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Valorisation of surplus food in the French retail sector: Environmental and economic impacts

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Abstract

The retail sector, generating large amounts of food waste in a limited and well-defined number of locations, represents a unique opportunity for the implementation of waste minimisation policies targeting food waste and surplus food. France has introduced policy measures forcing retailers to prioritise the redistribution of surplus food to charity (donation) and/or diversion to animal feed. To evaluate the environmental benefits from such initiatives, this study provides a bottom-up consequential life cycle assessment of surplus food management at twenty retail outlets in France. A cradle-to-grave assessment was performed,

AE, N: aquatic eutrophication, nitrogen; AE, P: aquatic eutrophication, phosphorus; ET: ecotoxicity; EU: European Union; FRD: fossil resource depletion; GW: global warming; HT, cancer: human toxicity, cancer; LCA: life cycle assessment; LUC: land-use change; PM: particulate matter; POF: photochemical ozone formation; SI: supporting information; TA: terrestrial acidification; WD: water depletion.

including land-use changes, and the impacts were evaluated for ten impact categories. Four scenarios were considered, using monthly data on waste flows and management. Alongside assessing the current management (i.e. redistribution and/or use of surplus food for animal feed with anaerobic digestion and incineration of residual streams), three additional scenarios were evaluated: i) prevention (used as benchmark), ii) anaerobic digestion and iii) incineration. The results demonstrated that redistribution leads to substantial environmental savings when accounting for all potentially induced benefits, second only to prevention but nevertheless of similar magnitude. Neither anaerobic digestion nor incineration can compete environmentally with redistribution and use as animal feed, especially in a low-carbon energy system. A cost analysis, including tax credits implemented in the French regulation, demonstrated that retailers donating high-value products also achieved lower costs and higher environmental savings overall. The results clearly suggest that similar initiatives should be encouraged, and the study offers a consistent basis for evaluating similar initiatives also for other countries.

Keywords: food waste; LCA; donation; waste hierarchy; prevention; redistribution

1. Introduction

To tackle the food waste problem, the European Union (EU) engaged in meeting Sustainable Development Goal (SDG) #12 (United Nations, 2015), which, among other objectives, aims to reduce food losses in the production and supply sectors as well as to halve food waste per capita by 2030, from both households and retailers (European Commission, 2017a). Although the retail sector is estimated to be responsible, on average, for only 5% of EU food waste (most of which is instead generated by production and households; Stenmark et al., 2016), it nevertheless is of key importance for food waste minimisation. Retail outlets represent collection points for large amounts of food in a limited and well-defined number of locations, thereby facilitating the implementation of effective policies and initiatives by connecting two sectors that would otherwise be separated, namely consumers and producers (Eriksson, 2015; Scholz et al., 2015). Initiatives implemented at this stage may thereby induce benefits both upstream and downstream the supply chain, in addition to the retail sector per se (Schönberger et al., 2013). While food waste prevention and the redistribution of surplus food (i.e. food that is suitable for human consumption but it is not marketable for several reasons (European Union, 2017)) should be prioritised, e.g. according to the Waste Framework Directive (European Parliament and Council, 2008), very few attempts have been made in the literature to assess systematically the environmental and economic benefits of such initiatives in the retail sector.

While very few European countries have yet implemented regulations addressing surplus food from retail outlets, France represents a prominent example by putting into force a specific legislation in 2016, law no. 2016-138 (Legifrance, 2016), with the aim of reducing food waste generation at the retail sector. In 2016, French food waste corresponded to 10 million tonnes, or 16 billion euros' worth, with 14% of the losses originating from the retail sector (Ministère de la Transition Écologique et Solidaire, 2017b). The French law requires all retail units larger than 400 m^2 to handle surplus food according to the waste hierarchy (Ministère de la Transition Écologique et Solidaire, 2017b), which means that whenever food is still suitable and safe for human consumption, conforming to the guidelines provided by European Commission (2010) and European Commission (2017b), it should be redistributed to charity organisations (European Federation of Food Banks et al., 2016; Mourad, 2015). If the surplus food is still safe but not edible for humans, it should be used as animal feed, and finally, if the food is suitable neither for human nor for animal consumption, then the food products should be sent to anaerobic digestion or composting (Mourad, 2015). Retailers may benefit from the new regulation by receiving a 60% tax credit corresponding to the economic value of the redistributed food, including both the stock value of the goods, their transport and storage (Mourad, 2015). The initiative is expected to have benefits for both the environment and economy, but food redistribution may also have positive social effects by, for example, increasing access to food for people with lower incomes (Mourad, 2015), improving the nutritional intake of people in need (Scherhaufer et al., 2015), integrating marginalised social groups (Vittuari et al., 2017), and involving different stakeholders that felt satisfied about making a difference in their local communities (Mirosa et al., 2016). Furthermore, tax credit policies are expected to lead to establishing new companies related to the organisation and management of food waste and redistribution programmes (Sud Ouest, 2017). With relatively few wide scale implementations of food waste prevention and food redistribution initiatives, so far no consistent comparison of the variability in environmental performance of individual retail outlets, and thereby the overall potential for contributing to environmental savings, have been provided.

Previous studies of surplus food generated by the retail sector have focused on techniques to improve its management, typically applying the life cycle assessment (LCA) methodology. However, a large majority of literature studies focus on the lower levels of the waste hierarchy, i.e. end-of-life treatments such as anaerobic digestion, composting, incineration and landfilling (e.g. Bernstad et al., 2013; Buratti et al., 2015; Cristóbal et al., 2016). Two studies, Brancoli et al. (2017) and Vandermeersch et al. (2014), investigated the effects of diverting surplus food to animal feed, considering as a case study a single Swedish retail outlet and the Belgian retail sector, respectively. Both studies concluded that the largest savings can be obtained if bread products are removed from their packaging and the main waste stream, and then used to substitute conventional animal feed (e.g. wheat) instead of anaerobic digestion. While prevention has been addressed in several LCA studies (e.g. Martinez-Sanchez et al., 2016; Oldfield et al., 2016; Tonini et al., 2018), highlighting significant environmental benefits under the condition that indirect (rebound) effects are minimised, so far few LCA studies have focused on redistribution. Among these, Eriksson et al. (2015) and Eriksson & Spångberg (2017) analysed the carbon footprint of the food waste management systems of retail outlets in Uppsala (Sweden) and Växjö (Sweden), respectively, in terms of redistribution and/or conversion of surplus food. Overall, the findings indicated that following the waste hierarchy for surplus food management resulted in the largest environmental benefits, with prevention followed by redistribution and conversion to be prioritised. While these studies address retailers and the implementation of redistribution initiatives, they do not i) consider the actual properties and distribution of individual food waste materials, ii) include land-use changes (LUCs) related to food production and substitution, iii) assess environmental impacts over a wide range of impact categories, or iv) address the economic aspects. Ignoring these aspects may lead to biased conclusions (Tonini et al., 2018).

Using data from twenty French retail outlets that have implemented surplus food redistribution and diversion to animal feed, this study builds on existing literature in the field and contributes further by: i) systematically assessing the environmental benefits associated with surplus food management as implemented in selected retailers in France, and ii) quantifying the associated economic implications for retailers.. The environmental performance of each retailer is compared against two benchmarks: a) the maximum level of prevention (i.e. assuming 100% prevention of surplus food) and b) the business-as-usual alternative management of such surplus food for the selected retailers, prior to enforcing law no. 2016-138, involving typically anaerobic digestion and incineration. It should be borne in mind that, while French food banking and donations exist since long time, a systematic and dedicated management of the surplus food was not common practice and business-as-usual practices typically involved biological treatment and/or incineration (Garot, 2015). This was the case for the retailers selected. The study involves state-of-the-art LCA modelling of individual food waste material fractions over a wide range of impact categories, and it also accounts for LUCs.

2. Materials and methods

2.1 Definitions

According to European Commission (2017b), *surplus food* is food and beverages that have not been sold or are not marketable but are still suitable for human consumption. Surplus food can either be redistributed or used as animal feed. These applications have to be compliant with the EU guidelines on food donations and use-as-feed (European Commission, 2009; European Commission, 2017b). Redistribution is then defined by the European Commission (2017a) as “a process whereby surplus food that might otherwise be wasted is recovered, collected and provided to people, in particular to those in need”. Redistribution of food can occur either via direct donations from donor to charities, or via food banks that store and distribute the donated food to end users, e.g. charities (Hanssen et al., 2014). The regulations concerning and influencing food redistribution are described in Appendix H in the Supporting Information (SI). In respect to *food waste*, while acknowledging that other definitions are available in the literature, we define it in this study as the share (or the totality, when it applies) of surplus food that is neither redistributed nor used as animal feed, but it is instead sent to the waste management in place, e.g. incineration.

2.2 The case of France

Amongst the EU Member States, France is recognised as a frontrunner in respect to food redistribution (Deloitte, 2014). To overcome the barriers highlighted in Appendix H (SI), France has implemented regulations at national level to ease the redistribution of surplus food. In respect to responsibility and traceability, France has implemented a transfer slip, which concerns the state (i.e. core temperature, use by/best before date) of the food product when donated and is co-signed by the food donor and the receiving organisation (e.g. charity) (Deloitte, 2014). Regarding liability, food donors and receiving organisations subscribe to liability insurance and sign a partnership agreement (Deloitte, 2014). To implement the *Food Hygiene Package*, the French Federation of Food Banks outlined a *best practice guide* to help food donors and receiving organisations (Deloitte, 2014). To further support redistribution France implemented a corporate tax incentive. As described earlier, this establishes that food donors can benefit from a tax credit of 60% on the monetary value of the food redistributed (Mourad, 2015).

2.3 Scope and functional unit

The functional unit of the study is the management of 1 tonne of surplus food, including associated packaging, as generated by the retail sector in France (ca. 0.98 t is food and 0.02 t is packaging). This, depending on the management of the retailer, may be partly redistributed or sent for use-as-feed, and partly become food waste.

The study is a cradle-to-grave LCA, encompassing the entire life cycle of the surplus food generated at the retail outlets. This included transport, redistribution of surplus food, reuse of the surplus food as animal feed, and other treatment pathways for the waste. When assessing the prevention scenario (used as benchmark), the upstream processes prior to the production of surplus food were accounted for, from production of the food and associated LUCs, to distribution (i.e. packaging production, transport and storage) to ensure system equivalence across scenarios. The assessment was performed in accordance with the ISO standards for LCA (ISO, 2006a, b), and a consequential approach was applied (Weidema, 2003; Weidema et al., 2009). The geographic scope of the study was France. The temporal perspective covered current retailers' management practices as well as those prior to the implementation of advanced management for surplus food. The consequential database provided by Ecoinvent v3.3 was used to model the life cycle impact assessment (Wernet et al., 2016), which was performed for ten impact categories, namely Global Warming (Forster et al., 2007), Terrestrial Acidification (Seppälä et al., 2006), Photochemical Ozone Formation (van Zelm et al., 2008), Particulate Matter (van Zelm et al., 2008), Aquatic Eutrophication Nitrogen (Struijs et al., 2009), Aquatic Eutrophication Phosphorous (Goedkoop et al., 2009), Human Toxicity, cancer(Rosenbaum et al., 2011), Ecotoxicity (Rosenbaum et al., 2011), Fossil Resource Depletion (van Oers et al., 2002) and Water Depletion (Goedkoop et al., 2009). Environmental exchanges were modelled by assuming a time horizon of 100 years. With respect to Global Warming, the uptake/release of biogenic CO_2 from the food was assigned a characterisation factor equal to 0, while the eventually sequestered biogenic CO_2 (within the 100-year time horizon) was assigned a factor equal to -1, following common practice for short-rotation biomass. The assessment was performed with the EASETECH LCA tool (Clavreul et al., 2014).

2.4 Description of the scenarios and system boundaries

The scenarios investigated were: *Scenario I (CM)*, representing the current management of surplus food, *Scenario II (AD)*, where surplus food is sent to anaerobic digestion (preceded by pre-treatment), *Scenario III (I)*, where surplus food is sent to incineration, and *Scenario IV (P)*, representing prevention of surplus food, and used as benchmark for the ideal management. *Scenario I (CM)* represents the current management of individual French retail outlets, in that only one out of 20 retailers sends a share of its surplus fruit and vegetables to animal feed, while all remaining retailers send the surplus food to redistribution only. In the default case we considered that no losses occurred when surplus food is redistributed, assuming that beneficiaries (or intermediate, e.g. charities) would waste the same amount if they would buy it or receive it from another party.

As illustrated in Figure 1, the surplus food generated is sorted on site and a share is sent to redistribution and/or animal feeding, while the rest (composed of food and packaging) to the waste management system in place, thus becoming food waste conforming to the definitions in section 2.1. According to Ministère de la Transition Écologique et Solidaire (2017a), food waste should be treated either through composting or anaerobic digestion, though the retail outlets analysed in this study send it to anaerobic digestion only. As food waste also includes packaging, pre-treatment is needed. Following the results of Bernstad et al. (2013), we assume that pre-treatment incurs 20% mass losses (i.e. all input-packaging and a share of the food) to be incinerated. The anaerobic digestion of food waste produces two outputs: biogas and digestate, with the former used to produce electricity and heat, while the latter is used as organic fertiliser. The residues are sorted out and transported to an incineration plant, according to the trends presented in the study by Ademe (2016). Thermal efficiencies (as a percentage of the incoming lower heating value of the waste, on a wet basis) at the incineration plant are 5.7% for electricity production and 41.2% for heat production, conforming with the average figures provided by a recent publication covering the entire French incineration sector (Beylot et al., 2017). Bottom ashes are assumed used for road construction, and fly ashes for backfilling of salt mines.

In *Scenario II (AD)*, surplus food is sent to anaerobic digestion, thus becoming waste. After pre-treatment, the separated food waste is digested, while a residual waste flow composed of both packaging and food waste is incinerated. The two streams are modelled similar to *Scenario I (CM)*. Likewise, in *Scenario III (I)*, surplus food is incinerated directly (both packaging and food products; no pre-treatment is needed). Incineration is modelled similarly to the other scenarios. *Scenario IV (P)* represents an ideal situation in which 100% of the surplus food is prevented, i.e. production is avoided and no waste management is required. As such, all activities occurring prior to its generation are thereby avoided. Accounting for these activities is necessary only in the prevention scenario to compare consistently the environmental impacts of the assessed scenarios (see also previous studies on prevention, most notably, Gentil et al., 2011; Martinez-Sanchez et al., 2016). For a complete description of all the processes included in the scenarios, refer to Appendix A (SI).

The multi-functionalities of the scenarios are handled through system expansion following consequential LCA principles. This means that any co-products or services arising along with the management of surplus food, i.e. the functional unit, are credited by accounting for the substitution of corresponding similar market products/services (Figure 1). These following consequential principles are identified in marginal products/services, i.e. those likely to respond to changes in demand/supply (for details refer to e.g. Weidema, 2003; Weidema et al., 2009). In our scenarios, co-products/services (Figure 1) are redistributed food (to secondary selling/people/charities, etc.), fruit/vegetables reused as animal feed, electricity, heat, and bottom ash used as sub-base material for road construction. With respect to redistribution, a marginal food mix is defined to represent what would otherwise be purchased by consumers (i.e. charities, people or third parties). It is assumed that this would be composed of the cheapest food products existing on the market within the following categories: *Fruit and vegetables* (banana (20%), apple (20%), potato (34%), and carrot (26%)), *Grain* (pasta (63%) and rice (37%)), *Meat* (egg (65%) and fish fingers (35%)), and *Dairy* (milk (75%) and yoghurt (25%)), which were identified based on EUROSTAT (2015).

For simplicity and lack of any detailed information, each macro-category was represented by two products: although consumers have multiple choices at retail outlets, forecasting changes in consumption behaviours caused by redistribution and donations involve a wide range of socio-economic factors (Gajjar, 2013). It is important to note that *Fruit and vegetables* is composed of four food products, as fruits and vegetables are here aggregated into one category. With respect to animal feed, marginal energy- and protein-feed are assumed to be maize and soymeal, following previous studies (Tonini et al., 2018; Tonini et al., 2016). As soymeal is co-produced with soy oil, the well-known soybean-loop detailed by Dalgaard et al. (2008) is applied and solved. The substitution of maize and soymeal by surplus food is based on relative digestible energy and protein content, following a common approach (e.g. Dalgaard et al., 2008). Electricity is assumed to be produced with the French mix provided in Ecoinvent v3.3 (80% nuclear, 11% hydro, 4% hard coal, 3% wind, 1% natural gas, 1% biogas) (Moreno Ruiz et al., 2014; IEA, 2018), while heat is assumed to be produced by natural gas boilers. Natural aggregates are taken as the likely material otherwise used as sub-base in road construction.

FIGURE 1

2.5 Inventory data

2.5.1 Surplus food composition

The data on surplus food are based on 20 French retail outlets over a period of 13 months. These data were provided by a French company that collaborates with retailers, manages the bureaucratic and logistical elements of food redistribution and educates personnel working in retail outlets (Phenix, 2018). For modelling purposes, surplus food composition is disaggregated into the following macro-categories according to the information provided by the company: *Dry sweet*, *Dry savoury*, *Frozen food*, *Deli meats*, *Fresh dairy products*, *Fruit and vegetables*, *Poultry*, *Meat*, *Cheese*, *Gourmet*, *Pastry*, *Bakery*, *Fish* and *Liquids*. The primary data provided by the company were expressed as monetary values (i.e. €) and represented the wholesale price, namely the price at which retailers buy the goods (FAO, 2018). It is assumed that the wholesale price covers both food production itself and packaging production. Based on Tonini et al. (2018), the amount of packaging was calculated for each food product in each of the considered macro-categories (Table B1, SI). It is important to note that in the retail outlets under assessment, fruit and vegetables are sold without any packaging. Therefore, their packaging was set to zero.

