasteful consumption. Circular economy has emerged as the alternative that could re-establish and maintain the circular flow of nutrients and energy between human society and the environment. The latter is achieved by either slowing, narrowing, or closing the resource loops through the retention options of reduce, reuse, and recycle.

Given the inherent relationship between agriculture and environment, attention is placed on the food sector. Globally, 1/3 of food is wasted, generating by-products which could be treated and processed. To evaluate the feasibility of a transition towards a circular economy in the agri-food sector, a literature review was conducted to identify the best practices and barriers to their implementation. Findings showed that the realisation of a CE transition needs to overcome an array of different barriers, not only technological, economic, legislative, or operational, but also structural, social, and cultural ones. Available food waste conversion pathways were identified, along with related trade-offs and opportunities. Analysis was extended to the qualitative and quantitative assessment of the availability of secondary raw materials and the classification of the different conversion systems using Life Cycle Assessment and Emergy Accounting methods.

Providing a commixture of reduce, reuse, and recycle practices while emphasising on food waste recovery and recycle pathways, this report aims at guiding the planning of required processes that could facilitate the transition towards a CE in the context of food supply chains. Apart from associated challenges and barriers this report analyses also the economic, technological and cultural opportunities that such a transition could offer.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

1 Introduction

The aim of this chapter is threefold; to provide a retrospective of the food systems development following the transition from an agrarian to industrial society; to analyse the ambiguity surrounding the definitions of food waste and food losses; to highlight the potential of Circular Economy towards the prevention and the valorisation of these.

1.1 The modernisation of food systems

The process of industrialisation signified not only a technical and economic transition but also a socio-metabolic one with distinct biophysical characteristics (Krausmann et al., 2008). Ongoing mass urbanisation, the gradual shift of population from rural areas to cities, contributed to a divide between nature and culture alienating the consumer from food production (Thyberg and Tonjes, 2016). Acknowledging the externalities of this divide, Engels (1877) set as the starting point of the failure of the linear production model the decoupling between the point of agricultural production and consumption. Markets' orientation towards globalisation and maximalist free-trade policy, shifted local and regional food networks to global in terms of quantity, type, cost and variety. The latter resulted in a transition of dietary patterns that significantly differed from local cuisine, thus affecting the type and amount of food that is disposed; people tend to waste food that they do not have an understanding of it. At the same time, the hegemonic establishment of economic growth as the overarching priority for national and international economic policies (Schmelzer, 2015), prompted the need for the commodification of food systems, transforming them into anonymous and homogeneous supply chains that compete for capital accumulation and self-expansion. This socio-metabolic transition culminated into the modern materialistic society where individuals comprise particles of mass, yet unequal consumption (Creutzig, 2020; Uusitalo and Takala, 2020).

1.2 Food loss and waste: An ambiguity

Despite the magnitude of the problem, the Swedish Institute for Food and Biotechnology (SIK) 2011 report for Food and Agriculture Organisation (FAO) (FAO, 2011), is, to date, the only one providing global estimates of food losses and waste across all levels of the food supply chain (FAO, 2019). According to SIK's report, 1.3 billion tonnes of food, roughly one-third of edible food produced for human consumption is lost or wasted every year. (Holt-Giménez et al., 2012). However, this appears not to be a problem of scarcity, but of inequality, considering that food production rate has increased faster than human population growth rate, producing nowadays enough food to feed 10 billion people (the projection of global population for 2050) (Holt-Giménez et al., 2012). This represents a major drawback from an environmental, social, and economic viewpoint. In detail, it results in an estimated of almost one trillion USD of economic losses, a quarter of the water required in agriculture, a crop area equivalent to the size of China, and 8 per cent of global greenhouse gas emissions (GHG) (FLW Protocol, 2016). An additional source of GHG emissions is linked to the decomposition of inedible parts of food (e.g. bones, rinds, pits) in landfills, that represents a form of resource inefficiency; a missed valorisation opportunity that could be captured through technological of behavioural changes. Acknowledging

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

this data is a rough estimate due to the intrinsic limitations in collecting all necessary information, FAO has coordinated efforts with UN Environment in recent years to gain a better understanding of the actual causes of food losses and waste at each supply chain stage, and subsequently provide a more accurate and broad valuation of these metrics (FAO, 2019). Efforts have been culminated to the development of two indicators, namely Food Loss Index (FLI), referring to food losses prior to the retail stage, and Food Waste Index (FWI), pertaining to amount of food wasted at the retail and consumption level of the supply chain. Analysis of data estimate that approximately 14 per cent of global food production is lost before reaching the retail stage. Still, projections regarding the level of food waste at retail and consumption stage are expected to be the highest. Given the methodological challenges associated with the collection of data related to food waste at the retail and consumer level, estimates for the FWI are still pending.

Another major drawback towards the prevention of food being wasted is the lack of consensus related to a standard definition about food waste and food losses (Chaboud and Daviron, 2017). The issue lies within the different perspectives and problems that stakeholders and analysts take into consideration when they use these terms (FAO, 2019). FAO differentiates among food loss, i.e. unintended loss of food preceding the retail stage, and food waste, i.e. the food is wasted at retail and consumption stages (FAO, 2011). On the other hand, World Resourced Institute (WRI), differentiates between food loss and food waste acknowledging them as "the unintended result of an agricultural process or technical limitation in storage, infrastructure, packaging, or marketing" (Lipinski et al., 2013, p. 1) and "food that is of good quality and fit for human consumption but that does not get consumed because it is discarded" (Lipinski et al., 2013, p. 4) respectively. The European Union (EU) defines food waste as "fractions of food and inedible parts of food removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)" (Stenmarck et al., 2016).

2 Food systems and the potential of Circular Economy

Despite the considerable technological advancements of our era, food losses are considered an intrinsic characteristic of agricultural activity. A fraction of food losses is considered unavoidable, owning to inedible parts under normal circumstances (e.g. fruit cores, peels, inedible slaughter waste), harvesting and processing losses that are not avoidable with best available technologies and reasonable extra costs (Beretta et al., 2013). However, a considerable stream of these losses is associated with the critical dependence of crops on weather conditions and their vulnerability to pest diseases (Beausang et al., 2017). Climate change poses an additional challenge since the increased fluctuation of temperatures, changes in precipitation patterns, and the frequency of extreme weather events have an amplified adverse effect on agricultural productivity (Antón et al., 2013).

In view of the dynamic feedback that exists between avoidable food waste and food production, it is important to separately consider the role of unavoidable food losses and develop solutions aiming at the prevention of food waste and the management of unpreventable losses in the post-disposal phase (Kibler et al., 2018). Recovering and using this unavoidable organic waste fraction could be considered a new way of mining resources, capable of reducing the depletion of non-

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

renewable stocks, thus increasing environmental integrity. Circular Economy has been proposed as a different approach for the sustainable recovery of such organic resources, leading to less environmental impacts and reducing the dependence on fossil fuels, with the result of mitigating climate change and leading toward a post-petroleum society (EU, 2012). Such valorisation practices include conversion of organic biomass into chemicals and biofuels (Bhaskar et al., 2016; Fiorentino et al., 2014; 2017; 2019; Florio et al., 2019; Ripa et al., 2014; Bayer et al., 2014) and conversion of animal by-products into commodities, fuel and electricity (Santagata et al., 2017; 2019). In order to achieve this, there is the need to go beyond the mere use of alternative raw materials and technologies, and to introduce innovations at all level of the various supply-chains affecting the entire network of systems (i.e. economical, technological, political and environmental, among others), so that the Circular Economy framework would be a component of the great transformation referred to as "worldwide remodelling of economy and society towards sustainability" (Urmetzer et al., 2020).

In view of these issues, initiatives have been focusing on approaches aimed at the prevention and minimisation of food losses at different supply chain stages. Following the criticism of previously formalised in European legislation waste hierarchy framework (Singh and Ordoñez, 2016), the European Union (EU) amended Directive 2008/98/EC (EC, 2008) and included a revised waste legislation in the Circular Economy Package (EC, 2018). Acknowledging the wide differences between the Member States regarding the treatment of municipal waste (Figure 1), the revised version prompted the reduction and monitoring of waste, communicating the possible achieved progresses. EU countries committed to halve food waste generated per capita at the retail and consumer level Union-wide food waste reaching the reduction target of 30% by 2025 and 50% by 2030, while committing to lower food losses across the whole supply chain (EC, 2018). FW is also addressed in the new EU Circular Economy Package, introducing a FW reduction target under the forthcoming Farm-to-Fork Strategy, within the European Green Deal, which will address comprehensively the food value chain (EC, 2020).

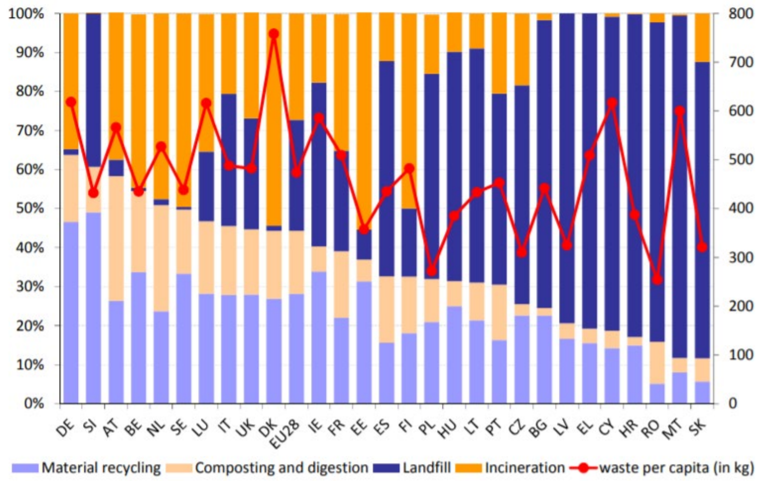


Figure 1
Percentage Municipal waste treatment methods and waste per capita in the EU-28 (EPRS, 2018). Data source: Eurostat (env_wasmun), 2016. Data for IE, EL and RO relate to 2013.

The aim of this report is to provide a review of current circular economy practices across all food supply chain stages, emphasising on presently available disposal and conversion options for

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

food waste. Using LCA and EMA to environmentally assess the identified food waste conversion options in EU28, it provides examples of multi-dimension process and biosphere-oriented tools for a deeper understanding of environmental costs and benefits of waste conversion processes. Section 2 provides the theoretical background of this report while Section 3 presents the CE practices per supply chain and identified food waste conversion processes along with their environmental assessment. Finally, Section 4 summarises the key challenges and opportunities related to the implementation of these practices to support the decision making towards the transition to a Circular Economy. Finally, some conclusions are drawn.

2.1 Circular Economy

Circular Economy (CE) is a paradigm aimed at overcoming the linear "take-make-dispose" model, endorsing a more responsible and appropriate exploitation of resources and reutilisation of resource-rich by-products. The underlying theoretical foundation of the CE concept is rooted in a wide array of academic disciplines and fields. Notwithstanding the significant contribution of certain elements of the latter, including *industrial symbiosis*, *cradle-to-cradle design* and *cleaner production*, the absence of clear boundaries with reference to relative school of thoughts such as *Bio-economics* and *Thermoeconomics* has hampered the development of a well-defined CE identity (Merli et al., 2018). Therefore, authors are orienting towards the conceptualisation of circular economy through an 'umbrella' concept framework, facilitating the identification of synergies and limits among related concepts (D'Amato et al., 2017; Homrich et al., 2018). As Korhonen et al. (2018) point out, the circular economy concept has been led and promoted mainly by practitioners (Ellen MacArthur Foundation, 2013a, 2013b, 2013c; WRAP, 2015; McKinsey, 2016) and governing bodies (McDowall et al., 2017). In addition, the dominant interpretation of CE is mainly promoting a reductionist perspective, mainly linked to improved waste management practices, advocating "enhanced" recycling, recovering and reusing patterns (Ghisellini et al., 2016; Genovese and Pansera, 2020). This would result to an unsuccessful transition towards a CE, given that some of the identified waste management pathways could be appropriate in certain conditions but may fail in other situations. In view of this problematic conceptualisation of CE due to its apolitical and technocratic framing, counter proposals have been emerged suggesting a countervailing discourse, such as convivial technology (Genovese and Pansera, 2020).

Allegedly, the most influential field to the formulation of CE paradigm is industrial ecology which established the concept of industrial metabolism (Blomsma and Brennan, 2017). CE aims at: (i) implementing better waste management systems through preventive design, reuse and recycle; (ii) reducing the use of fossil resources by increasing the use or renewable resources; (iii) reducing the production of unnecessary goods and at implementing a "circular" governance with increased participatory strategies. Given the diverse disciplinary and conceptual underpinnings as well as the absence of well-defined theoretical boundaries, there is a lack of consensus on a specific definition regarding circular economy (Kirchherr et al., 2017). The most prominent definition of CE appears to be the one provided by Ellen MacArthur Foundation (2013a, p. 7), according to which 'a circular economy is an industrial system that is restorative or regenerative by intention and design'. This system corresponds to an idealistic state where waste virtually seizes to exist, as materials are re-used and recycled indefinitely in a closed loop (Ellen MacArthur Foundation, 2013a). Nonetheless, acknowledging the reality of material leakages due to lost opportunities or

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

technological restrictions, CE aims at extending the life cycle of materials pursuant to Stahel's (2010) Inertia Principle (den Hollander et al., 2017). This can be achieved through minimising the material and energy leakages by either slowing, narrowing, or closing the resource loops by following the '3R' value retention options of reduce, reuse and recycling (Geissdoerfer et al., 2017).

Regardless of the evident environmental benefits of circular economy, the economic viability is questioned by market dynamics and regulatory inefficiencies which potentially can lead to higher production costs (Genovese et al., 2017). Another issue is the vulnerability of CE to rebound effects –the risk of increased efficiency eventually offsetting its benefits and successively leading to de-growth (Korhonen et al., 2018a). According to Zink and Geyer (2017), such effects can be either direct or indirect and are attributed to price and substitution effects, respectively. This fact justifies the shift of interest towards eco-industrial parks as the participating network of firms operates based on collaboration and not competition, thus developing the ability to reduce externalities (Bellantuono et al., 2017). The previous points highlight the need to examine the topic of circular economy using a systemic approach rather than perceive it as another set of sustainable practices.

2.2 Food waste in the context of EU

The aim of CE is to extend the lifetime of a product by retaining or restoring its economic value over time, in order to facilitate sustainable development in the form of enhanced economic, social and environmental performance (Ghisellini et al., 2016). Within this context, the unavoidable fraction of FW represents a huge opportunity for the bioconversion in useful materials (i.e. chemicals) and energy (i.e. biofuels and electricity) (Dahiya et al., 2018).

Table 1 and Figure 2 list respectively the share in terms of tonnes generated and in terms of percentages of the different waste components, identified using EWC-Stat 4 codes (EC, 2010), generated by EU-28 countries in 2016, as presented by Eurostat data (Eurostat, 2019). Food-related waste represents a significant part (≈ 4%) of total waste production in the year 2016, a proportion that exemplifies the potential for FW management and recovery. W09, as specified in EC (2010), represents the subtotal of W091 (Animal and mixed food waste), W092 (Vegetal wastes) and W093 (Animal faeces, urine, and manure). Production trends of each category in the 2010-2016-time interval are reported in Figure 3. The overall trend seems to increase in 2014 and 2016, with W091 decreasing in 2012 and 2014, and going back to 2010 level in 2016. W092 and W093 slightly increase over the course of 2014 and 2016.

Food and FW has been identified as a major hotspot of the bioeconomy development, including future and already implemented business models, that though still show very little participation from larger, multinational companies intended to maintain the status quo (Kristinsson and Jörundsdóttir, 2019). From this perspective, FW management and recovery becomes of maximum relevance.

Table 1
Waste generated within EU28 in 2016

EWC-Stat 4 codes	Tonnes (E+07)	Category
W01-05	5.4	Chemical and medical wastes (subtotal)

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

W061+W062+W063	9.9	Metal wastes
W071	1.9	Glass wastes
W072	5.1	Paper and cardboard wastes
W073+W074	2.1	Rubber & Plastic wastes
W075+W076	5.7	Wood + Textile wastes
W077_08	1.8	Equipment (subtotal, W077+W08A+W081+W0841)
W09	9.5	Animal and vegetal wastes (subtotal, W091+W092+W093)
W10	30.7	Mixed ordinary wastes (subtotal, W101+W102+W103)
W11	20.7	Common sludges
W121	34.5	Mineral waste from construction and demolition
W12B	70.4	Other mineral wastes (W122+W123+W125)
W124	11.8	Combustion wastes
W126	49.4	Soils
W127	90.3	Dredging spoils
W128	46.0	Mineral wastes from waste treatment and stabilised wastes

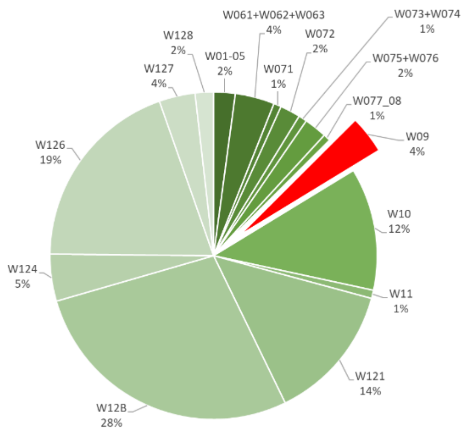


Figure 2
Percentage of each waste category on total waste production in 2016. W09 (Animal and vegetal wastes: W091+W092+W093) highlighted in red.

