LCA & LCC of food waste case studies

Assessment of food side flow prevention and valorisation routes in selected supply chains

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List of Abbreviations

AC	Acidification
AD	Anaerobic Digestion
CC	Climate Change
EU	European Union
FE	Freshwater Eutrophication
FLW	Food Loss and Waste
FR	France
FU	Functional Unit
FS	Food Surplus
GWP	Global Warming Potential
FE	Freshwater Eutrophication
FMD	Foot and Mouth Disease
IPCC	The Intergovernmental Panel on Climate Change
IT	Italy
JFEC	Japanese Food Ecology Centre
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LU	Land Use
LYS	Lysine (digestible)
ME	Marine Eutrophication
MFRD	Mineral, Fossil, and Renewable Resource Depletion
NE	Net Energy
N/A	Not Applicable

PN	Peaches and Nectarines
REFRESH	Resource Efficient Food and dRink for the Entire Supply cHain
RS	REFRESH Situation
SDGs	Sustainable Development Goals
SDU	Sink Disposal Units
SP	Spain
TE	Terrestrial Eutrophication
UK	United Kingdom
WP	Work Package
WRD	Water resource depletion
EFFPA	The European Former Foodstuffs Processors Association

1 Executive summary

Urged by the relevance of resource efficiency and achieving a circular economy in the agenda of EU and national policy makers, many stakeholders are seeking opportunities for the prevention, and when that option is not achievable, the valorisation of current surplus food and side flows deriving from the food supply chain. Before implementation, any new solution will likely be assessed on monetary and environmental impacts. Consistent science-based approaches can contribute significantly to support informed decision-making at all levels, from individual stakeholders to policy makers alike.

The EU H2020 funded project REFRESH (Resource Efficient Food and dRink for the Entire Supply cHain) aims to contribute to food waste reduction throughout the food supply chain and evaluation of its environmental impacts and life cycle costs. In particular, this report aims at providing scientific evidence on the environmental and economic consequences of food waste prevention and valorisation options. Based on the methodological framework proposed by the guidance document "Generic strategy LCA and LCC" (Davis et al. 2017), published earlier in the REFRESH project, life cycle assessment (LCA) and life cycle costing (LCC) were applied in two specific case studies, exemplifying different supply chains and EU Member States.

The first case study is focused on the potential valorisation of manufacturing, retail, and catering food surplus (intended as edible food thrown away) as pig feed, in two countries: UK and France. The goal of this case study is to assess the environmental impacts and cost of the valorisation of food surplus as pig feed through the introduction of the processing techniques currently applied in Japan, which allows using mixed surplus food as pig feed if it is thermally treated first. Today, surplus food is managed through a combination of landfill, incineration, composting facilities, and anaerobic digestion. The case study explores the impact of an alternative scenario: heat-treating the food surplus and using it as pig feed.

Results obtained from the LCA show that there could be greenhouse gas emissions savings of about 1 million tonnes and 2 million tonnes of carbon dioxide equivalents in the case of UK and France respectively. This corresponds respectively to a 63% and 52% reduction of emissions compared to current situation. These savings are equivalent to about 0.2-0.4% of the total greenhouse gas emissions of each respective country. The sensitivity analysis shows that the quantity of savings depends heavily on how much conventional feed is replaced and the transport distances covered by the surplus food for heat treatment and by the new feed product. The result should be interpreted as indicative of potential savings. Regarding the LCC analysis, in UK the net effect would be an overall saving of 278 million € (or 250 million £), especially thanks to the displacement of conventional feed products. This is equivalent to a 34% reduction of current costs. In France the net effect of using processed food surplus as animal feed would instead generate an increase of overall costs of 413 million € (+31%), mostly due to the larger distance between areas with higher food surplus density and pig farming regions.

The results provided detailed insights on the environmental and economic benefits of valorising food side flows from catering, manufacturing, and retail into pig feed.

This alternative to incineration, landfill, composting and anaerobic digestion is particularly of interest for countries or regions with high amounts of side flows and relatively nearby pig farms. Transport distance plays a major role in the trade-off between valorising side flows and potential environmental cost savings. As the valorisation of food waste to feed is currently unavailable due to the European legislation (EC 2002) and political concern, this case study provides new and more detailed scientifically based insights to take into consideration.

The second case study assessed the environmental impacts and cost of preventing peach/nectarine (PN) spoilage and overproduction along the supply chain, from cradle to gate, considering Italian and Spanish peach and nectarines (PN) production sold in the UK wholesale market. First, the study assesses the environmental and costing impacts of the current PN supply chain, including spoiled/overproduced PN and related handling. Second, it evaluates the environmental and economic impacts of a 50% prevention along the PN supply chain. The alternative scenario is not focusing on specific prevention measure, rather on a hypothetical combination of simultaneous measures in the various stages.

Results show that in the current scenario, the UK wholesaler is selling 1.4 million kg of PN. Total impact is about 1.37 million kg CO_2e/year, equivalent to 0,98 kg CO_2e/kg of PN. Total cost is about 3.8 Million €, equivalent to 2.7 €/kg of PN sold. Most of the environmental impacts and costs derive from the long-distance transport with climate-controlled trucks, and from PN handling (cleaning, storage, and packaging) at the wholesaler in the UK. In the whole supply chain, side flows amount at 0.5 million kg, mostly generated at wholesaler at the origin and farm levels. On average, 0.38 kg per kg of PN are lost before retail. In the prevention scenario, the study indicates a potential net reduction of total impacts. In particular, for the same amount of PN (1.4 million kg of PN sold to retail), 50% of current side flows is prevented and reduced to 0.26 million kg per year (0.18kg per every kg sold). The impact on climate change decreases to 1.33 million kg CO_2e/year, equivalent to a 4% reduction. The overall cost decreases to 3.7 Million €/year, with a 2.6% reduction. Since it is late in the chain that most of the impact occurs, the prevention of overproduction or spoilage at the wholesaler has a significant effect on the reduction of overall impacts (e.g. less fruit shipped per kg of fruit sold). At the wholesale level in the origin countries, there could be a net increase in both the environmental impact and costs, deriving from potential side effects of fruit surplus prevention. In particular, current destination of side flows includes some valorisations as donations and fruit processing, which are economically compensated (avoided costs in our approach) under the European Common Agricultural Policy (as product withdrawal) or in existing contracts with processors. In case of PN side flows prevention, other fruit (with related impacts) would be needed to supply charities and fruit processors, and wholesalers at origin would have to renounce to the economic compensation. However, this is counterbalanced by the reduced need of farmed PN per kg of functional unit (FU) and by the potential savings on PN purchase cost by wholesalers (that were not included in our costing approach).

The results showed evidence of lower environmental and economic impacts of the side flow prevention scenario from the supply chain perspective. Actions to reduce fruit spoilage and overproduction at the later stages in the supply chain should be prioritized. This might include actions being taken earlier in the chain, e.g. increased sorting to ship fruit with longer expected shelf life. To avoid unintended consequences in earlier stages, these measures could be coupled with relaxation of cosmetic standards not related with shelf life (e.g. size) and the promotion of secondary markets for surplus. In fact, preventing side flows earlier in the chain could have some side effects, especially when fruit is utilised for secondary markets (as processing), animal feed, anaerobic digestion, and, to a lesser extent, donations. These should be properly evaluated against, for example, the savings achieved in the farming stage. Finally, the study did not include later stages (retail and consumption) where most side flows are generated and disposed. This limitation should be the focus of further research.

The methodological framework applied in both case studies proved easy to follow and provided clear guidance on how to frame the goal and scope, covering different questions, countries, and supply chains. However, it was difficult to adhere to the guidance on specific data requirements (e.g. modelling of marginal data for external consequences) due to lack of data availability. Further research is needed to provide more readily available life cycle inventories and cost data on production of different commodities in specific markets, as well as models for better understanding market dynamics when introducing changes (e.g. reducing demand for conventional pig feed).

2 Introduction

The REFRESH project aims at contributing towards the EU Sustainable Development Goal 12.3 of halving per capita food waste at the retail and consumer level and reducing food losses along production and supply chains, reducing waste management costs, and maximising the value from un-avoidable food waste and packaging materials.

This goal can only be achieved if food is produced using the available resources efficiently and effectively, from both an economical and environmental perspective. This includes the prevention of unwanted side flows[1] from the food supply chain, as well as utilising any value from such side flows to the best effect.

Generally, prevention measures or valorisation routes for side flows from the food supply chain might have impacts (monetary and environmental), for example for capital investments or developing new technologies. In the long term, however, this might lead to better resource utilisation, which will result in lower running costs and reduced environmental impact. Informed decision making at all levels, from individual stakeholder to policy level, requires robust, science-based approaches to analyse such scenarios.

Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) are well-documented and common approaches for assessing the environmental impacts and costs of a system. Both LCA and LCC are characterised by allowing for a large flexibility in system scoping. Consistent approaches are required for reliable comparisons between different options. The REFRESH report "Generic strategy LCA and LCC" (Davis et al. 2017) provided guidelines on how to assess side flows combining LCA and LCC. Building on such guidelines, "FORKLIFT" - FOod side flow Recovery LIFe cycle Tool was developed and presented in "Simplified LCA & LCC of food waste valorisation" (Östergren et al. 2018), with the aim of providing stakeholders with a simplified hands-on tool for selected valorisation routes.

This report presents the results from the full application of the same methodological framework to two selected case studies. The first focused on the potential valorisation of manufacturing, retail, and catering food surplus as pig feed in two European countries, namely the UK and France. Currently, while allowed in some countries such as the US and Japan, in the EU not every side flow from those segments of the supply chain can be fed to animals. However, there is some debate about the option of lifting the ban and both policy makers and private stakeholders have significant interest in the potential environmental and economic effects of such decision.

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[1] From Davis et al. (2017, p.22): "A **side flow from the food supply chain** is a material flow of food and inedible parts of food from the FSC of the driving product, including wasted driving product, and also final disposal of inedible and edible parts of unconsumed food product after use, e.g. plate leftovers. Quality does not play a role in defining a side flow. The stakeholder in the FSC producing this flow tries to have as little as possible of it, "the less, the better" applies for this flow."

The second case study addressed the potential prevention of surplus up to wholesale in the peach and nectarine supply chain in Italy, Spain, and the UK. Despite its lower environmental impact, fruit and vegetable surplus contributes quite significantly to the overall food loss and waste mass, representing a hotspot for prevention. While most surplus for this category is generated at the consumer level, substantial amounts of surplus are caused in the upstream segments due to overproduction, market standards, policy measures, Unfair Trading Practices, especially in the case of products destined to fresh consumption. Therefore, decision makers and supply chain operators are quite interested in assessing prevention scenarios and in identifying thresholds and trade-offs.

By providing real examples with primary data and full environmental and economic assessment, this report is destined to policy makers, researchers, professionals, businesses, and other interested stakeholders and addresses the following REFRESH objectives:

- 1) Measures and methodologies for evaluating environmental sustainability life cycle costs dimension of food waste prevention, waste valorization and waste management activities
- 2) Support the development of a harmonized approach to EU food waste legislation by addressing environmental impacts and LCC of possible policy and consumption.

The two case studies were identified together with partners in REFRESH as relevant for support for possible policy interventions (2). The harmonised method was developed previously (1), but in this report it is tested in practice in two case studies.

3 Case study 1: Animal feed valorisation

The REFRESH perspective

This study follows the methodological framework proposed by the guidance "Generic strategy LCA and LCC - Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain" (Davis et al 2017). The recommendations provided in the framework were followed to frame the goal and scope and determine which REFRESH situation was applicable to the specific study. This research is focused on the potential valorisation of manufacturing, retail, and catering food surplus as pig feed in two European countries, namely UK and France. Currently, such valorisation is not allowed for all specific products in food surplus and some flows are disposed of or valorised within waste management. The aim of the study is to assess the potential benefit of such valorisation, imply moving from a RS3-4 (valorisation as part of waste management and end-of-life treatment) to a RS2 (side flow valorisation). Considering the type of question, the large-scale perspective of the study, and the potential effects on secondary markets, a consequential approach was selected to analyse the change produced when valorisation is allowed.