Process inventories for performing bottom-up LCAs are typically mass-based (Clavreul et al., 2014). To apply this approach, it was necessary to convert the data from euros to kg. First, wholesale prices were collected and expressed as [€ kg^{-1}]. Second, to have a detailed classification of the surplus food in terms of food products, the food consumption pattern in France was modelled (Table B2, SI). This approach is needed to model the impacts of food production using a bottom-up LCA when detailed disaggregated data on the individual food products composing the mix (in this case, the surplus food) are not available, as explained in recent studies (see Scherhaufer et al., 2018 and Tonini et al., 2018). Finally, the wholesale prices were weighted accordingly to the French consumption pattern (Table B3, SI), and then the contribution of each macro-category to total surplus food, both in monetary and mass terms, was calculated (Figure 2). The chemical/biochemical/physical properties of the individual food products were based on Tonini et al. (2018).

FIGURE 2

On average, across the 20 retail outlets, surplus food is mainly composed in monetary terms by *Fruit and vegetables* (23%), *Deli meats* (17%), and *Fresh dairy products* (13%). Mass-wise, the highest shares are associated with *Fruit and vegetables* (29%), *Fresh dairy products* (23%), and *Bakery* (19%). When looking at surplus food in monetary terms, *Deli meats* contributes more than *Bakery* due to the higher wholesale price (Table B3, SI). Overall, these results are in accordance with previous studies. For example, according to Teuber & Jensen (2016), most surplus food in terms of mass is associated with bread and bakery products, and fruit and vegetables. This is also supported by the study of Parfitt et al. (2010): most of surplus food includes fruit and vegetables, followed by bakery, dairy, meat and fish. This trend is also reflected in our results. Eventual differences in the ranking of the macro-categories might be due to the different retail outlets analysed, to the assumed wholesale prices, and to a different definition of the macro-categories (i.e. the specific food products included in each one).

2.5.2 Food production and distribution

The consequential database provided by Ecoinvent v3.3 was used to model the production of the food products (Wernet et al., 2016) (Table C1, SI). Their transport from the production stage to the retail sector was also based on information provided by Wernet et al. (2016). With respect to *Fruit and vegetables*, the transport inventory from Ecoinvent v3.3 already accounts for the food losses (12%) between the retail sector and the consumer (Gustavsson et al., 2011). To avoid double-counting, these losses were disregarded here. The industrial processing of meat, fish, flour and bread was based on the 2-0 LCA consultants (2007) (refer to Tonini et al., 2018, SI Tables S13, S14, S15). For drinks, the production process was based on information provided in Doublet et al. (2013) (refer to Tonini et al., 2018, SI Table S16). Cooling and storage at the retail were also based on 2-0 LCA consultants (refer to Tonini et al., 2018, SI Table S17).

2.5.3 Land-use changes

Following a consequential approach, the demand for/ prevention of an additional unit of food incurs a demand/prevention for land. This may be supplied by a combination of expansion on virgin nature and intensification of current production (e.g. see Schmidt et al., 2013 and Tonini et al., 2016) incurring (indirect) LUC effects. To include such impacts, we follow the modelling approach detailed in Tonini et al. (2016) and recently applied in a study on food waste management in the UK (Tonini et al., 2018). Please refer to the original publications for more details. Table D1 (SI) reports the land required for each food product included in the study.

2.6 Uncertainties: scenario analyses

To test the influence of choices in respect to marginal products/services (section 2.4), we performed three scenario analyses consisting in: i) changing the marginal electricity mix from the French mix provided in Ecoinvent v3.3 to 100% natural gas-based electricity, ii) changing the marginal food mix from the one that was detailed in section 2.4 to 100% bread and iii) changing the marginal food mix from the one that was detailed in section 2.4 to assuming that this would have exactly the same composition as the surplus food coming from the retail outlets (one-to-one product substitution). This equals to say that the portion of redistributed food is modelled as if it was prevented. Additionally, we also performed a scenario analysis on the fate of packaging, assuming 100% of food packaging is separated and recycled, thereby displacing virgin paper and virgin polyethylene terephthalate, polypropylene and polyethylene production. Finally, we also performed a fifth scenario analysis where we tested the assumption of not having losses when surplus food is redistributed (stated in section 2.4). According to Alexander & Smaje (2008) we assumed that beneficiaries waste 32% of the surplus food that they receive.

2.7 Cost analysis of the management of surplus food and food waste

A cost analysis was performed for *Scenario I (CM)* to illustrate economic implications for French retailers after the enforcement of law no. 2016-138. Retailers benefit from a tax credit of 60% (t_c in Eq. 1) on the monetary value of the food redistributed (d). Other companies typically take part in the redistribution process by handling administrative aspects and logistics. This service is added to the tax credits that retailers obtain for redistributing food, here assumed to correspond to about 35% (f) of the abovementioned amount. In addition, the management of the (remaining) food waste is also addressed when calculating the costs incurred by retailers (C_{sf}). As detailed in section 2.4, the analysed retailers send food waste to anaerobic digestion only, with a gate fee assumed to be 57 € t^{-1} (g_f) based on average values for the EU (Hogg, 2002). Notice that, while an EU average was here chosen for simplicity based on Hogg (2002), this figure nevertheless well represents fees in EU that currently span between -5 and 78 € t^{-1} (Wrap, 2018).Thereby, the overall cost is calculated as follows, where f_d is the share of donated food and f_w is the share of food waste in *Scenario I (CM)*:

$$C_{sf}\,[€] = f_d * d * (-\,t_c + t_c * f) + f_w * g_f \qquad \text{Eq. 1}$$

The economic gain generated in *Scenario I (CM)* was compared to the costs associated with *Scenario II (AD)* and *Scenario III (I)* (assumed at, respectively, 57 and 132 € t^{-1} from Hogg (2002). It is important to note that Eq. 1 does not account for the costs incurred when retailers purchase food products, as these would be the same regardless of the surplus food management system implemented, i.e. the same for *CM, AD* and *I*.

3. Results

The LCA results are presented in Figure 3 as characterised impacts per tonne of surplus food (including associated packaging), wet weight basis. The results obtained for *Scenario I (CM)* when assessing the two-different marginal food mixes (see section 2.6) are also displayed. The three remaining scenario analyses (natural gas-based electricity mix, 100% recycling of packaging, and including the losses from redistribution) are also thoroughly discussed, but, for the purpose of clarity, they are illustrated in the SI (Figures E1, E2, and E3). The complete list of the results and impact contributions may be found in Table F1 (SI).

FIGURE 3

3.1 LCA results: overall hierarchy and priorities for surplus food management

The trend shown by the results in all ten impact categories supported a clear hierarchy: surplus food prevention was, as expected, the best scenario, followed by current management, which included both redistribution and use-as-feed; the waste management scenarios were evidently the worst. Due to the modelling choices made in the default scenario, for some of the categories, e.g. Global Warming, incineration (*Scenario III (I))* performed better than anaerobic digestion (*Scenario II (AD))* when the marginal electricity was characterised by a low-carbon mix, thereby giving a low global warming substitution factor. However, when the marginal electricity was based on natural gas, *Scenario II (AD)* performed better than *Scenario III (I)*, as substituting electricity from natural gas induced greater environmental savings, which compensated for the burden associated with processing (e.g. pre-treatment, diesel, heat and electricity consumption for the operations, and fugitive CH_4 emissions). The results illustrated that the choice of the marginal food mix had a great impact on the results. When the marginal mix was composed of bread only, the savings were lower than those obtained in the baseline scenario for most of the impact categories (e.g. Global Warming and Fossil Resource Depletion). Conversely, when the mix was assumed to have the same composition as the incoming surplus food (i.e. thus to prevent this flow fully), higher savings were observed compared to the default results in most impact categories (e.g. Terrestrial Acidification and Particulate Matter). This illustrates that the choice of food products composing the marginal food mix is crucial with respect to the final magnitude of the LCA results and that future research should improve the basis for defining this mix. In respect to the scenario analysis in which packaging was fully recycled, the results did not change significantly compared to the default scenario, mainly because packaging only constituted 1-3% of the surplus food mix. When considering the scenario analysis where the losses incurred by beneficiaries were accounted for, the savings of *Scenario I (CM)* decreased. However, the hierarchy of the results was not affected and the same considerations can be made as for the default scenario.

3.2 Contributions to the impact

3.2.1 Global Warming, Fossil Resource Depletion, and Water Depletion

In *Scenario I (CM)* and *Scenario IV (P)*, the main contributions to environmental benefits were avoided food production, followed by the corresponding LUCs (Table F1, SI) for both Global Warming and Fossil Resource Depletion. In *Scenario II (AD)* and *Scenario III (I)*, the main contribution to the savings was the waste management system, because of the energy recovery and the substitution of alternative production sources in both of the abovementioned impact categories (Table F1, SI). However, the magnitude of the benefits incurred by these (–200 to -65 kg CO_2-eq t^{-1} and -3800 to -2000 MJ t^{-1}) were far lower compared with those obtained by prevention and redistribution pathways (–3900 to -400 kg CO_2-eq t^{-1} and -3.0E+4 to -3.9E+3 MJ t^{-1}).

The impact contributions for Water Depletion for *Scenario I (CM)* and *Scenario IV (P)*, differ from those highlighted earlier in the case of Global Warming and Fossil Resource Depletion. Indeed, processes fuelled by the marginal electricity (e.g. waste management, refrigeration) have a great impact on this environmental category, as they are mainly characterised by electricity produced from hydropower and nuclear electricity produced by a pressure water reactor (Table F1, SI). When considering the default scenario assumptions, the results did not follow the waste hierarchy for four out of the 20 retail outlets analysed in the study. However, the waste pyramid was reflected in the results when the marginal electricity was changed to a fossil fuel-based one (i.e. natural gas), showing that the marginal electricity assumed may affect the results in this category (Figure E1, SI). Furthermore, when considering the default scenario assumptions results, the environmental benefits incurred by *Scenario II (AD)* and *Scenario III (I)* (-2400 to -520 kg water t^{-1}) were lower than those obtained for *Scenario I (CM)* and *Scenario IV (P)* (-4100 to -1100 kg water t^{-1}).

3.2.2 Terrestrial Acidification, Photochemical Ozone Formation and Particulate Matter

The main contributor to savings was avoided food production, followed by the corresponding LUCs for *Scenario I (CM)* and *Scenario IV (P)* (Table F1, SI). In *Scenario II (AD)* and *Scenario III (I)*, the main contribution to the environmental savings came from waste management (Table F1, SI). Contrarily to the results for Terrestrial Acidification and Particulate Matter, in the impact category Photochemical Ozone Formation *Scenario III (I)* performed worse than *Scenario II (AD)*, due to higher emissions of NO_x in the incineration process.

3.2.3 Aquatic Eutrophication Nitrogen and Phosphorus

In *Scenario I (CM)* and *Scenario IV (P)*, the main contributors to the environmental savings were avoided food production, followed by the corresponding LUCs (Table F1, SI). With respect to *Scenario II (AD)* and *Scenario III (I)*, the main contribution to savings came from the waste management system (Table F1, SI). The environmental benefits incurred by these (0.26 to 2.7 kg N-eq t^{-1} and -3.8E-03 to -1.8E-03 kg P-eq t^{-1}), however, were far lower than those obtained by the current management and the prevention scenario (-26 to -0.98 kg N-eq t^{-1} and -0.41 to -0.049 kg P-eq t^{-1}). Further, when changing the marginal food mix, a different trend was observed for the environmental category Aquatic Eutrophication Phosphorus compared to, for instance, Global Warming. Indeed, compared to the baseline results, greater environmental savings were obtained when changing the marginal food mix to 100% bread.

3.2.4 Human Toxicity, cancer and Ecotoxicity

The main contributors to the environmental savings in *Scenario I (CM)* and *Scenario IV (P)* were food production followed by the corresponding LUCs (Table F1, SI). In *Scenario II (AD)* and *Scenario III (I)*, the main contributor to the savings was the waste management system (Table F1, SI). The savings incurred by these scenarios (-140 to -47 CTU_e t^{-1} and -1.9E-05 to -7.4E-07 CTU_h t^{-1}), however, were far lower than those obtained in the current management (*CM*) and prevention (*P*) scenarios (-3700 to -880 CTU_e t^{-1} and -9.3E-05 to -1.9E-05 CTU_h t^{-1}). The trends observed for the category Ecotoxicity were different compared to those of Global Warming for eight out of the 20 retail outlets analysed in the study. For these eight retail outlets, *Scenario I (CM)* led to higher savings than *Scenario IV (P)*, due to the assumption made on the marginal food mix, which was rich in grains that require an extensive use of herbicides and fertilisers, highly influencing the impact on the Ecotoxicity environmental category. However, the waste hierarchy, with prevention as the best scenario, was reflected again in the scenario analyses results when the marginal food mix was either composed of 100% bread or by a mix with the same composition as surplus food generated at the retail outlet, as both include food products that have a lower impact on this category.

3.3 Cost analysis

When comparing the costs across *Scenario I (CM)*, *Scenario II (AD)* and *Scenario III (I)*, retailers have an economic gain when handling surplus food, conforming to the current management (Figure 4). However, the costs of *Scenario I (CM)* varied for each retailer (Figure 4), not only due to exogenous factors, such as weather, but also because of local management affecting the redistribution of surplus food. The costs in *Scenario I (CM)* ranged from -40 € t^{-1} for retail #13, to -410 € t^{-1} for retail #1 (Table G1, SI). The former represented a retailer redistributing the lowest amount of surplus food containing mainly *Fruit and vegetables*, which were amongst the cheapest food products considered. The latter represented instead a retailer donating the largest amount of surplus food. This indicates that donating high amounts of surplus food is certainly important to achieve a maximum of monetary savings, but including expensive products (both from a monetary and resource perspective), such as *Meat*, *Fish* and *Deli meats*, increases the benefits. This is well-illustrated by retailer #19 that, while not having the largest food redistribution in terms of mass, nevertheless showed economic savings larger than other retailers, as mostly expensive food products were donated.

It is important to note that, even when enforcing the current surplus food management with redistribution and associated savings, retailers still suffer overall net economic burdens (i.e. positive values in Figure 4) as soon as they generate surplus food. This is clearly evident when the costs incurred for purchasing food products are included in the economic analysis (Figure 4; see indicator "Total cost including the purchase of food"). However, the total cost suffered is lower when implementing redistribution and diversion to animal feed practices and minimising the amount of food waste, i.e. when implementing *Scenario I (CM)*.

FIGURE 4*

4. Discussion

4.1 Comparison of the results with previous studies

Eriksson et al. (2015) performed a LCA in which the environmental benefits of redistributing 1 kg of food waste (including packaging) in the retail sector were assessed. According to the study, greater environmental benefits were associated with prevention and redistribution (i.e. the higher levels of the waste hierarchy) compared to composting, anaerobic digestion, use-as-feed, incineration, and landfilling. However, the results did not show a clear trend: depending on the food product characteristics, anaerobic digestion was in some cases preferable to animal feed production and redistribution. Such a trend is not in accordance with our results, mainly due to differences in methodological choices. Among these, the most important is the inclusion of indirect LUCs in our study, which has a great impact on the carbon footprint of biomasses, as illustrated in the extensive literature on biofuels/biomasses (e.g. Tonini et al., 2016). As such, neglecting LUCs may result in incorrect conclusions by underestimating the Global Warming impacts. The other methodological choices contributing, albeit to a lesser extent, to the difference in the results of the studies are the assumptions on the substituted products (animal feed, food mix, and energy mix). For example, the choice of the marginal redistribution mix can highly vary the benefits obtained from redistributing surplus food, and this can be seen in Eriksson et al. (2015) where a substitution of 100% bread was assumed and resulted not to be highly beneficial for the environment. The conclusions of Brancoli et al. (2017) are fully in agreement with those of our study and support the waste hierarchy: using surplus food as animal feed instead of producing energy appeared environmentally beneficial owing to the avoided production (and avoided LUCs) of conventional animal feeds. Brancoli et al. (2017) also demonstrated that recycling packaging further increased the savings, albeit this is not evident from the results of our study because of its low share in the mix. Eriksson & Spångberg (2017) also assessed the effect of food redistribution, though not including indirect LUCs. The results, though different in magnitude because of not including LUCs, are nevertheless in agreement with our study and support the waste hierarchy: donating surplus food and re-using it is environmentally preferable to conversion for energy purposes. Oldfield et al. (2016) evaluated the carbon footprint of different food waste management options in Ireland (including all food supply chain sectors), including the retail sector. In agreement with our results, food waste minimisation, i.e. prevention, was found to provide the largest savings. Overall, our results, in combination with other studies in the literature, thereby question the current and widely established focus of utilising surplus food for biogas production through anaerobic digestion. If feasible, the food should be redistributed or utilised for animal feed, thus minimising food waste flows and costs (Lebersorger & Schneider, 2014).

4.2 Economic implications

The cost analysis on the 20 retailers varied greatly from month to month for *Scenario I (CM)*, due mainly to exogenous factors, e.g. weather, tourism, seasonality, etc., as also explained elsewhere (COMERSO/OID consulting/TRINOV, 2016). Considerable variations between the individual retailers were also observed. This was most likely influenced by managerial choices as well as by differences in local implementations of the French regulation, e.g. challenges associated with establishing an action plan, and time required by personnel to familiarise and adjust to the regulation (COMERSO/OID consulting/TRINOV, 2016). As expensive food products, e.g. animal-based, represented both high wholesale prices and environmental impacts, maximising their redistribution should be encouraged. The cost analysis fully supported the waste hierarchy: the current management involving redistribution and/or animal feed offered lower costs than the traditional waste management-focused scenarios involving energy production (*Scenario II (AD)* and *Scenario III* (*I)*).