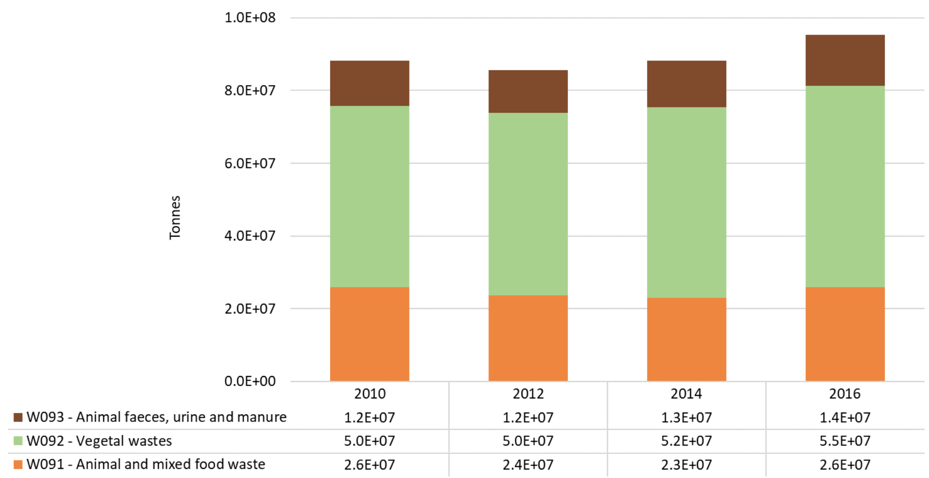


Figure 3

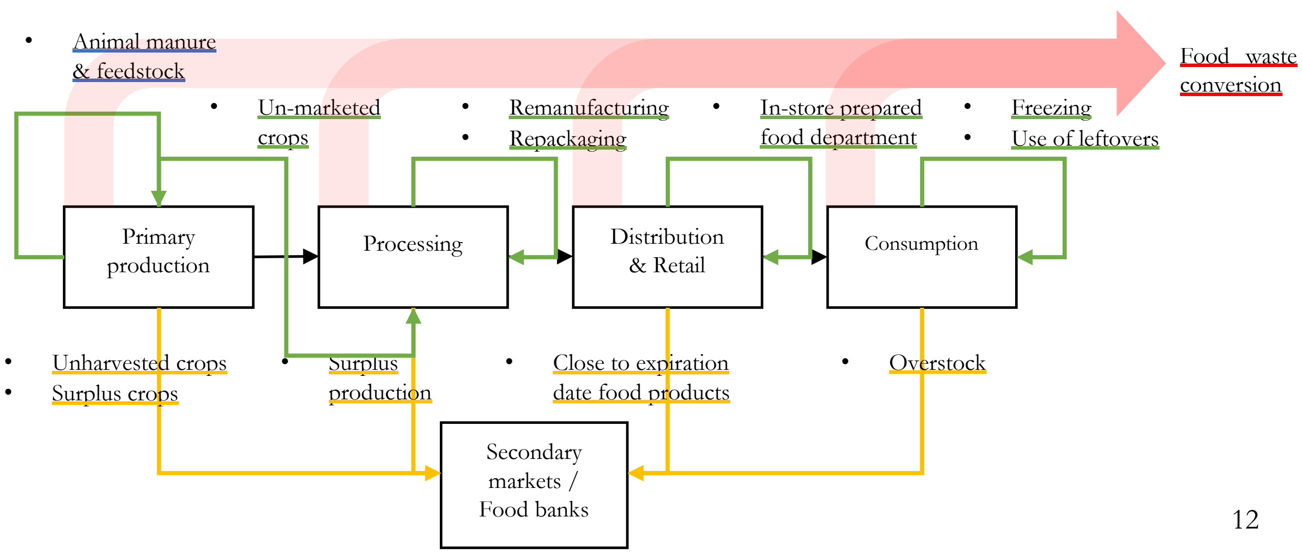
This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Percentage of each waste category on total waste production in 2016. W09 (Animal and vegetal wastes: W091+W092+W093) highlighted in red.

Next section aims to provide an overview of CE practices at each food supply chain stages according to the 3R retention options (i.e. reduce, reuse and recycle) and identify conversion pathways and consequent bio-products (i.e. bio-materials, bio-fuels, bio-energy). Presenting the findings from the classification of the reviewed scientific works and providing some explanatory assessment of treatments of EU28 generated food related waste, this report seeks to add value through the commixture between the analysis of specific FW conversion pathways and the comprehensive assessment of opportunities and constraints associated with FW strategies, still quite lacking and much needed for a successful transition towards a Circular Economy. It should be noted that preventing and recovering food waste is a multi-dimensional issue that requires a multi-dimensional approach, achieved through a multi-method assessment. In addition, FW conversion processes are usually either take place at a laboratory or pilot scale, while their implementation at a real, industrial scale level, is not even mentioned. Yet, the environmental assessment of FW conversion processes should not be overlooked, since solutions that could be beneficial in certain contexts may not represent a feasible option in others (Fiorentino et al., 2017).

3 Overview of Circular Economy practices per supply chain stage

Figure 4 provides a simplified model of the food supply chain and the loops pertaining to the most prominent CE practices. It consists of four distinct stages, namely primary production, processing, retail, and consumption. In detail, primary production stage includes pre-harvest, harvest and post-harvest processes including storage, processing stage refers to food manufacturing and packaging, retail includes supermarkets as well as wholesale distributors while consumption, pertains to public and household consumption. Green, yellow and red arrows represent food flows between supply chain stages. Specifically, the yellow ones pertain to the redistribution of surplus crops and food products to secondary markets or food aid organisations, the green ones refer to re-use loops that retain the value of food waste and losses at the same supply chain stage, and the red ones involve the food waste and losses stream towards their conversion to energy, active bio-compounds or other uses. A detail overview of these flows is provided in sections 3.1-3.4 and 4.



This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Figure 4
Food supply chain stages

3.1 Primary production stage

Circular Economy practices at this stage are related to both direct causes, factors beyond the farmers' control (e.g. climate, pests, available harvest and post-harvest technologies) and indirect causes, which are more systemic and relate to economic, legislative and cultural factors (e.g. market pressures, legal framework, culture and retailers' standards). It is important to note that the scope of food losses has changed since SIK's report in 2011 (FAO, 2011). Specifically, pre-harvest and harvest losses have been excluded from FAO's global FLI indicator to ensure consistency with the definition of agricultural production – relevant activity variables are area sown and area harvested (FAO, 2017) – within the Food Balance Sheet framework (FAO, 2019).

Acknowledging the association of losses at pre-harvest and harvest levels with inadequate agronomic practices and harvest planning as well as handling, we have included these to the scope of our CE practices review – adhering to the retention option of *reduce*. Referring to pest, nutrient, water and crop management, agronomic practices aim at improving soil's structural properties, optimising water usage, preventing eutrophication and minimising crop's vulnerability to pest and diseases (HLPE, 2014). The selection of appropriate cultivar varieties is important as it affects food waste losses at subsequent supply chain stages. According to Opara and Pathare (2014), cultivars that incorporate the physiological characteristics that increase crops' resistance to temperature variations and bruises is crucial towards the prevention of food losses during handling and storage. Given the dependence of agricultural losses on weather conditions and regional characteristics (Beretta et al., 2013), optimal harvest planning is critical to achieve maximum crop yields while optimising production rates (HLPE, 2014). The rate of agricultural losses is also affiliated with the use of mechanical or manual harvesting techniques as handling specifications vary across different crops, thus increasing the risk of damage in the field (Beausang et al., 2017). Thus, investing in new technologies and the adequate training of on-farm employees, is vital to the mitigation of harvest losses (Bilska et al., 2016). Following harvest, food losses prevention practices are aiming at the minimisation of spoilage and degradation through temperature storage control and compliance with hygienic rules (HLPE, 2014; Bilska et al., 2016).

Reuse practices are focusing on the redistribution of crops suitable for human consumption either through gleaning (Lee et al., 2017) or donation to food aid organisations (Bilska et al., 2016). In cases of fresh fruits and vegetables that do not comply with retailers' cosmetic requirements but are suitable for human consumption, best practice relates to their redirection to alternative market channel, such as farmers' markets.

On the other hand, inedible parts are used typically for animal feed or non-food purposes such as compost or production of biofuels (Redlingshöfer et al., 2017). Due to the proximity of animal and arable farms, use of animal-derived organic fertilisers is considered the most common *recycling* practice in the primary production stage (Case et al., 2017). With reference to energy recovery, on-farm anaerobic co-digestion of animal manure and domestic food waste is acknowledged as a recycling practice that offers a wider distribution of economic gains while capturing a larger

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

proportion of losses flow leakages (Banks et al., 2011). This type of decentralised waste treatment practice not only increases the efficiency of the process through co-digestion (Agyeman and Tao, 2014), but also enables farmers to manage their agricultural waste on site and subsequently increase their income from the sale of energy outputs (Banks et al., 2011).

Table 2
Overview of Circular Economy practices at the primary production stage

3Rs	Circular economy practices	Key references
Reduce	Adequate agronomic practices (i.e. pest/disease management; fertilisation; water management; selection of appropriate cultivars)	HLPE (2014); Opara and Pathare (2014); Beausang et al. (2017); FAO (2019);
	Optimal harvest planning	HLPE (2014); Beausang et al. (2017)
	Appropriate post-harvest handling practices	HLPE (2014); Beretta et al. (2013); Bilska et al. (2016); Beausang et al. (2017)
	Adequate control of storage conditions (e.g. proper temperature control, compliance with hygienic rules)	HLPE (2014); Bilska et al. (2016); Beausang et al. (2017)
Reuse	Gleaning of unharvested crops	Lee et al. (2017); Muriana (2017)
	Donation to food aid organisations	Bilska et al. (2016)
	Redirection of cosmetically imperfect edible produce to alternative distribution channels	de Hooge et al. (2018)
Recycle	Use of animal manure/inedible crops as organic fertiliser	Beausang et al. (2017); Case et al. (2017); Redlingshöfer et al. (2017)
	Direct use as animal feed	Beausang et al. (2017); Redlingshöfer et al. (2017); Willersinn et al. (2017)
	Energy recovery (e.g. biofuels, biogas)	Banks et al. (2011); Agyeman and Tao (2014); Beausang et al. (2017); Redlingshöfer et al. (2017)

3.2 Processing stage

Food losses at this stage are mainly associated with technical issues during operations, safety hazards and inability to meet trade quality specifications. First line measures for the reduction of food waste are orientated towards the mitigation of technical as well as human errors occurrence through the prompt maintenance or technological renewal of equipment, the development of emergency power supply systems (EPSS), and the application of training and competency protocols (Raak et al., 2017). With respect to the incidence of safety hazards that could result in waste at retail and consumption stages, food processors are emphasising on the implementation of safety management systems such as Hazard Analysis and Critical Control Point (HACCP) or ISO22000 (Bilska et al., 2016). In addition, expansion of production options conveys the potential of reducing waste downstream in the supply chain through the extension of shelf-life, either by incorporating lines for frozen foods (Banasik et al., 2017) or through the adoption of intelligent and smart packaging systems (Muriana, 2017). The latter provides both retailers and consumers

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

the ability to reduce food waste by monitoring the perishability of food through time temperature (TTI) or other quality and freshness indicators (Priefer et al., 2016; Raak et al., 2017). Nevertheless, the prominent issue of demand variability due to seasonality, promotions and retailer service level requirements necessitate the implementation of holistic adaptive forecasting models (Muriana, 2017).

In the event of production or packaging errors, re-manufacturing and re-packaging constitute the most suitable food waste prevention approaches respectively. The former approach is not only confined to the boundaries of processing stage as a response to operation errors but poses a suitable option in the supplier-retailer interface (Garrone et al., 2016). Specifically, when operationally feasible, unsold products can be returned to food manufacturers to be processed and successively re-incorporated into the production process (Banasik et al., 2017a). Apart from instances of demand fluctuations, a substantial amount of surplus production is owning to internal sell-by dates (Garrone et al., 2016). In detail, products reaching their internal sell-by date are preferably redistributed to the primary market at discounted prices or promotional offers. On the other hand, food products exceeding their sell-by date are not compliant with retailers' standards, hence they reach consumers through secondary markets or in the form of donations to food aid organisations (Priefer et al., 2016). Alternative options include remanufacturing, distribution within the organisation as gifts to employees, events sponsorships or sent as samples to potential customers (Garrone et al., 2016).

If surplus food products are not suitable for human consumption, they are redirected for recycling. Recycling approaches pertain to the conversion to animal feed (Ebner et al., 2014), production of compost (Sánchez et al., 2017), energy recovery (Ujor et al., 2014; Santagata et al., 2017) and extraction of bioactive compounds (Mirabella et al., 2014). The latter practice receives growing attention during the past years as the antioxidant, absorbing and antimicrobial capacity of these value-added compounds, provides the potential for them being utilised on nutraceutical, pharmaceutical and cosmetic industries (Mirabella et al., 2014). Emphasis is also placed on the industrial and municipal wastewater treatment potential as the absorbing capacity of active ingredients in agro-industrial waste makes it suitable for the removal of pollutants, such as heavy metals and dyes (Grace et al., 2016).

Table 3
Overview of Circular Economy practices at the processing stage

3Rs	Circular economy practices	Key references
Reduce	Prompt maintenance, repair and renewal of technological equipment as well as adequate employee training and development	Raak et al. (2017)
	Implementation of food safety management systems (e.g. HACCP, ISO22000)	Bilska et al. (2016); Raak et al. (2017)
	Incorporation of production lines for frozen products	Banasik et al. (2017)
	Adoption of intelligent packaging technologies (e.g. TTI)	Priefer et al. (2016); Muriana (2017); Raak et al. (2017)
	Implementation of holistic adaptive forecasting models	Muriana (2017)
Reuse	Remanufacturing in the case of production errors or returned food products	Garrone et al. (2016); Banasik et al. (2017)
	Repackaging in the case of packaging errors	Garrone et al. (2016); Raak et al. (2017)

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

	Redistribution of close to internal sell-by or surplus food products either internally (e.g. employees, customer samples) or externally (e.g. secondary markets, sponsorships, donations to food aid organisations)	Garrone et al. (2016); Priefer et al. (2016); Raak et al. (2017)
Recycle	Conversion to animal feed	Garrone et al. (2016); Raak et al. (2017)
	Production of bio-fertilisers	Garrone et al. (2016); Sánchez et al. (2017)
	Energy recovery (e.g. biogas, butanol)	Ebner et al. (2014); Ujor et al. (2014); Santagata et al. (2017)
	Extraction of valuable compounds	Mirabella et al. (2014); Grace et al. (2016)

3.3 Retail stage

At the retail stage, food waste mainly occurs due to the surplus of food products. Therefore, primary focus is placed on the development of advanced forecasting models which incorporate the impact of external variables beyond annual seasonality to short-term dynamics pertaining to holidays, weather, and discount prices (Arunraj and Ahrens, 2015). However, in view of the occurrence of un-avoided food surpluses due to unprecedented events, discount pricing strategies on close to expiration date as well as suboptimal products have been the most common effective control approach towards avoiding food waste (Buisman et al., 2019). Reduced prices create an incentive for consumers to buy products which otherwise would had been discarded, thus minimising retail profit losses (Aschemann-Witzel et al., 2017). Further reduction in food waste can be achieved by applying discounts based on a dynamically adjustable expiration date (Buisman et al., 2019). Essential to the application of the latter practice is the use of intelligent packaging technologies, such as TTI, which allow the determination of the optimal level of discount that should be applied according to the shelf-life expectancy of the food product (Muriana, 2017). In recent years, alternative food retail concepts such as zero-packaging grocery stores (Beitzen-Heineke et al., 2017) and subscription-based box schemes (Tua et al., 2017) are gaining traction in the market. Enabling consumers to control the portions of food they purchase, zero-packaging stores facilitate the reduction of food waste at the consumption stage (Beitzen-Heineke et al., 2017). Prospective benefits are extending to the primary production level as such alternative grocery models emphasise on seasonal and local fresh produce while releasing farmers from compliance with packaging requirements, thus limiting large supermarkets' market power (Tua et al., 2017). Better portion control can be also achieved through the availability of smaller and divisible packaging, minimising simultaneously the level of expected food waste at the retail stage (Aschemann-Witzel et al., 2017). Retailer cosmetic standards regarding fresh fruits and vegetables have been highlighted in the literature as the key cause of food waste in the primary production stage (Beausang et al., 2017). Corresponding interventions at retail stage relate to the introduction of cosmetically imperfect ranges of fresh fruits and vegetables (Cicatiello et al., 2016), a practice that is gaining popularity among retailers in the UK in the past years (Guardian, 2018). Similarly, ranges of available fresh products can be confined only to seasonal foods benefiting local and regional farmers (Beitzen-Heineke et al., 2017). Another issue responsible for a large proportion of food waste at the retail stage is the ambiguity of existing food labels (Lebersorger and Schneider, 2014). Related initiatives are orientated to the prevalence of 'use by' rather than 'best before' date,

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

as the latter creates confusion among consumers regarding the food product's safety (Wilson et al., 2017). Marketing interventions include the substitution of bulk promotions in the form of "Buy one, get one free" (BOGO) by discounts in local fresh produce to incentivise their sale (Delley and Brunner, 2017). The effects of such practices could be amplified through in-store food waste awareness campaigns aiming at educating consumers about food labels as well as providing them with food storage and preparing guidelines (Priefer et al., 2016). According to Eriksson et al. (2016) the perishability rate of food products at the retail stage could be achieved by reducing the storage temperature.