State of the art

The European Former Foodstuffs Processors Association (EFFPA) estimates that 5 million tonnes of former foodstuffs (FFs) are currently processed into animal feed in the European Union, most of it originated from bakery and confectionary-type goods (EFFPA, 2017). Zu Ermgassen et al. (2016) have estimated that maximising the uptake of currently permissible former foodstuffs into feed could reduce land use for pig feed crops by 1.2%. However, if the EU were to process surplus food into feed at rates similar to Japan, "the land requirement of EU pork could shrink by 1.8 million hectares. This represents a **21.5 % reduction in the current land use of large-scale EU pork production**" (zu Ermgassen et al. 2016, 37). The present REFRESH study goes beyond these initial findings by presenting calculations drawing on more recent and more detailed food surplus data.

In comparison to other FS processing technologies, animal feed valorisation could present lower health and environmental impacts. Assessments like the one conducted by Salemdeeb et al. (2016), hybrid consequential life cycle assessment-LCA, compared four technologies for FS processing: two technologies for animal feed production (based on the South Korean style-animal feed production, such as a wet pig feed and a dry pig feed) and two commonly disposal technologies used in the UK: anaerobic digestion and composting. While comparing the environmental and health impacts of 14 mid-point impact categories, results showed that best and second-best scores, for 13/14 and 12/14 in environmental and health impacts were achieved by the processing of food surplus as a wet pig feed and a dry pig feed, respectively. These calculations did not include a landfill scenario.

Regulatory aspects are key elements in the current and possible scenarios. Prior REFRESH deliverable "Food waste prevention and valorisation: relevant EU policy areas / D3.3 Review of EU policy areas with relevant impact on food waste prevention and valorisation", pointed out the potentially significant volume of food surplus (unfit for human consumption) could be kept in the food chain if more FS was turned into animal feed. However, current legislation for risk management of prion and other foodborne animal diseases regulates the use of 'former foodstuffs' in animal feed. This represents the ban to use meat, fish, ruminant collagen and gelatine, or any products containing these to feed both ruminants and non-ruminant terrestrial animals.

Box 1: The Japanese Food Ecology Center

Background: The Japan Food Ecology Center (JFEC) is one of the many surplus-food to feed treatment facilities currently operating in Japan. These facilities can be seen in two scopes: a feed manufacturing business or a waste treatment business. A strong reliance of the Japanese livestock sector on import of animal feed (and the associated challenges this means) has been one of the drivers of the country's interest in a circular economy approach. In the case of JFEC, 15 farmers feed their pigs on the liquid fermented feed that JFEC produces. The need to observe the Japanese Recycling Law, the risks and challenges to obtain safe animal products, and the challenge in cost to both manage/dispose wastes as to feed the livestock, motivated JFEC to produce fermented feed from recycled food resources. This feed results from a strict quality and safety procedure that transforms food surplus into animal feed, used to produce good quality meat, sold in department stores and supermarkets under the brand names 'Yuton' (superior pork) and 'Umakabuta' (delicious, flavourful pork). The full recycling loop results from the involvement of farmers using "the manufactured feed and then the businesses outputting the food surplus adding value in the form of quality and safety to the resulting products and selling them to consumers". In the case of JFEC, the recycling loop works with the Odakyu department stores who supply JFEC with their surplus and sell the pork produced with the JFEC feed (JFEC, 2015). Please see D6.7 for additional recycling loop examples with retail, farm and feed manufacturers.

Process: Data from JFEC in 2015 indicated that the Plant processes 34 tonnes of food surplus/day all around the year, in a 1,527m^2 Plant. The waste is composed from kitchen waste, animal and plant residues, alkali and acid waste, and sludge (from food surplus only). Once affiliated transporters bring the waste in refrigerated conditions to the Plant, it is measured and identified by a bar code. The waste enters the input area and begins to be sorted, then it passes to a shredding operation and the obtained material is sterilized. Afterwards, the sterilized material will go into a fermentative process and once ready, it will be loaded into trucks that will deliver this wet feed to pig farms.

Product Characteristics: The wet feed production would have lower energy costs because does not need to be dried, resulting in a feed that can roughly be 50% less expensive than other commercial blends. The easily digested feed results in less released excess nitrogen therefore controlled odours in the livestock operation. It also present lowers disease rates, linked to the use of lactic acid bacteria in the feed. In consequence, it aids the pork sector to provide consumers with safe and healthy pork.

While recycling food surplus into animal feed is very restricted in the EU because of the EU's approach to the risk management of infectious diseases of animals (Garcia et al., 2005), other countries, like the United States feed heat-treated meat-containing surplus food to pigs (Semley 2017), and are reported to be Foot and Mouth Disease ("FMD") free since 1929 (National Cattlemen's Beef Association

2017). In addition, no reported outbreaks have ever been linked to the use of catering and retail waste in Japan (zu Ermgassen et al. 2016). In this case, safety and quality of food surplus procedures promote strict testing of the FS before entering the processing facilities (Takata et al. 2012). A specific study is being carried out on these issues with REFRESH, which will lead to technical guidelines on the safety aspects of using meat-containing surplus food in pig feed.

In addition, the own-initiative report on "resource efficiency: reducing food waste, improving food safety" (2016/2223(INI) by the European Parliament's Committee on the Environment, Public Health and Food Safety notes "the potential for optimisation of use of food unavoidably lost or discarded and by-products from the food chain, in particular those of animal origin, in feed production" (Borzan 2017 Section 34) and "calls on the Commission and the Member States to promote the higher-grade use of former foodstuffs and by-products from the entire food chain in the production of animal feed" (Borzan 2017 Section 38).

The current 'recycling loop' in Japan allows the recycling facilities to not only collect food surplus, but also transport it across municipal boundaries. It also establishes the requirement for the emitters to report the amount of recycled food surplus, and to purchase farm products that use food surplus-derived products, e.g. animal feed. Studies show that the global warming potential (GWP) of manufacturing liquid feed from food surplus represents only one-quarter (approximately) of dry feed manufacturing GWP, and is lower than the estimated GWP for composting and bio-gasification of food surplus (Takata et al., 2012), and landfilling (Kim and Kim, 2010). Special attention is taken for the collection and sorting of the FS that could enter the process, therefore infrastructural, collection, and transport considerations are needed, such as separate containers from the generation point, refrigerated and pest-free storage and transport equipment, among others.

Despite the evidence of the environmental benefits of allowing food surplus being used as pig feed, there has not been a study that integrates the nutritional composition of food surplus from potential sources that can be used as pig feed, the environmental impacts of such valorisation, and the costing perspective, in a European context. This is the focus in this study.

3.1 Goal and scope

The goal of this study was to assess the environmental impacts and cost of an intervention, consisting in the **valorisation of food surplus as pig feed in the UK and France respectively, in specialist licensed treatment plants inspired by the Japanese Ecofeed sector**[2]. In particular, the study wants to provide an indication of the potential impacts based on a specific set of boundaries and assumptions, listed in the following sections.

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[2] Please see REFRESH D6.7 (Technical Guidelines Animal Feed) for more information the Japanese Ecofeed sector and the proposed criteria for the production of safe non-ruminant feed in the European context. Also refer to Sugiura et al. (2009).

3.1.1 REFRESH Situations

The study applied the stepwise procedure for LCA/LCC studies on food surplus in Davis et al. (2017). Once the purpose of the study was phrased, the next step was to determine whether we were actually exploring side-flows (and not driving flows) and which REFRESH situations (RS) were applicable.

Food surplus from the retail, manufacturing and catering (food service) were evaluated. Prior research, literature reviews, interviews and data showed that under the current situation, the flow was not considered a product but rather a 'side flow from the food supply chain', since the stakeholders generating it want to have as little of this flow as possible.

We explored two scenarios: the current treatment of food surplus from these actors and an alternative scenario where the food surplus is processed into pig feed.

Regarding the current scenario, we have not considered food surplus that is currently being donated from these entities since this would conflict with the food waste hierarchy (use as human food is prioritised over feeding animals). Furthermore, since the study aims to investigate the effect of allowing food surplus being used as animal feed, what is already sent to animal feed has not been considered as there wouldn't be any resulting environmental or economic costs of this flow being used as animal feed (no change). Therefore, the flows that are currently sent to waste treatment such as AD, landfill, incineration, sink disposal units and composting has been taken into account. This corresponds to RS3 (valorisation as part of waste management) and RS4 (end-of-life treatment).

In the new scenario, the food surplus is processed into pig feed; this categorises the situation as either RS2 (Side-flow valorisation) or RS3 (Valorisation as a part of waste management), depending on if the food surplus is of value for the generator of the food surplus or not.

3.1.2 Type of study

In this study, the purpose is to explore the effects of making a change. Following the decision tree in Davis et al. (2017), the study thereby is an intervention study. There could potentially be large-scale consequences for processes in the background system (e.g. on demand for certain feed components in each respective country), implying that processes affected by the change should be modelled with long-term marginal data. However, for practical reasons of data availability we have resorted to use of average data available in LCI databases, which is a limitation of the study. The modelling framework is a consequential one, which has been used when determining the functional unit and system boundaries of the study.

3.1.3 Functional unit

We are moving from RS3&4 to RS2, i.e. RS1 is not applicable (prevention); therefore, the functional unit is set as the amount of side flow utilised, over a specified period. This translates in our case to: the **yearly amount of food surplus generated from the manufacturing (not primary production),**

retail, and catering sectors in UK or France, which can be converted into pig feed (treated FS tonnes/year).

3.1.4 System description and boundaries

We followed the recommendation on system boundaries for studies that do not focus on prevention (RS1): from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include also replaced production (avoided impact). In our study this translates to generation of side flow (passing through collection and transport), to the treatment of the side flow, including the replaced production (avoided impact). Figure 1 and Figure 2 show the resulting system boundaries for the case study of UK and France respectively. The calculation of amount of food surplus, pigs produced and co-products from current waste treatment is described in the inventory section. The resulting environmental impact and cost of the change will be derived from adding the effects of the new system and deducting the effects of the current system.