4.3 Data uncertainty and future perspectives

The main source of uncertainty in this study relates to the primary data provided, which are expressed as monetary values (i.e. €) and need therefore to be converted into masses (i.e. kg) to apply a bottom-up LCA approach. This conversion included several assumptions that caused uncertainty in the data used in the environmental assessment. Indeed, the wholesale prices used as conversion factors (expressed as € kg^{-1}) were not all based on French statistics, and they were found only for a limited number of the food products included in the macro-categories. However, adding an uncertainty on the conversion factors used would only affect the composition of the surplus food. We believe that including 20 different retail outlets well represents the variability in the composition of surplus food. Further, the focus of the present study is not on comparing the performance of the individual retail outlets, but rather to assess the impact trend of different management options for surplus food. Additional uncertainties are associated with the modelling of the food products composing the macro-categories. As discussed in Tonini et al. (2018), the choice of the background dataset to model the food production processes affects the magnitude of the results significantly. Another source of uncertainty is the marginal food mix, as the results of the scenario analyses did indeed show that this affects the magnitude of the savings incurred by redistribution. Some studies (e.g. Eriksson et al., 2015) even tested the assumption that the substitution effect would be null, meaning that people in need (themselves or through charities/third parties) would not otherwise purchase food. This assumption ultimately implies death. Another source of uncertainty relates to the French food consumption pattern used to disaggregate macro-categories into the individual food products composing them, as this pattern was based on several studies that were performed in different years. Considering these uncertainties, the numerical results of the study should be used carefully, as a different mix of food products constituting the surplus food would lead to a (even substantially) different magnitude of the results. However, while the magnitude of the environmental impacts may change following a different assortment of food products composing the mix, the ranking of the management scenarios is unlikely to be affected, as also illustrated and discussed in Tonini et al. (2018).

To improve the robustness of the results, we envision as necessary to: i) facilitate the access to disaggregated food surplus and food waste data (i.e. breakdown of specific food products, e.g. chicken, beef, cheese, etc.) both in terms of mass and price, ii)improve the identification of the marginal food mix (substitution effects), and iii) elaborate up-to-date and consistent (consequential and non) databases for all food products available in the market.

5. Conclusion

Based on a life cycle assessment of 20 French retail outlets, the results clearly indicate that surplus food management in the retail sector should prioritise redistribution through donations and/or conversion to animal feed over anaerobic digestion and incineration. Accounting for individual food product categories in the surplus food mix, land-use changes associated with food production, and food production itself resulted in Global Warming savings of -1900 to -400 kg CO_2-eq t^{-1} when surplus food was redistributed and diverted to animal feed. The economic gains for the French retailers were in the range of -410 to -40 € t^{-1} of surplus food donated. By offering incentives, in particular through a tax credit system for donating expensive food products, such as meat, the French regulation also provides incentives to increase environmental savings, as relatively greater environmental impacts are often associated with these food products. This suggests that the current focus in many countries on directing surplus food to anaerobic digestion cannot be justified by environmental arguments; rather, the focus should be directed towards promoting food redistribution, e.g. by addressing liability aspects, food labelling and durability, as well as economic incentives. While the results obtained herein for the French retailers are considered generally applicable, the study provides a consistent basis for also evaluating similar initiatives in other countries according with their waste management system and policy framework.

Disclaimer

The views expressed in the article are the sole responsibility of the authors and in no way represent the view of the European Commission and its services.

Declaration of interest:

None.

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Highlights:

Environmental impacts of surplus food management scenarios assessed for 20 retailers;

Anaerobic digestion and incineration outcompeted by redistribution and use-as-feed;

Environmental and economic assessment results support the waste hierarchy priorities;

Practices favouring redistribution and use-as-feed should be encouraged;

Further research needed for identification of displaced/substituted food products.

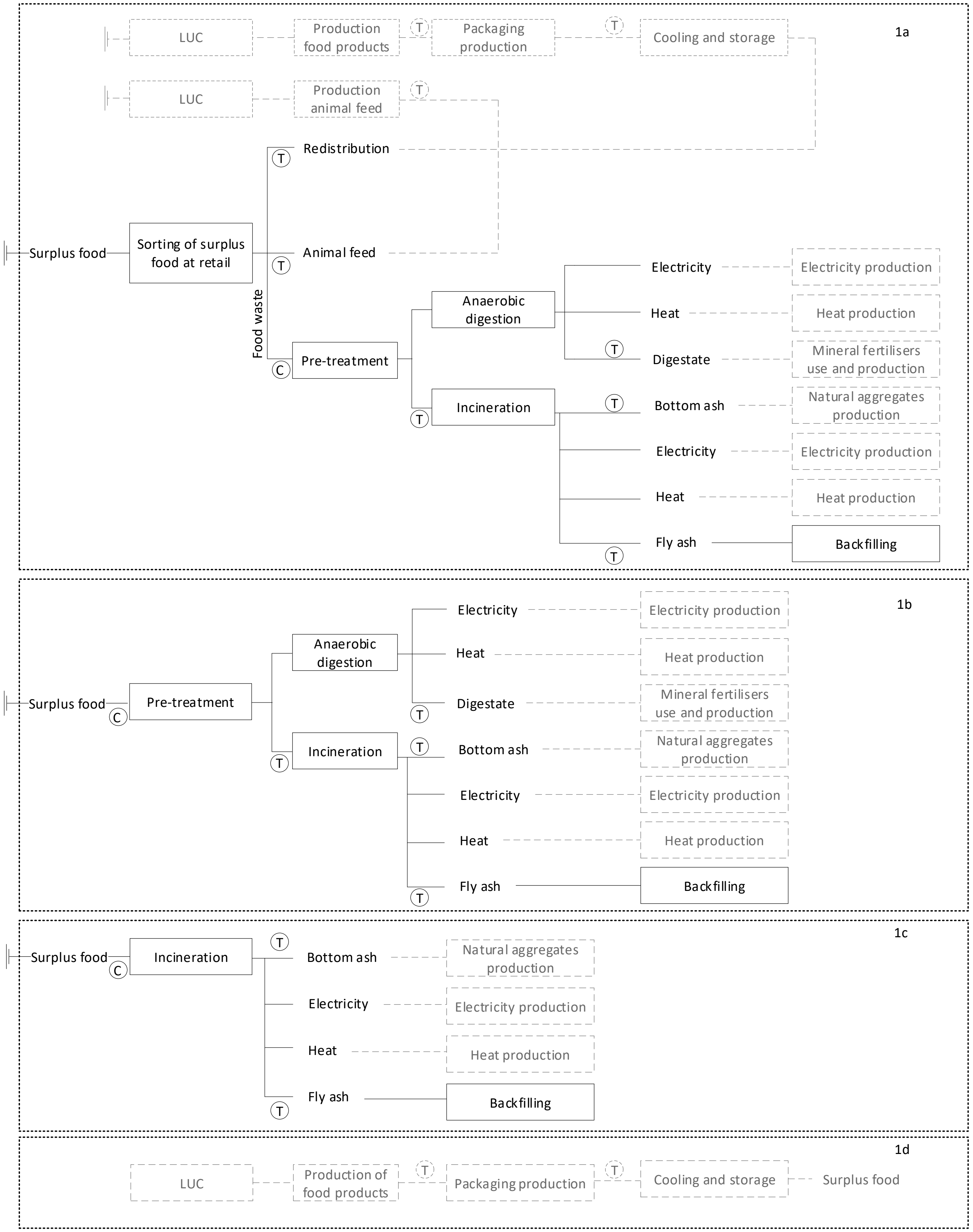
Figure Captions

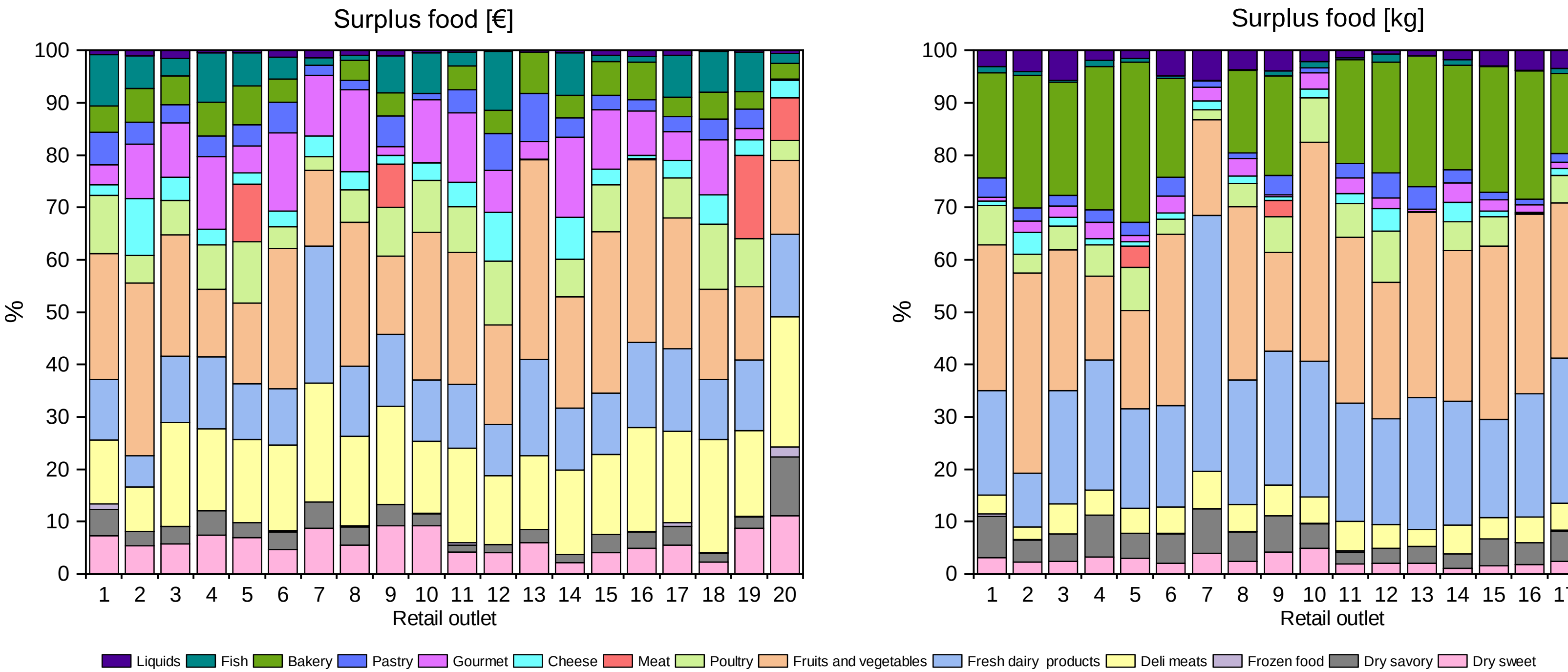
Figure 1: The system boundaries (black, dashed line) are displayed for the four scenarios considered. The black lines in 1a, 1b, and 1c indicate the processes prior to the generation of surplus food, which are not considered in *Scenario I (CM)*, *Scenario II (AD)*, and *Scenario III (I)* due to system equivalence. The grey, dashed boxes and lines represent displacement of market processes/technologies. Note that LUC (land-use-changes; here as avoided effect) accounts both for expansion and intensification. “C”:collection; “T”:transport; “Figure 1a”:*Scenario I (CM)*; “Figure 1b”:*Scenario II (AD)*; “Figure 1c”*Scenario III (I)*; “Figure 1d”:*Scenario IV (P)*.

Figure 2: Contribution of each macro-category to the total surplus food, for each retail outlet considered in the study. The graph on the left expresses the surplus food as monetary values, whereas the one on the right as mass values. Note that retailers 1 to 19 redistribute the surplus food, whilst retail #20 both redistributes and sends it for use as animal feed.

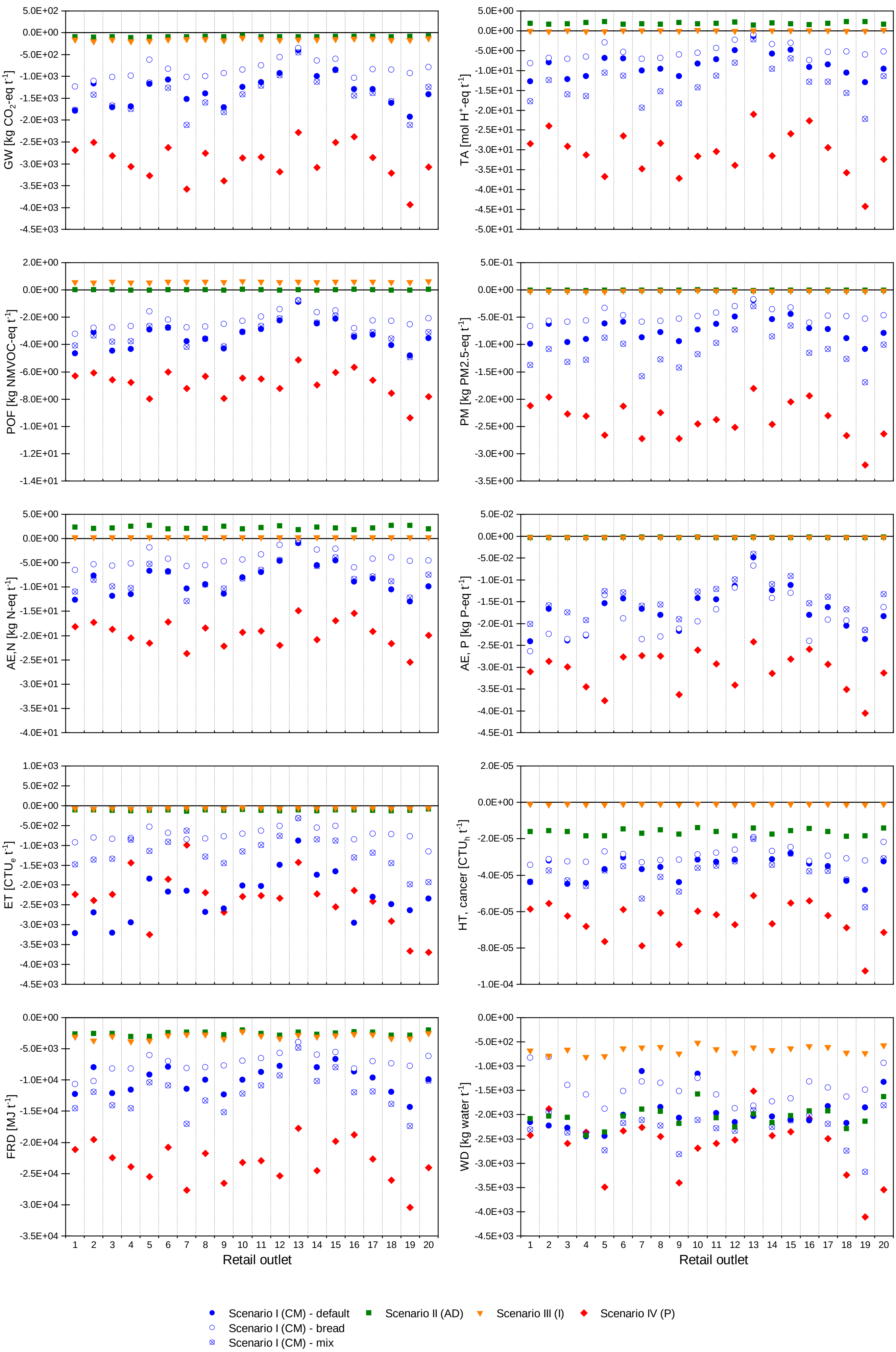
Figure 3: Characterized results for the ten environmental impact categories, expressed per tonne of surplus food, wet weight basis. The baseline results are illustrated together with those of the scenario analyses where we change the marginal redistribution mix (see section 2.6). Values above the zero-line are burdens, whilst below are savings to the environment. “GW”: Global Warming; “TA”: Terrestrial Acidification; “POF”: Photochemical Ozone Formation; “PM”: Particulate Matter; “AE, N”: Aquatic Eutrophication, Nitrogen; “AE, P”: Aquatic Eutrophication, Phosphorus; “ET”: Ecotoxicity; “HT, cancer”: Human Toxicity, cancer; “FRD”: Fossil Resource Depletion; “WD”: Water Depletion.

Figure 4: Costs [€ t^{-1}] for the management of one tonne of surplus food at each individual retail outlet. For comparison, the cost for the current management (involving redistribution and diversion to animal feed) is compared to a situation where 100% of the surplus food is sent to either anaerobic digestion (AD; 57 € t^{-1}) or incineration (I; 132 € t^{-1}). Costs are shown with and without including the upstream cost incurred by the retailers for purchasing the food. Note that negative costs are savings, and positive costs are expenses.