Reuse practices are focusing on the edible fraction of surplus food that is either close to their expiry date or suboptimal, i.e. cosmetically 'imperfect' or its packaging is damaged. The most common reuse practice is the redistribution of such products through donations to food aid organisations (Cicatiello et al., 2017). In other cases, surplus fresh produce can be redirected to in-store prepared food department and be used as an ingredient (Lee and Tongarlak, 2017).

Anaerobic digestion is the most common treatment of retail food waste. Treatment usually includes the co-digestion of food waste and animal manure. Since food products are not segregated from their packaging prior to its arrival, pre-treatment is essential (Brancoli et al., 2017). Recycling into animal feed is confined to specific food product categories of higher dry matter content, such as bread, which is an indicator of feed quality (Vandermeersch et al., 2014; Brancoli et al., 2017).

Table 4
Overview of Circular Economy practices at the retail stage

3Rs	Circular economy practices	Key references
Reduce	Improvement of demand forecast accuracy	Arunraj and Ahrens (2015)
	Discount pricing strategies for close to the expiration date or suboptimal products	Aschemann-Witzel et al. (2017); Buisman et al. (2019)
	Availability of active/intelligent/smart packaging	Muriana (2017); Buisman et al. (2019)
	Zero-packaging grocery stores	Beitzen-Heineke et al. (2017)
	Subscription-based box schemes	Tua et al. (2017)
	Availability of smaller and divisible packaging	Aschemann-Witzel et al. (2017); Wilson et al. (2017)
	Introduction of cosmetically imperfect range of fruits and vegetables	Cicatiello et al. (2016); Beausang et al. (2017); Hermsdorf et al. (2017)
	Introduction of local and seasonal range of fruits and vegetables	Beausang et al. (2017); Beitzen-Heineke et al. (2017); Delley and Brunner (2017)
	Minimise ambiguity with reference to food labels (e.g. streamlined expiry dates, information related to storage and preparing best practices)	Lebersorger and Schneider (2014); Wilson et al. (2017)
	Abolishment of bulk discounts	Delley and Brunner (2017)
	In-store food waste awareness campaigns	Priefer et al. (2016); Delley and Brunner (2017)
	Reduction of storage temperature	Eriksson et al. (2016)
Reuse	Donation and redistribution of edible fraction of suboptimal or close to expiration date food products	Cicatiello et al. (2017)
	Redirection of surplus fresh produce to in-store prepared food department	Lee and Tongarlak (2017)

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Recycle	Treatment using anaerobic digestion (production of biogas and digestate)	Vandermeersch et al. (2014); Brancoli et al. (2017)
	Conversion into animal feed	Vandermeersch et al. (2014); Brancoli et al. (2017)

3.4 Consumption stage

The topic of food waste generation at the household stage is complex as it depends on contextual and individual variables related to socio-economic, cultural, attitudinal, and demographic factors (Secondi et al., 2015; Visschers et al., 2016). Given the complexity of this issue, attention is placed on prevention practices related to planning, shopping, preparing, storing and leftover routines (Hebrok and Boks, 2017). Planning routines are pivotal to the reduction of food waste. Related practices comprise planning of meals in advance, inventory control, tracking of expiration dates, and compilation of shopping lists (Stancu et al., 2016). The criticality of these routines lies within their ability to regulate the flow of products according to household size, existing stock and storing capacity, thus mitigating the risk of food spoilage (Richter and Bokelmann, 2017). On the other hand, shopping routines primarily aim at purchasing the right quantity of food according to household size while avoiding impulsive buys related to promotional offers such as "Buy one, get one free" (Ponis et al., 2017). Preference to smaller and divisible packaging is essential not only to portion control but also towards optimising storage at home (Williams et al., 2012). In addition, the impact of specific consumer purchasing decisions is conveyed to upstream stages. For instance, an increase in consumption of local, seasonal or 'imperfect' produce (Beretta et al., 2013) could significantly reduce the food losses at farm level related to cosmetic requirements and unpredictable orders set by retailers (Beausang et al., 2017). Awareness and knowledge regarding food labels is essential to assess product quality and subsequently avoid waste due to misinterpretation of expiration dates or storage guidelines (Aschemann-Witzel et al., 2017; WRAP, 2017). Good storage practices pertain to appropriate food storage and preservation techniques that aim at extending product life while minimising spoilage risks (Richter and Bokelmann, 2017). Nonetheless, these practices diversify across different product categories, such as bananas or avocados, since very low temperature environments are damaging them (Hebrok and Boks, 2017). Tracking of expiration dates and temperature variations can be facilitated by technological innovations related to smart kitchen applications (Janssen et al., 2017). Special attention is placed on freezing and defrosting guidance for leftovers as improper handling increases the risk of food safety (Schmidt, 2016; FAO, 2017). A significant proportion of food waste also occurs during preparation, usually due to overcooking, improper recipe execution or excess trimming (Richter and Bokelmann, 2017). Culinary skills are also affecting the ability to manage leftovers, especially incorporate them in new dishes (Abeliotis et al., 2016).

Alternatively, leftovers can be properly stored and kept for next meals (Delley and Brunner, 2017), redistributed through gifting (Evans, 2012) or food donation networks (Hebrok and Boks, 2017). The latter practice could be also adopted in the case of ambient food products that are close to their expiration date (FAO, 2017).

Recycling process can take place either domestically as in the case of home composting (Storino et al., 2016), or through the treatment channel of municipal waste (Evangelisti et al., 2017). Proper segregation of organic and non-organic waste at the point of consumption as well as separate

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

collection from municipal services is vital for both composting and anaerobic digestion process (Senthilkumar et al., 2014; Bees and Williams, 2017). Another practice that is gaining traction is the production of biodiesel from used cooking oils (UCO), though collection of these is hindered by the lack of an extensive collection network (Genovese et al., 2017; Wallace et al., 2017).

Table 5
Overview of Circular Economy practices at the consumption stage

3Rs	Circular economy practices	Key references
Reduce	Meal planning (Inventory control, weekly menu, grocery lists)	Hebrok and Boks (2017)
	Avoidance of impulse purchases	Beitzen-Heineke et al. (2017); Ponis et al. (2017); Wilson et al. (2017)
	Preference towards smaller and divisible packages	Wilson et al. (2017)
	Consumption according to seasonal produce	Beretta et al. (2013)
	Acceptance of cosmetically imperfect produce	Schmidt (2016); Aschemann-Witzel et al. (2017)
	Knowledge and correct interpretation of food labels	Wilson et al. (2017)
	Adequate storage practices	Williams et al. (2012); Hebrok and Boks (2017)
	Improvement of culinary skills	Richter and Bokelmann (2017)
	Control of portions	Beretta et al. (2013)
Reuse	Incorporate leftovers in new recipes	Hebrok and Boks (2017)
	Adequate store and reheat leftovers	Delley and Brunner (2017); Hanssen et al. (2017); Hebrok and Boks (2017)
	Redistribution of surplus food (leftovers; close to expiration date products)	Evans (2012)
Recycle	Home composting for soil amendment	Cole et al. (2014); Edjabou et al. (2016)
	Production of biogas and digestate through the anaerobic digestion of municipal waste stream	Bees and Williams (2017)
	Production of biodiesel from used cooking oils (UCO)	Genovese et al. (2017); Wallace et al. (2017)

4 Food waste conversion pathways

This section provides an overview of the identified conversion pathways. These pathways involve only the stream of unavoidable food losses. Recovering and using this unavoidable organic waste fraction could be considered a new way of mining resources, capable of reducing the depletion of non-renewable stocks, thus increasing environmental integrity. Following the identification of these pathways, this section extends to the environmental assessment of each option, using Life Cycle Assessment (LCA) and Emergy Analysis (EMA). Prior to the analysis, an overview of each of these aforementioned methods is provided, pointing out the characteristics that justify their adoption.

Analysis of these conversion pathways was based on 27 scientific papers, which are presented in Table 6 and Table 7. The scientific works has been obtained by means of a Boolean search using

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

the operators "Food AND Supply Chain AND Waste AND Recovery" on the Scopus database, selecting only scientific works reporting food waste conversion pathways. Table 6 lists the 9 identified Literature Review papers that set the foundations for the identification of FW conversion paths. Item A (Breitenmoser et al., 2019) focuses on the anaerobic digestion of different kinds of waste and agri-food waste in order to generate biogas, accounting for different digestion systems. Item B (Facchini et al., 2018) considers FW throughout UK food supply chain and redistribution of surplus food still edible. Item C (Koller et al., 2017) reviews the biological synthesis of polymers from different microbial strains applied to different food related waste. Item D (Verstraete et al., 2016) is about recovery of nutrient from municipal, industrial and manure wastewater streams. Item E (Uçkun Kiran et al., 2015) is a review about the state of the art of the recovery of platform chemicals from various kinds of food waste through fermentation technologies. Enzyme production from conversion processes of food related, mainly agricultural, waste is assessed in Item F (Uçkun Kiran et al., 2014a). Item G (Uçkun Kiran et al., 2014b) reviews the possibilities of useful biofuels production from fermentation of food waste. Items H (Reijnders, 2014) is about phosphorus resources pathways and their possible conservation and recovery, including phosphorus contained in food waste and in food losses at different levels. The last review item, Item R (Girotto et al., 2015), assesses possible uses of FW within the industry sector. Item R was erroneously identified by Scopus as an "Article" item, thus in this work it has been classified within "Review" items.

Table 6
Outline of "Review" items on conversion pathways of food related waste

Item	Authors	Pathway	Source
A	Breitenmoser et al., 2019	Anaerobic digestion	Journal of Environmental Management
B	Facchini et al., 2018	Food redistribution	Journal of the Air and Waste Management Association
C	Koller et al., 2017	Biopolyesters production	New Biotechnology
D	Verstraete et al., 2016	Water and nutrient recovery	Bioresource Technology
E	Uçkun Kiran et al., 2015	Platform chemical production	Journal of Chemical Technology and Biotechnology
F	Uçkun Kiran et al., 2014a	Enzyme production	Waste and Biomass Valorisation
G	Uçkun Kiran et al., 2014b	Energy generation	Fuel
H	Reijnders, 2014	Phosphorus conservation and recovery	Resources, Conservation and Recycling
R	Girotto et al., 2015	FW use within industry	Waste Management

The other scientific works (i.e. articles, book chapters, conference papers and conference reviews), included in the construction of the FW conversion pathways are listed in Table 7. Most items in both Table 6 and Table 7 present alternative, novel or specific physical, chemical or biological processing and/or conversion treatments of selected FW materials, far looking into not yet explored perspectives.

Table 7

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Scientific works providing a FW conversion pathway included in the database.

Item	Authors	Pathway	Source
I	Piccolella et al., 2019	Recovering *Cucurbita pepo* cv. 'Lungo Fiorentino' Wastes: UHPLC-HRMS/MS metabolic profile, the basis for establishing their nutra- and cosmeceutical valorisation	Molecules
J	Ghosh et al., 2019	Towards waste meat biorefinery: Extraction of proteins from waste chicken meat with non-thermal pulsed electric fields and mechanical pressing	Journal of Cleaner Production
K	Carraresi et al., 2018	Emerging value chains within the bioeconomy: Structural changes in the case of phosphate recovery	Journal of Cleaner Production
L	Hu et al., 2018	A Supply Chain Framework for the Analysis of the Recovery of Biogas and Fatty Acids from Organic Waste	ACS Sustainable Chemistry and Engineering
M	Ohnishi et al., 2018	Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city	Resources, Conservation and Recycling
N	Tanguy et al., 2017	Service area size assessment for evaluating the spatial scale of solid waste recovery chains: A territorial perspective	Waste Management
O	Sgarbossa and Russo, 2017	A proactive model in sustainable food supply chain: Insight from a case study	International Journal of Production Economics
P	Eriksson et al., 2017	Take-back agreements in the perspective of food waste generation at the supplier-retailer interface	Resources, Conservation and Recycling
Q	Safar et al., 2016	Energy recovery from organic fractions of municipal solid waste: A case study of Hyderabad city, Pakistan	Waste Management and Research
S	Tamis et al., 2015	Lipid recovery from a vegetable oil emulsion using microbial enrichment cultures	Biotechnology for Biofuels
T	Wang et al., 2017	Waste-Energy-Water systems in sustainable city development using the resilience.io platform	Computer Aided Chemical Engineering
U	Prasad, 2016	Recovery of Resources From Biowaste for Pollution Prevention	Environmental Materials and Waste: Resource Recovery and Pollution Prevention
V	Slorach et al., 2019	Energy demand and carbon footprint of treating household food waste compared to its prevention	Energy Procedia
W	Kirby et al., 2017	The role of thermo-catalytic reforming for energy recovery from food and drink supply chain wastes	Energy Procedia
X	Inayati et al., 2018	Extraction of pectin from passion fruit rind (Passiflora edulis var. flavicarpa Degener) for edible coating	AIP Conference Proceedings
Y	Distantina et al., 2018	Carboxymethyl Konjac Glucomannan from Konjac Flour: The Effect of Media and Temperature on Carboxymethylation Rate	AIP Conference Proceedings

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Z	Fadilah et al., 2018	Study on the Carboxymethylation of Glucomannan from Porang	AIP Conference Proceedings
AA	Sembodo et al., 2018	Effect of Sodium Carbonate Catalyst Weight on Production of Bio-Oil via Thermochemical Liquefaction of Corncobs in Ethanol-Water Solution	AIP Conference Proceedings

Identified pathways for the conversion of FW are presented in Figure 5. They comprise of 189 combinations of different pre-treatment and conversion processes leading to different types of bio-products. In detail, each FW conversion pathway includes:

- The type of food related waste, namely: i) Agricultural biomass (waste generated within the agricultural crop processing), ii) Animal biomass (waste generated during livestock rearing), iii) Biomass from vegetables, fruits and seeds (waste generated by the use and processing of plant products), iv) Herbaceous and woody biomass (energy crops, waste wood), v) Food waste (mixed waste generated by food consumption), vi) Waste water (organic fraction of wastewater)
- The type of pre-treatment classification: i) Biological (e.g. aerobic fermentation), ii) Chemical (e.g. hydrolysis), iii) Physical (e.g. grinding), iv) Physicochemical (e.g. ultrasonic with acid), v) Physicothermal (e.g. grinding/steaming), vi) Thermal (e.g. drying), vii) Thermo-chemical (e.g. organosolvation), viii) Thermo-physico-chemical (e.g. drying/grinding/hydrolysis), N/A (when pre-treatment processes are not present or not indicated)
- The type of conversion process: i) Biological (e.g. anaerobic digestion), ii) Chemical (e.g. transesterification), iii) Physical (e.g. ultrasound-assisted extraction), iv) Thermal (e.g. incineration), v) Thermo-chemical (e.g. liquefaction), vi) Physico-chemical (e.g. upgrading)
- The final bio-product from conversion: i) Biofuel, ii) Bio-polymers, iii) Chemical, iv) Electricity, v) Food and feed ingredients, vi) Bio-Materials

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

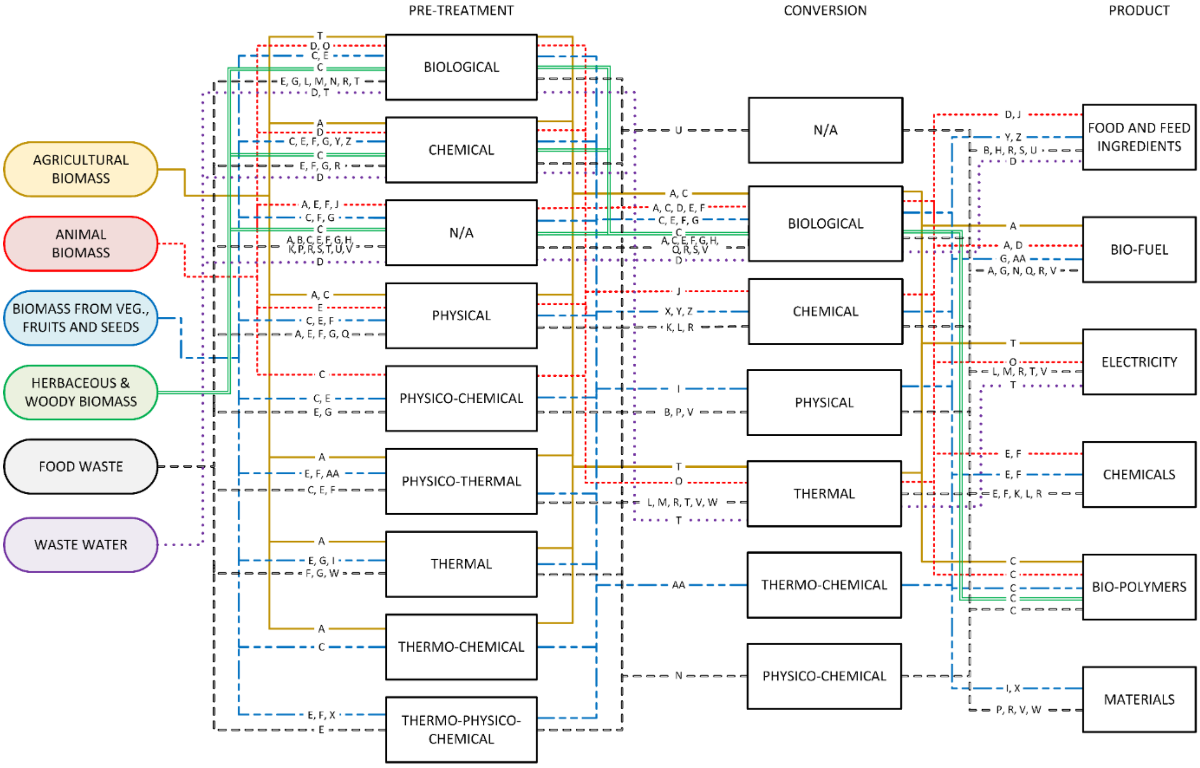


Figure 5
Identified pathways for the conversion of FW, classifying the starting material, pre-treatment processes, conversion processes and final outputs (N/A implies non present or not specified processes).