Figure 1: Overview of FU and products for scenarios compared for UK

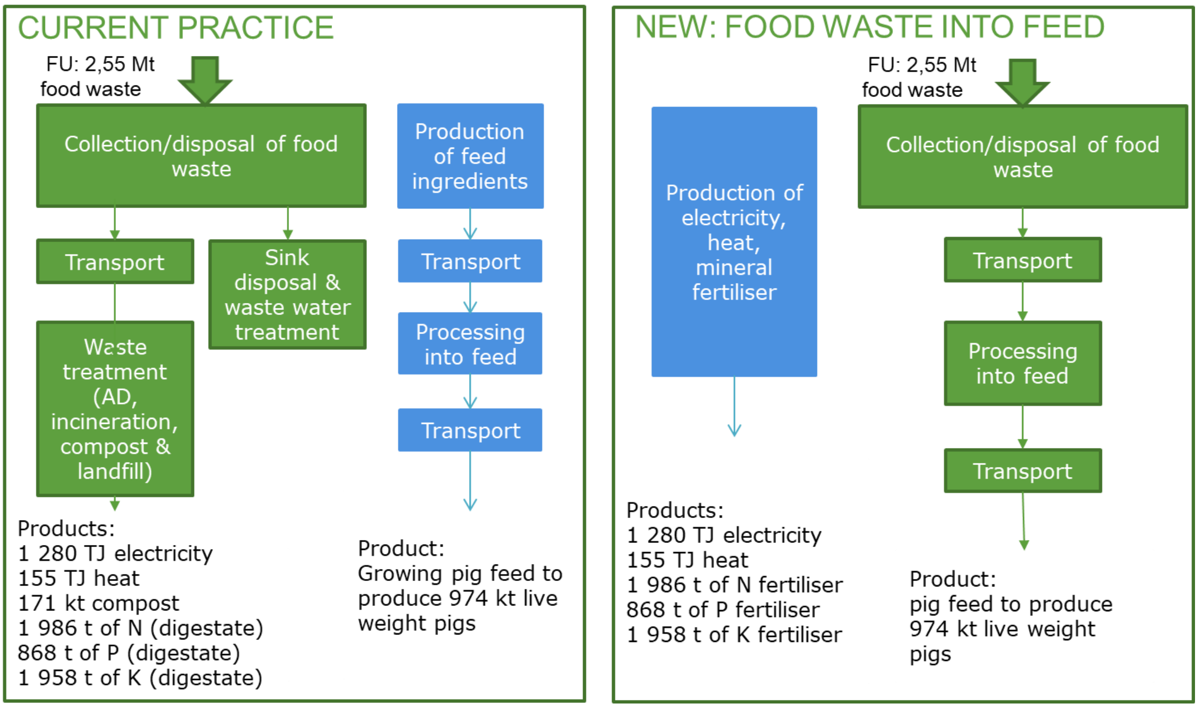
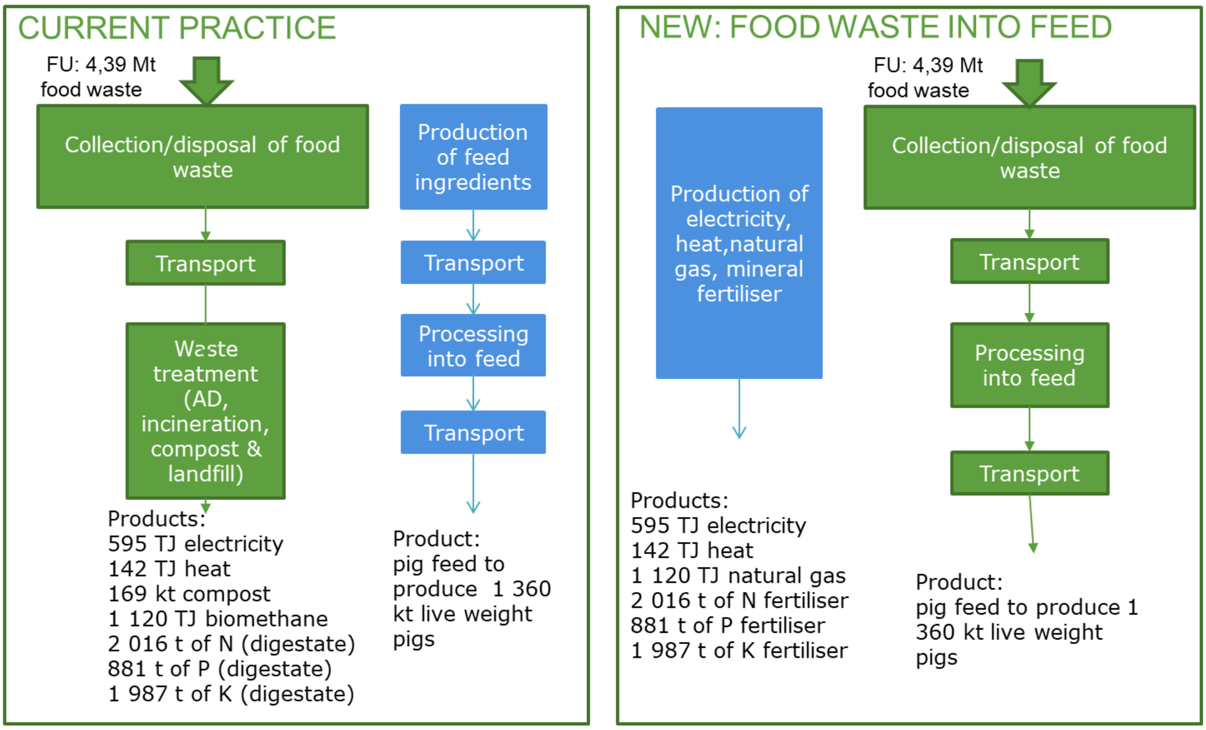


Figure 2: Overview of FU and products for scenarios compared for France



3.2 Life cycle inventory

The data and data sources used in the LCA/LCC study are described in this chapter.

3.2.1 Current practice scenario

Food surplus Quantification

Stage 1: Data was first gathered on the amount of food surplus at each stage of the supply chain in the UK and France. The stages of the supply chain chosen were retail, manufacturing, and catering. This is because we believe there would be additional safety issues associated with consumer food surplus that would make this more difficult to process into eco-feed safely, and primary production data was not available for the UK. To be consistent in the two countries primary production was not included for France either. However, in France, food surplus data for manufacturing is mixed with that for primary production, so here the data had to be separated to pick out what was generated from manufacturing (or transformation). Food surplus that is currently used as animal feed or donated destined for human consumption was taken out from the data. The amount of food that did not have a clear destination (unknown) was included.

Stage 2: For each stage, we aimed to collect as specific data as possible, preferably at the ingredient level. Disaggregated data for the composition of the food surplus, however, was usually available only by broad categories, e.g. “meat and fish”. For some ingredients tonnages were available directly (e.g. 28 000 tonnes of dairy and eggs wasted at retail level in the UK), while sometimes overall tonnage was calculated from percentages given for composition of the category.

Data for Stage 1 and 2 can be found in Table 1 and Table 2 below.

Table 1: Sources for UK food surplus data

Statistic	Source
UK retail food surplus composition	WRAP (2016), Quantification of food surplus, waste and related materials in the grocery supply chain, p8, Figures S8a & S8b
UK manufacturing food surplus composition	WRAP (2016), Quantification of food surplus, waste and related materials in the grocery supply chain, p15, Figure S5
UK catering food surplus composition	WRAP (2013), Waste in the UK Hospitality and Food Service Sector - Full Technical Report. Link to summary report. Full technical report available on request from WRAP: hafs@wrap.org.uk

Table 2: Sources for French food surplus data

Statistic	Source
French retail food surplus composition	Pertes et gaspillages alimentaires : l'état des lieux et leur gestion par étapes de la chaîne alimentaire (ADEME, 2016)
French primary production and transformation food surplus composition	Pertes et gaspillages alimentaires : l'état des lieux et leur gestion par étapes de la chaîne alimentaire (ADEME, 2016)
French catering food surplus (total tonnage)	Pertes et gaspillages dans les métiers de la remise directe (restauration et distribution), MAAPRAT, 2011 http://www.auvergne.ademe.fr/sites/default/files/files/Actualite/Actualites/cout-complet-pertes-gaspillage-restauration-collective-synthese.pdf https://www.planetoscope.com/fruits-legumes/1257-le-gaspillage-alimentaire-en-france.html
French catering food surplus (% composition)	Approche coût complet des pertes et gaspillage alimentaire, Rapport final, 2016

A summary of the amount of food surplus potentially available for animal feed valorisation but currently sent to landfill, compost, anaerobic digestion, incineration or unknown treatment in the UK and France is shown in Table 3. In both countries, we assumed that all available food surplus would be valorised as animal feed. However, it must be noted that currently the Ecofeed system in Japan manages to utilise 52% of potentially available food surplus. The interpretation section discusses results also in light of this assumption as well as in terms of data quality.

Table 3: A summary of food surplus available for valorisation in UK and France

Food surplus quantity that could potentially be used as animal feed	UK [tonnes]	France [tonnes]
Retail	199 000	1 339 960
Manufacturing	1 484 000	1 921 210
Catering	864 800	1 125 000
Total	2 547 800	4 386 170

Food surplus Composition and Nutritional Calculations

Stage 3: Within these broad categories e.g. meat and fish, average nutritional value (with a focus on dry matter, energy, protein and lysine as this is needed to calculate pig growth) per tonne was calculated by:

a) Gathering data on the average composition of these categories in the national consumption (production or sales figures were used where consumption figures were not available), e.g. the percentage of UK "meat and fish" which is "beef", "pork", "chicken", etc. consumed (Tables 4 and 5).
b) Gathering nutritional data on the nutrition of these disaggregated food types, e.g. nutrition for "pork" (Table 3).
c) Multiplying the nutritional value of each food type by the proportion of the broad category it makes up in national consumption or production, and then combining all these together, e.g. nutritional value for pork multiplied by 23% as constitutes 23% of national meat and fish consumption, then added to other values for beef, chicken, etc.

Stage 4: The total volume in tonnes of the broad categories were then multiplied by the average nutritional composition for that category per tonne, to arrive at the overall nutritional values for each category.

Stage 5: The total nutrition for all categories was then aggregated for each stage of the supply chain, to yield total nutrition from catering, retail, and manufacturing stages in UK and France respectively.

Assumptions:

- Data for “new foods” was used from McCance and Widdowson's composition of foods integrated dataset (CoFID), rather than data for “old foods”, because the data for “old foods” was patchy and not available for many of the disaggregated food types under examination. Some cross-checks were made between comparable new and old food data, and nutritional data was not found to be significantly different.
- In most cases, the nutritional values for raw foods were chosen, though in some cases due to data availability or the source of food surplus (e.g. if it was from a kitchen and likely to be cooked), cooked food nutrition was selected. This may have an effect on the results, since raw foods tend to have a higher moisture content, with correspondingly lower dry matter, protein and energy. Hence, it is possible that some of the results will be slight under-estimates of the nutrition available in the food surplus.
- As the exact composition of food surplus categories such as “meat and fish” was not available, the study assumed that the composition of national consumption was representative of the composition of national food surplus. However, some foods may be wasted more than others, and this may vary at different stages of the supply chain, so the exact composition of the food surplus categories is by necessity an assumption until more detailed data is available.
- Where data on the composition of a food category at Stage 3. a) were not available (for either consumption or production data), proxies were used of varying degrees of accuracy. For instance, for the category of “Confectionary”, the nutritional value of the single proxy of "Chocolate, milk" was used. Where these categories were more significant in size, it was checked that varying the use of proxy did not significantly affect total nutrition (by >5%). However, for the majority of categories, production or consumption data was available, so a weighted average of food nutrition from that category was used.