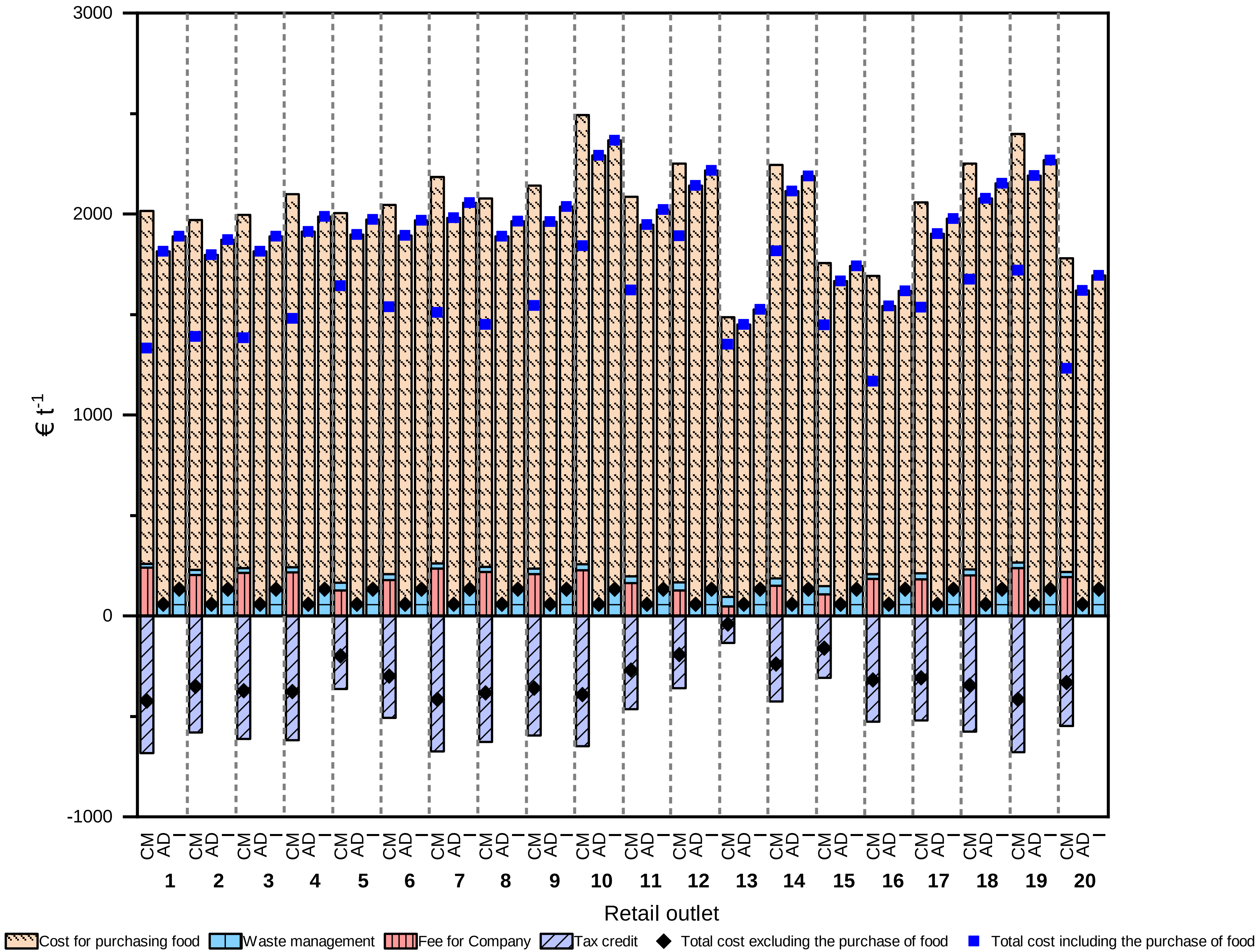

1a
LUC
Production food products
Packaging production
Cooling and storage
LUC
Production animal feed
Redistribution
Surplus food
Sorting of surplus food at retail
Animal feed
Food waste
Pre-treatment
Anaerobic digestion
Electricity
Electricity production
Heat
Heat production
Digestate
Mineral fertilisers use and production
Incineration
Bottom ash
Natural aggregates production
Electricity
Electricity production
Heat
Heat production
Fly ash
Backfilling
1b
Surplus food
Pre-treatment
Anaerobic digestion
Electricity
Electricity production
Heat
Heat production
Digestate
Mineral fertilisers use and production
Incineration
Bottom ash
Natural aggregates production
Electricity
Electricity production
Heat
Heat production
Fly ash
Backfilling
1c
Surplus food
Incineration
Bottom ash
Natural aggregates production
Electricity
Electricity production
Heat
Heat production
Fly ash
Backfilling
1d
LUC
Production of food products
Packaging production
Cooling and storage
Surplus food

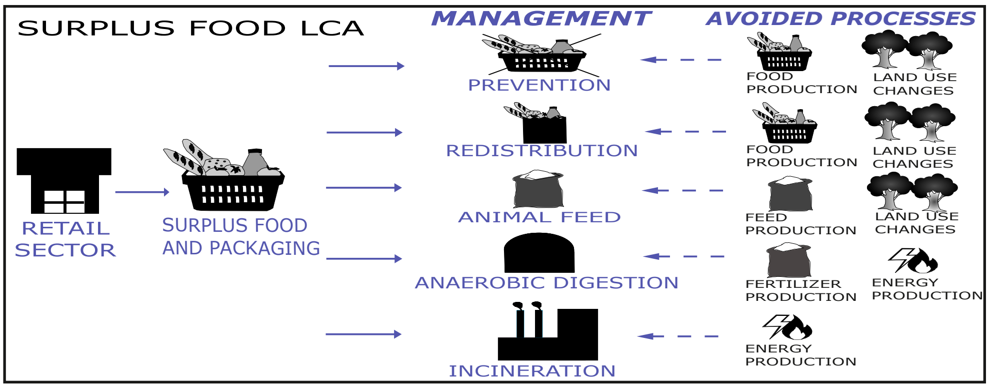


Surplus food [€]
Surplus food [kg]
%
Retail outlet
Liquids
Fish
Bakery
Pastry
Gourmet
Cheese
Meat
Poultry
Fruits and vegetables
Fresh dairy products
Deli meats
Frozen food
Dry savory
Dry sweet



GW [kg CO2-eq t-1]
TA [mol H+-eq t-1]
POF [kg NMVOC-eq t-1]
PM [kg PM2.5-eq t-1]
AE,N [kg N-eq t-1]
AE, P [kg P-eq t-1]
ET [CTUe t-1]
HT, cancer [CTUh t-1]
FRD [MJ t-1]
WD [kg water t-1]
Retail outlet
Retail outlet
Scenario I (CM) - default
Scenario I (CM) - bread
Scenario I (CM) - mix
Scenario II (AD)
Scenario III (I)
Scenario IV (P)


3000
2000
1000
0
-1000
€ t-1
CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD CM AD
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Retail outlet
Cost for purchasing food
Waste management
Fee for Company
Tax credit
Total cost excluding the purchase of food
Total cost including the purchase of food


SURPLUS FOOD LCA
MANAGEMENT
AVOIDED PROCESSES
PREVENTION
FOOD PRODUCTION
LAND USE CHANGES
REDISTRIBUTION
FOOD PRODUCTION
LAND USE CHANGES
RETAIL SECTOR
SURPLUS FOOD AND PACKAGING
ANIMAL FEED
FEED PRODUCTION
LAND USE CHANGES
ANAEROBIC DIGESTION
FERTILIZER PRODUCTION
ENERGY PRODUCTION
INCINERATION
ENERGY PRODUCTION

Supporting Information

For the article:

Valorisation of surplus food in the French retail sector: Environmental and economic impacts

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Table of Contents

Appendix A

Herein a detailed list of all the processes included in the system boundaries of each scenario is presented. In *Scenario I (CM)*, *Scenario II (AD)*, *Scenario III (I)* (Figure 1a, 1b, 1c, respectively in the main report), the system boundaries account for: the collection of the surplus food, the redistribution process, the use of the surplus food as animal feed, transport, the digestion of the food waste, and the incineration of the residual waste flows (i.e. from pre-treatment, both food and packaging). The boundaries are further expanded to account for, when applicable: the avoided indirect land use changes (both intensification and expansion) due to food production, the avoided production of food products and the corresponding packaging, the avoided transport of the food products and the corresponding packaging, the avoided cooling and storage of the food products at retails, the avoided production of the conventional animal feed and its transport, the avoided indirect land use changes (both intensification and expansion) due to animal feed production, the avoided production of marginal heat, electricity, mineral fertilizers, gravel and natural aggregates. In *Scenario IV (P)* (Figure 1d in the main report), the system boundaries include: the indirect land use changes due to the production of the food products (both intensification and expansion), the production of food products, the transport and refrigeration of the food products, the packaging production, the transport of the packaging, and the cooling and storage at retails.

Appendix B

Table B1 summarises the information related to the packaging assumed for each food product and the conversion factor applied to obtain the quantity of packaging. Notice that in the retails considered in the study, *Fruit and* vegetables are sold without packaging. Hence, their packaging was set to 0.

Table B2 provides the information regarding the assumed French consumption pattern together with the food products included and their share in each macro-category. The French consumption pattern was characterized based on Agence française de sécurité sanitarie des aliments (2007), Interfel (2018), Maison du Lait (2018), Les fabricants de Biscuits & Gâteaux de France (2016), and France AgriMer (2014).

Table B3 presents the conversion factors of the wholesale prices expressed as [€ kg^{-1}]. Note that the wholesale prices were based on Ministère de l'agriculture & France AgriMer (2016), Camera di Commercio Industria Artigianato e Agricoltura di Roma (2015), and information provided by the company Phenix. The conversion factors reported in Table B3 where obtained by weighting the wholesale prices accordingly to the French consumption pattern.

Table B1: Information regarding the type of packaging assumed for all the food products included in the mix. The conversion factor expressed as [$kg_{packaging}\ kg_{food\ product}^{-1}$] is also reported.

Macro-category	Type of food product	Type of packaging	$kg_{packaging}\ kg_{food\ product}^{-1}$
Dry sweets	Biscuits	Paper	0.028
	Cakes	Paper	0.028
Dry savoury	Pasta	Paper	0.028
	Rice and Wheat	Paper	0.028
	Pizza, salty pastries	Paper	0.028
	Sandwiches, hamburgers	Paper	0.028
Frozen food	Meat	PET	0.056
	Poultry	PET	0.056
	Bread	PP	0.02
	Fruit and Vegetables	PP	0.01
	Fish	PET	0.056
	Pastry	Paper	0.028
	Dry savoury	Paper	0.028
Deli meats	Deli meats	PET	0.056
Fresh dairy products	Milk	PE	0.035
	Fresh products	PE	0.036
	Eggs and egg products	Paper	0.028
	Cream	PE	0.035

	Butter	PP	0.02
Fruit and Vegetables	Potato	-	0
	Apple	-	0
	Tomato	-	0
	Banana	-	0
	Orange	-	0
	Lettuce	-	0
	Carrot	-	0
	Clementine	-	0
	Peach	-	0
	Melon	-	0
	Pear	-	0
	Endive	-	0
	Chicory	-	0
	Zucchini	-	0
	Onion	-	0
	Pepper	-	0
	Grape	-	0
	Cucumber	-	0
	Lemon	-	0
	Watermelon	-	0
	Pomelo	-	0
	Kiwi	-	0
	Strawberry	-	0
	Leek	-	0
	Avocado	-	0
	Apricot	-	0
	Plum	-	0
	Beetroot	-	0
	Champignon	-	0
	Pineapple	-	0
	Cauliflower	-	0
	Artichoke	-	0
	Celeriac	-	0
	Savoy cabbage	-	0
	Radish	-	0
	Walnut	-	0
	Broccoli	-	0

	Pumpkin	-	0
	Shallot	-	0
	Celery	-	0
	Aubergine	-	0
	Valerian	-	0
	Asparagus	-	0
	Chestnuts	-	0
	Spinach	-	0
	Cherry	-	0
	Green beans	-	0
	Fennel	-	0
	Turnip	-	0
	Brussels sprouts	-	0
	Peas	-	0
Poultry	Chicken	PET	0.056
	Elaborated poultry	PET	0.056
	Turkey	PET	0.056
	Other poultry	PET	0.056
	Duck	PET	0.056
	Fresh rabbit	PET	0.056
Meat	Fresh pork	PET	0.056
	Beef	PET	0.056
	Other elaborated	PET	0.056
	Fresh minced meat	PET	0.056
	Veal	PET	0.056
	Ovine	PET	0.056
	Offal of meat	PET	0.056
	Horse	PET	0.056
Cheese	Cheese	PP	0.02
Gourmet	Gourmet	Paper	0.028
Pastry	Pastries and cakes	Paper	0.028
	Croissants	Paper	0.028
Bakery	Bread	PP	0.02
Fish	Fish	PET	0.056
	Shellfish and molluscs	PET	0.056
Liquids	Water	PE	0.035
	Non-alcoholic beverages	PE	0.035

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Table B2: The assumed French consumption pattern is presented together with the food products included in each macro-category and their contribution to it.

Macro-category	Food products	Share [%]
Dry sweet	Biscuits	85
	Cakes	15
Dry savoury	Pasta	38.1
	Rice and Wheat	24
	Pizza, salty pastries	22.2
	Sandwiches, hamburgers	15.7
Frozen food	Meat	14.3
	Poultry	14.3
	Bread	14.3
	Fruit and vegetables	14.3
	Fish	14.3
	Pastry	14.3
	Dry savoury	14.3
Deli meats	Deli meats	100
Fresh dairy products	Milk	48.7
	Yogurt	35.9
	Eggs and egg products	6.7
	Cream	4.7
	Butter	4
Fruit and Vegetables	Potato	26.7
	Apple	6.5
	Tomato	5.7
	Banana	4.9
	Orange	4.5
	Lettuce	4.1
	Carrot	3.6
	Clementine	3.2
	Peach, melon	2.4
	Pear, endive, chicory, zucchini, onion	2
	Pepper, grape, cucumber	1.6
	Lemon	1.5
	Watermelon	1.3
	Pomelo, kiwi, strawberry, leek	1.2
	Avocado	1
	Apricot	0.9
	Plum, beetroot, champignon, pineapple, cauliflower	0.8
	Artichoke	0.7
	Celeriac, savoy cabbage, radish	0.6

	Walnut, broccoli	0.5
	Pumpkin, shallot, celery, aubergine	0.4
	Valerian, asparagus, chestnut, spinach, cherry, green beans, fennel, turnip	0.3
	Brussels sprouts, peas	0.1
Poultry	Chicken	44
	Elaborated poultry	24.4
	Turkey	12.7
	Other poultry	7.7
	Duck	5.8
	Fresh rabbit	5.5
Meat	Fresh pork	25.1
	Beef	22.7
	Other elaborated	21.5
	Fresh minced meat	12.2
	Veal	7.4
	Ovine	6
	Offal of meat	4.3
	Horse	0.8
Cheese	Cheese	100
Gourmet	Gourmet	100
Pastry	Pastries and cakes	74.1
	Croissants	25.9
Bakery	Bread	100
Fish	Fish	86.7
	Shellfish and molluscs	13.3
Liquids	Water	82.8
	Non-alcoholic beverages	17.2

Table B3: Conversion factors of the wholesale prices of the macro-categories considered in the study.

Macro-category	Conversion factor [€ kg^{-1}]
Dry sweet	4.17
Dry savoury	1.105
Frozen food	4.06
Deli meats	6.06
Fresh dairy products	1.019
Fruit and Vegetables	1.508
Poultry	2.6
Meat	4.891
Cheese	4.49
Gourmet	8.45
Pastry	3.01
Bakery	0.44
Fish	14.85
Liquids	0.47

Appendix C

Table C1 provides the processes used for the modelling of the food products considered in the study. Both the assumptions made, the processes used to model the production and transport of the food products are listed. All the processes are based on Ecoinvent v3.3 Consequential (Wernet et al., 2016).

Table C1: List of processes based on Ecoinvent v3.3 Consequential (Wernet et al., 2016) for the modelling of the food products considered in the study.