Half of the generated database (≈ 52%) includes recovery pathways of mixed end use materials (i.e. food waste, waste waters), 33% includes by-product biomass from the processing of vegetables, fruits and seeds, about 4% is agricultural biomass and 9% animal biomass. The remaining part (≈ 2%) is represented by food surplus or inadequate food and by-products of other agricultural processes (i.e. energy crops). Considering pre-treatment processes, about 7% are of biological or biochemical nature (anaerobic fermentation or digestion), 8% of chemical nature, 30% are of physical or physico-related mixed nature (physico-chemical, physico-thermal, etc.), 29% of the reviewed literature does not present or does not specify any pre-treatment of food materials, the remaining ≈13% are of thermal, or thermal-related mixed nature (i.e. thermo-physico-chemical). When taking into consideration the main conversion pathways, almost all the FW elements within the database (≈ 85%) are processed through biological treatments, such fermentation, anaerobic digestion or polymer biosynthesis; 8% of the assessed conversion pathways are classified as thermal, 4% as chemical and 3% as physical. Finally, 6% of the obtained bio-products are identified as feed or food ingredients, 7% as bioenergy (i.e. biopower), 22% as biofuel, 13% as bio-materials, including biomass, and about 50% as chemicals and enzymes. These numbers clearly indicate the direction taken by bioeconomy research in the last years.

The generated outputs are expected to decrease the burdens related to extraction, production and perhaps use of virgin resources and energy, which have been the foundation of the traditional “linear economy”. This means that the production of goods, fuels and energy (and then, the extraction of needed raw materials and the use of needed energy) may be partially replaced by bio-products coming from valuable sources that normally would be wasted and disposed of. The added value of these conversion processes resides in re-establishing the *right worth* (economic, social and

This project has received funding from the European Union’s Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

environmental) of the so-called "waste materials" and exploiting their full potential, instead of disposing them in useless and less environmentally feasible ways (i.e. landfills or incinerator). In natural ecosystems, the concept of "waste" is not applicable: every material and/or energy stream discarded from a certain subsystem represents a valuable resource for another subsystem, keeping all these streams in the substantially closed loop of Earth biosphere, driven by solar energy. Thus, the *right worth* is established by the availability to fruitfully employ such streams. This concept, together with economic and social considerations, might be adopted when dealing with by-products and "waste" flows by human activities.

In Figure 6, the NACE Statistical Classification of Economic Activities adopted within European Community (Eurostat, 2008) is used to identify the confluences of different activities related to the conversion of food waste, in order to avoid the generation of the same category of materials and energy. Specifically, all categories in the left column generate food related waste, to be treated in order to achieve materials/energy in the central column (in red). The generated goods will impact on the global economy by providing an alternative production process in substitution of the common ones classified in the activities in the right column. (e.g. a NACE C 10.3 activity generating apple pomace waste that is treated in order to obtain lactic acid, an organic chemical, avoiding its fossil-based equivalent production, classified as a NACE C 20.14 activity).

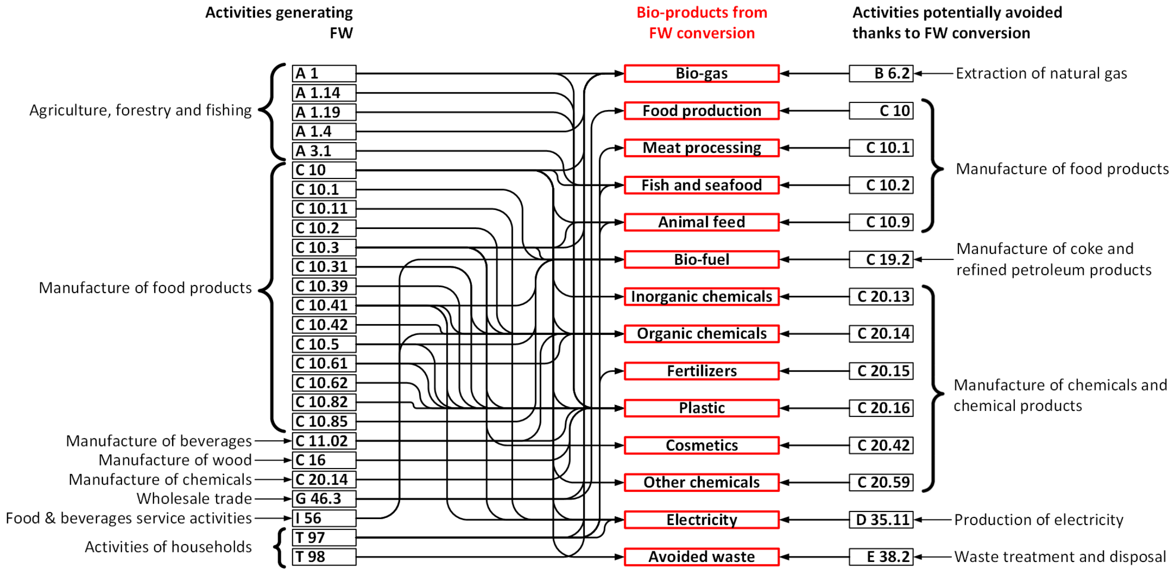


Figure 6
NACE activities generating the identified classes of FW (on the left), treated in order to obtain bio-products (in the centre), in so replacing previous business-as-usual NACE activities generating analogous products (on the right).

4.1 LCA and EMA analysis of EU28 generated FW conversion options.

To assess the identified disposal and conversion options for food waste, LCA (Life Cycle Assessment) and EMA (EMergy Accounting) methods were used. Acknowledging the wide array of environmental assessment methods in the literature, this report has selected the aforementioned methods due to their multidimensional design and their broad perspective which highlights the importance of adopting a holistic perspective to increase the level of understanding of the available conversion options; LCA being process chain oriented and EMA being biosphere space and time

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

scale oriented. The two methods have been applied to selected disposal and/or recovery pathways of W091, W092 and W093 FW generated within EU28 countries. An overview of both of these methods

4.1.1 Life Cycle Assessment (LCA)

This work uses the LCA method, standardised by ISO standards and ILCD Handbook guidelines (BMJ, 2006; ISO, 2006; JRC, 2010) as a four steps procedure (definition of goal and scope, inventory analysis, impact assessment and interpretation), to evaluate potential burdens and depletion of resources throughout a product's life cycle. LCA results are presented as a set of environmental impact categories, including, among others, climate change, stratospheric ozone depletion, depletion of resources, toxicological effects (Pennington et al., 2004). The study has been performed utilising the SimaPro software version 9.0.0.30 (https://simapro.com/), the Ecoinvent database version 3.6 (Wernet et al., 2016), and the ReCiPe method (Goedkoop et al., 2009) for impacts assessment. ReCiPe Midpoint (H) v.1.03 method has been chosen. The ReCiPe method incorporates characterisation factors to evaluate the potential contributions to each impact category and normalisation factors to allow a comparison across categories (Europe ReCiPe Midpoint (H), 2000, revised 2010). Characterised results cannot be compared, due to different physical units; therefore, a normalisation procedure is applied. Normalisation is a life cycle impact assessment tool used to express characterised impact indicators in a way that they can be compared, with reference to average impact values calculated for a given area in a given year. The impact categories explored in this study are listed in Table 1.

Table 8
Impact Categories considered within the ReCiPe Midpoint (H) v.1.03 impact method.

Impact category	Unit	Abbreviation
Climate change potential	kg CO_2 eq	CCP
Stratospheric ozone depletion potential	kg CFC11 eq	SODP
Ionising radiation potential	kBq Co-60 eq	IRP
Ozone formation, Human health potential	kg NO_x eq	OFHP
Fine particulate matter formation potential	kg PM2.5 eq	PMFP
Ozone formation, Terrestrial ecosystems potential	kg NO_x eq	OFEP
Terrestrial acidification potential	kg SO_2 eq	TAP
Freshwater eutrophication potential	kg P eq	FEP
Marine eutrophication potential	kg N eq	MEP
Terrestrial ecotoxicity potential	kg 1,4-DCB	TETP
Freshwater ecotoxicity potential	kg 1,4-DCB	FETP
Marine ecotoxicity potential	kg 1,4-DCB	METP
Human carcinogenic toxicity potential	kg 1,4-DCB	HCTP
Human non-carcinogenic toxicity potential	kg 1,4-DCB	HNCTP
Land use potential	m^2a crop eq	LUP
Mineral resource scarcity potential	kg Cu eq	MRSP
Fossil resource scarcity potential	kg oil eq	FRSP
Water consumption potential	m^3	WCP

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

4.1.2 Emergy Accounting (EMA)

EMA accounts for the energy directly or indirectly available for transformations in a system, to obtain a product or a service. (Brown and Ulgiati, 2004; Odum, 1996). The different emergy contributions to a system, in the form of material, energy and information resources, are classified as local renewable (R) and nonrenewable (N) and imported resources (F), including labour and services (L&S). The unit used is the solar emjoule (sej), expressing the amount of energy of one kind (solar) needed for a product or a service. The resulting total emergy (U) is the total contribution from the environment to products and services, calculated as the addition of all inflow amounts multiplied by the related emergy conversion factor, called Unit Emergy Value (UEV, measured as sej/unit-of-inflow). The UEV is calculated by dividing U by the yield of related product or service. A UEV defined as sej/J is called 'transformity'. UEVs are calculated with relation to a Global Emergy Baseline (GEB), accounting for the annual total emergy driving the biosphere. In this work, the 12E+24 seJ/yr GEB (Brown et al., 2016) is adopted. All UEVs related to previous GEBs are converted accordingly.

4.1.3 Analysis

According to the most "mainstream" conversion processes reported within the Ecoinvent database (Wernet et al., 2016), biowaste can undergo incineration, anaerobic digestion (AD) or industrial composting (IC), while manure can be used for the production of biogas through anaerobic digestion (AD), or used directly as fertiliser. Table 9 and Figure 7 show respectively characterised and normalised LCA results for generic 2016 EU-28 generated biowaste (i.e. W091+W092) as starting material for incineration, AD or IC (LCA Impact Categories are listed according to Table 2). Comparison of these conversion processes shows how AD seems to be the overall most impacting system, with lower impacts within IRP, PMFP, TAP and LUP, where the highest values are related to IC system. However, the overall impact of IC seems to be the lowest, with Incineration standing in between IC and AD systems.

Table 9

Recipe Midpoint (H) characterised impacts for the incineration, anaerobic digestion and industrial composting of the EU28 generated biowaste (Acronyms according to Table 2)

Impact category	Unit	Incineration	AD	IC
CCP	kg CO_2 eq	3.27E+09	9.82E+09	5.49E+09
SODP	kg CFC11 eq	4.73E+04	7.90E+04	2.34E+04
IRP	kBq Co-60 eq	3.93E+07	7.98E+07	1.39E+08
OFHP	kg NO_x eq	2.05E+07	2.27E+07	6.78E+06
PMFP	kg PM2.5 eq	4.50E+06	9.22E+06	1.75E+07
OFEP	kg NO_x eq	2.06E+07	2.30E+07	6.92E+06
TAP	kg SO_2 eq	1.13E+07	2.44E+07	1.19E+08
FEP	kg P eq	3.96E+06	2.06E+07	6.95E+05
MEP	kg N eq	9.47E+05	1.13E+06	1.50E+05
TETP	kg 1,4-DCB	6.08E+09	1.09E+10	5.19E+09
FETP	kg 1,4-DCB	5.29E+08	1.92E+09	6.86E+07
METP	kg 1,4-DCB	7.06E+08	2.53E+09	9.30E+07

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

HCTP	kg 1,4-DCB	6.95E+08	1.36E+09	2.41E+08
HNCTP	kg 1,4-DCB	1.15E+10	4.14E+10	1.33E+09
LUP	m^2a crop eq	5.81E+07	1.32E+08	2.55E+08
MRSP	kg Cu eq	1.42E+07	1.49E+07	8.75E+06
FRSP	kg oil eq	4.79E+08	1.14E+09	6.95E+08
WCP	m^3	4.58E+07	1.79E+07	1.85E+06

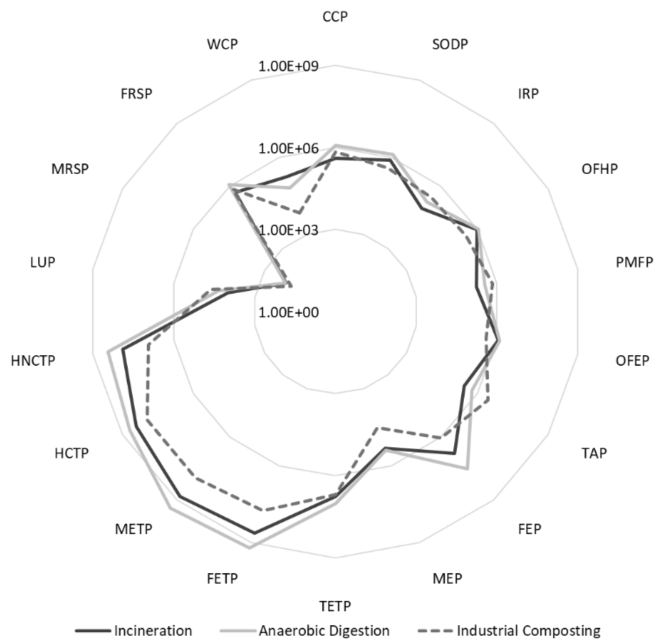


Figure 7
Recipe Midpoint (H) normalisation for the incineration, anaerobic digestion and industrial composting of the EU28 generated biowaste (W091+W092) (Acronyms according to Table 2).

On the other hand, Table 10 and Figure 8 respectively show characterised and normalised LCA results for the anaerobic digestion and the direct spreading of manure (W093). The two systems show a similar trend related to most and least impacted categories. However, it is evident that AD is the most impacting system, from one order of magnitude (IRP, OFHP, TETP, MRSP, FRSP, WCP) to three orders of magnitude (SODP, TAP, MEP, HNCTP).

Table 10
Recipe Midpoint (H) characterised impacts for the spreading and the digestion of the EU28 generated manure (Acronyms according to Table 2).

Impact category	Unit	Spreading	AD
CCP	kg CO_2 eq	5.0E+07	1.9E+09
SODP	kg CFC11 eq	2.3E+01	2.3E+04
IRP	kBq Co-60 eq	1.5E+06	2.1E+07
OFHP	kg NO_x eq	4.1E+05	5.2E+06
PMFP	kg PM2.5 eq	1.2E+05	1.6E+07
OFEP	kg NO_x eq	4.2E+05	5.3E+06
TAP	kg SO_2 eq	2.4E+05	1.2E+08
FEP	kg P eq	1.2E+04	5.4E+06
MEP	kg N eq	8.1E+02	5.8E+05

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

TETP	kg 1,4-DCB	1.6E+08	2.4E+09
FETP	kg 1,4-DCB	1.1E+06	5.1E+08
METP	kg 1,4-DCB	1.6E+06	6.7E+08
HCTP	kg 1,4-DCB	2.6E+06	3.4E+08
HNCTP	kg 1,4-DCB	8.5E+07	1.1E+10
LUP	m^2a crop eq	2.2E+06	2.2E+08
MRSP	kg Cu eq	4.9E+05	3.3E+06
FRSP	kg oil eq	1.3E+07	1.6E+08
WCP	m^3	1.9E+05	8.9E+06

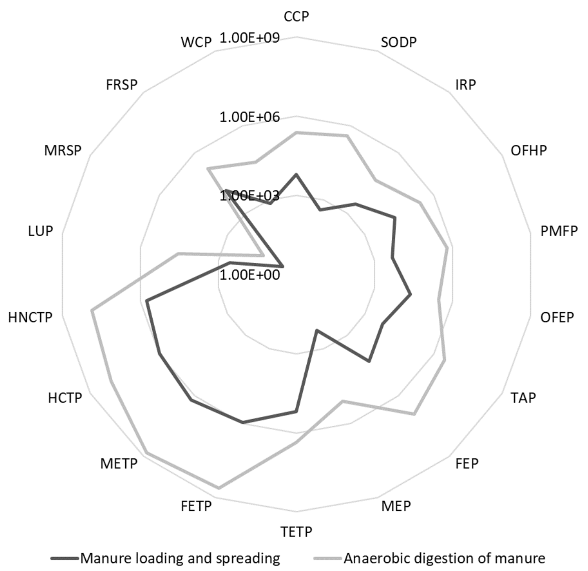


Figure 8
Recipe Midpoint (H) normalisation for the spreading and the anaerobic digestion of the EU28 generated manure (W093) (Acronyms according to Table 2).