Table 4: Nutritional data for both UK and France

Statistic	Source	Notes
Nutritional data of foods	McCance and Widdowson's composition of foods integrated dataset (CoFID)	Values from this analysis of UK foods used for both UK and France. Provided data on dry matter content, protein and energy – but no lysine values
Lysine data for foods	USDA Food Composition Databases	US database used as above UK database had no lysine values

Table 5: Sources for UK food production/consumption data

Category	Source	Note
Fruit and veg (production, factoring in import/export balance)	https://www.gov.uk/government/statistics/latest-horticulture-statistics	Used provisional 2017 data. Assumed 4 769 000 tonnes total supply of vegetables and 4 578 000 tonnes total supply of fruit (national production + imports - exports)
Potatoes	No specific data on volumes consumed of different types of potato beyond rough indications from e.g. https://potatoes.ahdb.org.uk/sites/default/files/GB_Potatoes_2017_18.pdf, p14	Assumed roughly 50% of potatoes eaten at catering level are chips, and rest are nutritionally equivalent to baked potatoes
Meat and fish - Meat	p15 of http://beefandlamb.ahdb.org.uk/wp-content/uploads/2017/07/UK-Yearbook-2017-Cattle.pdf	
Meat and fish - Fish	p8 of http://www.seafish.org/media/publications/seafood_consumption_2016_update.pdf	
Dairy and eggs – Cheese (retail sales)	Cheese data: https://dairy.ahdb.org.uk/market-information/dairy-sales-consumption/cheese-market/	NOTE: Data only on retail sales, no data available on hospitality.
Dairy and eggs – Milk (retail sales)	Milk data - Source: https://dairy.ahdb.org.uk/market-information/dairy-sales-consumption/liquid-milk-market/	NOTE: Data only on retail sales, no data available on hospitality. NOTE: Total given as 5,530,201 litres. Assumed density of 1035 kg/m3, so this equal to 5,723 tonnes - based on https://www.thecalculatorsite.com/conversions/common/liters-to-metric-tons.php
Dairy and eggs – Eggs (sales)	Eggs data - Source: https://www.egginfo.co.uk/egg-facts-and-figures/industry-information/data And: AHDB (2018), Poultry Pocketbook – 2018 https://pork.ahdb.org.uk/media/275384/poultry-pocketbook-2018.pdf , p22	NOTE: Generic sales, not specified if retail, catering, hospitality. Data not available in tonnes, so converted from number of eggs. 12,913 million eggs sold in 2017. Assumed 60g per egg as this is approximately average for a medium egg:

		https://www.egginfo.co.uk/egg-facts-and-figures/industry-information/egg-sizes Therefore 12 913 million eggs multiplied by 60g per egg = 774 780 tonnes
Pasta and rice (N/A)	No specific data on volumes consumed of different types of pasta and rice.	Assumed roughly 50% pasta, and 50% rice, and used proxies for each from common pasta/rice types
Sugar (N/A)	Used single proxy of "Sugar, white" – no breakdown used due to low data availability	
Milling (N/A)	Used single proxy of "Flour, wheat, bread/strong, white" – no breakdown used due to low data availability	
Bread (N/A)	Used rough proxy of stat "White bread accounts for 76% of the bread sold in the UK" - https://fabflour.co.uk/fab-bread/facts-about-bread/	No data available on tonnage of compositional breakdown. Assumed 76% bread was white, and remaining 24% is brown bread.
Confectionary (N/A)	Used single proxy of "Chocolate, milk"	
Ambient products (N/A)	No proxies used - based on weighted average of nutritional values of known food surplus at this stage of supply chain	
Pre-prepared meals (N/A)	No proxies used - based on weighted average of nutritional values of known food surplus at this stage of supply chain	Pre-prepared meals would probably have higher protein and energy content than average food, so this may yield a slight under-estimate
Frozen (N/A)	No proxies used - based on weighted average of nutritional values of known food surplus at this stage of supply chain	

Table 6: Sources for French food production/consumption data

Statistic	Source
Meat and fish – Meat (consumption)	http://agreste.agriculture.gouv.fr/IMG/pdf/conjsynt322201804cons.pdf

Meat and fish – Fish (consumption)	http://www.franceagrimer.fr/content/download/52763/508694/file/STA-MER-CONSO%202016-juil2017.pdf
Fruit and vegetables – Fruit (consumption)	https://fr.statista.com/statistiques/529254/evolution-consommation-volume-fruits-france/
Fruit and vegetables – Vegetables (mainly production, some with import/export balance)	https://fr.statista.com/statistiques/602638/production-agricole-legumes-frais-france/ http://www.franceagrimer.fr/content/download/54724/529440/file/chiffres%20cl%C3%A9s%20FL2016.pdf https://fr.statista.com/statistiques/541093/champignons-industriels-production-agricole-france/
Bread and pastry (consumption)	https://www.statista.com/statistics/766631/consumption-volume-of-bread-by-type-france/
Biscuits and cakes (consumption)	https://www.statista.com/statistics/764743/annual-consumption-of-biscuits-and-cakes-per-capita-by-volume-in-france/
Pasta, rice and cereals (sales)	https://fr.statista.com/statistiques/585991/tonnages-ecoules-pates-riz-couscous-cereales-semoule-ble-france/
Milk, cheese and butter (consumption)	https://fr.statista.com/statistiques/653774/produits-laitiers-consommation-france/
Eggs (production)	http://www.franceagrimer.fr/fam/content/download/55662/538163/file/fiche%20oeufs.pdf

Current FS Handling

The total amount of food surplus from catering, manufacturing and retail in the UK, taken into account in the study, is 2 547 800 tonnes. The data collection for food surplus arisings are described in the previous section.

Information on the current waste handling of food surplus in the UK has been collected from WRAP (2018) and Parfitt et al. (2013). The data are summarised for the different sectors in Table 7, Table 8 and Table 9.

Table 7: Current waste handling of food surplus from manufacturing, UK

Disposal routes for manufacturing food surplus	Share [%]	Amount [tonnes]	Comment
Compost and AD	29	430 360	We assume 50% to each disposal route
Incineration with energy recovery	71	1 053 640	

Source: WRAP 2018.

Table 8: Current waste handling of food surplus from retail, UK

Disposal routes for retail food surplus	Share [%]	Amount [tonnes]	Comment
Compost and AD	50	99 500	We assume 50% to each disposal route
Incineration with energy recovery	50	99 500	

Source: WRAP 2018.

Parfitt et al (2013) gives the waste disposal routes for food surplus from the UK Hospitality and Food Service Sector.

Table 9: Current waste handling of food surplus from catering, UK

Disposal routes for catering waste	Share [%]	Amount [tonnes]	Comment
SDU (sink disposal units)	5	129 720	The destination is waste water treatment
Compost and AD	12	103 776	We assume 50% to each disposal route
Via residual waste stream	73	631 304	
1. *out of which goes to incineration with energy recovery*	*63*	397 722	Based on the same treatment as for mixed household waste with statistics from Defra (2017)
2. *out of which goes to landfill*	*37*	233 582	Based on the same treatment as for mixed household waste with statistics from Defra (2017)

Source: Parfitt et al. 2013.

The total amount of food surplus from catering, manufacturing and retail in France, taken into account in the study is 4 386 170 tonnes. The data collection for food surplus is described in the previous section.

The data for current waste handling of food surplus in France have been collected from a number of sources, summarised in Table 10.

Table 10: Current waste handling of food surplus from catering, retail and manufacturing, France

	Catering [tonnes]	Retail [tonnes]	Manufacturing [tonnes]	Total [tonnes]
Anaerobic digestion	191 250	130 278		321 528
Composting	191 250	121 938		313 188
Incineration	337 500	486 848	591 235	1 415 583
Landfill	405 000	584 217	591 235	1 580 452
Donation (not included in study)			182 622	182622
Other *(not included in impact of waste treatment, but is included in nutrition for pig feed)*		8 340	738 740	747 080

Sources:
https://www.lesechos.fr/02/01/2017/lesechos.fr/0211651913021_les-restaurateurs-peinent-a-recycler-leurs-dechets.htm (catering)
http://www.cniid.org/Les-dechets-en-France-quelques-chiffres,151 (catering and retail)
Baromètre 2018 de la valorisation des Invendus en Grande Distribution - Tous droits réservés comerso © 2018 (retail)
Pertes et gaspillages alimentaires : l'état des lieux et leur gestion par étapes de la chaîne alimentaire, ADEME (manufacturing)

LCI for food surplus treatment processes

Anaerobic digestion

Models for anaerobic digestion (AD) of food surplus that reflect UK and French conditions need to be adapted to the following relevant parameters:

- Utilization of biogas: CHP or upgrade to bio-methane and fed into grid
- If CHP:
    - Biogas yield of plants which use food surplus: can range from 80 to even 170 m3/t (Kern et al., 2010; Lampert et al., 2011)
    - Digestate storage of plants which use food surplus: open or closed
    - Efficiency and Heat utilization ratio
- If bio-methane:
    - Biogas yield of plants which use food surplus
    - Digestate storage and application of plants which use food surplus
    - Efficiency (product gas output per biogas input)

- Amount of waste gas

United Kingdom

There are now 473 operational anaerobic digestion plants in the UK, including 80 biomethane-to-grid plants, and a further 327 anaerobic digestion projects under development (NFCC, 2018). There are 91 food surplus AD facilities operational in the UK which is 31.9% of the 285 CE plants treating biowaste, agricultural waste and industrial waste (not including landfills and sewage sludge) (De Clercq et al., 2017).

In Styles et al. (2016) statistics on current and planned AD deployment were combined with operational data from a survey of biogas plant operators to evaluate the environmental balance of the UK biogas sector for the years 2014 and 2017. They conducted a questionnaire survey among biogas plants and received 24 responses of which five also used food surplus as a feedstock.

Their survey has shown that only large-scale plants use food surplus as a feedstock. Of those which use food surplus the fraction of electricity used in the process is 6% or 8% and of heat is 23%, 37%, 20% or 14%. The estimated biogas conversion capacity was reported to be 57% for a plant that uses high amounts of food surplus. The fraction of surplus heat replacing fossil fuels was reported as zero. Digestate storage takes place in a lagoon, except of one plant that uses less amounts of food surplus which stores in a gas-tight tank. Digestate application is done with a boom as well as a dribble bar.

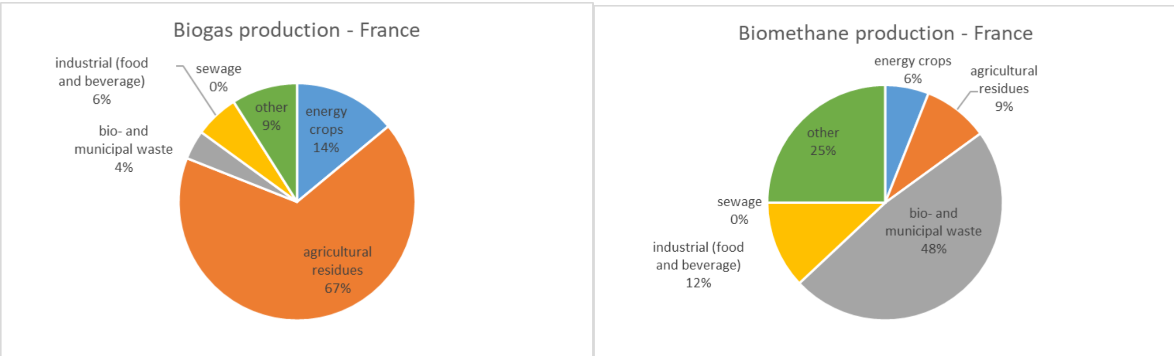
Biomethane-to-grid plants still plays a minor role with a number of 17% of the total biogas plants on the biogas sector in the UK. It is reported in De Clercq et al. (2017) that only two plants which use food surplus do have biomethane grid injection. Therefore, only biogas plants with CHP is considered for the biogas sector in the UK in this study.

France

France is facing severe issues regarding food surplus source separation (De Clercq et al., 2017) which result in leaving French domestic biogas projects with a waste shortage. Furthermore, biogas projects in neighbouring countries can afford to pay more to acquire this waste. For example, Belgium and Germany have higher electricity tariffs (30 c€/kWh maximum) compared to France (20 c€/kW h maximum) reported in De Clercq et al. (2017). Of the total biogas plant inventory in 2014 of 502 facilities, only 11 (2.2%) were treating municipal solid waste (MSW). However, food-derived wastes are predicted to become a more important contributor to the total waste-derived biogas output by 2030. Source separation is stipulated by law now (e.g. decree of 12th July 2011 in article R-543225 which is applicable for establishments that produce 10 t/year of bio-waste and 60 l/year of waste oil).

Predominant feedstock for biogas plants in France (total 18 284 TJ in 2015) are landfill and agricultural waste. Food surplus has only a minor role. However, biomethane plants (total 8.7 Mio Nm^3 in 2015) in France use mainly bio- and municipal waste and industrial food and beverage waste (see Figure 3 below). This fact could lead to the assumption that food surplus is primarily used for biomethane production in France now. In future the situation may shift to biogas production with CHP as this is the more prominent option for biogas use.

Figure 3: Feedstock distribution for AD facilities in France



Source: Stambasky et al. (2017)

Biomethane production aims to produce a gas of natural gas quality and feed it into the gas network or as a car fuel. It is essential to remove CO_2 to shift the heating value of the gas and H_2S and water to tackle the corrosive quality of H_2S in water (Jungbluth et al., 2007). In Jungbluth et al. (2007) which is a dataset in the ecoinvent database (Wernet et al., 2016) the fermentation of biowaste is modelled. A dry matter content of 40% is used for bio-waste in this case, which is higher than for typical food surplus streams. Therefore, data from ecoinvent cannot be directly applied. However, the background data of ecoinvent (Jungbluth et al. 2007) is used for the calculation.