Macro-categories	Food products	Assumptions for LCA modelling	Process(es) in Ecoinvent for the production	Process(es) in Ecoinvent for the transport
Dry sweet	Biscuits	Estimated on a mix of ingredients based on Halaal Recipes (2017). The energy consumption is based on Masanet et al. (2012).	• *Butter production, from cow milk; GLO* • *Beet sugar production; RoW* • *Petrol, unleaded, burned in machinery; GLO* • *Electricity production, natural gas, conventional power plant; RoW* • *Wheat flour; GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Cakes	Estimated on a mix of ingredients based on Paul Holliwood (2017). The energy consumption is based on Masanet et al. (2012).	• *Tap water production, conventional treatment; RoW* • *Milk production, from cow; RoW* • *Beet sugar production; RoW* • *Butter production, from cow milk; GLO* • *Heat production, natural gas, at industrial furnace > 100 kW; RoW* • *Petrol, unleaded, burned in machinery; GLO* • *Electricity production, natural gas, conventional power plant; RoW* • *Wheat flour; GLO* • *Cheese production soft, from cow milk, GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*

Dry savoury	Pasta	Based on the LCI reported in the study by Lo Giudice & Clasadonte (2014)	For the semolina production: • *Electricity production, natural gas, conventional power plant; RoW* • *Tap water production, conventional treatment; RoW* • *Natural gas, burned in gas motor, for storage; RoW* • *Wheat production; GLO* For the pasta production: • *Semolina production* • *Electricity production, natural gas, conventional power plant, RoW* • *Tap water production, conventional treatment; RoW* • *Petrol, unleaded, burned in machinery; GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Rice		• *Rice production; GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Wheat		• *Wheat production; GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Pizza, salty pastries	Estimated on a mix of ingredients based on Lillywhite et al. (2013).	• *Tomato production, fresh grade, open field; RoW* • *Cheese production, soft, from cow milk; GLO* • *Cattle*[1] • *Natural gas, burned in gas motor, for storage; RoW* • *Wheat flour; GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*

	Sandwiches,hamburgers	Assumed as *Pizza, salty pastries*	• *Tomato production, fresh grade, open field; RoW* • *Cheese production, soft, from cow milk; GLO Cattle for slaughtering, live weight to generic market for red meat, live weight; GLO* • *Natural gas, burned in gas motor, for storage; RoW* • *Wheat flour; GLO* • *Cattle*[1]	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Frozen food	Meat	Calculated as the average of all the *Meat* items	Average of: • *Swine*[2] • *Cattle*[1] • *Sheep*[3]	Average of: • *Transport of swine* • *Transport of cattle* • *Transport of sheep*
	Poultry	Calculated as the average of all the *Poultry* items	• *Chicken*[4]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Bread	Based on LCA food DK "Bread, wheat, conventional fresh" (2-0 LCA Consultants, 2007).	• *Drinking water from groundwater, RER, ELCD 2005-corrected* • *Wheat flour: GLO* • *Market for electricity, low voltage; GB* • *Marginal heat; UK*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Fruits and Vegetables	Assumed as the average of all the *Fruit and Vegetables* items	All the fruit and vegetables items (see list below)	Calculated as the average of the transport of the *Fruit and Vegetables*
	Fish		• *Fish*[5]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Pastry	Assumed as the average of all the *Dry sweet* items	The LCI is based on: • *Production of croissants* • *Production of pastry*	Average of: • *Transport of croissants* • *Transport of pastry*

	Dry savoury	Assumed as the average of all the *Dry savoury* items	The LCI is based on: • *Production of pasta* • *Production of rice* • *Production of wheat* • *Production of pizza, salty pastries* • *Production of sandwiches, hamburgers*	Average of: • *Transport of pasta* • *Transport of rice* • *Transport of wheat* • *Transport of pizza, salty pastries* • *Transport of sandwiches, hamburgers*
Deli meats	Deli meats		• *Swine*[2]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
Fresh dairy products	Milk		• *Milk productin, from cow, RoW*	• *Transport, freight train; FR* • *Transport, freight, light commercial vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship, GLO*
	Fresh products		• *Yogurt production, from cow milk, RoW*	• *Transport, freight train; FR* • *Transport, freight, light commercial vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship, GLO*
	Eggs and egg products		• *Cheese production soft, from cow milk, GLO*	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Cream		• *Butter proudction, from cream, from cow milk; GLO*	• *Transport, freight train; FR* • *Transport, freight, light commercial vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship, GLO*
	Butter		• *Butter production, from cow milk, GLO*	• *Transport, freight train; FR*

				• *Transport, freight, light commercial vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship, GLO*
Fruit and vegetables	Potato		• *Potato production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO Transport, freight, train with reefer, cooling; GLO*
	Apple		• *Apple production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Tomato		• *Tomato production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO*

				• *Transport, freight, train with reefer, cooling; GLO*
	Banana		• *Banana production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Orange		• *Orange production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, aircraft with reefer, cooling; GLO* • *Transport, freight, inland waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*

	Lettuce		• *Lettuce production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Carrot		• *Carrot production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Clementine		• *Mandarin production; RoW*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*

	Peach		• *Peach production; RoW*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO Transport, freight, aircraft with reefer, cooling; GLO* • *Transport, freight, inland waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Melon		• *Melon production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market GLO* • *Transport, freight, train with reefer cooling; GLO*
	Pear		• *Pear production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*

	Endive	Assumed as *Lettuce* as they belong to the same family	• *Lettuce production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Chicory	Assumed as Lettuce as they belong to the same family	• *Lettuce production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Zucchini		• *Zucchini production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Onion		• *Onion production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO*

				• *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Pepper		• *Green bell pepper production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Grape		• *Grape production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Cucumber		• *Cucumber production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Lemon		• *Lemon production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO*

				• *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Watermelon	Based on the study by Shamshirband et al. (2015)	• *Diesel, burned in agricultural machinery; GLO* • *Urea ammonium nitrate production; RoW* • *Potassium chloride production; ROW* • *Electricity production, natural gas, conventional power plant; RoW* • *Diammonium phosphate production; RoW*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Pomelo	Assumed as *Lemon* as they belong to the same family	• *Lemon production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Kiwi		• *Kiwi production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO*

				• *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Strawberry		• *Strawberry production, open field, macro tunnel; RoW*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, aircraft with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling, GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling GLO*
	Leek	Assumed as *Onion* as they belong to the same family	• *Onion production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Avocado		• *Avocado production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market GLO* • *Transport, freight, train with reefer cooling; GLO*
	Apricot		• *Apricot production; RoW*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO*

				• *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Plum	Assumed as *Pear* as they belong to the same family	• *Pear production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, aircraft with reefer, cooling; GLO* • *Transport, freight, inland waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Beetroot	Assumed as *Spinach* as they belong to the same family	• *Spinach production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market GLO* • *Transport, freight, train with reefer cooling; GLO*
	Champignon	Assumed as *Apple* as no other information was available	• *Apple production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO*

				• *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Pineapple		• *Pineapple production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, aircraft with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport freight, train with reefer, cooling; GLO*
	Cauliflower		• *Cauliflower production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Artichoke	Assumed as *Lettuce* as they belong to the same family	• *Lettuce production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO*

				• *Transport, freight, train with reefer, cooling; GLO*
	Celeriac	Assumed as *Carrot* as they belong to the same family	• *Carrot production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Savoy cabbage	Assumed as *Cauliflower* as they belong to the same family	• *Cauliflower production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Radish		• *Radish production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GL* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*

	Walnut	Assumed as *Apple* as no other information was available	• *Apple production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Broccoli		• *Broccoli production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Pumpkin	Assumed as *Melon* as they belong to the same family	• *Melon production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Shallot	Assumed as *Onion* as they belong to the same family	• *Onion production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO*

				• *Transport, freight, train with reefer, cooling; GLO*
	Celery		• *Celery 675 production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Aubergine		• *Aubergine production, GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Valerian	Assumed as *Lettuce* as they are both salad	• *Lettuce production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Asparagus		• *Green asparagus production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, aircraft with reefer, cooling; GLO*

				• *Transport, freight, inland waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Chestnuts	Based on the study by Rosa et al. (2016)	• *Urea ammonium nitrate production; RoW* • *Potassium chloride production; RoW* • *Diammonium phosphate production; ROW* • *Lime to generic market for soil pH raising agent; GLO* • *Diesel, burned in agricultural machinery; GLO* • *Petrol, unleaded, burned in machinery; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Spinach		• *Spinach production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market GLO* • *Transport, freight, train with reefer cooling; GLO*
	Cherry	Assumed as *Apple* as they belong to the same family	• *Apple production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GL* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO*

				• *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Green beans	Assumed as *Peas* as they belong to the same family	• *Protein pea production; GLO*	• *Transport, freight train; FR* • *Transport, fright, inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for* • *Transport, freight, lorry unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Fennel		• *Fennel production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Turnip	Assumed as *Radish* as they belong to the same family	• *Radish production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Brussels sprouts	Assumed as *Broccoli* as they belong to the same family	• *Broccoli production; GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, train with reefer, cooling; GLO*

	Peas		• *Protein pea production; GLO*	• *Transport, freight train; FR* • *Transport, fright, inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for* • *Transport, freight, lorry unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Poultry	Chicken	Assumed on information provided by LCA food DK (2-0 LCA Consultants, 2007)	• *Chicken production, GLO* • *Market for electricity, low voltage, GB* • *Heat production, natural gas at boiler condensing modulating>100kW; Europe without Switzerland* • *Treatment of wastewater, average, capacity 1E9l/year, Europe without Switzerland*	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Elaborated poultry	Assumed as *Chicken*	• *Chicken*[4]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Turkey	Assumed as *Chicken*	• *Chicken*[4]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Other poultry	Assumed as *Chicken*	• *Chicken*[4]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Duck	Assumed as *Chicken*	• *Chicken*[4]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Fresh rabbit	Assumed as *Chicken*	• *Chicken*[4]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
Meat	Fresh pork	Assumed on information provided by LCA food DK (2-0 LCA Consultants, 2007)	• *Swine production; RoW* • *Market for electricity, RoW* • *Heat production, natural gas, at boiler condensing modulating>100kW; Europe without Switzerland* • *Treatment of wastewater, average, capacity 1E9l/year; Europe without Switzerland*	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Beef	Assumed on information provided by LCA food DK (2-0 LCA Consultants, 2007)	• *Cattle for slaughtering, live weight to generic market for red meat, live weight; GLO* • *Market for electricity, low voltage, GB* • *Heat production, natural gas, at boiler condensing modulating>100kW; Europe without Switzerland*	• *Transport, freight, aircraft, intracontinental; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW*

			• *Treatment of wastewater, average, capacity 1E9l/year; Europe without Switzerland*	
	Other elaborated	Assumed as *Pork*	• *Swine*[2]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Fresh minced meat	Assumed as *Pork*	• *Swine*[2]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Veal	Assumed as *Beef*	• *Cattle*[1]	• *Transport, freight, aircraft, intracontinental; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW*
	Ovine	Assumed on information provided by LCA food DK (2-0 LCA Consultants, 2007)	• *Sheep for slaughtering, live weight to generic market for red meat, live weight, GLO* • *Market for electricity, low voltage, GB* • *Heat production, natural gas, at boiler condensing modulating>100kW; Europe without Switzerland* • *Treatment of wastewater, average, capacity 1E9l/year; Europe without Switzerland*	• *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW*
	Offal of meat	Assumed as *Pork*	• *Swine*[2]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Horse	Assumed as *Beef*	• *Cattle*[1]	• *Transport, freight, aircraft, intracontinental; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW*
Cheese	Cheese		• *Cheese production, soft, from cow milk; GLO*	• *Transport; freight train; FR* • *Transport, freight, light commerical vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*

Gourmet	Gourmet	Assumed as *Production of pastry*	• *Tap water production, conventional treatment; RoW* • *Milk production, from cow; RoW* • *Beet sugar production; RoW* • *Butter production, from cow milk; GLO* • *Heat production, natural gas, at industrial furnace > 100 kW; RoW* • *Petrol. Unleaded, burned in machinery; GLO* • *Electricity production, natural gas, conventional power plant; RoW* • *Wheat flour; GLO* • *Chicken*[4]	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Pastry	Pastries and cakes	Estimated on a mix of ingredients based on Paul Holliwood (2017). The energy consumption is based on Masanet et al. (2012).	• *Tap water production, conventional treatment; RoW* • *Milk production, from cow; RoW* • *Beet sugar production; RoW* • *Butter production, from cow milk; GLO* • *Heat production, natural gas, at industrial furnace > 100 kW; RoW* • *Petrol. Unleaded, burned in machinery; GLO* • *Electricity production, natural gas, conventional power plant; RoW* • *Wheat flour; GLO* • *Cheese production soft, from cow milk, GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
	Croissants	Estimated on a mix of ingredients based on ChefSteps (2017). The energy consumption is based on Masanet et al. (2012).	• *Tap water production, conventional treatment; RoW* • *Milk production, from cow; RoW* • *Beet sugar production, RoW* • *Heat production, natural gas, at industrial furnace >100 kW; RoW* • *Petrol, unleaded, burned in machinery; GLO* • *Electricity production, natural gas, conventional power plant; RoW* • *Wheat flour; GLO*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Bakery	Bread	Based on LCA food DK "Bread, wheat, conventional fresh" (2-0 LCA Consultants, 2007).	• *Drinking water from groundwater, RER, ELCD 2005-corrected Wheat flour: GLO* • *Market for electricity, low voltage; GB*	• *Transport, freight train; FR* • *Transport freight inland waterways, barge; RoW*

			• *Heat production, natural gas, at boiler fan burner low-NOx non-modulating>100kW; Europe without Switzerland* • *Heat production, at hard coal industrial furnace 1-10MW, Europe without Switzerland* • *Heat production, heavy fuel oil, at industrial furnace 1MW, Europe without Switzerland*	• *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Fish	Fish	Assumed on information provided by LCA food DK (2-0 LCA Consultants, 2007)	• *Other drivable machines, combustion 1L of diesel, 2003/2011* • *Market for electricity, low voltage, GB* • *Heat production, natural gas, at boiler condensing modulating>100kW; Europe without Switzerland* • *Treatment of wastewater, average, capacity 1E9l/year; Europe without Switzerland* • *Market for soybean, GLO* • *Market for palm fruit bunch, GLO* • *Market for urea, as N, GLO* • *Market for potassium chloride, as K2O, GLO* • *Market for phosphate fertilizer, as P2O5, GLO* • *Hydrated Lime, CaOH2, EU-27, ELCD, 2007* • *Hydrogen chloride (HCl), gas, RER, ELCD, 2000* • *Sodium hydrozide (NaOH), RER, ELCD, 1996* • *Ammonia production, steam reforming, liwuid*	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
	Shellfish and molluscs	Assumed as *Fish*	• *Fish*[5]	• *Transport, freight, lorry, all sizes, EURO 4 to generic market for transport, freight, lorry, unspecified; RoW*
Liquids	Water		• *Tap water production, conventional treatment, RoW*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, inland, waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO*

				• *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*
	Non-alcoholic beverages	Based on a study by Doublet et al. (2013)	• *Orange production, fresh grade; RoW* • *Orange production, fresh grade, ES* • *Orange production, fresh grade, US* • *Orange production, fresh grade, ZA* • *Market for electricity, low voltage, GB* • *Heat production, natural gas, at boiler condensing modulating>100kW; Europe without Switzerland* • *Market for nitric acid, without water, in 50% solution state, GLO* • *Sodium hydroxide to generic market for neutralizing agent, GLO* • *Drinking water from groundwater, RER, ELCD, 2005* • *Market for packaging film, low density polyethylene, GLO* • *Market for soybean, GLO* • *Market for palm fruit bunch, GLO* • *Market for maize grain, feed, GLO* • *Market for urea, as N, GLO* • *Market for potassium chloride, as K2O, GLO* • *Market for phosphate fertilizer, as P2O5, GLO*	• *Operation, reefer, cooling, 40-foot, high-cube, R134a as refrigerant; GLO* • *Transport, freight, aircraft with reefer, cooling; GLO* • *Transport, freight, inland waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry with reefer, cooling; GLO* • *Transport, freight, small lorry with refrigeration machine, EURO4, R134a refrigerant, cooling to generic market; GLO* • *Transport, freight, sea, transoceanic ship with reefer, cooling; GLO* • *Transport, freight, train with reefer, cooling; GLO*

Cattle[1]: Refer to *Beef;* Swine[2]: Refer to *Fresh pork;* Sheep[3]: Refer to *Ovine;* Chicken[4]: Refer to *Chicken;* Fish[5]: Refer to *Fish*

The list of the processes related to other products and technologies are listed in Table C2. All the processes are based on Ecoinvent 3.3 Consequential (Wernet et al., 2017).

Table C2: List of the processes related to other products and technologies. All the processes are based on Ecoinvent 3.3 Consequential (Wernet et al., 2017).

Process	**Process(es) in Ecoinvent for the production**	**Process(es) in Ecoinvent for the transport**
PET	• *Polyethylene terephthalate production, granulate, bottle grade; RoW*	• *Transport, freight train; FR* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*

PP	• *Polypropylene production, granulate; RoW*	• *Transport, freight train; FR* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
PE	• *Polyethylene production, high density, granulate; RoW*	• *Transport, freight train; FR* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Marginal electricity	• *Market for electricity, high voltage; FR*	
Marginal N-fertilizer	• *Urea ammonium nitrate production; RoW*	
Marginal K-fertilizer	• *Potassium chloride production; RoW*	
Marginal P-fertilizer	• *Diammonium phosphate production; RoW*	
Marginal energy-feed	• *Maize grain, feed production; RoW*	• *Transport, freight train; FR* • *Transport, freight, inland waterways, barge with reefer, cooling; GLO* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Marginal protein-feed	• *Soybean production; RoW*	• *Transport, freight train; FR* • *Transport, freight, light commercial vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Palm oil		• *Transport, freight train; FR* • *Transport, freight, light commercial vehicle; RoW* • *Transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified; RoW* • *Transport, freight, sea, transoceanic ship; GLO*
Refrigeration, electricity	• *Market for electricity, low voltage; FR*	
Marginal electricity, sensitivity analysis	• *Electricity production, natural gas, conventional power plant; FR*	

The LCIs of some processes were based on the ones present in EASETECH (Clavreul et al., 2014). These processes are listed in Table C3.

Table C3: Processes selected from the library of EASETECH (Clavreul et al., 2014).

Process	Process in EASETECH
Collection truck	• *Collection Vehicle, 10t Euro3, urban traffic, 1 litre diesel, 2006*
Recycling of Paper	• *Paper (Cardboard and mixed paper) to cardboard, Fiskybybruk, Sweden, 2006 [with substitution]*
Palm fruit	• *Palm fruit, conventional. Global 2000-2010*
Transport	• *Truck, <7.5, Euro6, urban traffic*
Refrigeration, heat	• *Heat production, natural gas, at boiler fan burner low-NOx non-modulation <100kW; Europe without Switzerland*
Marginal heat	• *Heat production, natural gas, at boiler fan burner low-NOx non-modulation <100kW; Europe without Switzerland*
Paper production	• *Cardboard, 1 kg, Skoghall Mill, Sweden, weighted average 2005+2007*

Appendix D

Table D1 provides the land demanded for all the food products considered in the study.

Table D1: Land demanded for the food products considered in the study.