To complement assessment perspective and cross validate results, we employ EMA to determine the environmental performance associated to the reported EU28 food related waste. Figure 9 shows the total emergy U (i.e. total demand of direct and indirect support by biosphere processes) associated to the conversion processes of incineration (Liu et al., 2017), composting (Liu et al., 2017) and anaerobic digestion (Moss et al., 2014) of 2016 EU28 generated W091 + W092. Compared to LCA, results differentiate as AD is showcased as a better performing option, with just 0.1E+21 sej more than IC without L&S.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

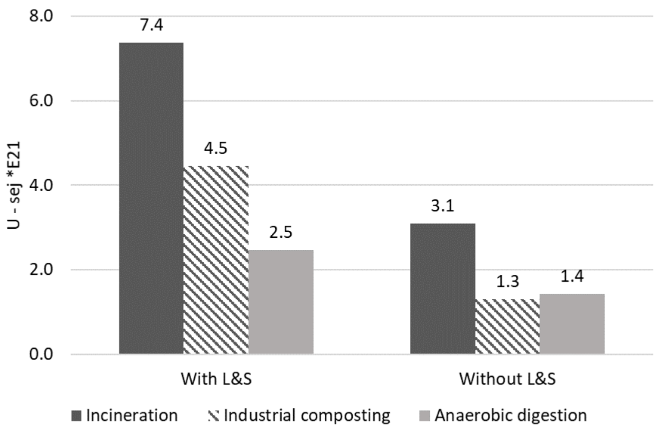


Figure 9
Total Emergy U with and without L&S related to the incineration, industrial composting and anaerobic digestion of EU28 generated biowaste (W091+W092).

Similarly, Figure 10 shows the total emergy needed for the anaerobic digestion (After Moss et al., 2014) as well as for the loading and spreading (estimated from Ecoinvent database) of EU28 generated W093 in 2016. Results show that there is a huge difference in terms of U when including or not including L&S.

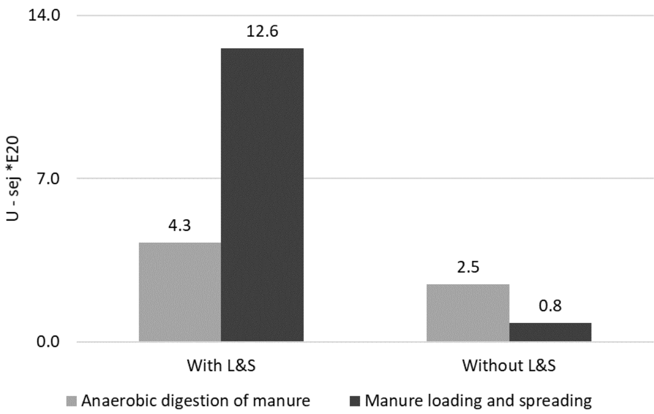


Figure 10
Total Emergy U with and without L&S related to anaerobic digestion and loading and spreading of EU28 generated manure (W093).

4.2 Impacts and performance of the recovery of EU28 food related waste

When considering W091+W092 biowaste, LCA results shown in Figure 7 highlight how the overall impacts for incineration are smaller than those related to the anaerobic digestion, while lower impacts are related to industrial composting. On the other hand, Figure 9 highlights how the total emergy U needed (environmental support from the larger space-time scale of biosphere), considering the same processes, is higher for incineration (7.4E+21 sej with L&S and 3.1E+21 sej without L&S), while U values associated to industrial composting (4.5E+21 sej with L&S and 1.3E+21 sej without L&S) and to anaerobic digestion (2.5E+21 sej with L&S and 1.4E+21 sej without L&S), are significantly lower. Incineration can recover a certain amount of electricity

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

and/or heat from the combustion of waste, also producing fly ash and bottom ash as by-products. Both are potentially dangerous materials, containing heavy metals and toxic substances. Anaerobic digestion results in the production of biogas and digestate, the latter which is used in agricultural systems as organic fertiliser. The result of composting is a bio-fertiliser, used for food or non-food crops based on the composition of the starting material.

Regarding W093 treatment, Figure 10 shows that the LCA impacts of anaerobic digestion of manure are higher than the simple loading and spreading in crop fields. Figure 8 shows that U related to the AD processing of manure is 4.3E+20 sej with L&S and 2.5E+20 sej without L&S, while U for the loading and spreading of manure is 12.6E+20 sej with L&S and 0.8E+20 sej without L&S. These numbers are very representative of the two compared processes. Anaerobic digestion is a kind of conversion system very relying on machinery and external input sources, resulting in a very slight difference when considered with and without contribution of direct and indirect labour, while the spreading of manure on crops is very dependent on direct labour contributions.

The type of assessment presented in this work shows how different solutions can be implemented when dealing with a problem, in this case FW management and recovery in a bioeconomy perspective. This is clearly a multiscale and multilevel problem that requires multilevel and multiscale solutions, that needs to be addressed by a multi-methods assessment. Of course, the presented results are from a general, broader perspective, considering average processes from the Ecoinvent database. Another very important aspect is represented by the correct characterisation of the material under consideration and its properties, to be carefully assessed from case to case. Household and restaurants FW, for instance, present different characteristics and different main causes for their generation. Household FW, accounting for more than a half of European food waste generation (Stenmarck et al., 2016), is strictly linked to behaviours and social aspects (among others demographics, attitude, regulations, awareness) (Boulet et al., 2021), and more than 1/3 of it seems to be avoidable (Schott and Andersson, 2015). The hospitality sector is responsible of enormous amounts of FW (e.g. 920000 tonnes/yr in UK, 1700 tonnes/day in Beijing), of which globally 56% is coming from restaurants and 28% from hotels (Gandhi et al., 2020). FW in hospitality sector can happen before preparation to improper handling, or after preparation, mainly due to non-edible parts, over-portioning, inability to meet consumer expectancy, use of buffet systems generating large amounts of FW (Bolton et al., 2008; Giorgi, 2013; Hackes et al., 1997; Papargyropoulou et al., 2016). In these cases, FW composition is very variable depending on location and to eating habits, asking for different approaches and management options, to be planned in advance. Planning and implementation actions of new design and recovery pathways in a bioeconomy perspective cannot neglect to investigate local constraints and features, to provide proper benefits. The added value of using a multi-method approach, namely a combination of LCA and EMA in this work, is the holistic understanding from different perspectives. LCA and EMA answer to different questions from different point of views: the first adopting a consumer side, burdens related assessment of activities and processes under human control; the latter providing a donor side set of indicators expanding over the entire biosphere and over time for the generation of materials needed in activities and processes. Addressing only one aspect of the issue (e.g. focusing only on the reduction of CO2 or the reduced dependence from fossil fuels) may result in the disregarding of other, perhaps more important, perspectives. A multi-dimensional focus allows to operate on different aspects to achieve a better performance that can be maximised on minimised on choice. LCA and EMA point out the benefit

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

of circular pathways converting co-products or by-products to be fed back in the same system or becoming useful in outside systems. When broadening the scale, both physically and temporally, the joint use of LCA and EMA can provide very interesting and useful insights than other, mono-dimensional indicators.

The conducted literature review allowed the analysis of the actual worth of starting new patterns compared to old ones as far as other aspects (social, economic, employment, wellbeing, among others), all related to decreased resource waste and increased recovery of still useful materials. Food waste recovery may, for example positively affect some economic sectors and increase jobs, while pulling down other sectors and activities. Although nobody can provide 100% certainty of achievable benefits, technically feasible and environmentally friendly alternatives need to be put within a more complex context in order to address the multiple demands that arise from present daily life and planning of future. Opportunities and can be evaluated from different points of views and perspectives. The simultaneous consideration of different dimensions may be very helpful in the general understanding of the matter, i.e. bioeconomy and food waste, in order to recognize benefits and barriers, which anyway needs increased efforts towards broadening and deepening the view over actual opportunities and viable challenges. Table 11 reports main opportunities and challenges addressed by the 9 "Review" items assessed, highlighting the need for a strong connection between academia and policy-making clearly defining the actions and strategies to tackle FW issues in a way capable of addressing also environmental and financial constraints. The vast majority of the reviewed processes are still at laboratory scale, calling for major efforts to convert them to industrial scale.

Table 11
Opportunities and Challenges addressed by Review items.

Item	Opportunities	Challenges
A	Anaerobic digestion (AD) converts waste in energy and simultaneously produces a digestate used as bio-fertiliser. AD is an effective kind of treatment to avoid harmful impacts on human health and environment.	Technical-operational, economic and regulatory challenges have to be mutually addressed by decision-makers, researchers and end users. Resources availability, financial issues and institutional competences are crucial aspects for the long-term feasibility.
B	Food recovery actions can be addresses as strategies for the restoration of a potentially lost value, addressing environmental, economic and social aspects.	The exact fraction food that could be redistributed is hard to estimate.
C	Carbon-rich waste conversion to polyhydroxyalkanoate (PHA) products offers new opportunities to reduce issues related to waste disposal, avoiding industry generated environmental impacts and preserving food resources.	Different branches of scientific and academic areas should cooperate together with industry to implement at industrial level techniques still at laboratory level.
D	The efficiency within food supply chain can gain benefits from microbial protein and organic fertilisers.	Technological applications for the recovery of added value components from waste streams need to be broadly implemented.
E	The initial highly expensive investments for the implementation of biorefineries could be balanced by the minimal price of food waste, avoiding burdens and disposal costs.	Most of the presented techniques are only at the lab scale and only a few have been carried out at pilot scale.
F	Economic benefits could be achieved by using inexpensive biomass as FW.	FW biorefineries are not yet implemented at industrial scale, making economic assessments

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

		(including difficulties and costs related to collection and transportation operations) impossible.
G	Bioconversion of FW to energy is economically viable. Additional improvements can result from further research.	Preliminary feasibility studies must include collection and transportation costs.
H	The reduction of the demand of fossil phosphate could lower burdens and improve phosphate security in the future	P recycling must address problems related to recovery efficiency, hygiene and contaminating substances
R	Bio-plastics, fuels and added value components can be generated from the conversion of FW.	Conversion strategies and information campaigns must be modeled according to the specific locations.

The analysis of the other reviewed scientific works allowed the identification of opportunities and challenges tackling three main aspects: technological (i.e. benefits and barriers due to technology involved, design and technical skills), economic (i.e. cost/benefits, viability and prices) and cultural (i.e. stakeholders acceptance/denial, regulations and behaviours).

5 Opportunities

The aim of this section is to provide an overview of the opportunities associated with the conversion of food waste and losses. Identified opportunities have been grouped into three categories, namely technological, economic, and cultural. Technological opportunities focus on the utilisation of existing technologies, such as anaerobic digestion (AD), and their potential to recover energy, compost, or other bioactive compounds. Furthermore, economic opportunities analyse the potential economic benefits associated with the conversion of FW streams, while cultural focus on the prospective of these conversion options towards changing the way we perceive food waste.

5.1 Technological opportunities

FW could be reduced by a better management throughout the whole supply chain, in addition to sustainable food management and food redistribution (Facchini et al., 2018; Girotto et al., 2015; Kirby et al., 2017). Performances associated with recovery operations are based on geographical characteristics and on the availability of the different types of feedstocks, defining an optimal service area to overcome waste disposal problems, avoiding industrial pollution and protecting food resources, since the feasibility of these kind of operations is strongly distance related (Ohnishi et al., 2018; Tanguy et al., 2017). Thus, new research can be developed and adapted in order to design and control new closed-loop supply chains (Sgarbossa and Russo, 2017). FW is a valuable source of renewable energy for developing countries, in substitution of common, more impacting ones (i.e. coal, firewood, crop residues, etc.), at the same time disposing waste in a more environmentally feasible way (Ohnishi et al., 2018; Safar et al., 2016; Uçkun Kiran et al., 2014b). Practices like AD recovery significantly reduce CO2 emissions, taking into consideration also the fuel replacement within the power grid (Breitenmoser et al., 2019; Prasad, 2016; Safar et al., 2016; Sgarbossa and Russo, 2017; Slorach et al., 2019; Uçkun Kiran et al., 2015; Verstraete et al., 2016). FW is also beneficial to polymers production, from bacteria processing carbon-rich, and as

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

potential feedstock for the production of value added chemicals and for cosmeceutical valorisation biomass (Girotto et al., 2015; Piccolella et al., 2019; Prasad, 2016; Tamis et al., 2015; Uçkun Kiran et al., 2015). FW could be crucial in the perspective of phosphorus recovery, avoiding rock mining for the phosphorus used in agri-food, medical, construction and industrial systems (Carraresi et al., 2018; Reijnders, 2014; Verstraete et al., 2016).

5.2 Economic opportunities

10% of annual FW production is food surplus still suitable for consumption (Facchini et al., 2018). Food redistribution and reuse initiatives can be seen as a value recovery strategy, side-products of FW processing can be fed back to the economy, offering additional economic benefits (i.e. digestate, side product of biogas production in AD systems, used as fertiliser and soil enhancer) (Tamis et al., 2015; Verstraete et al., 2016). Processes can also benefit from the exchange of side streams of carbon-rich materials (i.e. from processing of bio-diesel, olive oil, cheese, sugar, etc.) assisting the labor market situation in countries with economic problems (Carraresi et al., 2018; Koller et al., 2017; Sgarbossa and Russo, 2017). Various processes needing carbon rich materials as feedstock could reduce their expenses by using FW (Koller et al., 2017; Prasad, 2016). Energy production from FW follows this outlook, avoiding also costs for disposal (Prasad, 2016; Sgarbossa and Russo, 2017). In a biorefinery perspective, the high initial cost of developing a biorefinery would be balanced by the inexpensive cost of the FW feedstock (Uçkun Kiran et al., 2015).

5.3 Cultural opportunities

FW recovery practices may be capable in reducing energy scarcity and reduce wood burning in the countryside of low-income nations (Breitenmoser et al., 2019). Recovery processes recognize an added value in materials, previously considered of low or no value, showing the same potential as raw materials (Breitenmoser et al., 2019; Girotto et al., 2015; Piccolella et al., 2019; Safar et al., 2016; Sgarbossa and Russo, 2017). Efficient supply chain management and consumers behavior are the most important hot-spots to be considered in order to implement food redistribution activities, suitable surplus food can be redistributed, through appropriate organisations, charities, etc., to underprivileged people (Facchini et al., 2018). Recovery of phosphorus from FW could be of importance in a geopolitical framework, since the vast majority of phosphorus reservoirs are located in politically unstable countries (Reijnders, 2014).

6 Barriers and Challenges

6.1 Technological

The importance of recovery technology determining product quality and hygienic challenges, are very important when dealing with specific materials like FW or faecally contaminated waters

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

(Breitenmoser et al., 2019; Verstraete et al., 2016). Different factors have to be put into account when planning FW recovery actions, like large amounts of water needed by certain AD systems (Breitenmoser et al., 2019; Ghosh et al., 2019; Ohnishi et al., 2018; Sgarbossa and Russo, 2017; Tanguy et al., 2017; Wang et al., 2017). Installation of factories needs to consider the source of feedstock, source segregation, theoretical yield of products, like the yield of AD biogas, depending on the contents of organic constituents in biomass (Breitenmoser et al., 2019; Girotto et al., 2015; Safar et al., 2016). Food losses occur at all levels of food supply chain, mainly due to technical and infrastructural reasons; technical limitations, spillage and contamination eventually occurring at processing level also contribute to FW and losses (Carraresi et al., 2018; Facchini et al., 2018; Girotto et al., 2015; Piccolella et al., 2019; Sgarbossa and Russo, 2017). Almost all reviewed items agree on the need of further assessments and broad implementation of solutions to effectively improve resource efficient usage and reduce waste. Most of the assessed pathways are at laboratory level, but they seem to have a good potential scalability, after further analysis and scale up studies (Ghosh et al., 2019; Girotto et al., 2015; Koller et al., 2017; Uçkun Kiran et al., 2015, 2014a). Future studies need to increment the attention about local characteristics, other technological options, and time series analysis (Ohnishi et al., 2018). Local characteristics strongly influence waste quality, separation policy, and collection costs (Ohnishi et al., 2018; Reijnders, 2014). The feasible recovery of resources from FW must understand how to implement different configurations of food supply chain, to reduce the output flow of FW and introduce new relations between the nodes currently in the supply chain (Carraresi et al., 2018; Eriksson et al., 2017; Sgarbossa and Russo, 2017). Further, energy self-sufficiency in food supply chain could help in reducing impacts of food production/processing (Sgarbossa and Russo, 2017). Better data is needed for the assessment of potentially redistributable food (Facchini et al., 2018). Recovery processes need to be assessed in order to understand the impacts of large scale integration starting from laboratory scale, so to avoid potential environmentally dangerous pathways (Ohnishi et al., 2018). Feedstock should meet the demand, and, in certain cases, high carbon concentrations (Breitenmoser et al., 2019; Hu et al., 2018; Kirby et al., 2017; Koller et al., 2017; Uçkun Kiran et al., 2015, 2014a).