The resulting LCI data for the AD in UK and France are summarised in Table 11.

We assume that the food surplus is transported on average 50 km to the AD plant in UK and 100 km in France (Truck: ecoinvent process "Lorry 7.5-16 ton, EUR4 {GLO} Alloc Rec").

Table 11: LCI data used for AD

	UK	France	Comment
Emissions from AD	208 kg CO2e/t food surplus	266 CO2e/t food surplus	Includes the upgrade to biomethane in French case

Electricity produced from CHP	553.5 kWh/t food surplus	-	Small compared to total UK primary energy supply of 7.25 mill. TJ (IEA, 2018), we assume this electricity replaces average grid mix
Biomethane produced	-	3 482 MJ/ t food surplus	Small compared to total primary energy supply in France of 10.1 mill. TJ (IEA, 2018), we assume this biomethane replaces average natural gas production in FR
Digestate produced	893 kg / t food surplus 3. 6.27 kg N 4. 2.74 kg P 5. 6.18 kg K	893 kg / t food surplus 6. 6.27 kg N 7. 2.74 kg P 8. 6.18 kg K	The digestate is assumed to replace production of mineral fertiliser in corresponding N,P,K amounts

Compost

We assume that the food surplus is transported on average 50 km to the composting plant in UK and 100 km in France (Truck: "Lorry 7.5-16 ton, EUR4 {GLO} Alloc Rec"). The LCI has been modelled by using the ecoinvent dataset: "Biowaste (CH) treatment of, composting, Alloc Rec". The process yields 540 kg compost per tonne of food surplus processed. No replacement of production of compost has been assumed, since there is a surplus of compost available, i.e. no production would actually be replaced if less food surplus were sent to composting.

Incineration with energy recovery

We assume that the food surplus is transported on average 50 km to the incineration plant in UK and 100 km in France (Truck: "Lorry 7.5-16 ton, EUR4 {GLO} Alloc Rec").

The LCI has been modelled by using the ecoinvent dataset: "Biowaste {CH} treatment of municipal, incineration with fly ash extraction, Alloc Rec". The process 0.42 MJ electricity/kg waste and 1 MJ heat/kg waste. We assume that this replaces UK and FR grid mix respectively, as well as heat from natural gas in food surplus valorisation scenario.

SDU, Waste water treatment

For food surplus that is deposited via sink disposal units (SDUs), the waste treatment process "Wastewater {CH} treatment of, capacity 1.1 x 10^{10}l/year, Alloc Rec", has been used form the ecoinvent database. This process includes mechanical, biological and chemical treatment and is described to be well applicable to modern treatment practices in Europe. We have approximated 1 tonne of food surplus in SDU to 1 m3 of wastewater going to the treatment plant. No energy output from biogas from digestion of sludge has been taken into account.

Landfill

We assume that the food surplus is transported on average 50 km to the landfill site in UK and 100 km in France (Truck: "Lorry 7.5-16 ton, EUR4 {GLO} Alloc Rec"). The ecoinvent process "Municipal solid waste {CH}, treatment of, sanitary landfill, Alloc Rec", has been used to model the landfill process.

Cost inventory for food surplus transport and handling

Unit cost for collection, transport, and disposal of food surplus respectively in UK and France are listed in Table 12. France cost data were converted using inflation rates. Influence of data quality and assumption is discussed in the interpretation.

Table 12: LCI cost data used for current FS handling

	Type of data	UK	France	Sources
Collection	Unit cost (€/t)	29.16	46.8	WRAP 2018 and Eunomia 2002
Transport	Unit cost (€/tkm)	0.17		Based on interviews (see section 4.2.1)
Compost	Gate fee (€/t)	54.96	83.85	WRAP 2018 and Eunomia 2002
Anaerobic Digestion	Gate fee (€/t)	29.16	74.1	WRAP 2018 and Eunomia 2002
Incineration with energy recovery	Gate fee (€/t)	96.46	127.4	WRAP 2018 and Eunomia 2002

Sink	Disposal fee (€/t)	139.09	n.a	WRAP 2018 and Eunomia 2002
Landfill	Gate fee (€/t)	120.02	97.1	WRAP 2018 and Eunomia 2002

3.2.2 Feed valorisation scenario

Processing of food surplus into feed

The data used for processing the collected food surplus into liquid feed for pigs have been taken from a study by Kitani (2018) and from personal communication with Voogt (2018). In the study by Kitani (2018), data were collected from a Japanese processing plant that processes food surplus into liquid feed. In this plant, the food surplus is treated at 80-90°C for 5-10 minutes. Since requirements in Europe might demand more processing due to hygienic precautions, we have adapted the figures with input from Voogt (pers. comm., 2018), based on a sterilization step for milk. Also, use of chemicals and heat for cleaning has been estimated by Voogt (pers. comm., 2018). The data are summarised in Table 13.

Table 13: Data inventory for processing of food surplus into liquid feed

Inputs/outputs		Source/comment
Inputs :		
Electricity	72 kWh/tonne processed food surplus	Kitani (2018) and adapted by Voogt (pers. comm., 2018)
Heat from natural gas	72 kWh fuel/tonne processed food surplus	Kitani (2018) and adapted by Voogt (pers. comm., 2018)
Water	3.4 m3/tonne processed food surplus	Voogt (pers. comm., 2018), includes cleaning
Heat for cleaning	48 kWh/tonne processed food surplus	Voogt (pers. comm., 2018)
Sodium hydroxide	1.2 kg/tonne processed food surplus	Voogt (pers. comm., 2018)
Sulphuric acid	1.2 kg/tonne processed food surplus	Voogt (pers. comm., 2018)
Output:		

Liquid feed	2.4 tonnes/tonne processed food surplus	Derived based on DM of food surplus (48%) and liquid feed (20%)

LCI data for production of electricity, heat, water and chemicals have been taken from the ecoinvent version 3 database (Wernet et al., 2016).

Financial information from Kitani (2018) was used to derive the yearly life cycle cost of the potential processing plants in UK and France. All variable costs were proportionally adjusted to the larger scale assumed. An exponential scaling factor of 0,6 (Voogt, pers. comm., 2018) was used in the case of fixed costs. Start-up costs were allocated to a life span of 20 years.

Potential amount and cost of replaced conventional feed

In each country, the potential substitution of conventional feed derived from the valorisation of food surplus was derived according to the following methodology:

1. Estimation of the potential amount of live weight pigs that could be reared with food surplus
2. Estimation of the corresponding amount of conventional mix of feed

In order to calculate the amount of protein from pig meat we used the energy and lysine required to produce a growing pig of 116 kg calculated by Van Zanten et al. (2015 and 2016). The start phase of the growing pigs started at 70 days, with a weight of 23.6 kg and a final age of 180 days. Table 14 summarizes the energy and lysine for growing pigs in the required ratio based on Van Zanten et al. (2015). In addition, feed is needed for piglet production. Piglet production includes rearing gilts and sows and their piglets needed for the production of finishing pigs. In our calculation, we assumed all food surplus is used to feed growing pigs and additional conventional feed is needed for piglet production (i.e. this feed has not been considered in this study).

Table 14: Energy (NE) and digestible lysine required to produce a growing pig of 116 kg, for the required piglet and the related sows and gilts

	Feed intake	NE (MJ) g/kg	LYS g/kg	NE (MJ)	Lysine, g	Lysine/MJ
Growing pig	226	9.59	7.59	2167	1715	0.79
Piglets	30	9.68	11.70	290	315	1.08
Gilt	6.7	9.24	8.99	62	32	0.60
Sow	40	9.06	7.42	362	297	0.82

Source: Van Zanten et al., 2015.

The total amount of food surplus from catering, manufacturing and retail in the UK is estimated to contain 18.2 PJ. The total amount of lysine is about 27 388 ton. A growing pig needs about 2 167 MJ NE and about 1 715 g of lysine. Based on the energy content of the food surplus in total 8 395 277 growing pigs can be reared (973 852 tonnes of live weight pigs). With a slaughter weight of 116 kg, a conversion factor of 0.53 from live weight to edible product and 0.19 from edible product to edible protein (De Vries and De Boer, 2010), and a population of about 66.02 million people we could produce about 2 kg of pork protein person per year. If we apply the same calculation based on the availability of lysine, we could produce 3 kg of pork protein per person per year, which means that energy is the limiting factor. To get a better ratio between energy and lysine, one could consider avoiding feeding food surplus products with a high lysine content to growing pigs or to add conventional energy rich feed ingredient, such as oils or grains. The optimal energy and lysine concentration differ between growing pigs, piglets, gilts and sows (see Table 14). Hence, optimizing the diet composition for each of the different groups of pigs and targeted allocation of waste products can be used to optimise the conversion of feed to pork.

To derive how much conventional feed this corresponds to, we have collected data from Stephen (2012) who gives data on finisher diet composition in UK: Barley (28.4%), Wheat (15.8%), Soya (7%), rapeseed meal (14%), wheat feed (27.5%) and rest (7.3%). This is consistent with Smith (2013) who states that pig feed in UK consists mainly of wheat, barley, wheat feed and soybean meal. The grains stem mainly from Europe, whereas the soybean meal mainly comes from Brazil (>90% in 2012). Then, the feed composition has been adapted to fit the energy and lysine content (see Table 14) that was used to estimate the amount of growing pigs that can be produced form the valorised food surplus. The nutritional data used to adjust the feed composition is shown in Table 15. The resulting amount of replaced feed is summarised in Table 16.

Table 15: Nutritional data for feed components, values for content of net energy and digestible lysine ("NEv" and "sisLys" in source)

	NE [MJ/kg DM]	SID LYS [g/kg ts]	Corresponding name in SLU (2010)
Barley	11	3,3	Korn
Wheat	12,1	2,8	Vete
Soya	9,3	28,4	Sojamjöl 45% Rp i vara
Rapeseed meal	7,1	15,2	Rapsmjöl
Wheat feed	8,7	2,8	Vetefodermjöl
Triticale	11,9	3,7	Rågvete
Maize	12,8	2,2	Majs

Pea	11,2	14,4	Ärter
Rape cake	9,7	13,3	Rapskaka
Cane molasses	8,7	0,2	Melass, rör
L-Lysine HCl	14,2	802	Lysin, L-HCL

Source: SLU (2011)

Table 16: Conventional feed for 8 395 277 growing pigs in UK

Feed component	Amount [tonnes]	LCI data used/comment
Barley	671 622	"Barley grain, consumption mix, at feed compound plant/IE Economic" from the Agri footprint database
Wheat	209 882	"Wheat grain, consumption mix, at feed compound plant/IE Economic" from the Agri footprint database
Soya	125 929	"Soybean, consumption mix, at feed compound plant/IE Economic" from the Agri footprint database
Rapeseed meal	386 183	"Rapeseed meal, consumption mix, at feed compound plant/IE Economic" from the Agri footprint database
Wheat feed	503 717	"Wheat feed meal, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database
L-Lysine	923	*Not included due to lack of LCI data*
Total	1 898 256	

Unit prices for feed products used in UK were derived from the AHDB Market data centre. The price of Barley and Wheat was estimated according to the price of 'delivered feed product' reported by the AHDB Market data centre, which consist of prices for grain (set specifications) and rapeseed delivered to the range of UK regions, with weekly surveys carried out by AHDB[3] . Soya, rapeseed meal, and wheat feed cost data were extracted from indicative prices for a selection of 'animal

[3] https://cereals.ahdb.org.uk/market-data-centre/uk-delivered-prices/uk-delivered-prices.aspx

feed ingredients' collected by AHDB[4] as well. In the case of soya, the soymeal ex-shore price was considered as no import or delivered soya price was found in the database.