Name of process	Amount	Unit	Per	Source
Swine production, live weight; GLO	5.94	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Cattle production for slaughtering, live weight to generic market for red meat, live weight; GLO	9.98	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Chicken production; GLO	2.36	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Sheep production; GLO	23.86	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Cow milk production; GLO	1.31	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Cheese production, from cow milk, fresh, unripened; GLO	9.01	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Production of butter; GLO	-24.81	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Yogurt production, from cow milk; GLO	1.35	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Fish products	0.00	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Wheat bread, conventional, fresh; GLO (adapted)	2.17	m2*y	kg Total Wet Weight	*Ecoinvent 3.3 + LCA food DK*
Rice production; GLO	0.01	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Flour production; GLO	3.10	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Orange production; GLO	0.22	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Lemon production; GLO	0.37	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Apple production; GLO	0.36	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Pear production; GLO	0.49	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Grape production; GLO	0.36	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Banana production; GLO	0.20	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Melon production; RoW	0.09	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Cauliflower production; GLO	0.17	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Lettuce production; GLO	3.44	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Pea protein production; GLO	3.09	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Carrot production; GLO	0.21	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Onion production; GLO	0.21	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Tomato production; GLO	0.23	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Potato production; GLO	0.41	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Apricot production; GLO	0.36	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Aubergine production; GLO	4.22	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Avocado production; GLO	1.11	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Broccoli production; GLO	0.17	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Cream production; GLO	-0.10	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Celery production; GLO	0.16	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Cucumber production; GLO	3.27	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Fennel production; GLO	0.23	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Green asparagus production; GLO	3.46	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Green bell pepper; GLO	2.06	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Kiwi production; GLO	0.32	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Mandarin production, RoW	0.70	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Peach production; RoW	0.42	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Pineapple production; GLO	0.25	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Spinach production, GLO	0.06	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Strawberry production; GLO	0.26	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Zucchini production, GLO	0.15	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Orange juice production	0.50	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Radish production, GLO	7.93	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Watermelon production	0.01	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Artichoke production	0.03	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Chestnut production	0.43	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Pasta production	6.48	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*

Pastry production	-3.53	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Croissant production	1.17	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Biscuit production	-3.84	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*
Pizza production	6.63	m2*y	kg Total Wet Weight	*Ecoinvent 3.3*

Appendix E

The default results together with the scenario analysis where the marginal electricity is changed are displayed in Figure E1. The default results together with the scenario analysis where the management of the packaging is varied are displayed in Figure E2. The default results together with the scenario analysis where the losses incurred by beneficiaries are accounted for are displayed in Figure E3. Note that “GW” =Global Warming; “TA”=Terrestrial Acidification; “POF”=Photochemical Ozone Formation; “PM”=Particulate Matter; “AE, N”=Aquatic Eutrophication, Nitrogen; “AE, P”=Aquatic Eutrophication, Phosphorus; “ET”= Ecotoxicity; “HT, cancer”=Human Toxicity, cancer; “FRD”=Fossil Resource Depletion; “WD”=Water Depletion.

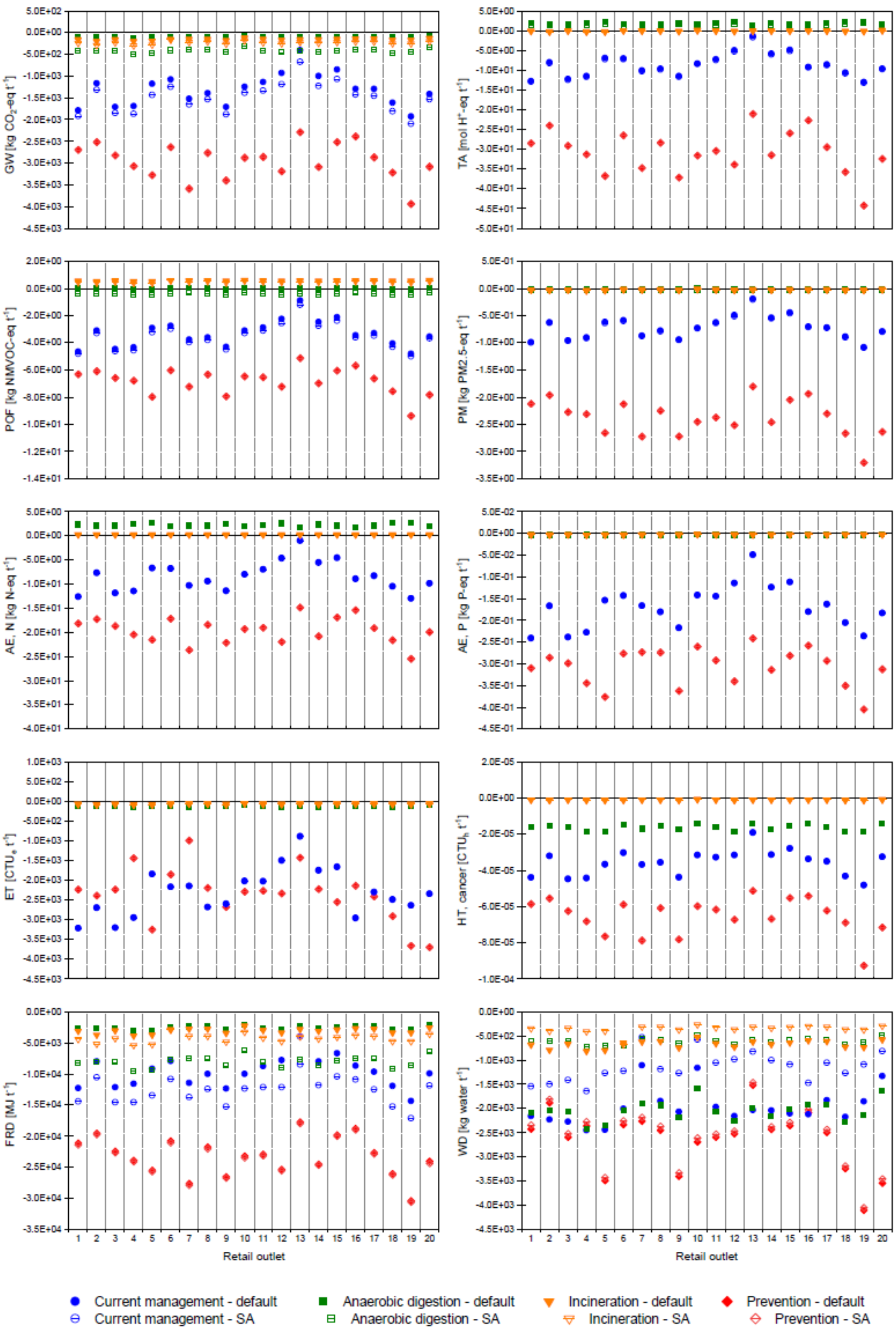
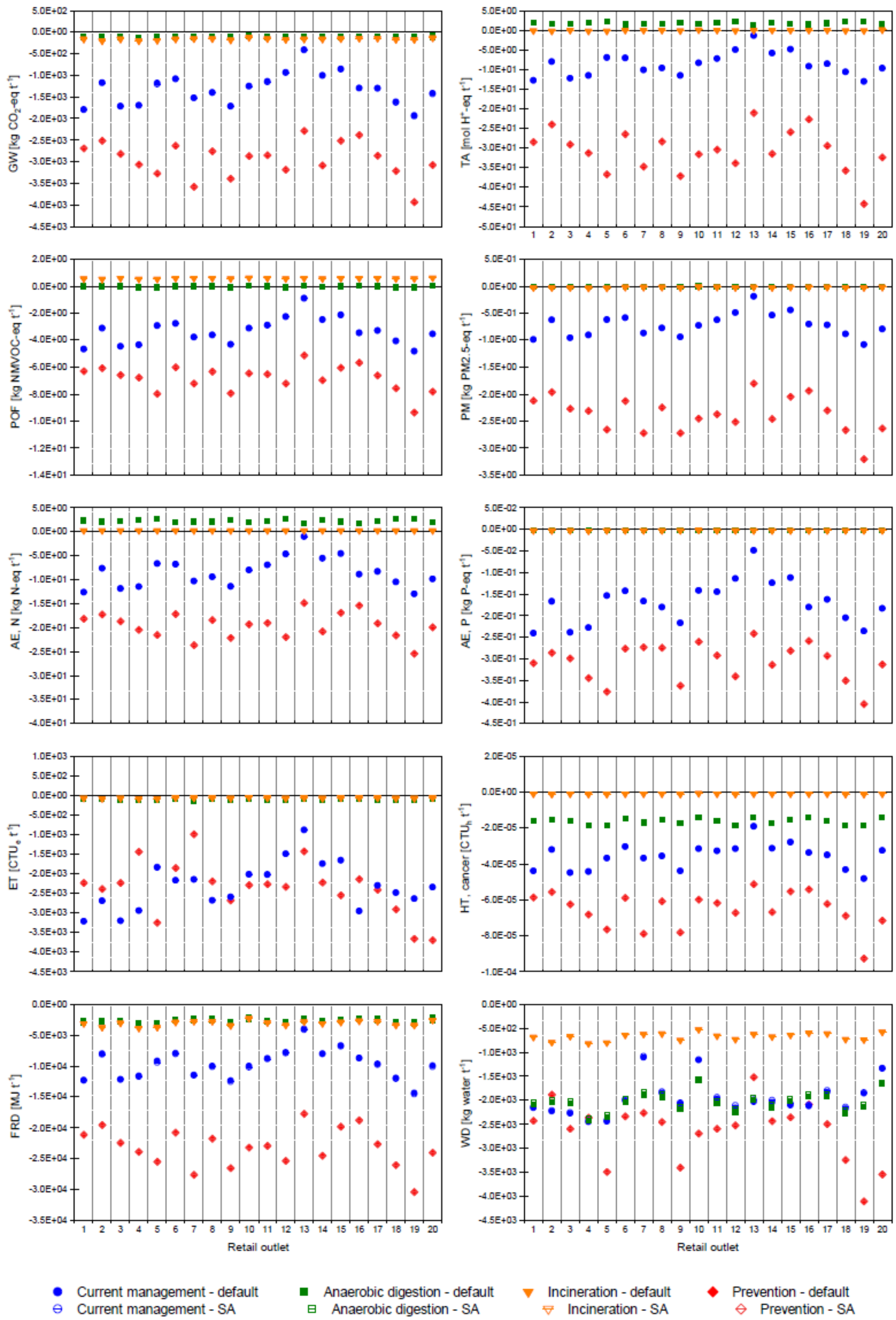


Figure E1: The default results are displayed together with the scenario analysis performed on the marginal electricity.



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88 Figure E2: The default results are displayed together with the scenario analysis on the management of the packaging.

Figure E 3: The default results are displayed together with the scenario analysis performed on the losses incurred by the beneficiaries of the redistribution of surplus food.

Appendix F

Table F1 summarises the results of the environmental assessment. The total, together with the main contributors to the savings/impacts are reported for all the retails, all the scenarios, and all the impact categories considered in the study. Note that: LUC=indirect land use changes; FP=food production; PP=packaging production; AFP=animal feed production; TRCS=transport, refrigeration, cooling and storage; WM&C=waste management and collection. Note that all numbers are rounded.

Table F1: Note that "LUC"=indirect land use changes; "FP"=food production; "PP"=packaging production; "AFP"=animal feed production; "TRCS"= transport, refrigeration, cooling and storage; "WM&C"=waste management and collection. Please note that the numbers were rounded to two significant digits.

Global Warming		**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**	**#18**	**#19**	**#20**
Current management	LUC	31%	34%	27%	32%	29%	30%	25%	29%	28%	23%	28%	27%	28%	28%	30%	33%	28%	28%	26%	34%
	FP	64%	58%	67%	62%	62%	61%	69%	64%	66%	70%	64%	63%	48%	63%	59%	60%	65%	66%	69%	57%
	PP	1%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%
	TRCS	2%	3%	2%	2%	2%	3%	2%	3%	2%	3%	2%	2%	3%	2%	3%	3%	3%	2%	2%	2%
	WM&C	2%	4%	2%	3%	6%	5%	3%	3%	3%	3%	5%	7%	20%	6%	7%	3%	3%	3%	2%	2%
	Total [$kgCO_{2-eq}\ t^{-1}$]	**-1800**	**-1200**	**-1700**	**-1700**	**-1200**	**-1100**	**-1500**	**-1400**	**-1700**	**-1200**	**-1100**	**-920**	**-400**	**-990**	**-840**	**-1300**	**-1300**	**-1600**	**-1900**	**-1400**
Prevention	LUC	19%	22%	19%	18%	20%	18%	12%	17%	17%	13%	17%	18%	18%	17%	21%	20%	18%	19%	17%	20%
	FP	76%	74%	77%	78%	76%	78%	85%	78%	79%	83%	79%	78%	78%	79%	75%	76%	78%	77%	80%	77%
	PP	2%	1%	2%	2%	2%	1%	1%	1%	2%	2%	2%	2%	1%	2%	2%	2%	2%	2%	2%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	3%	3%	3%	2%	2%	3%	2%	3%	2%	3%	3%	2%	3%	2%	3%	3%	3%	2%	2%	2%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [$kgCO_{2-eq}\ t^{-1}$]	**-2700**	**-2500**	**-2800**	**-3100**	**-3300**	**-2600**	**-3600**	**-2800**	**-3400**	**-2900**	**-2800**	**-3200**	**-2300**	**-3100**	**-2500**	**-2400**	**-2900**	**-3200**	**-3900**	**-3100**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-1%	0%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%
	WM&C	101%	100%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%
	Total [$kgCO_{2-eq}\ t^{-1}$]	**-90**	**-130**	**-92**	**-110**	**-100**	**-94**	**-90**	**-90**	**-95**	**-65**	**-90**	**-95**	**-95**	**-94**	**-89**	**-88**	**-84**	**-95**	**-88**	**-69**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-2%	-1%	-2%	-1%	-2%	-2%	-2%	-2%	-2%	-3%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%
	WM&C	102%	101%	102%	101%	102%	102%	102%	102%	102%	103%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%

	Total [$kgCO_{2-eq}$ t^{-1}]	**-160**	**-200**	**-150**	**-200**	**-180**	**-150**	**-150**	**-140**	**-170**	**-110**	**-150**	**-160**	**-150**	**-150**	**-140**	**-140**	**-140**	**-160**	**-160**	**-130**
Terrestrial acidification																					
Current management	LUC	21%	24%	19%	23%	24%	23%	18%	21%	20%	17%	22%	25%	42%	23%	26%	23%	21%	21%	19%	24%
	FP	81%	81%	85%	82%	95%	86%	86%	83%	85%	90%	90%	104%	140%	95%	95%	79%	87%	87%	87%	72%
	PP	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%
	TRCS	3%	4%	2%	2%	2%	3%	2%	3%	2%	3%	3%	3%	7%	3%	4%	4%	3%	2%	2%	2%
	WM&C	-5%	-9%	-6%	-8%	-22%	-12%	-7%	-8%	-9%	-11%	-15%	-32%	-89%	-22%	-25%	-7%	-11%	-11%	-8%	-7%
	Total [$molH^{+}_{-eq}$ t^{-1}]	**-13**	**-7.9**	**-12**	**-11**	**-6.9**	**-7.0**	**-10**	**-10**	**-11**	**-10**	**-10**	**-10**	**-10**	**-10**	**-10**	**-10**	**-10**	**-11**	**-13**	**-10**
Prevention	LUC	9%	11%	9%	9%	9%	9%	6%	8%	8%	6%	8%	8%	9%	8%	10%	10%	8%	8%	7%	9%
	FP	89%	86%	89%	89%	89%	89%	92%	89%	90%	92%	90%	90%	87%	89%	87%	87%	89%	90%	91%	89%
	PP	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	2%	2%	2%	2%	1%	2%	2%	2%	1%	2%	2%	2%	3%	2%	2%	2%	2%	1%	1%	2%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [$molH^{+}_{-eq}$ t^{-1}]	**-28**	**-24**	**-29**	**-31**	**-37**	**-26**	**-35**	**-28**	**-37**	**-32**	**-30**	**-34**	**-21**	**-31**	**-26**	**-23**	**-29**	**-36**	**-44**	**-32**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [$molH^{+}_{-eq}$ t^{-1}]	**1.9**	**1.5**	**1.8**	**2.0**	**2.2**	**1.6**	**1.7**	**1.7**	**2.1**	**1.7**	**1.8**	**2.2**	**1.4**	**2.0**	**1.8**	**1.5**	**1.8**	**2.2**	**2.3**	**1.7**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	12%	-6%	7%	-4%	-6%	5%	4%	4%	-19%	2%	7%	-44%	4%	9%	5%	3%	4%	-42%	-28%	3%
	WM&C	88%	106%	93%	104%	106%	95%	96%	96%	119%	98%	93%	144%	96%	91%	95%	97%	96%	142%	128%	97%
	Total [$molH^{+}_{-eq}$ t^{-1}]	**0.040**	**-0.077**	**0.063**	**-0.11**	**-0.083**	**0.089**	**0.12**	**0.12**	**-0.025**	**0.22**	**0.072**	**-0.011**	**0.11**	**0.051**	**0.97**	**0.14**	**0.12**	**-0.011**	**-0.017**	**0.16**
Photochemical Ozone Formation																					
Current management	LUC	23%	25%	21%	24%	23%	24%	20%	22%	22%	18%	22%	22%	25%	22%	24%	25%	22%	22%	21%	27%
	FP	69%	65%	72%	68%	70%	68%	73%	69%	71%	73%	70%	70%	66%	69%	68%	66%	70%	71%	72%	61%
	PP	1%	1%	1%	1%	1%	1%	3%	2%	1%	2%	1%	1%	2%	2%	1%	1%	2%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%
	TRCS	6%	8%	6%	5%	5%	7%	5%	7%	5%	8%	7%	6%	9%	7%	7%	8%	7%	5%	5%	5%
	WM&C	0%	0%	0%	0%	1%	0%	0%	0%	0%	-1%	0%	1%	-2%	0%	0%	0%	0%	0%	0%	0%
	Total [$kgNMVOC_{-eq}t^{-1}$]	**-4.7**	**-3.1**	**-4.4**	**-4.3**	**-2.9**	**-2.8**	**-3.8**	**-3.6**	**-4.3**	**-3.1**	**-2.9**	**-2.2**	**-0.88**	**-2.5**	**-2.1**	**-3.5**	**-3.3**	**-4.1**	**-4.8**	**-3.5**
Prevention	LUC	16%	18%	16%	16%	16%	15%	11%	15%	15%	12%	15%	16%	16%	15%	17%	17%	15%	16%	14%	15%
	FP	74%	72%	74%	75%	75%	74%	79%	75%	77%	78%	75%	76%	72%	75%	72%	72%	75%	75%	79%	76%
	PP	3%	2%	3%	3%	2%	2%	3%	2%	3%	2%	2%	2%	2%	2%	2%	2%	3%	3%	2%	2%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	8%	8%	7%	7%	6%	8%	7%	8%	6%	8%	7%	6%	9%	7%	8%	9%	8%	6%	5%	7%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [$kgNMVOC_{-eq}t^{-1}$]	**-6.3**	**-6.1**	**-6.6**	**-6.8**	**-8.0**	**-6.0**	**-6.5**	**-6.3**	**-7.9**	**-6.5**	**-6.5**	**-7.2**	**-5.1**	**-7.0**	**-6.0**	**-5.7**	**-6.6**	**-7.6**	**-9.4**	**-7.8**

Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-15%	0%	1253%	-2%	-2%	9%	5%	5%	-3%	2%	-29%	-3%	4%	-6%	10%	3%	6%	-2%	-3%	2%
	WM&C	115%	100%	-12153%	102%	102%	91%	95%	95%	103%	98%	129%	103%	96%	106%	90%	97%	94%	102%	103%	98%
	Total [kgNMVOC-eq t⁻¹]	**-4.6E-03**	**-1.8E-01**	**-5.5E-05**	**-3.9E-02**	**-3.9E-02**	**7.4E-03**	**1.4E-02**	**1.4E-02**	**-2.1E-02**	**4.1E-02**	**-2.4E-03**	**-2.7E-02**	**1.7E-02**	**-1.2E-02**	**6.6E-03**	**2.2E-02**	**1.2E-02**	**-3.0E-02**	**-2.4E-02**	**3.7E-02**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	WM&C	99%	99%	99%	99%	99%	99%	99%	99%	99%	100%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
	Total [kgNMVOC-eq t⁻¹]	**0.58**	**0.54**	**0.59**	**0.53**	**0.54**	**0.60**	**0.61**	**0.61**	**0.56**	**0.65**	**0.59**	**0.57**	**0.61**	**0.59**	**0.60**	**0.62**	**0.61**	**0.57**	**0.56**	**0.63**
Particulate matter																					
Current management	LUC	18%	20%	16%	19%	18%	18%	14%	17%	17%	13%	17%	16%	19%	17%	18%	20%	16%	16%	15%	19%
	FP	77%	74%	80%	76%	78%	76%	81%	78%	79%	82%	78%	78%	70%	78%	75%	74%	78%	79%	81%	66%
	PP	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%
	TRCS	4%	5%	3%	3%	3%	4%	3%	4%	3%	4%	4%	3%	5%	4%	4%	5%	4%	3%	3%	3%
	WM&C	0%	1%	0%	1%	1%	1%	0%	0%	0%	0%	1%	1%	5%	1%	1%	1%	0%	0%	0%	0%
	Total [kgPM2.5-eq t⁻¹]	**-0.99**	**-0.63**	**-0.96**	**-0.91**	**-0.62**	**-0.58**	**-0.87**	**-0.78**	**-0.94**	**-0.73**	**-0.62**	**-0.49**	**-0.19**	**-0.54**	**-0.44**	**-0.71**	**-0.72**	**-0.89**	**-1.1**	**-0.79**
Prevention	LUC	8%	9%	7%	8%	8%	7%	5%	7%	7%	5%	7%	7%	7%	7%	8%	8%	7%	7%	7%	7%
	FP	88%	87%	89%	89%	89%	89%	92%	89%	90%	91%	90%	89%	89%	89%	88%	88%	89%	89%	90%	89%
	PP	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	3%	3%	3%	2%	2%	3%	2%	3%	2%	3%	2%	2%	3%	2%	3%	3%	3%	2%	2%	2%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [kgPM2.5-eq t⁻¹]	**-2.1**	**-2.0**	**-2.3**	**-2.3**	**-2.7**	**-2.1**	**-2.5**	**-2.3**	**-2.7**	**-2.5**	**-2.4**	**-2.5**	**-1.8**	**-2.5**	**-2.1**	**-1.9**	**-2.3**	**-2.7**	**-3.2**	**-2.6**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-1%	0%	0%	0%	-1%	0%	-1%	-1%	-1%	-2%	-1%	-1%	0%	-1%	-1%	0%	-1%	-1%	-1%	-1%
	WM&C	101%	100%	100%	100%	101%	100%	101%	101%	101%	102%	101%	101%	100%	101%	101%	100%	101%	101%	101%	101%
	Total [kgPM2.5-eq t⁻¹]	**-7.1E-03**	**-1.4E-02**	**-8.3E-03**	**-1.1E-02**	**-7.6E-03**	**-9.2E-03**	**-7.9E-03**	**-7.4E-03**	**-7.1E-03**	**-1.9E-03**	**-7.5E-03**	**-6.7E-03**	**-1.1E-02**	**-7.9E-03**	**-7.6E-03**	**-9.5E-03**	**-6.2E-03**	**-6.8E-03**	**-4.4E-03**	**-3.7E-03**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-2%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%
	WM&C	101%	101%	101%	101%	101%	101%	101%	101%	101%	102%	101%	101%	101%	101%	101%	101%	101%	101%	101%	101%

	Total [$kgPM2.5_{-eq}\ t^{-1}$]	**-0.020**	**-0.027**	**-0.019**	**-0.028**	**-0.027**	**-0.017**	**-0.016**	**-0.016**	**-0.024**	**-0.010**	**-0.018**	**-0.023**	**-0.016**	**-0.020**	**-0.017**	**-0.015**	**-0.016**	**-0.023**	**-0.023**	**-0.013**
Aquatic Eutrophication Nitrogen																					
Current management	LUC	33%	38%	29%	35%	39%	36%	28%	33%	32%	27%	35%	40%	86%	37%	42%	36%	33%	33%	29%	36%
	FP	72%	72%	77%	73%	87%	78%	80%	75%	78%	84%	83%	99%	160%	89%	88%	70%	79%	80%	79%	64%
	PP	1%	1%	1%	1%	1%	1%	0%	1%	1%	0%	1%	1%	2%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%
	TRCS	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%	1%
	WM&C	-6%	-12%	-8%	-10%	-27%	-16%	-8%	-9%	-11%	-13%	-19%	-41%	-150%	-28%	-32%	-8%	-14%	-13%	-10%	-8%
	Total [$kgN_{-eq}t^{-1}$]	**-13**	**-7.7**	**-12**	**-11**	**-6.7**	**-6.8**	**-10**	**-9.4**	**-11**	**-8.0**	**-6.9**	**-4.6**	**-0.98**	**-5.5**	**-4.6**	**-8.9**	**-8.3**	**-10**	**-13**	**-10**
Prevention	LUC	21%	24%	21%	20%	23%	20%	13%	20%	20%	15%	19%	19%	21%	19%	23%	23%	20%	21%	19%	23%
	FP	77%	74%	78%	79%	76%	78%	86%	79%	79%	84%	80%	80%	78%	80%	75%	75%	79%	78%	80%	76%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [$kgN_{-eq}t^{-1}$]	**-18**	**-17**	**-19**	**-20**	**-22**	**-17**	**-24**	**-18**	**-22**	**-19**	**-19**	**-22**	**-15**	**-21**	**-17**	**-15**	**-19**	**-22**	**-26**	**-20**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [$kgN_{-eq}t^{-1}$]	**2.3**	**2.0**	**2.2**	**2.5**	**2.7**	**2.0**	**2.1**	**2.0**	**2.5**	**2.0**	**2.2**	**2.6**	**1.8**	**2.4**	**2.1**	**1.8**	**2.2**	**2.7**	**2.7**	**1.9**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [$kgN_{-eq}t^{-1}$]	**0.27**	**0.26**	**0.27**	**0.26**	**0.26**	**0.28**	**0.28**	**0.28**	**0.27**	**0.28**	**0.27**	**0.27**	**0.28**	**0.27**	**0.28**	**0.28**	**0.28**	**0.27**	**0.27**	**0.28**
Aquatic Eutrophication Phosphorus																					
Current management	LUC	6%	6%	5%	6%	6%	6%	6%	6%	6%	5%	6%	6%	6%	6%	6%	6%	6%	6%	5%	7%
	FP	93%	92%	94%	92%	92%	92%	92%	92%	93%	92%	92%	91%	88%	91%	91%	92%	92%	92%	93%	78%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%
	TRCS	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	WM&C	0%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%	2%	5%	2%	2%	1%	1%	1%	1%	1%
	Total [$kgP_{-eq}t^{-1}$]	**-0.24**	**-0.17**	**-0.24**	**-0.23**	**-0.15**	**-0.14**	**-0.17**	**-0.18**	**-0.22**	**-0.14**	**-0.14**	**-0.11**	**-0.05**	**-0.12**	**-0.11**	**-0.18**	**-0.16**	**-0.21**	**-0.24**	**-0.18**
Prevention	LUC	4%	5%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	5%	5%	4%	4%	4%	5%
	FP	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	93%	94%	94%	94%	94%	93%
	PP	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%	1%	1%	0%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [$kgP_{-eq}t^{-1}$]	**-0.31**	**-0.29**	**-0.30**	**-0.35**	**-0.38**	**-0.28**	**-0.27**	**-0.27**	**-0.36**	**-0.26**	**-0.29**	**-0.34**	**-0.24**	**-0.31**	**-0.28**	**-0.26**	**-0.29**	**-0.35**	**-0.41**	**-0.31**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [$kgP_{-eq}t^{-1}$]	**-3.2E-03**	**-3.1E-03**	**-3.1E-03**	**-3.7E-03**	**-3.8E-03**	**-2.9E-03**	**-2.9E-03**	**-2.9E-03**	**-3.5E-03**	**-2.5E-03**	**-3.1E-03**	**-3.6E-03**	**-2.8E-03**	**-3.3E-03**	**-3.0E-03**	**-2.8E-03**	**-3.0E-03**	**-3.6E-03**	**-3.6E-03**	**-2.6E-03**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [$kgP_{-eq}t^{-1}$]	**-2.5E-03**	**-2.9E-03**	**-2.4E-03**	**-3.0E-03**	**-2.9E-03**	**-2.3E-03**	**-2.2E-03**	**-2.2E-03**	**-2.7E-03**	**-1.8E-03**	**-2.3E-03**	**-2.6E-03**	**-2.2E-03**	**-2.4E-03**	**-2.3E-03**	**-2.1E-03**	**-2.2E-03**	**-2.6E-03**	**-2.7E-03**	**-2.0E-03**
	Ecotoxicity																				
Current management	LUC	3%	2%	2%	3%	3%	3%	3%	3%	3%	2%	3%	3%	2%	3%	3%	2%	3%	3%	3%	3%
	FP	93%	93%	94%	92%	90%	92%	91%	93%	92%	91%	91%	88%	85%	90%	90%	94%	92%	91%	91%	65%
	PP	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	27%
	TRCS	2%	2%	2%	2%	2%	2%	3%	2%	2%	3%	2%	2%	2%	2%	2%	2%	3%	2%	3%	2%
	WM&C	1%	2%	2%	2%	4%	3%	3%	2%	2%	3%	4%	7%	10%	5%	5%	1%	3%	3%	2%	2%
	Total [CTU_et^{-1}]	**-3200**	**-2700**	**-3200**	**-2900**	**-1800**	**-2200**	**-2100**	**-2700**	**-2600**	**-2000**	**-2000**	**-1500**	**-900**	**-1700**	**-1700**	**-3000**	**-2300**	**-2500**	**-2600**	**-2300**
Prevention	LUC	4%	4%	4%	6%	3%	4%	7%	4%	4%	3%	4%	4%	5%	4%	4%	4%	4%	3%	3%	3%
	FP	89%	91%	89%	83%	92%	88%	76%	89%	90%	90%	90%	89%	86%	89%	91%	90%	90%	91%	92%	93%
	PP	1%	1%	1%	2%	1%	1%	3%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	6%	5%	6%	8%	4%	6%	14%	6%	5%	6%	6%	5%	8%	6%	5%	5%	5%	5%	4%	4%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [CTU_et^{-1}]	**-2200**	**-2400**	**-2200**	**-1400**	**-3300**	**-1900**	**-1000**	**-2200**	**-2700**	**-2300**	**-2300**	**-2300**	**-1400**	**-2200**	**-2500**	**-2100**	**-2400**	**-2900**	**-3700**	**-3700**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [CTU_et^{-1}]	**-120**	**-120**	**-120**	**-140**	**-120**	**-110**	**-140**	**-110**	**-120**	**-100**	**-120**	**-140**	**-110**	**-130**	**-110**	**-110**	**-120**	**-130**	**-120**	**-90**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-2%	-2%	-2%	-1%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%
	WM&C	102%	102%	102%	101%	103%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%	102%
	Total [CTU_et^{-1}]	**-65**	**-76**	**-63**	**-79**	**-76**	**-60**	**-58**	**-57**	**-71**	**-47**	**-62**	**-70**	**-58**	**-64**	**-59**	**-55**	**-57**	**-70**	**-70**	**-53**
Human Toxicity, cancer																					
Current management	LUC	3.3%	3.2%	2.8%	3.2%	2.5%	2.9%	2.7%	3.1%	2.9%	2.4%	2.6%	2.1%	1.6%	2.3%	2.4%	3.4%	2.8%	2.8%	2.8%	3.9%
	FP	82.2%	73.4%	80.8%	76.9%	62.7%	69.6%	76.3%	76.8%	76.7%	73.1%	66.9%	55.0%	34.8%	59.9%	58.2%	77.3%	71.3%	73.2%	77.9%	74.0%
	PP	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.6%	0.4%	0.4%	0.4%	0.3%	0.3%	0.2%	0.3%	0.2%	0.3%	0.4%	0.3%	0.4%	0.4%
	AFP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%
	TRCS	1.1%	1.3%	1.0%	1.0%	0.7%	1.1%	1.0%	1.2%	0.9%	1.1%	0.9%	0.7%	0.7%	0.8%	0.9%	1.4%	1.0%	0.9%	0.8%	0.9%
	WM&C	13.0%	21.8%	15.2%	18.6%	33.8%	26.1%	19.4%	18.6%	19.1%	23.0%	29.3%	42.0%	62.8%	36.6%	38.2%	17.6%	24.6%	22.8%	18.1%	18.0%