6.2 Economic

Economic barriers refer to investment costs which are stemming from the systemic changes that are required throughout the food supply chain in order to achieve transition towards a Circular Economy. The issue does not purely originate in the initial cost but most importantly to the return on investment as the latter constitutes the greatest barrier to convincing involved stakeholders to adopt the suggested circular economy interventions (Ritzén and Sandström, 2017). Analysis of the literature showed that there is a strong correlation between economic and operational barriers as failure to implement these, results in the partial adoption of measures that are only fractionally effective in minimising food waste. Specifically, focus is placed on the high cost of logistical, marketing and technical interventions (Mourad, 2016). Focusing on the primary production stage, a large proportion of food waste is related to fresh fruits and vegetables that either do not meet retailers' quality standards or are not economically viable to be harvested due to market saturation (Beausang et al., 2017). Corresponding circular economy practices focus on the redistribution of these crops to secondary markets, food aid organisations or food processors (Bilska et al., 2016; Guardian, 2018a). Nonetheless, this would require the development of a logistics network able to collect and deliver these products to respective stakeholders or organisations in a timely manner,

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

without compromising the food safety during transportation. In addition, retailers would have to bare the extra cost associated with transportation, marketing, personnel and storage, thus decreasing their profit margin (Hermsdorf et al., 2017). Similarly, gleaning of unharvested crops requires a large amount of resources for coordination and personnel costs which, in most instances, are not possible to be covered by fundraising (Schneider, 2013). The latter argument is supported by the fact that cold supply chains entail higher costs (Eriksson and Spångberg, 2017). With reference to the inedible fraction of agricultural waste, the development of on-farm waste processing facilities entails a high cost of investment that small-scale farmers are unable to bare (Case et al., 2017). As regards packaging defects or damage, repackaging in most cases, unless of high value food product, is not economically feasible as it entails the additional cost of removal (Garrone et al., 2016). Despite the positive impact of discounted suboptimal food products on retailers' reputation and social responsibility image, a high volume of them bears the risk of the cannibalisation of 'optimal' product sales (Aschemann-Witzel et al., 2017). On the other hand, the implementation of discounting strategies based on dynamic shelf life would significantly reduce food waste, yet the cost of adoption of smart packaging technology would outweigh retailers' profits (Buisman et al., 2019).

From a conversion perspective, the use of FW as feedstock represent an opportunity to reduce industry and disposal cost, at the same time producing commodities and/or energy, only if proper governmental incentives are implemented, reducing the high initial costs (Carraresi et al., 2018; Ohnishi et al., 2018; Uçkun Kiran et al., 2015). Another factor affecting the economic feasibility of FW recovery sector is the low price of fossil fuels, enhancing the production from raw materials: in order to really implement FW recovery, products should be able to compete in a market framework (Verstraete et al., 2016). Moreover, extensive economic analyses of biorefineries are still missing, due to the absence of real biorefineries implementations (Uçkun Kiran et al., 2014a). Costs are also very important when producing electric energy, in order to assess the total benefits, and when considering collection and transportation of FW materials (Ohnishi et al., 2018). In cases like the recovery of phosphorus, alternative pathways are still more expensive than the traditional production from raw materials (Carraresi et al., 2018; Reijnders, 2014). Economic related matters are also important with regards to food losses at agricultural level, in particular when occurring in developing countries due to economic constraints (Facchini et al., 2018). Furthermore

6.3 Cultural

In order to reduce the amount of FW produced, the very first step is the reduction of the unwanted food surplus, preventing over-production and over-supply (Facchini et al., 2018; Girotto et al., 2015; Sgarbossa and Russo, 2017). Cultural/regulatory matters are addressed as the primary cause, in developed countries, of food wastage at industry and consumers level, related to changing lifestyles, dietary patterns, and aesthetic demands (Facchini et al., 2018; Piccolella et al., 2019). Food wastage can occur also because of problematic relationships between producers and retailers and because of food standards, contractual conditions and wrong product forecasting (Eriksson et al., 2017; Facchini et al., 2018; Girotto et al., 2015; Piccolella et al., 2019; Sgarbossa and Russo, 2017). Household level is a very important part of FW generation, where it occurs, mainly due to bad management, in varying forms from whole materials to fractions or mixtures (Breitenmoser et al., 2019; Facchini et al., 2018; Girotto et al., 2015; Slorach et al., 2019; Uçkun Kiran et al.,

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

2014a). Different definitions of FW cause a difficult monitoring and present regulation may be contrasting with food redistribution in order to preserve human health (Facchini et al., 2018; Girotto et al., 2015). Feedstock chosen for the different recovery practices should, anyway, not interfere with food and feed productions (Breitenmoser et al., 2019; Girotto et al., 2015). The logistics for different systems is still challenging, and losses may occur throughout the feedstock supply chain (Breitenmoser et al., 2019; Ohnishi et al., 2018; Sgarbossa and Russo, 2017). It's also highlighted how the value of recovered products is only depending from its acceptance by stakeholders: products recovered starting from waste streams should be unconnected to waste (Carraresi et al., 2018; Verstraete et al., 2016). Further, policies for recovery of specific substances (e.g. phosphorus) are held back by the uncertainty in forecasting current reserves (Facchini et al., 2018). Often recovery facilities and know how are located in developed countries, while the feedstock markets are in developing countries (Reijnders, 2014).

6.4 Social

Social barriers pertain to consumers' behaviours and perceptions that prevent them from implementing circular economy practices. The social dominance of the recycling norm as a synonym for food waste prevention constitutes a significant barrier towards the diffusion of circular economy practices at the consumption stage (Cox et al., 2010). As a result, practices related to reducing or reusing waste tend to be overlooked as people tend to misperceive recycling as a sufficient good environmental practice. In order to reduce food waste generation at the household level, awareness campaigns should take an alternative approach by emphasising on moral intuition along with providing advice (Stefan et al., 2013). Campaigns that communicate social norms were found to be more effective in enhancing consumer environmental awareness as well as incentivising adoption of reduce, reuse or recycling food waste practices (Geislar, 2017). In the case of deprived urban areas, low participation in government programmes related to waste management may be hampered by local residents' perception of having received poorer quality services, thus rejecting engagement in government request (Rispo et al., 2015). Based on susceptibility of food waste behaviour to socio-cultural norms, Delley and Brunner (2017) classified consumers into two categories, namely consumerists and eco-responsible. The former is acknowledged as the prominent members of Veblen's (1899), leisure class; advocates of excess consumption and waste. On the other hand, eco-responsible consumers are characterised by a high level of environmental awareness, individual responsibility and adoption of waste prevention practices.

The moderating role of socioeconomic and sociocultural milieu on the relationship between quality and price, may discourage consumers from purchasing discounted suboptimal products under misconceptions related to inferior quality and food safety risks (Van Boxstael et al., 2014; Aschemann-Witzel et al., 2017). In order to overcome the fallacy of the aforementioned concerns, the improvement of households' education on food labels, product quality assessment skills and storage guidance is vital (de Hooge et al., 2017). Social barriers are also related to the feeling of inconvenience associated with provisional activities pertaining to meal planning, shopping routines and food waste sorting (Graham-Rowe et al., 2014). For instance, the potential of zero-packaging stores to reduce food waste is hampered by shopping experience inconveniences related to limited range of products, carrying of reusable containers and time intensity (Beitzen-Heineke et al., 2017).

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

6.5 Operational

Barriers in this category refer mainly to factors that limit the capacity of food systems to manage food surpluses and treat organic waste. With regard to redistribution of surplus food, donations are confined only to certain product categories that do not require refrigerated transportation in order to avoid the costs entailed in cold chains (Eriksson and Spångberg, 2017). In addition, food banks require sorting of food products prior to collection which is hampered by the misalignment of operational and collection schedules between retailers and food aid organisations respectively (Hermsdorf, 2017). Similarly, gleaning of unharvested crops does not constitute a reliable practice as it requires a high level of coordination and collaboration which is hard to achieve since it is heavily relying on volunteer organisations (Schneider, 2013). In detail, due to the absence of a centralised coordination system in these organisations, collection is not organised according to the availability of unharvested crops but to the availability of volunteers, hence resulting in missed opportunities (Lee et al., 2017). Considering the aforementioned barriers, it is evident that the increased complexity affiliated with certain practices is also an important inhibiting factor. For instance, the correlation between consumers' discount preferences and product type – i.e. higher discounts are required for products entailing a high level of perceived safety risk, such as milk – necessitate not only the improvement of sales forecasting accuracy but also the development of a discount pricing policy that differentiates among different product categories (de Hooge et al., 2017). Other operational barriers refer to common practices such as the discard of the whole food package even if only a single piece is spoilt, to avoid liability in the case of food safety incidents (Lebersorger and Schneider, 2014). Similarly, farmers tend to plough back into the ground unharvested crops which could otherwise be redistributed (Beausang et al., 2017).

A critical component of effective resident participation in waste management activities is the quality of services provided and the relevant infrastructure. This can contribute to maximising the amount of source-segregated materials (Rispo et al., 2015). Providing supportive infrastructure for separate food waste collection services, such as curbside carts, regular collections and treatment facilities, is found to have a positive effect on household participation in these programmes (Bees and Williams, 2017; Geislar, 2017). Examining the household food waste behaviour of a residential area in Sweden, Bernstad (2014) showed that the installation of source-segregation recycling equipment increased both the source separation ratio and the amount of separately collected food. This extends to the quality of food waste pre-treatment as well as treatment facilities since lower efficiency would discourage household participation in waste separation schemes (Bernstad et al., 2013). In addition, there is a lack of consensus on identifying the most effective pre-treatment technology for energy recovery (Bundhoo et al., 2015). In the case of biohydrogen production, this is due to the yield's dependence on technical factors related to type of treatment, compositional variability of feedstock and physicochemical parameters (e.g. pH, temperature) while taking into account economic and ecological viability (Yasin et al., 2013; Alibardi and Cossu, 2015). In other cases, the potential for energy or nutrient recovery from food waste is reduced due to local governments' inability to collect separately household and agro-industrial organic waste (Liu et al., 2016).

6.6 Legislative

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Legislative barriers pertain to regulative inefficiencies which either hinder or decelerate the implementation of circular economy practices. With respect to waste management systems, there is a lack of clear and cohesive legislative framework that creates an obligation for local authorities to divert food waste from landfills (Bee and Williams, 2017). This is accredited to the limitations of Waste Framework Directive 2008/98/EC which does not provide a clear guidance for decision-makers while failing to integrate sector-specific characteristics (Singh and Ordoñez, 2016).

In addition, the effectiveness of economic incentives towards the reduction of food waste and the promotion of more environmentally friendly approaches such as recycling, has been widely criticised as they legitimise the disposal of food at the expense of a designated fee (Kalmykova et al., 2016; Bees and Williams, 2017). Examining the impact of such policies at the household level, Chalak et al. (2016) notes that their effectiveness depends on their scope and the ability to minimise the substitution effect on other preferable practices. The latter is demonstrated at Lee and Tongarlak (2017) simulation model, where the substitution mechanism between disposal fee and tax credit incentivises food donation only in the absence of an in-store prepared food department. Similarly, current EU legislative framework focus solely on the reduction of packaging material without taking into consideration the different packaging requirements for each product category, thus increasing the risk of food losses (Williams and Wikström, 2011).

Furthermore, EU regulatory reforms regarding the harmonisation of conditions and certification guidelines for the production of bio-derived fertilisers are developing at a slow pace, halting large-scale farm adoption (Case et al., 2017; EC, 2017). On a different note, although EU legislation has simplified food label framework by confining it to best before and use by dates (EC, 2000), it has failed to effectively disseminate knowledge about it through existing governmental structures and communication media (Aschemann-Witzel et al., 2017). This inability has increased the vulnerability of consumers to food safety risks linked to the growth of pathogens by consuming products past their use by date (Van Boxstael et al., 2014). As Hebrok and Boks (2017) points out, there is a debate whether the diffusion of waste prevention practices in consumer stage should be dependent on individual initiatives (bottom-up) or structural reforms imposed by policies (top-down). Delley and Brunner (2017) argue that the role of government bodies is pivotal towards the success of food waste awareness campaigns. In detail, authors propose a set of policy interventions such as compulsory education courses, abolishment of agricultural subsidies and increase of food prices in order to induce thriftier behaviours

6.7 Structural

Structural barriers are related to constraints emerging from market inefficiencies. These stem from the conflicting interests between stakeholders in food supply chains (Alexander and Smaje, 2008). Key characteristic of these conflicts is the disproportional level of retailers' market power who dictate supply chain partners through the imposition of food quality specifications and standards (Cicatiello et al., 2016). Through these standards, retailers are able to control the type of fresh produce that enters the market resulting in a large quantity of discarded edible crops (HLPE, 2014). The aforementioned dependence of marketable crops on predetermined quality specifications, increase the exposure of farmers to adverse weather conditions, as the latter affect yields and crops' physical properties (Beausang et al., 2017). In detail, in order to ensure that they can meet contractual agreements, farmers increase their production to hedge potential losses, leaving them

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

with surpluses which are not economically feasible to harvest (Hermsdorf et al., 2017). Moving downstream in the supply chain, retailers' power is exerted on food processors through take-back agreements (TBA). TBA are referred in the literature as the dark side of retail food waste, since they are used as a method to 'hide' its amount at the supplier-retailer interface (Cicatiello et al., 2017). They are part of a wider set of retailers' rejection policies on products of 'inadequate quality' or products that are close to their expiration date, a common case for bread (Eriksson et al., 2017).

Lack of economic incentives towards the use of bioenergy and bio-fertilisers constitutes an additional structural inefficiency. The prevalent allocation of AD plants involves a centralised anaerobic digester which receives and treats organic waste. Nonetheless, the effectiveness of this development concept is limited due to the lack of economic incentives to encourage farmers using waste-based fertilisers. This is accredited to their exclusion from the financial gains associated with the conversion of their agricultural waste into energy outputs, as profits are accumulated by plant owners (Banks et al., 2011). Similarly, the unavailability of government economic incentives hinders the use of biofuel. A good example of this issue can be seen in the case of biodiesel derived from used cooking oils. As Genovese et al. (2017) pointed out, despite the abundance of used cooking oil supply, the lack of government support hampers the conversion process as the economic gains are incremental to manufacturing costs.

7 Conclusions

The performed review analysis highlighted a general interest within scientific community towards biological conversion pathways, to generate energy and fuels, of mainly FW or mixed FW generated after consumption, highlighting the need to reduce human dependence from depleting resources and to implement operations for achieving more environmentally feasible materials, energy and fuels. This could be driven both by ecological awareness or by the opportunity of new 'green' markets. Recovering instead of disposal of a material still presenting an added value that otherwise would be lost and that is not going to disappear soon (even with a better management through the entire food supply chain) is a priority. The bioeconomy framework may contribute in making common production pathways obsolete. Further, the idea of "closing the loop", so much advocated within CE theoretical approach, should be really taken in consideration when dealing with FW issue.

This work reviewed recent scientific production about food waste recovery pathways in a bioeconomy and circular economy perspective. Thus, the reduction of waste is the main aim both from a business and scientific point of view. Food waste is of particular importance, because it engages social and cultural features, in addition to technological and economic ones. The reduction of food losses and the recovery of lost parts through food supply chain could provide food to currently starving communities. FW is a carbon rich waste stream that can be used for the recovery of a wide range of energy and materials, from fuels/energy to chemical components to bio-plastics, among others. The so generated commodities show different benefits like the reduced environmental impacts, deriving from the avoided disposal and the avoided extraction of natural resources, and the reduced economic cost of FW as a feedstock. However, FW exploitation is also affected by different constraints, the more relevant one being that there's no one fits all solution. Recovery pathways must be carefully designed and planned, based on local characteristics. Care

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

should be devoted to the fact that such pathways should not interfere with food supply, also regarding geopolitical aspects, and keeping in mind that the overall main goal is the reduction of food losses and wastage. Resulting materials and energies should be competitively priced on the global market in order to be fully implemented. Another major problem is related to the so called Jevons Paradox: improving the efficiency of a sector, meaning in this case a better use of resources through recovery to reduce the exploitation of raw materials, could result in an even larger increase of the rate of consumption of the specific resource of concern. For this reason, already available tools and methods, like the presented LCA and EMA frameworks, should be actively implanted within decision making, and policy makers have to carefully acknowledge and thoroughly coordinate the guidelines suggested by different categories of stakeholders, including local communities and scientific experts.

Contents of this deliverable are currently under review for publication in international journals

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

References

Abeliotis, K., Lasaridi, K., & Chroni, C. (2016). Food waste prevention in Athens, Greece: The effect of family characteristics. *Waste Management & Research*, *34*(12), 1210-1216.

Agyeman, F. O., & Tao, W. (2014). Anaerobic co-digestion of food waste and dairy manure: effects of food waste particle size and organic loading rate. *Journal of Environmental Management*, *133*, 268-274.

Alexander, C., & Smaje, C. (2008). Surplus retail food redistribution: An analysis of a third sector model. *Resources, Conservation and Recycling*, *52*(11), 1290-1298.

Alibardi, L., & Cossu, R. (2015). Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials. *Waste Management*, *36*, 147-155.

Antón, J., Cattaneo, A., Kimura, S., & Lankoski, J. (2013). Agricultural risk management policies under climate uncertainty. *Global Environmental Change*, *23*(6), 1726-1736.