The total amount of food surplus from catering, manufacturing and retail in France contains 25.4 PJ. The total amount of lysine is about 23.6 thousand tonnes. A growing pig needs about 2 167 MJ NE and about 1 715 g of lysine. Based on the energy content of the food surplus in total 11 727 768 growing pigs can be reared. With a slaughter weight of 116 kg, a conversion factor of 0.53 from live weight to edible product and 0.19 from edible product to edible protein (De Vries and De Boer, 2010), and a population of about 66.12 million people we could produce about 2 kg of pork protein person per year, which is about 11 g of meat per person per day in France. If we apply the same calculation based on the availability of lysine, we could produce 2 kg of pork protein, which is about 13 g of meat per person per day.

To derive how much conventional feed this corresponds to, we have collected data from van der Werf (2005) who gives data on growing pigs in France. Then, the feed composition has been adapted to fit the energy and lysine content (see Table 14) that was used to estimate the amount of growing pigs that can be produced from the valorised food surplus. The resulting amount of replaced feed is summarised in Table 17.

Table 17: Conventional feed for 11 727 768 growing pigs in France

Feed component	Amount [tonnes]	LCI data used/Comment
Wheat	1 231 416	"Wheat grain, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database
Triticale	410 472	"Triticale, consumption mix, at feed compound plant/IE Economic" from the Agri footprint database
Maize	58 639	"Maize, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database
Pea	140 733	"Pea dry, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database
Rape cake	351 833	"Rapeseed meal, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database
Cane molasses	117 278	"Sugar cane molasses, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database
Soymeal	293 194	"Soybean meal, consumption mix, at feed compound plant/NL Economic" from the Agri footprint database

[4] https://cereals.ahdb.org.uk/market-data-centre/feed-ingredients/feed-ingredients.aspx

Total	2 603 564

Unit prices for most feed ingredients were sourced from the agricultural market monitoring webpage of Terre-net online, except for cane molasses[5] and soy products[6].

Growing pigs are typically supplied with water corresponding to 2.5-3 litres per kg dry feed (Jordbruksverket, 1999). The dry matter content in the liquid feed from heat processed food waste is 20%. We therefore assume that an equivalent amount of water as is contained in this liquid feed is supplied at the farm in the conventional system. This corresponds to 2,4 x 2 547 800 tonnes liquid feed from food waste x 0.8 = 4.81 Mtonnes water in UK conventional system, and 2,4 x 4 386 170 tonnes liquid feed from food waste x 0.8 = 8.41 Mtonnes water in FR conventional system.

Transport

Food surplus transport to processing plant

In order to establish an average transport distance between the collection of food surplus and the processing plant, we calculated the catchment area of the processing plant in Japan in Kitani (2018) based on data from interviews. Based on the relative population density, we derived the equivalent areas in UK and France (Japan is more densely populated than UK and France, so it can be assumed that catchment areas will be on average larger than for the Japanese plant). We multiplied it by 20 since it is assumed that the size of the plant will be larger in EU than in Japan (Voogt, pers. comm., 2018). The resulting distance between food surplus arisings and processing is reported in Table 18.

Table 18: Transport distance between food surplus arisings and processing plant (UK)

	Amount	Unit	Note	Source
Food surplus transport distance	20	km	Normally distribution with low SD	Interview with JFEC
Catchment area for JFEC plant	1256	sqkm	Circular area based on above	
Avg population density JAP	335	p/sqkm	Oct 18	Statistic Bureau of Japan

[5] https://www.sra.gov.ph/wp-content/uploads/2018/11/Millsite-Prices-Nov-11-2018.pdf
[6] http://www.grainwiz.com/contrats/tableaux?type=soybean-oil&currency=EUR&volumeUnit=metric_ton&interval=day&chartType=candlestick

Population in catchment area		420 760	p		
Avg population density	UK	272	p/sqkm	Jun 17	Office for National Statistics
	France	124		Oct 18	Institut National de la statistique et des etudes economique
Catchment area	UK	30 938	sqkm	Assumed plant size 20 times larger than JFEC and same food surplus levels	
	France	67865			
Food surplus transport distance	**UK**	**99**	**km**	**Rounded to 100 km**	
	France	**147**	**km**	**Rounded to 150 km**	

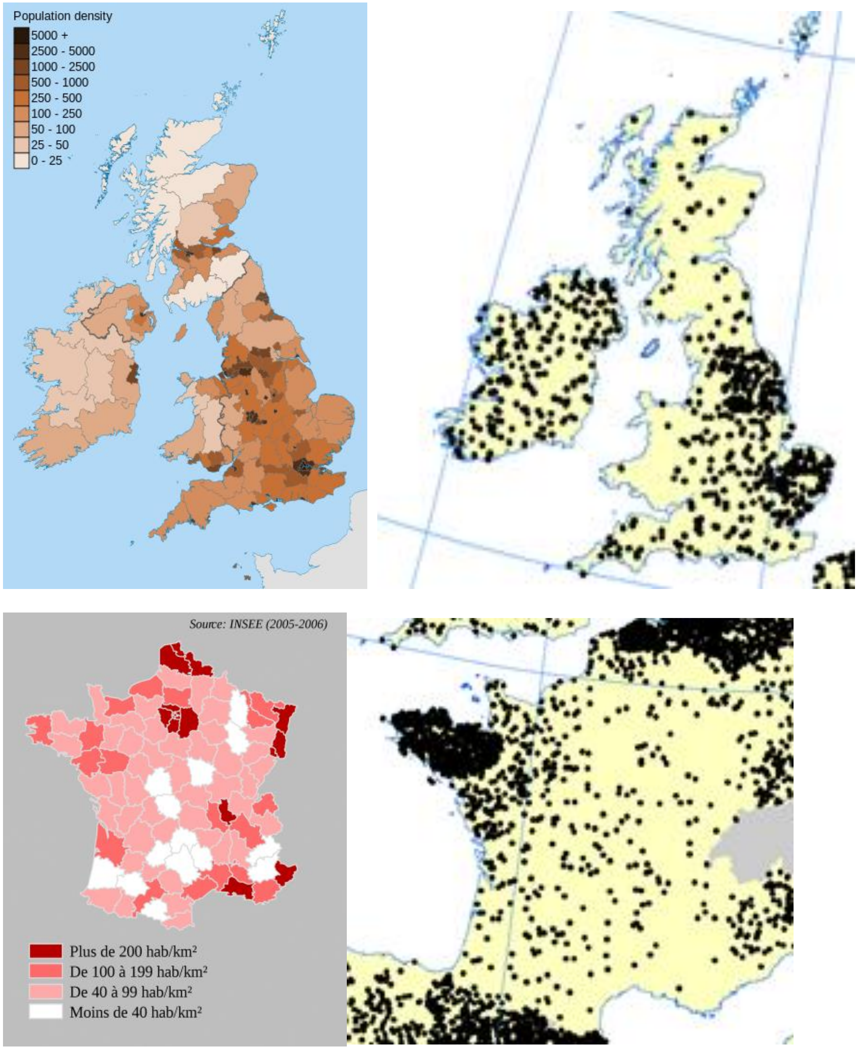
Feed transport to pig farms

Considering the difference between population density and pig farms density, and the regional concentration (see Figure 4), it was possible to derive some assumptions on the potential average distance travelled for the feed.

In particular, in UK most feed from valorised food surplus will likely travel from the areas of London and Manchester towards east and northeast respectively. This will result in an outbound average transport distance of about 100km with a left skewed distribution (few farms close, more farms far). For the conventional feed, we assumed an average distance between feed plants in UK to UK pig farm of 200 km.

In France most feed should travel towards Brittany starting from the areas of Paris, Lille, Strasbourg, Lyon, and Marseille. In a realistic scenario, food surplus generated in the NE and E districts could potentially be conferred to Netherlands and Germany, while food surplus generated in SE would be sent to Italy. However, in our analysis, we assume that food surplus is processed and utilised in French pig farms. We estimated an average outbound transport distance of 650km with a left skewed distribution (few farms close, more farms far). For the conventional feed, we assume an average distance between feed plant in France to French pig farm of 400 km.

Figure 4: Overview of population density (left) and location of pig farms (right) in the UK and France



Source: Wikimedia 2018, INSEE 2018, EUROSTAT 2013

Transport distances are summarised in Table 19 below. The LCI data for the truck transport have been taken from the ecoinvent version 3 database (Wernet et al., 2016); the specific datasets chosen are shown in the table.

Table 19: Summary of food surplus and feed transport in the study

Material transported	Distance	Transport mode	Data set used
UK: Food surplus (catering, retail and manufacturing) to processing plant	100 km	Truck	"Lorry with refrigeration 7.5-16 ton, EUR4, carbon dioxide, cooling, alloc rec"

UK: Liquid feed from food surplus to pig farm	100 km	Truck	"Transport, freight, lorry 16-32 metric tons, EURO6 {GLO}".
UK: conventional feed to pig farm	200 km	Truck	"Transport, freight, lorry 16-32 metric tons, EURO6 {GLO}".
FR: Food surplus (catering, retail and manufacturing) to processing plant	150 km	Truck	"Lorry with refrigeration 7.5-16 ton, EUR4, carbon dioxide, cooling, alloc rec "
FR: Liquid feed from food surplus to pig farm	650 km	Truck	"Transport, freight, lorry 16-32 metric tons, EURO6 {GLO}".
FR: conventional feed to pig farm	400 km	Truck	"Transport, freight, lorry 16-32 metric tons, EURO6 {GLO}".

Unit cost for the transport of 1tkm of feed was assumed to be the same as for food surplus (see Section 3.2.1).

The cost of transportation of conventional feed to farms took into account a calculation of 0.16 tkm and 200 km transport, as well as an additional average charge for 83.3 km for the feed ingredients, assuming an average distance from main milling facilities close to UK main ports and possible distances to main farm clusters.

The collection of FS into the processing plant assumed the current collection fee for FS in the UK only for retail and catering (not for manufacturing) and the refrigerated transport was assumed to have a cost of by a 0.83 €/tkm cost multiplied by the 100 km estimated for FS being sent to the processing plant. Then, the FS feed transportation costs considered a charge of 0.16 €/tkm per the 100 km estimated from the plant to the farms.

In the French case, the same costs were considered together with 150 km distance for FS collection to the processing plant, and 400 km from the plant to the farms to deliver the wet feed.

3.3 Impact assessment

3.3.1 Methodology

The environmental impacts have been assessed using the ILCD impact assessment methodology recommended by the European commission (EC, 2012). For climate impact, the Intergovernmental Panel on Climate Change (IPCC) released new characterisation factors for greenhouse gas emissions in 2013 (IPCC, 2013); therefore, we have used these for climate impact results. The climate impact using the ILCD method are however also available in the Annex. Environmental indicators considered in this study:

- Climate change according to IPCC 2013 GWP 100a characterisation factors
- Climate change according to ILCD (IPCC 2007 GWP 100a characterisation factors)
- Water resource depletion
- Mineral, fossil and resource depletion
- Freshwater eutrophication
- Marine eutrophication
- Terrestrial eutrophication
- Acidification
- Land use (expressed as kg C deficit in ILCD method)
- Land use as LCI result has also been included (m2 land occupation)

As far as cost modelling is regarded, costs were categorized by stage and, when possible, by specific typology: material, energy, labour, transport. No evaluation of net present value or added value was carried out.

3.3.2 Results

UK

The results for all impact categories studied are provided in Table 24 in Annex. In this section, the results for climate impact and costs are first shown, followed by a short description of effects on the other environmental impacts.