	Total [CTU$_h$t^{-1}]	**-4.4E-05**	**-3.2E-05**	**-4.5E-05**	**-4.4E-05**	**-3.7E-05**	**-3.0E-05**	**-3.7E-05**	**-3.6E-05**	**-4.4E-05**	**-3.2E-05**	**-3.3E-05**	**-3.2E-05**	**-1.9E-05**	**-3.1E-05**	**-2.8E-05**	**-3.4E-05**	**-3.5E-05**	**-4.3E-05**	**-4.8E-05**	**-3.3E-05**
Prevention	LUC	2%	3%	2%	2%	2%	2%	1%	2%	2%	2%	2%	2%	2%	2%	3%	2%	2%	2%	2%	2%
	FP	96%	95%	96%	96%	96%	96%	97%	96%	96%	96%	96%	96%	96%	96%	95%	96%	96%	96%	96%	96%
	PP	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [CTU$_h$t^{-1}]	**-5.9E-05**	**-5.5E-05**	**--6.3E-05**	**-6.8E-05**	**-7.7E-05**	**-5.9E-05**	**-7.9E-05**	**-6.1E-05**	**-7.8E-05**	**-6.0E-05**	**-6.2E-05**	**-6.7E-05**	**-5.1E-05**	**-6.7E-05**	**-5.5E-05**	**-5.4E-05**	**-6.2E-05**	**-6.9E-05**	**-9.3E-05**	**-7.2E-05**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [CTU$_h$t^{-1}]	**-1.6E-05**	**-1.6E-05**	**-1.6E-05**	**-1.8E-05**	**-1.8E-05**	**-1.5E-05**	**-1.7E-05**	**-1.5E-05**	**-1.8E-05**	**-1.4E-05**	**-1.6E-05**	**-1.9E-05**	**-1.4E-05**	**-1.8E-05**	**-1.6E-05**	**-1.5E-05**	**-1.6E-05**	**-1.9E-05**	**-1.8E-05**	**-1.4E-05**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [CTU$_h$t^{-1}]	**-9.9E-07**	**-1.2E-06**	**-9.6E-07**	**-1.2E-06**	**-1.2E-06**	**-9.3E-07**	**-8.9E-07**	**-8.8E-07**	**-1.1E-06**	**-7.4E-07**	**-9.5E-07**	**-1.1E-06**	**-9.0E-07**	**-9.8E-07**	**-9.2E-07**	**-8.6E-07**	**-8.8E-07**	**-1.1E-06**	**-1.1E-06**	**-8.2E-07**
	Fossil Resource																				
Current management	LUC	11%	12%	10%	11%	9%	10%	8%	10%	10%	7%	9%	8%	7%	9%	10%	12%	9%	9%	9%	12%
	FP	72%	63%	73%	67%	61%	63%	71%	69%	71%	72%	65%	58%	35%	61%	57%	65%	67%	69%	74%	63%
	PP	4%	3%	4%	4%	3%	4%	7%	4%	4%	4%	4%	3%	3%	4%	3%	4%	4%	4%	4%	3%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%
	TRCS	6%	7%	5%	5%	4%	6%	5%	6%	5%	6%	5%	4%	4%	5%	5%	8%	6%	5%	4%	4%
	WM&C	8%	15%	9%	12%	22%	17%	9%	10%	11%	10%	17%	26%	50%	22%	25%	11%	13%	13%	9%	9%
	Total [MJt^{-1}]	**-1.2E+04**	**-8.0E+03**	**-1.2E+04**	**-1.2E+04**	**-9.1E+03**	**-7.9E+03**	**-1.1E+04**	**-1.0E+04**	**-1.2E+04**	**-1.0E+04**	**-8.8E+03**	**-7.8E+03**	**-3.9E+03**	**-7.9E+03**	**-6.6E+03**	**-8.7E+03**	**-9.6E+03**	**-1.2E+04**	**-1.4E+04**	**-9.9E+03**
Prevention	LUC	6%	7%	6%	6%	6%	6%	4%	5%	5%	4%	5%	6%	6%	5%	7%	6%	6%	6%	5%	6%
	FP	82%	82%	83%	83%	82%	83%	85%	83%	83%	84%	83%	84%	82%	84%	81%	81%	83%	83%	84%	84%
	PP	7%	5%	6%	6%	7%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	7%	6%	4%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	6%	6%	5%	5%	5%	6%	5%	6%	5%	6%	5%	5%	6%	5%	6%	6%	6%	5%	4%	5%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total [MJt^{-1}]	**-2.1E+04**	**-1.95E+04**	**-2.2E+04**	**-2.4E+04**	**-2.5E+04**	**-2.1E+04**	**-2.8E+04**	**-2.2E+04**	**-2.7E+04**	**-2.3E+04**	**-2.3E+04**	**-2.5E+04**	**-1.8E+04**	**-2.5E+04**	**-1.98E+04**	**-1.9E+04**	**-2.3E+04**	**-2.6E+04**	**-3.0E+04**	**-2.4E+04**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [MJt^{-1}]	**-2.6E+03**	**-2.7E+03**	**-2.6E+03**	**-3.1E+03**	**-3.0E+03**	**-2.5E+03**	**-2.4E+03**	**-2.4E+03**	**-2.8E+03**	**-2.0E+03**	**-2.6E+03**	**-2.9E+03**	**-2.4E+03**	**-2.7E+03**	**-2.5E+03**	**-2.3E+03**	**-2.4E+03**	**-2.9E+03**	**-2.8E+03**	**-2.0E+03**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-2%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-2%
	WM&C	101%	101%	101%	101%	101%	101%	101%	101%	101%	102%	101%	101%	101%	101%	101%	101%	101%	101%	101%	102%
	Total [MJt^{-1}]	**-3.1E+03**	**-3.6E+03**	**-3.0E+03**	**-3.8E+03**	**-3.7E+03**	**-2.8E+03**	**-2.7E+03**	**-2.7E+03**	**-3.4E+03**	**-2.2E+03**	**-2.9E+03**	**-3.3E+03**	**-2.7E+03**	**-3.0E+03**	**-2.8E+03**	**-2.6E+03**	**-2.7E+03**	**-3.3E+03**	**-3.4E+03**	**-2.5E+03**
Water Depletion																					
Current management	LUC	-2%	-1%	-2%	-2%	-1%	-1%	-3%	-2%	-2%	-2%	-1%	-1%	0%	-1%	-1%	-2%	-2%	-2%	-2%	-3%
	FP	61%	55%	58%	54%	33%	42%	25%	51%	46%	28%	35%	24%	16%	29%	32%	58%	41%	42%	43%	49%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-3%
	TRCS	6%	6%	5%	4%	3%	5%	6%	6%	5%	4%	4%	3%	2%	3%	3%	6%	5%	4%	5%	6%
	WM&C	34%	41%	38%	44%	65%	55%	72%	46%	51%	71%	62%	75%	82%	69%	65%	37%	56%	55%	55%	51%
	Total [$kg_{water}t^{-1}$]	**-2.2E+03**	**-2.2E+03**	**-2.3E+03**	**-2.4E+03**	**-2.4E+03**	**-2.0E+03**	**-1.1E+03**	**-1.8E+03**	**-2.1E+03**	**-1.2E+03**	**-2.0E+03**	**-2.2E+03**	**-2.0E+03**	**-2.0E+03**	**-2.1E+03**	**-2.1E+03**	**-1.8E+03**	**-2.2E+03**	**-1.9E+03**	**-1.3E+03**
Prevention	LUC	-2%	-3%	-2%	-2%	-2%	-2%	-2%	-2%	-1%	-1%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-1%	-1%
	FP	95%	95%	96%	94%	97%	95%	95%	95%	97%	96%	96%	97%	94%	96%	96%	95%	96%	97%	98%	97%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	7%	8%	6%	7%	4%	7%	7%	6%	4%	5%	5%	5%	9%	5%	6%	7%	6%	4%	3%	5%
	WM&C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%
	Total [$kg_{water}t^{-1}$]	**-2.4E+03**	**-1.9E+03**	**-2.6E+03**	**-2.4E+03**	**-3.5E+03**	**-2.3E+03**	**-2.3E+03**	**-2.4E+03**	**-3.4E+03**	**-2.7E+03**	**-2.6E+03**	**-2.5E+03**	**-1.5E+03**	**-2.4E+03**	**-2.4E+03**	**-2.1E+03**	**-2.5E+03**	**-3.2E+03**	**-4.1E+03**	**-3.6E+03**
Anaerobic digestion	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [$kg_{water}t^{-1}$]	**-2.1E+03**	**-2.0E+03**	**-2.1E+03**	**-2.4E+03**	**-2.4E+03**	**-2.0E+03**	**-1.9E+03**	**-1.9E+03**	**-2.2E+03**	**-1.6E+03**	**-2.1E+03**	**-2.3E+03**	**-2.0E+03**	**-2.2E+03**	**-2.0E+03**	**-1.9E+03**	**-1.9E+03**	**-2.3E+03**	**-2.1E+03**	**-1.6E+03**
Incineration	LUC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	FP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	AFP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	TRCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	WM&C	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total [$kg_{water}t^{-1}$]	**-6.6E+02**	**-7.8E+02**	**-6.6E+02**	**-8.1E+02**	**-7.9E+02**	**-6.4E+02**	**-6.1E+02**	**-6.1E+02**	**-7.4E+02**	**-5.2E+02**	**-6.5E+02**	**-7.2E+02**	**-6.2E+02**	**-6.7E+02**	**-6.2E+02**	**-5.9E+02**	**-6.1E+02**	**-7.3E+02**	**-7.3E+02**	**-5.7E+02**

Appendix G

Herein the results obtained for the economic assessment of *Scenario I (CM)*, *Scenario II (AD)*, and *Scenario III (I)* are listed in Table G1. Note that t_c stands for the tax deduction, *f* for the fee paid to the company, *WM* for the the waste management of the wasted food, *Sf* for the cost of purchasing the surplus food, C_{sf} for the total costs incurred by the retailer excluding the purchase of the food products, and C_{sf}* for the total costs incurred by the retailer including the purchase of the food products.

Table G1: Costs calculated for each retail over the 13 months for *Scenario I (CM)*, *Scenario II (AD)*, and *Scenario III (I)*. Please note that the numbers were rounded to two significant digits.

Retail	***Scenario***	t_c ***[€ t^{-1}]***	***f [€ t^{-1}]***	***WM [€ t^{-1}]***	***Sf [€ t^{-1}]***	C_{sf} ***[€ t^{-1}]***	C_{sf}****[€ t^{-1}]***	***Retail***	***Scenario***	t_c ***[€ t^{-1}]***	***f [€ t^{-1}]***	***WM [€ t^{-1}]***	***Sf [€ t^{-1}]***	C_{sf} ***[€ t^{-1}]***	C_{sf}****[€ t^{-1}]***
1	Scenario I (CM)	-680	240	20	1800	-420	1300	2	Scenario I (CM)	-580	200	26	1700	-350	1400
	Scenario II (AD)	0	0	57	1800	57	1800		Scenario II (AD)	0	0	57	1700	57	1800
	Scenario III (I)	0	0	130	1800	130	1900		Scenario III (I)	0	0	130	1700	130	1900
3	Scenario I (CM)	-610	210	24	1800	-370	1400	4	Scenario I (CM)	-620	220	25	1900	-380	1500
	Scenario II (AD)	0	0	57	1800	57	1800		Scenario II (AD)	0	0	57	1900	57	1900
	Scenario III (I)	0	0	130	1800	130	1900		Scenario III (I)	0	0	130	1900	130	2000
5	Scenario I (CM)	-360	130	38	1800	-200	1600	6	Scenario I (CM)	-510	180	31	1800	-300	1500
	Scenario II (AD)	0	0	57	1800	57	1900		Scenario II (AD)	0	0	57	1800	57	1900
	Scenario III (I)	0	0	130	1800	130	2000		Scenario III (I)	0	0	130	1800	130	2000
7	Scenario I (CM)	-680	240	24	1900	-410	1500	8	Scenario I (CM)	-630	220	25	1800	-380	1400
	Scenario II (AD)	0	0	57	1900	57	2000		Scenario II (AD)	0	0	57	1800	57	1900
	Scenario III (I)	0	0	130	1900	130	2100		Scenario III (I)	0	0	130	1800	130	2000
9	Scenario I (CM)	-600	210	27	1900	-360	1500	10	Scenario I (CM)	-650	230	30	2200	-390	1800
	Scenario II (AD)	0	0	57	1900	57	2000		Scenario II (AD)	0	0	57	2200	57	2300
	Scenario III (I)	0	0	130	1900	130	2000		Scenario III (I)	0	0	130	2200	130	2400
11	Scenario I (CM)	-470	160	34	1900	-270	1600	12	Scenario I (CM)	-360	130	41	2100	-190	1900
	Scenario II (AD)	0	0	57	1900	57	1900		Scenario II (AD)	0	0	57	2100	57	2100
	Scenario III (I)	0	0	130	1900	130	2000		Scenario III (I)	0	0	130	2100	130	2200
13	Scenario I (CM)	-130	47	48	1400	-40	1400	14	Scenario I (CM)	-430	47	37	2100	-240	1800
	Scenario II (AD)	0	0	57	1400	57	1400		Scenario II (AD)	0	0	57	2100	57	2100
	Scenario III (I)	0	0	130	1400	130	1500		Scenario III (I)	0	0	130	2100	130	2200
15	Scenario I (CM)	-310	110	39	1600	-160	1400	16	Scenario I (CM)	-530	180	23	1500	-320	1200
	Scenario II (AD)	0	0	57	1600	57	1700		Scenario II (AD)	0	0	57	1500	57	1500
	Scenario III (I)	0	0	130	1600	130	1700		Scenario III (I)	0	0	130	1500	130	1600

17	Scenario I (CM)	-520	180	30	1800	-310	1500	18	Scenario I (CM)	-580	200	30	2000	-340	1700
	Scenario II (AD)	0	0	57	1800	57	1900		Scenario II (AD)	0	0	57	2000	57	2100
	Scenario III (I)	0	0	130	1800	130	2000		Scenario III (I)	0	0	130	2000	130	2200
19	Scenario I (CM)	-680	240	27	2100	-410	1700	20	Scenario I (CM)	-550	190	25	1600	-330	1200
	Scenario II (AD)	0	0	57	2100	57	2200		Scenario II (AD)	0	0	57	1600	57	1600
	Scenario III (I)	0	0	130	2100	130	2300		Scenario III (I)	0	0	130	1600	130	1700

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The contribution of each cost incurred by the retail in *Scenario I (CM)* is summarised in Table G2.

Table G 2: Costs [€ t^{-1}] incurred by the retailer when managing the surplus food accordingly to the current management. Please note that numbers were rounded to two significant digits.

Retail	Tax credit [€ t^{-1}]	Fee for Company [€ t^{-1}]	Avoided Waste Management [€ t^{-1}]	Waste Management [€ t^{-1}]
1	-4700	1600	-270	140
2	-2800	980	-150	120
3	-8800	2900	-490	360
4	-4400	1500	-250	210
5	-2200	770	-110	210
6	-3400	1200	-180	220
7	-3600	1300	-210	160
8	-7700	2600	-420	340
9	-3700	1300	-180	160
10	-3600	1300	-180	180
11	-2900	1000	-170	240
12	-2700	920	-120	290
13	-900	310	-56	290
14	-3400	1200	-170	320
15	-5200	1700	-360	750
16	-5100	1800	-380	260
17	-3600	1200	-200	180
18	-4400	1500	-230	230
19	-5500	1900	-220	200
20	-5700	2000	-260	290

Appendix H

Herein the European laws regulating food redistribution are discussed. The main barriers and possible ways to overcome their limitations are also presented.The laws concerning and influencing food donations are the following: (i) the *General Food Law*; (ii) the *Food Hygiene Package*; (iii) *Food Labelling and Durability*; (iv) the *VAT Directive*; and (v) the *Waste Framework Directive (WFD)* (Deloitte 2014). These are discussed below together with their key barriers and the solutions proposed by the Member States to overcome their limitations.

The *General Food Law* (Regulation (EC) No 178/2002) provides guidelines to assure a coherent approach when developing food legislations at national level (Deloitte, 2014). All food business operators have to comply with this regulation, including charities and redistribution organisations (European Commission, 2017). The law concerns responsibility, liability, traceability, and food hygiene and safety. The latter are intended to ensure the safety of food products for consumers. Nevertheless, the requirements of food safety and hygiene should not be exceeded, otherwise the risk of generating more food waste could arise (European Union, 2016). Regarding responsibility, all food business operators are responsible for the hygiene of the food at the stage of the FSC under their responsibility (Deloitte, 2014). In respect to traceability, food business operators have to ensure that consumers are protected against any risk and, hence, have to implement a traceability system at their stage of the FSC (European Commission, 2017). Finally, liability concerns that food business operators are liable with damage if a product is defective (Deloitte, 2014). Liability is one of the main barriers in respect to food donations (De Pieri et al., 2017). Indeed, in case of food poisoning, food producers and retailers would compromise their reputation (Deloitte, 2014). To overcome these problems, several solutions have been applied at national level across Member States. For instance, the Good Samaritan legislation was approved in Italy, recognising food charities as the final consumers and hence avoiding that people could sue food donors (Deloitte, 2014). The Good Samaritan legislation is a clear example of policy that encourages retailers to prefer redistribution to options that are lower in the hierarchy. This highly affects their environmental performance, as supported by this study.

The *Food Hygiene Package* includes both Regulation (EC) No 852/2004 and Regulation (EC) No 853/2004, which have to be observed by all food business operators (Deloitte, 2014). The former focuses on the hygiene of food products, whilst the second on the hygiene requirements for redistribution of food of animal origin (European Commission, 2017). The main limitation of these regulations is the lack of knowledge at European level (European

Union, 2016). Furthermore, these legislations were transported into stricter regulations at national level (Deloitte, 2014). To overcome these problems, the European Commission decided to simplify the regulations without jeopardizing food safety (Deloitte, 2014). Hence, if this law is perceived as too strict, retailers would be discouraged to donate food, even if this could lead to a significant reduction in emissions compared to recovering energy from food waste.

The *Food Labelling and Durability* (Regulation (EC) No 1169/2011) concerns the conveyance of information to consumers to ensure their protection and health, but also to allow them to make aware choices and safe use of food (European Commission, 2017). Food manufacturers have to establish whether to label a food product with a “use by” or a “best before” date (European Commission, 2017). “Use by” dates are applied to food products that are no longer safe to eat from a microbiological standpoint and pose a danger to human health (Deloitte, 2014; European Commission, 2017). On the other hand, “best before” dates are used for food products that are still safe to eat and only present flaws in the quality (e.g. appearance) (Deloitte, 2014; European Commission, 2017). Therefore, “use by” dates are related to food safety, whilst “best before” dates to food quality (European Commission, 2017). Across the European Union there is a general confusion in regards to “best before” dates and it is thought that food products that have exceeded it cannot be donated (Deloitte, 2014). To overcome this problem, Belgium, for instance, provided guidelines on how to assess the additional lifetime of food products that have reached their “best before” date (Deloitte, 20214). This, along with initiatives such as the Samaritan law, may ultimately encourage redistribution of surplus food over less environmentally and socially sound management options.

The *VAT Directive* (Directive 2006/112/EC) controls the Value Added Tax (VAT) at European level and has to be implemented at national level (European Commission, 2017). The directive states that food donations are taxable if they are made by a taxable person and whether the VAT on the purchase of the goods is entirely or partially deductible (Deloitte, 2014). Further, the taxable amount is calculated as the purchase price at the moment of the donation corrected by the state of the goods at the time of the donation (European Commission, 2017). However, food donors are not subject to VAT if the food donated is close to its expiration date, as the value of the food products is considered as low or close to zero (when donated), thus having negative effects for food donations (Deloitte, 2014; European Commission, 2017). To encourage food donations, some of the Member States implemented tax deductions, tax credits, or corporate tax incentives (European Commission, 2017). The latter was implemented in France and the results obtained in this study for the cost analysis on *Scenario I (CM)* show that such an incentive can boost the amount of surplus food donated as the retailers would generate income from donations.

The *Waste Framework Directive* (Directive 2008/98/EC) establishes that the first stage of the waste hierarchy is prevention, and that Member States have to implement prevention programs (European Commission, 2017). However, the directive neither specifies how the hierarchy should be applied to the food waste case nor gives a common definition of what food waste is (European Union, 2016). On top of these barriers, many of the Member States have implemented fiscal incentives at the lower stages of the hierarchy (e.g. for anaerobic digestion), *de facto* preventing or making less economically attractive food redistribution (Deloitte, 2014).

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