Arunraj, N. S., & Ahrens, D. (2015). A hybrid seasonal autoregressive integrated moving average and quantile regression for daily food sales forecasting. *International Journal of Production Economics*, *170*, 321-335.

Aschemann-Witzel, J., Jensen, J. H., Jensen, M. H., & Kulikovskaja, V. (2017). Consumer behaviour towards price-reduced suboptimal foods in the supermarket and the relation to food waste in households. *Appetite*, *116*, 246-258.

Banasik, A., Kanellopoulos, A., Claassen, G. D. H., Bloemhof-Ruwaard, J. M., & van der Vorst, J. G. (2017). Assessing alternative production options for eco-efficient food supply chains using multi-objective optimization. *Annals of Operations Research*, *250*(2), 341-362.

Banks, C. J., Salter, A. M., Heaven, S., & Riley, K. (2011). Energetic and environmental benefits of co-digestion of food waste and cattle slurry: A preliminary assessment. *Resources, Conservation and Recycling*, *56*(1), 71-79.

Bayer, I. S., Guzman-Puyol, S., Heredia-Guerrero, J. A., Ceseracciu, L., Pignatelli, F., Ruffilli, R., Cingolani, R. & Athanassiou, A. (2014). Direct transformation of edible vegetable waste into bioplastics. *Macromolecules*, *47*(15), 5135-5143.

Beausang, C., Hall, C., & Toma, L. (2017). Food waste and losses in primary production: Qualitative insights from horticulture. *Resources, Conservation and Recycling*, *126*, 177-185.

Bees, A. D., & Williams, I. D. (2017). Explaining the differences in household food waste collection and treatment provisions between local authorities in England and Wales. *Waste Management*, *70*, 222-235.

Beitzen-Heineke, E. F., Balta-Ozkan, N., & Reefke, H. (2017). The prospects of zero-packaging grocery stores to improve the social and environmental impacts of the food supply chain. *Journal of Cleaner Production*, *140*, 1528-1541.

Bellantuono, N., Carbonara, N., & Pontrandolfo, P. (2017). The organization of eco-industrial parks and their sustainable practices. *Journal of Cleaner Production*, *161*, 362-375.

Beretta, C., Stoessel, F., Baier, U., & Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. *Waste Management*, *33*(3), 764-773.

Bernstad, A. (2014). Household food waste separation behavior and the importance of convenience. *Waste Management*, *34*(7), 1317-1323.

Bernstad, A., Malmquist, L., Truedsson, C., & la Cour Jansen, J. (2013). Need for improvements in physical pretreatment of source-separated household food waste. *Waste Management*, *33*(3), 746-754.

Bhaskar, T., Chang, J. S., Khanal, S., Lee, D. J., Mohan, S. V., & Rittmann, B. (2016). Waste biorefinery-advocating circular economy. *Bioresource Technology*, *215*, 1-396.

Bilska, B., Wrzosek, M., Kołożyn-Krajewska, D., & Krajewski, K. (2016). Risk of food losses and potential of food recovery for social purposes. *Waste Management*, *52*, 269-277.

Blomsma, F., & Brennan, G. (2017). The emergence of circular economy: A new framing around prolonging resource productivity. *Journal of Industrial Ecology*, *21*(3), 603-614.

Boulet, M., Hoek, A. C., & Raven, R. (2020). Towards a multi-level framework of household food waste and consumer behaviour: Untangling spaghetti soup. *Appetite*, 104856.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Brancoli, P., Rousta, K., & Bolton, K. (2017). Life cycle assessment of supermarket food waste. *Resources, Conservation and Recycling*, *118*, 39-46.

Breitenmoser, L., Gross, T., Huesch, R., Rau, J., Dhar, H., Kumar, S., Hugi, C., Wintgens, T. (2019). Anaerobic digestion of biowastes in India: Opportunities, challenges and research needs. *Journal of Environmental Management. 236*, 396-412.

Brown, M. T., & Ulgiati, S. (2004). Emergy Analysis and Environmental Accounting,[in:] Encyclopedia of Energy. *Elsevier, Oxford, UK*, *329*, 354.

Buisman, M. E., Haijema, R., & Bloemhof-Ruwaard, J. M. (2019). Discounting and dynamic shelf life to reduce fresh food waste at retailers. *International Journal of Production Economics*, *209*, 274-284.

Bundhoo, M. Z., Mohee, R., & Hassan, M. A. (2015). Effects of pre-treatment technologies on dark fermentative biohydrogen production: a review. *Journal of Environmental Management*, *157*, 20-48.

Carraresi, L., Berg, S., Bröring, S. (2018). Emerging value chains within the bioeconomy: Structural changes in the case of phosphate recovery. *Journal of Cleaner Production, 183*, 87–101.

Case, S. D. C., Oelofse, M., Hou, Y., Oenema, O., & Jensen, L. S. (2017). Farmer perceptions and use of organic waste products as fertilisers–A survey study of potential benefits and barriers. *Agricultural Systems*, *151*, 84-95.

Chaboud, G., & Daviron, B. (2017). Food losses and waste: navigating the inconsistencies. *Global Food Security*, *12*, 1-7.

Chalak, A., Abou-Daher, C., Chaaban, J., & Abiad, M. G. (2016). The global economic and regulatory determinants of household food waste generation: A cross-country analysis. *Waste Management*, *48*, 418-422.

Cicatiello, C., Franco, S., Pancino, B., & Blasi, E. (2016). The value of food waste: An exploratory study on retailing. *Journal of Retailing and Consumer Services*, *30*, 96-104.

Cicatiello, C., Franco, S., Pancino, B., Blasi, E., & Falasconi, L. (2017). The dark side of retail food waste: Evidences from in-store data. *Resources, Conservation and Recycling*, *125*, 273-281.

Cole, C., Osmani, M., Quddus, M., Wheatley, A., & Kay, K. (2014). Towards a zero waste strategy for an English local authority. *Resources, Conservation and Recycling*, *89*, 64-75.

Cox, J., Giorgi, S., Sharp, V., Strange, K., Wilson, D. C., & Blakey, N. (2010). Household waste prevention—a review of evidence. *Waste Management & Research*, *28*(3), 193-219.

Creutzig, F. (2020). Limits to Liberalism: Considerations for the Anthropocene. *Ecological Economics*, *177*, 106763.

D'Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J., Leskinen, P., Matthies, B. D. & Toppinen, A. (2017). Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production*, *168*, 716-734.

Dahiya, S., Kumar, A. N., Sravan, J. S., Chatterjee, S., Sarkar, O., & Mohan, S. V. (2018). Food waste biorefinery: Sustainable strategy for circular bioeconomy. *Bioresource Technology*, *248*, 2-12.

de Hooge, I. E., van Dulm, E., & van Trijp, H. C. (2018). Cosmetic specifications in the food waste issue: Supply chain considerations and practices concerning suboptimal food products. *Journal of Cleaner Production*, *183*, 698-709.

Delley, M., & Brunner, T. A. (2017). Food waste within Swiss households: A segmentation of the population and suggestions for preventive measures. *Resources, Conservation and Recycling*, *122*, 172-184.

Distantina, S., Kaavessina, M., Fadilah, Putrie, A.S., Novianti, I. (2018). Carboxymethyl konjac glucomannan from konjac flour: The effect of media and temperature on carboxymethylation rate. *AIP Conference Proceedings, 1931*, 1-7.

Ebner, J., Babbitt, C., Winer, M., Hilton, B., & Williamson, A. (2014). Life cycle greenhouse gas (GHG) impacts of a novel process for converting food waste to ethanol and co-products. *Applied Energy*, *130*, 86-93.

EC. (2000). *Directive 2000/13/EC of the European Parliament and of the council of 20 March 2000 on the approximation of the laws of the Member States relating to the labelling, presentation and advertising of foodstuffs.* Retrieved May 8 from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32000L0013&from=en

EC. (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives.* Retrieved November 11, 2020 from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

EC. (2010). *Commission Regulation (EU) No 849/2010 of 27 September 2010 amending Regulation (EC) No 2150/2002 of the European Parliament and of the Council on waste statistics Text with EEA relevance*. Retrieved November 11, 2020 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010R0849

EC. (2012). *Innovating for sustainable growth: A bioeconomy for Europe*. Retrieved November 10, 2020 from https://op.europa.eu/en/publication-detail/-/publication/1f0d8515-8dc0-4435-ba53-9570e47dbd51

EC. (2017). *Report on the proposal for a regulation of the European Parliament and of the Council laying down rules on the making available on the market of CE marked fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 (COM(2016)0157 – C8-0123/2016 – 2016/0084(COD))*. Retrieved May 8, 2018 from http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A8-2017-0270+0+DOC+PDF+V0//EN

EC. (2018). *Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste*. Retrieved November 10, 2020 from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0851&from=EN

EC. (2020). *Circular Economy Action Plan - For a cleaner and more competitive Europe*. Retrieved November 10, 2020 from https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

Edjabou, M. E., Petersen, C., Scheutz, C., & Astrup, T. F. (2016). Food waste from Danish households: Generation and composition. *Waste Management*, *52*, 256-268.

Ellen MacArthur Foundation. (2013a). *Towards the Circular Economy Vol. 1: Economic and business rationale for an accelerated transition*. Retrieved November 11, 2020. from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Ellen MacArthur Foundation. (2013b). *Towards the Circular Economy Vol. 2: Opportunities for the consumer goods sector*. Retrieved November 11, 2020. from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/TCE_Report-2013.pdf

Ellen MacArthur Foundation. (2013c). *Towards the Circular Economy Vol. 3: Accelerating the scale-up across global supply chains*. Retrieved November 11, 2020 from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Towards-the-circular-economy-volume-3.pdf

Ellen MacArthur Foundation. (2015). *Delivering the Circular Economy a Toolkit for Policymakers*. Retrieved November 20, 2020 from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_PolicymakerToolkit.pdf

Engels, F. (1877). Anti-Duhring: Herr Eugen Duhring's Revolution in Science in Marx and Engels Collected Works, Vol. 25. *Moscow: Progress Publishers*, *8*(1987), 3-309.

EPRS. (2018). *Briefing: EU Legislation in Progress - Circular economy package: Four legislative proposals on waste*. Retrieved November 11, 2020 from https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/614766/EPRS_BRI(2018)614766_EN.pdf

Eriksson, M., Ghosh, R., Mattsson, L., Ismatov, A. (2017). Take-back agreements in the perspective of food waste generation at the supplier-retailer interface. *Resources, Conservation and Recycling, 122*, 83–93.

Eriksson, M., & Spångberg, J. (2017). Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. *Waste Management*, *60*, 786-799.

Eriksson, M., Strid, I., & Hansson, P. A. (2016). Food waste reduction in supermarkets–Net costs and benefits of reduced storage temperature. *Resources, Conservation and Recycling*, *107*, 73-81.

Eurostat. (2008). *NACE Rev. 2 - Statistical classification of economic activities in the European Community*. Retrieved November 11, 2020. From https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

Eurostat. (2019). *Generation of waste by waste category, hazardousness and NACE Rev. 2 activity*. Retrieved November 11, 2020 from https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en

Evangelisti, S., Clift, R., Tagliaferri, C., & Lettieri, P. (2017). A life cycle assessment of distributed energy production from organic waste: Two case studies in Europe. *Waste Management*, *64*, 371-385.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Evans, D. (2012). Binning, gifting and recovery: the conduits of disposal in household food consumption. *Environment and Planning D: Society and Space*, *30*(6), 1123-1137.

Fadilah, Distantina, S., Kaavessina, M., Wijayanti, S.T., Andayani, R. (2018). Study on the carboxymethylation of glucomannan from porang. *AIP Conference Proceedings, 1931*.

FAO. (2011). *Global food losses and food waste – Extent, causes and prevention.* Retrieved November 10, 2020 from http://www.fao.org/docrep/014/mb060e/mb060e.pdf

FAO. (2017). *Guidelines for the compilation of Food Balance Sheets*. Retrieved November 10, 2020 from http://www.fao.org/3/ca6404en/ca6404en.pdf

FAO. (2019). *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction.* Retrieved November 10, 2020 from http://www.fao.org/3/CA6030EN/CA6030EN.pdf

Facchini, E., Iacovidou, E., Gronow, J., Voulvoulis, N. (2018). Food flows in the United Kingdom: The potential of surplus food redistribution to reduce waste. *Journal of the Air and Waste Management Association 68*, 887-899.

Fiorentino, G., Ripa, M., Mellino, S., Fahd, S., & Ulgiati, S. (2014). Life cycle assessment of Brassica carinata biomass conversion to bioenergy and platform chemicals. *Journal of Cleaner Production*, *66*, 174-187.

Fiorentino, G., Ripa, M., & Ulgiati, S. (2017). Chemicals from biomass: technological versus environmental feasibility. A review. *Biofuels, Bioproducts and Biorefining*, *11*(1), 195-214.

Fiorentino, G., Zucaro, A., & Ulgiati, S. (2019). Towards an energy efficient chemistry. Switching from fossil to bio-based products in a life cycle perspective. *Energy*, *170*, 720-729.

Florio, C., Fiorentino, G., Corcelli, F., Ulgiati, S., Dumontet, S., Güsewell, J., & Eltrop, L. (2019). A life cycle assessment of biomethane production from waste feedstock through different upgrading technologies. *Energies*, *12*(4), 718.

FLW Protocol. (2016). *Food Loss and Waste Accounting and Reporting Standard*, Version 1. Retrieved November 10, 2020 from https://flwprotocol.org/wp-content/uploads/2017/05/FLW_Standard_final_2016.pdf

Gandhi, P., Yadav, M., Paritosh, K., Pareek, N., Lizasoain, J., Bauer, A., & Vivekanand, V. (2020). Food wastes from hospitality sector as versatile bioresources for bio-products: an overview. *Journal Of Material Cycles And Waste Management.*

Garrone, P., Melacini, M., Perego, A., & Sert, S. (2016). Reducing food waste in food manufacturing companies. *Journal of Cleaner Production*, *137*, 1076-1085.

Geislar, S. (2017). The new norms of food waste at the curb: evidence-based policy tools to address benefits and barriers. *Waste Management*, *68*, 571-580.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The circular economy–A new sustainability paradigm?. *Journal of Cleaner Production*, *143*, 757-768.

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. L. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega*, *66*, 344-357.

Genovese, A., & Pansera, M. (2020). The Circular Economy at a Crossroads: Technocratic Eco-Modernism or Convivial Technology for Social Revolution?. *Capitalism Nature Socialism*, 1-19.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11-32.

Ghosh, S., Gillis, A., Sheviryov, J., Levkov, K., Golberg, A. (2019). Towards waste meat biorefinery: Extraction of proteins from waste chicken meat with non-thermal pulsed electric fields and mechanical pressing. *Journal of Cleaner Production, 208,* 220-231.

Giorgi, S. (2013). *WRAP: Understanding out of home consumer food waste*. Retrieved November 20, 2020 from http://www.wrap.org.uk/sites/files/wrap/OOH%20Report.pdf

Girotto, F., Alibardi, L., Cossu, R. (2015). Food waste generation and industrial uses: A review. *Waste Management. 45*, 32–41.

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & Van Zelm, R. (2009). ReCiPe 2008. *A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*, *1*, 1-126.

Grace, M. A., Clifford, E., & Healy, M. G. (2016). The potential for the use of waste products from a variety of sectors in water treatment processes. *Journal of Cleaner Production*, *137*, 788-802.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Graham-Rowe, E., Jessop, D. C., & Sparks, P. (2014). Identifying motivations and barriers to minimising household food waste. *Resources, Conservation and Recycling*, *84*, 15-23.

Guardian. (2018). *'Wonky' fruit and veg sales put Morrisons on straight path to growth*. Retrieved November 20, 2020 from https://www.theguardian.com/business/2018/jun/26/wonky-fruit-veg-sales-growth-supermarkets

Hackes, B. L., Shanklin, C. W., Kim, T., & Su, A. Y. (1997). Tray service generates more food waste in dining areas of a continuing-care retirement community. *Journal of the American Dietetic Association*, *97*(8), 879-882.

Hanssen, O. J., Vold, M., Schakenda, V., Tufte, P. A., Møller, H., Olsen, N. V., & Skaret, J. (2017). Environmental profile, packaging intensity and food waste generation for three types of dinner meals. *Journal of Cleaner Production*, *142*, 395-402.

Hebrok, M., & Boks, C. (2017). Household food waste: Drivers and potential intervention points for design–An extensive review. *Journal of Cleaner Production*, *151*, 380-392.

Hermsdorf, D., Rombach, M., & Bitsch, V. (2017). Food waste reduction practices in German food retail. *British Food Journal*, *119*(12), 2532-2546.

HLPE. (2014). *Food losses and waste in the context of sustainable food systems: A report by The High Level Panel of Experts on Food Security and Nutrition.* Retrieved November 20, 2020 from http://www.fao.org/3/a-i3901e.pdf

Holt-Giménez, E., Shattuck, A., Altieri, M., Herren, H., & Gliessman, S. (2012). We already grow enough food for 10 billion people… and still can't end hunger. *Journal of Sustainable Agriculture, 36*(6), 595-598.

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production*, *175*, 525-543.

Hu, Y., Scarborough, M., Aguirre-Villegas, H., Larson, R.A., Noguera, D.R., Zavala, V.M. (2018). A Supply Chain Framework for the Analysis of the Recovery of Biogas and Fatty Acids from Organic Waste. *ACS Sustainable Chemistry and Engineering, 6*, 6211-6222.