Figure 5 shows the climate impact of current waste treatment of food surplus that has been identified as available for valorisation into feed, from catering, retail and manufacturing. The single most important contributor of greenhouse gas emissions is the waste sent to landfill, due to emissions of methane from this treatment. The transport of food surplus from place of generation to treatment facility also contributes significantly to the overall climate impact of this stage. Note that the impact of replacing the products from the waste treatments (e.g. energy from incineration) if the waste is sent to feed production instead, is not taken into account in this figure; this is shown in Figure 11.

Figure 5: Climate impact from current treatment of food surplus in UK

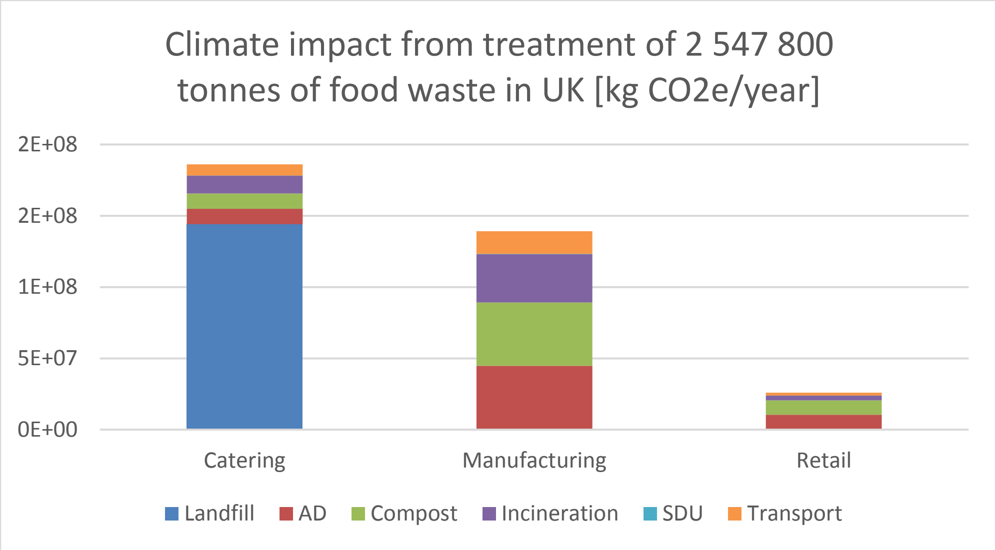


Figure 6 shows the cost of current waste treatment of food surplus that has been identified as available for valorisation into feed, from catering, retail and manufacturing. Unlike GHG emissions, the largest contributor to costs is represented by incineration, likely because of the relatively high gate fee and the large amount of FS disposed in this way. It must be noted that gate fee is not considering the potential revenues from electricity and heat sales, as the impact of replacing such products in the feed valorisation scenario is taken into account in Figure 12. Collection costs are the second hotspot of cost in current waste management, followed by landfill and sink disposal for catering waste.

Figure 6: Cost of current treatment of food surplus in UK

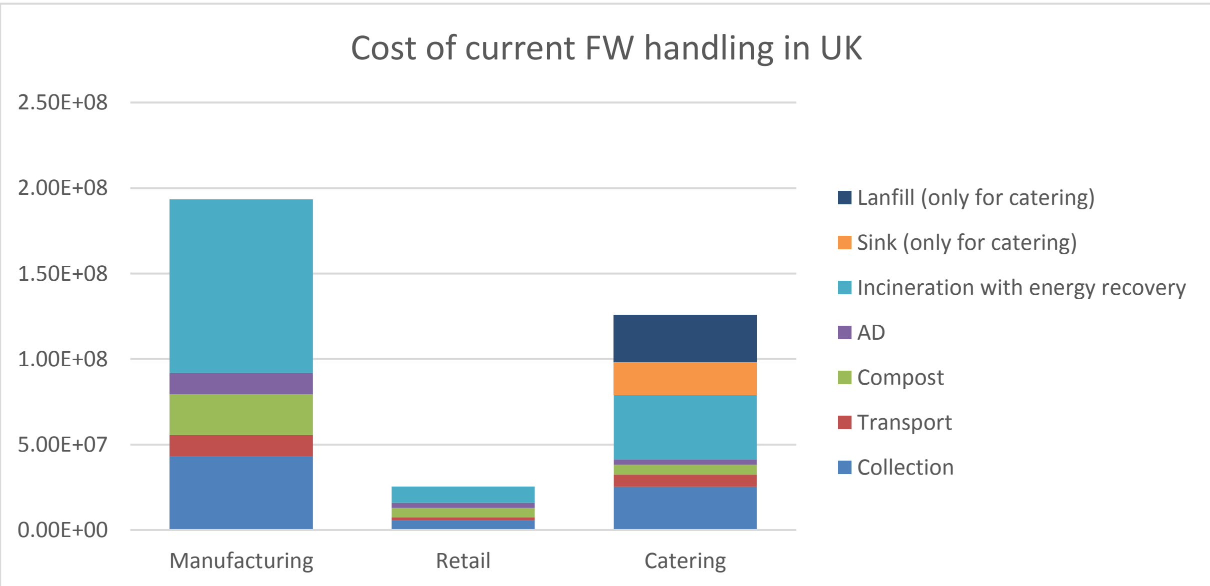


Figure 7: Climate impact from production of conventional UK pig feed

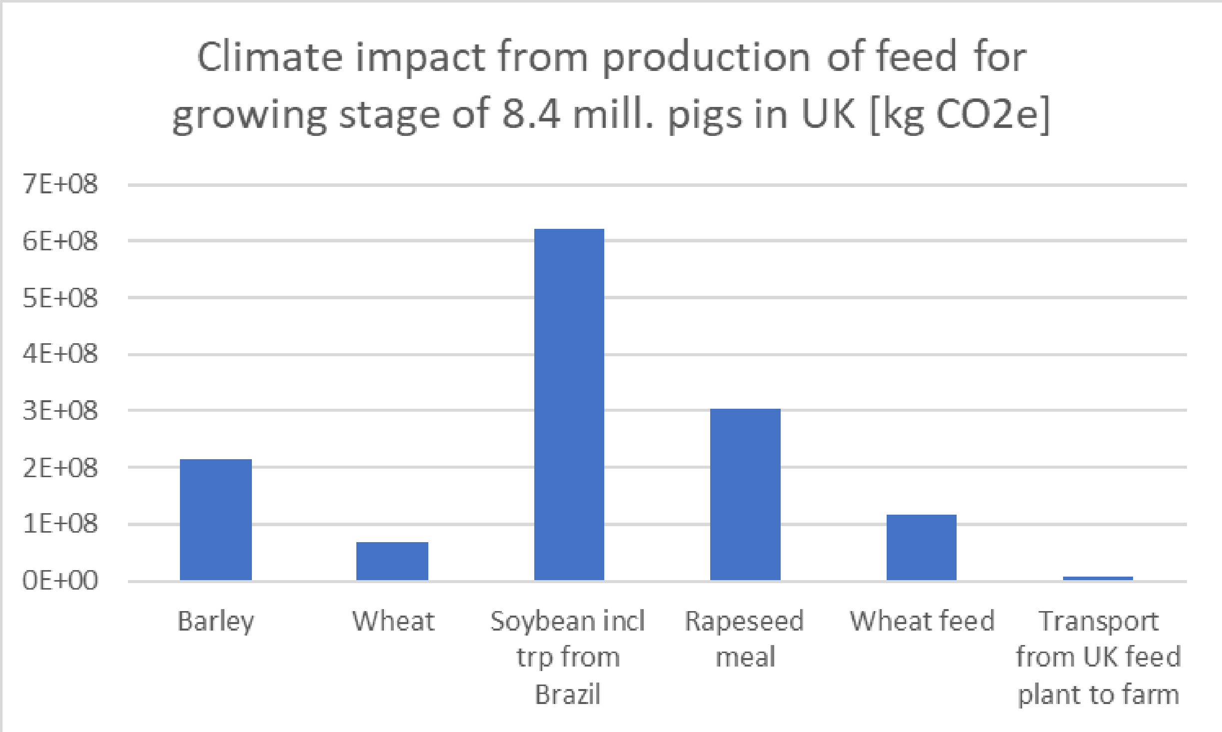


Figure 7 shows the climate impact of producing a conventional mix of growing feed for 8.4 million pigs in the UK. This corresponds to the number of pigs that can be - fed (or finished) with the identified food surplus from catering, retail and manufacturing in the UK that today goes to waste treatment. As can be seen in the figure, the main climate impact comes from production of soybean, despite it represents less than 10% of the total mass. The reason why the soybean cultivation has such a high climate impact is due to emissions of carbon dioxide from land transformation (burning of rainforest to make land for fields). The transport of soybean from Brazil to the UK is not significant, nor is the transport of all feed components from the feed plant in UK to the farm, compared to the impact of the cultivation of the different feed ingredients.

Figure 8 reports the costs related to market prices of conventional mix of growing feed in UK. Barley has the largest share of the overall cost followed by the feed ingredients such as rapeseed meal and wheat feed. Transport to the farm represents a quite relevant cost despite its relatively low share of GHG emissions.