Inayati, Puspita, R.I., Fajrin, V.L. (2018). Extraction of pectin from passion fruit rind (Passiflora edulis var. flavicarpa Degener) for edible coating. *AIP Conference Proceedings 1931*, 632-635.

ISO. (2006). *UNI EN ISO 14040 - Environmental management - Life cycle assessment - Principles and framework*. Retrieved November 20, 2020 from https://www.iso.org/standard/37456.html

BMJ. (2006). *UNI EN ISO 14044: Life cycle assessment — Requirements and guidelines*. https://doi.org/10.1136/bmj.332.7550.1107

Janssen, A. M., Nijenhuis-de Vries, M. A., Boer, E. P., & Kremer, S. (2017). Fresh, frozen, or ambient food equivalents and their impact on food waste generation in Dutch households. *Waste Management*, *67*, 298-307.

JRC. (2018). *ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance*. Retrieved November 20, 2020 from https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf

Kalmykova, Y., Rosado, L., & Patrício, J. (2016). Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale. *Journal of Cleaner Production*, *132*, 70-80.

Kibler, K. M., Reinhart, D., Hawkins, C., Motlagh, A. M., & Wright, J. (2018). Food waste and the food-energy-water nexus: a review of food waste management alternatives. *Waste Management*, *74*, 52-62.

Kirby, M.E., Hornung, A., Ouadi, M., Theodorou, M.K. (2017). The role of thermo-catalytic reforming for energy recovery from food and drink supply chain wastes. *Energy Procedia 123*, 15-21.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221-232.

Koller, M., Maršálek, L., de Sousa Dias, M.M., Braunegg, G. (2017). Producing microbial polyhydroxyalkanoate (PHA) biopolyesters in a sustainable manner. *New Biotechnology. 37*, 24-38.

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, *175*, 544-552.

Krausmann, F., Fischer-Kowalski, M., Schandl, H., & Eisenmenger, N. (2008). The global sociometabolic transition: Past and present metabolic profiles and their future trajectories. *Journal of Industrial Ecology*, *12*(5-6), 637-656.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Kristinsson, H. G., & Jörundsdóttir, H. Ó. (2019). Food in the bioeconomy. *Trends in Food Science & Technology*, *84*, 4-6.

Lebersorger, S., & Schneider, F. (2014). Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. *Waste Management*, *34*(11), 1911-1919.

Lee, D., Sönmez, E., Gómez, M. I., & Fan, X. (2017). Combining two wrongs to make two rights: Mitigating food insecurity and food waste through gleaning operations. *Food Policy*, *68*, 40-52.

Lee, D., & Tongarlak, M. H. (2017). Converting retail food waste into by-product. *European Journal of Operational Research*, *257*(3), 944-956. Lebersorger, S., & Schneider, F. (2014). Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. *Waste Management*, *34*(11), 1911-1919.

Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., & Searchinger, T. (2013). *Reducing Food Loss and Waste.* Working Paper, Installment 2 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute. Available online at http://www.worldresourcesreport.org.

Liu, C., Hotta, Y., Santo, A., Hengesbaugh, M., Watabe, A., Totoki, Y., Allen, D. & Bengtsson, M. (2016). Food waste in Japan: Trends, current practices and key challenges. *Journal of Cleaner Production*, *133*, 557-564.

Liu, G., Hao, Y., Dong, L., Yang, Z., Zhang, Y., & Ulgiati, S. (2017). An emergy-LCA analysis of municipal solid waste management. *Resources, Conservation and Recycling*, *120*, 131-143.

McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., Kemp, R. & Doménech, T. (2017). Circular economy policies in China and Europe. *Journal of Industrial Ecology*, *21*(3), 651-661.

McKinsey. (2016). *The circular economy: Moving from theory to practice.* Retrieved November 11, 2020 from https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/The%20circular%20economy%20Moving%20from%20theory%20to%20practice/The%20circular%20economy%20Moving%20from%20theory%20to%20practice.pdf

Merli, R., Preziosi, M., & Acampora, A. (2018). How do scholars approach the circular economy? A systematic literature review. *Journal of Cleaner Production*. *178*, 703-722.

Mirabella, N., Castellani, V., & Sala, S. (2014). Current options for the valorization of food manufacturing waste: A review. *Journal of Cleaner Production*, *65*, 28-41.

Moss, A. R., Lansing, S. A., Tilley, D. R., & Klavon, K. H. (2014). Assessing the sustainability of small-scale anaerobic digestion systems with the introduction of the emergy efficiency index (EEI) and adjusted yield ratio (AYR). *Ecological Engineering*, *64*, 391-407.

Mourad, M. (2016). Recycling, recovering and preventing "food waste": competing solutions for food systems sustainability in the United States and France. *Journal of Cleaner Production*, *126*, 461-477.

Muriana, C. (2017). A focus on the state of the art of food waste/losses issue and suggestions for future researches. *Waste Management*, *68*, 557-570.

Odum, H.T. (1996). *Environmental Accounting: Emergy and Environmental Decision Making.* New York: John Wiley & Sons.

Ohnishi, S., Fujii, M., Ohata, M., Rokuta, I., Fujita, T. (2018). Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city. *Resources, Conservation and Recycling, 128*, 394–405.

Opara, U. L., & Pathare, P. B. (2014). Bruise damage measurement and analysis of fresh horticultural produce—A review. *Postharvest Biology and Technology*, *91*, 9-24.

Papargyropoulou, E., Wright, N., Lozano, R., Steinberger, J., Padfield, R., & Ujang, Z. (2016). Conceptual framework for the study of food waste generation and prevention in the hospitality sector. *Waste Management*, *49*, 326-336.

Piccolella, S., Bianco, A., Crescente, G., Santillo, A., Chieffi Baccari, G., Pacifico, S. (2019). Recovering Cucurbita pepo cv. 'Lungo Fiorentino' Wastes: UHPLC-HRMS/MS Metabolic Profile, the Basis for Establishing Their Nutra- and Cosmeceutical Valorisation. *Molecules 24*.

Ponis, S. T., Papanikolaou, P. A., Katimertzoglou, P., Ntalla, A. C., & Xenos, K. I. (2017). Household food waste in Greece: A questionnaire survey. *Journal of Cleaner Production*, *149*, 1268-1277.

Prasad, M.N.V. (2016). Recovery of Resources From Biowaste for Pollution Prevention, *Environmental Materials and Waste: Resource Recovery and Pollution Prevention*. Elsevier Inc.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Priefer, C., Jörissen, J., & Bräutigam, K. R. (2016). Food waste prevention in Europe–A cause-driven approach to identify the most relevant leverage points for action. *Resources, Conservation and Recycling*, *109*, 155-165.

Raak, N., Symmank, C., Zahn, S., Aschemann-Witzel, J., & Rohm, H. (2017). Processing-and product-related causes for food waste and implications for the food supply chain. *Waste Management*, *61*, 461-472.

Redlingshöfer, B., Coudurier, B., & Georget, M. (2017). Quantifying food loss during primary production and processing in France. *Journal of Cleaner Production*, *164*, 703-714.

Reijnders, L. (2014). Phosphorus resources, their depletion and conservation, a review. *Resources, Conservation and Recycling. 93*, 32-49.

Richter, B., & Bokelmann, W. (2016). Approaches of the German food industry for addressing the issue of food losses. *Waste Management*, *48*, 423-429.

Ripa, M., Buonaurio, C., Mellino, S., Fiorentino, G., & Ulgiati, S. (2014). Recycling Waste Cooking Oil into Biodiesel: A Life Cycle Assessment. *International Journal of Performability Engineering*, *10*(4), 347-356.

Rispo, A., Williams, I. D., & Shaw, P. J. (2015). Source segregation and food waste prevention activities in high-density households in a deprived urban area. *Waste Management*, *44*, 15-27.

Ritzén, S., & Sandström, G. Ö. (2017). Barriers to the Circular Economy–integration of perspectives and domains. *Procedia CIRP*, *64*, 7-12.

Safar, K.M., Bux, M.R., Aslam, U.M., Ahmed, M.S., Ahmed, L.I. (2016). Energy recovery from organic fractions of municipal solid waste: A case study of Hyderabad city, Pakistan. *Waste Management and Research, 34*, 327-336.

Sánchez, A. S., Silva, Y. L., Kalid, R. A., Cohim, E., & Torres, E. A. (2017). Waste bio-refineries for the cassava starch industry: New trends and review of alternatives. *Renewable and Sustainable Energy Reviews*, *73*, 1265-1275.

Sembodo, B.S.T., Sulistyo, H., Sediawan, W.B., Fahrurrozi, M. (2018). Effect of sodium carbonate catalyst weight on production of bio-oil via thermochemical liquefaction of corncobs in ethanol-water solution. *AIP Conference Proceedings, 1931*.

Santagata, R., Ripa, M., & Ulgiati, S. (2017). An environmental assessment of electricity production from slaughterhouse residues. Linking urban, industrial and waste management systems. *Applied Energy*, *186*, 175-188.

Santagata, R., Viglia, S., Fiorentino, G., Liu, G., & Ripa, M. (2019). Power generation from slaughterhouse waste materials. An emergy accounting assessment. *Journal of Cleaner Production*, *223*, 536-552.

Schmelzer, M. (2015). The growth paradigm: History, hegemony, and the contested making of economic growthmanship. *Ecological Economics*, *118*, 262-271.

Schmidt, K. (2016). Explaining and promoting household food waste-prevention by an environmental psychological based intervention study. *Resources, Conservation and Recycling*, *111*, 53-66.

Schneider, F. (2013). The evolution of food donation with respect to waste prevention. *Waste Management*, *33*(3), 755-763.

Schott, A. B. S., & Andersson, T. (2015). Food waste minimization from a life-cycle perspective. *Journal of Environmental Management*, *147*, 219-226.

Secondi, L., Principato, L., & Laureti, T. (2015). Household food waste behaviour in EU-27 countries: A multilevel analysis. *Food Policy*, *56*, 25-40.

Senthilkumar, K., Mollier, A., Delmas, M., Pellerin, S., & Nesme, T. (2014). Phosphorus recovery and recycling from waste: an appraisal based on a French case study. *Resources, Conservation and Recycling*, *87*, 97-108.

Sgarbossa, F., Russo, I. (2017). A proactive model in sustainable food supply chain: Insight from a case study. *International Journal of Production Economics, 183*, 596-606.

Singh, J., & Ordoñez, I. (2016). Resource recovery from post-consumer waste: important lessons for the upcoming circular economy. *Journal of Cleaner Production*, *134*, 342-353.

Slorach, P.C., Jeswani, H.K., Cuéllar-Franca, R., Azapagic, A. (2019). Energy demand and carbon footprint of treating household food waste compared to its prevention. *Energy Procedia 161*, 17-23.

Stahel, W. R. (2010). *The performance economy*, 2nd ed. London: Palgrave Macmillan.

Stancu, V., Haugaard, P., & Lähteenmäki, L. (2016). Determinants of consumer food waste behaviour: Two routes to food waste. *Appetite*, *96*, 7-17.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Stenmarck, Â., Jensen, C., Quested, T., Moates, G., Buksti, M., Cseh, B., Juul, S., Parry, A., Politano, A., Redlingshofer, B. & Scherhaufer, S. (2016). *Estimates of European food waste levels.* IVL Swedish Environmental Research Institute.

Storino, F., Arizmendiarrieta, J. S., Irigoyen, I., Muro, J., & Aparicio-Tejo, P. M. (2016). Meat waste as feedstock for home composting: Effects on the process and quality of compost. *Waste Management*, *56*, 53-62.

Tamis, J., Sorokin, D.Y., Jiang, Y., Van Loosdrecht, M.C.M., Kleerebezem, R. (2015). Lipid recovery from a vegetable oil emulsion using microbial enrichment cultures. *Biotechnology for Biofuels, 8*, 1-11.

Tampio, E., Lehtonen, E., Kinnunen, V., Mönkäre, T., Ervasti, S., Kettunen, R., Rasi, S., & Rintala, J. (2017). A demand-based nutrient utilization approach to urban biogas plant investment based on regional crop fertilization. *Journal of Cleaner Production*, *164*, 19-29.

Tanguy, A., Villot, J., Glaus, M., Laforest, V., Hausler, R. (2017). Service area size assessment for evaluating the spatial scale of solid waste recovery chains: A territorial perspective. *Waste Management, 64*, 386-396.

Thyberg, K. L., & Tonjes, D. J. (2016). Drivers of food waste and their implications for sustainable policy development. *Resources, Conservation & Recycling*, *106*, 110-123.

Tua, C., Nessi, S., Rigamonti, L., Dolci, G., & Grosso, M. (2017). Packaging waste prevention in the distribution of fruit and vegetables: An assessment based on the life cycle perspective. *Waste Management & Research*, *35*(4), 400-415.

Uçkun Kiran, E., Trzcinski, A.P., Liu, Y. (2015). Platform chemical production from food wastes using a biorefinery concept. *Journal of Chemical Technology and Biotechnology. 90*, 1364-1379.

Uçkun Kiran, E., Trzcinski, A.P., Ng, W.J., Liu, Y. (2014a). Enzyme Production from Food Wastes Using a Biorefinery Concept. *Waste and Biomass Valorisation 5*, 903-917.

Uçkun Kiran, E., Trzcinski, A.P., Ng, W.J., Liu, Y. (2014b). Bioconversion of food waste to energy: A review. *Fuel 134*, 389-399.

Ujor, V., Bharathidasan, A. K., Cornish, K., & Ezeji, T. C. (2014). Feasibility of producing butanol from industrial starchy food wastes. *Applied Energy*, *136*, 590-598.

Urmetzer, S., Lask, J., Vargas-Carpintero, R., & Pyka, A. (2020). Learning to change: Transformative knowledge for building a sustainable bioeconomy. *Ecological Economics*, *167*, 106435.

Uusitalo, O., & Takala, T. (2020). From Scarcity to Abundance: Food Waste Themes and Virtues in Agrarian and Mature Consumer Society. In: E. Närvänen, N. Mesiranta, M. Mattila, and A. Heikkinen, ed. *Food Waste Management: Solving the Wicked Problem.* Cham: Palgrave Macmillan. pp. 257-288.

Van Boxstael, S., Devlieghere, F., Berkvens, D., Vermeulen, A., & Uyttendaele, M. (2014). Understanding and attitude regarding the shelf life labels and dates on pre-packed food products by Belgian consumers. *Food Control*, *37*, 85-92.

Vandermeersch, T., Alvarenga, R. A. F., Ragaert, P., & Dewulf, J. (2014). Environmental sustainability assessment of food waste valorization options. *Resources, Conservation and Recycling*, *87*, 57-64.

Veblen, T. (1899). *The theory of the leisure class: An economic study in the evolution of institutions.* Macmillan: New York.

Verstraete, W., Clauwaert, P., Vlaeminck, S.E. (2016). Used water and nutrients: Recovery perspectives in a "panta rhei" context. *Bioresource Technology. 215*, 199-208.

Visschers, V. H., Wickli, N., & Siegrist, M. (2016). Sorting out food waste behaviour: A survey on the motivators and barriers of self-reported amounts of food waste in households. *Journal of Environmental Psychology*, *45*, 66-78.

Wallace, T., Gibbons, D., O'Dwyer, M., & Curran, T. P. (2017). International evolution of fat, oil, and grease (FOG) waste management–a review. *Journal of Environmental Management*, *187*, 424-435.

Wang, X., Guo, M., van Dam, K.H., Koppelaar, R.H.E.M., Triantafyllidis, C., Shah, N. (2017). Waste-Energy-Water systems in sustainable city development using the resilience.io platform, *Computer Aided Chemical Engineering.* Elsevier Masson SAS.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*, *21*(9), 1218-1230.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Willersinn, C., Möbius, S., Mouron, P., Lansche, J., & Mack, G. (2017). Environmental impacts of food losses along the entire Swiss potato supply chain–Current situation and reduction potentials. *Journal of Cleaner Production*, *140*, 860-870.

Williams, H., & Wikström, F. (2011). Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. *Journal of Cleaner Production*, *19*(1), 43-48.

Williams, H., Wikström, F., Otterbring, T., Löfgren, M., & Gustafsson, A. (2012). Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production*, *24*, 141-148.

Wilson, N. L., Rickard, B. J., Saputo, R., & Ho, S. T. (2017). Food waste: The role of date labels, package size, and product category. *Food Quality and Preference*, *55*, 35-44.

WRAP. (2015). *Economic growth potential of more circular economies*. Retrieved November 11, 2020 from http://www.wrap.org.uk/sites/files/wrap/Economic%20growth%20potential%20of_more%20circular%20economies.pdf

WRAP. (2017). *Household Food Waste in the UK, 2015*. Retrieved November 20, 2020 from http://www.wrap.org.uk/sites/files/wrap/Household_food_waste_in_the_UK_2015_Report.pdf

Yasin, N. H. M., Mumtaz, T., & Hassan, M. A. (2013). Food waste and food processing waste for biohydrogen production: a review. *Journal of Environmental Management*, *130*, 375-385.

Zink, T., & Geyer, R. (2017). Circular economy rebound. *Journal of Industrial Ecology*, *21*(3), 593-602.

This project has received funding from the European Union's Horizon 2020 Marie Sklodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.