Figure 8: Cost of production of conventional UK pig feed

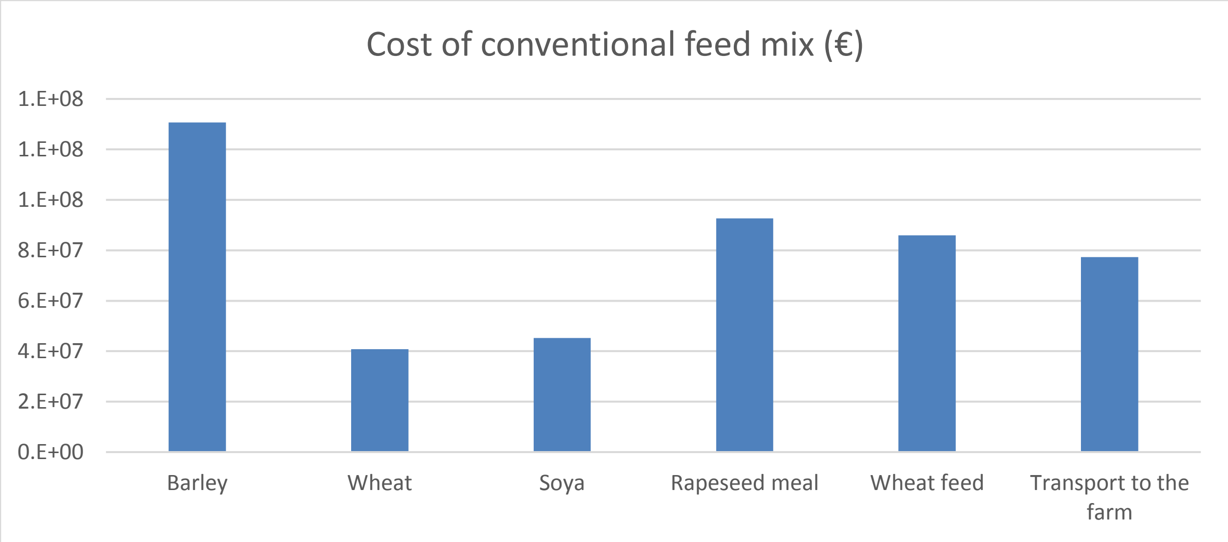


Figure 9: Climate impact from processing of UK food surplus into pig feed

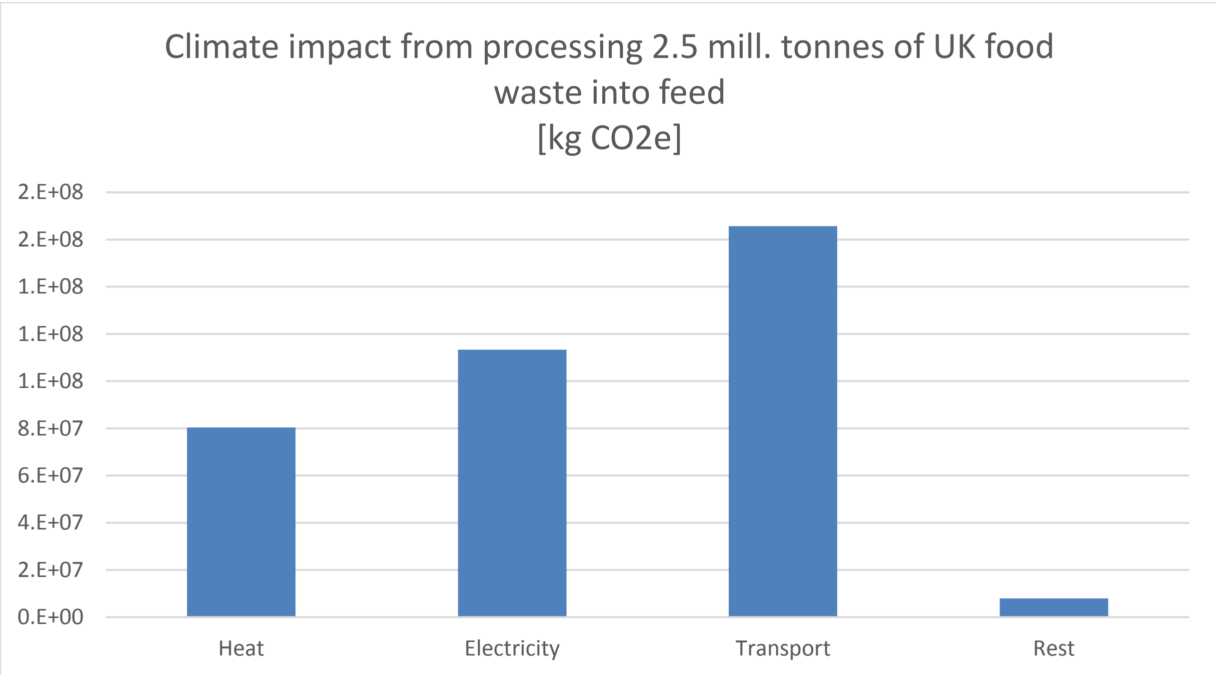
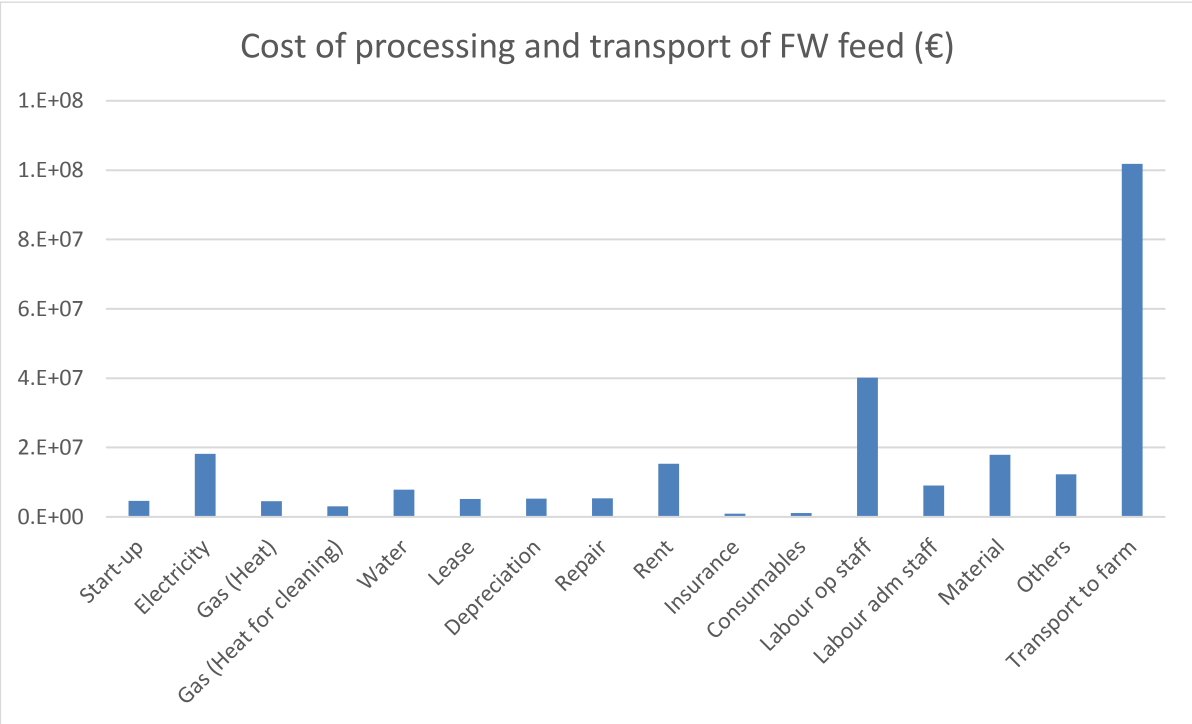


Figure 9 shows the climate impact of making feed out of the identified food surplus from catering, retail, and manufacturing in the UK that today goes to waste treatment. The main impact comes from collecting the food surplus and distributing the heat-treated liquid feed to the farms; the collection of waste results in more climate impact than the delivery of feed. The item “rest” includes production of cleaning agents and supply of water for the processing and cleaning.

Figure 10 shows the cost of producing pig feed out of food surplus, according to the Japanese process costs as adapted to the UK context. Transport, labour related to operators and electricity are the highest contributors to the total figure. It must be highlighted how energy and water consumption was assumed higher in the UK case rather than the Japan case and that no scaling factor was applied to labour despite some economies of scale might be reached in a larger plant. Materials are the fourth item by importance, while rent and other categories of cost are less the 5% of the total.

Figure 10: Cost of processing of UK food surplus into pig feed



The current waste treatment in the UK results in outputs of electricity, heat as well as nitrogen (N), phosphorous (P) and potassium (K) in the digestate from AD that can be used instead of mineral fertilisers. If this food surplus were used as animal feed, these outputs would need to be supplied to the market in another way. The impact of producing these outputs is shown in Figure 11. The process that contributes most to climate impact is production of electricity and heat (to replace what is generated from current incineration of food surplus), but also electricity production (from replacing AD output). Impact in terms of costs is also generated mostly by electricity and heat needed to substitute for replaced incinerators and AD outputs, while despite the relatively higher prices, fertilizers are not generating a large impact (Figure 12).

Figure 11: Climate impact of alternative production of outputs of current UK waste treatment of food surplus

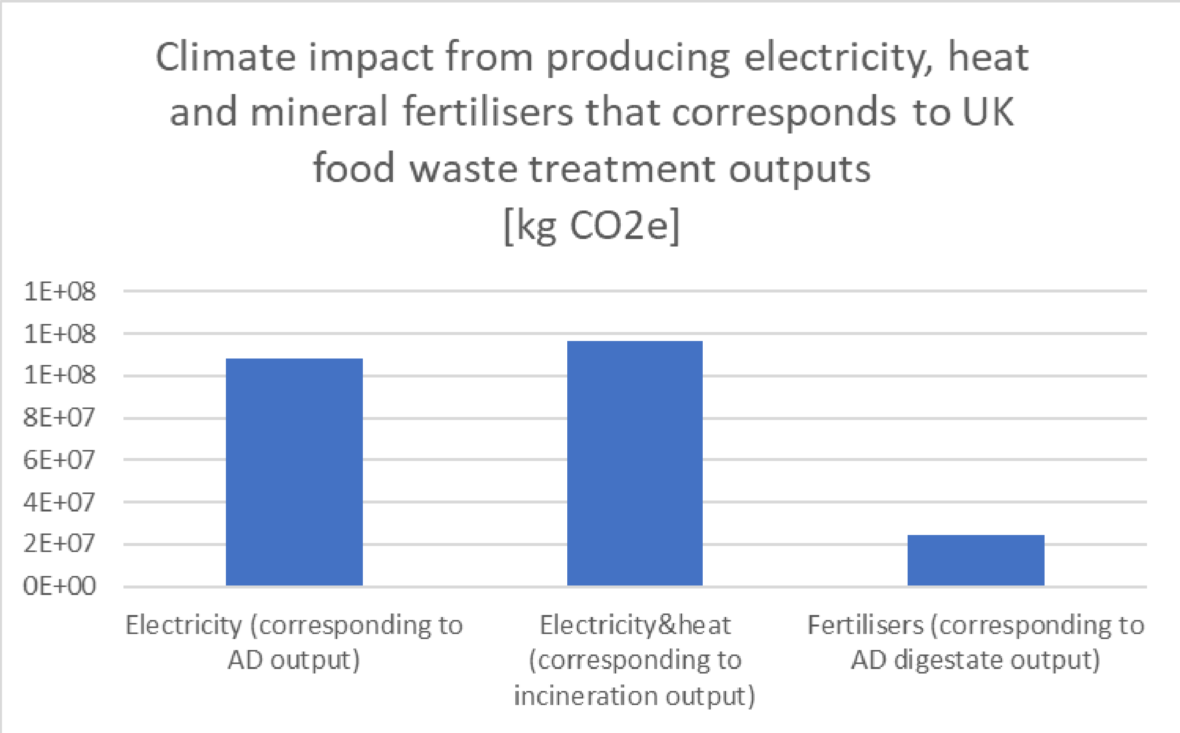
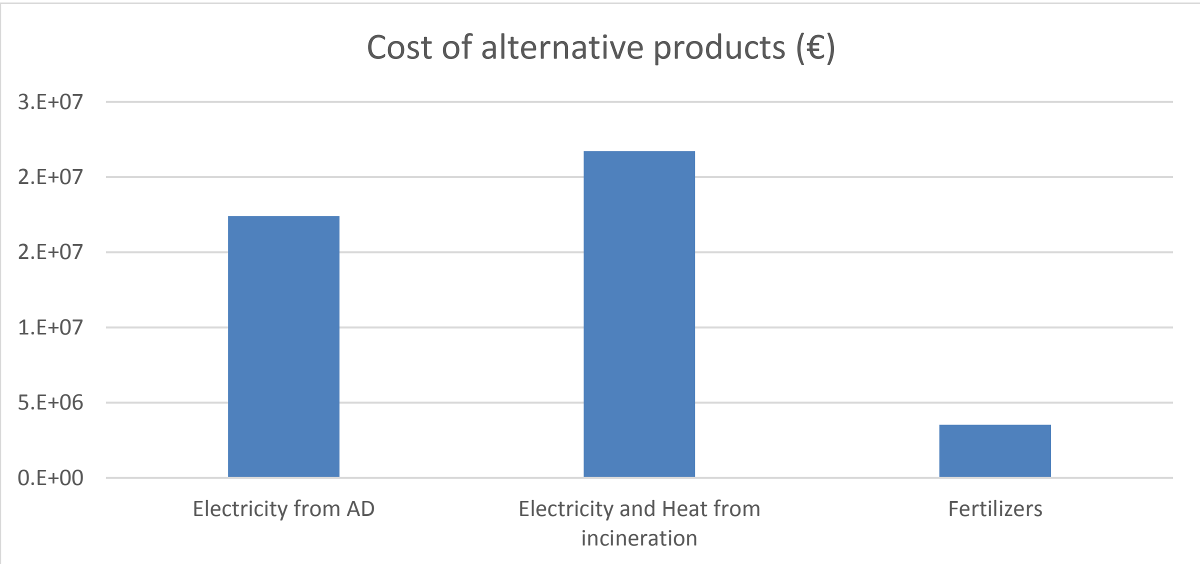


Figure 12: Cost of alternative production of outputs of current UK waste treatment of food surplus



In summary, Figure 13 shows the net climate impact of utilising identified food surplus as pig feed in the UK instead of sending it to current waste treatments. The resulting savings in greenhouse gas emissions are about 1 million tonnes of carbon dioxide equivalents. The main benefit comes from reduction of conventional feed components used in pig production in the UK (avoided emissions).

Figure 13: Net climate impact of using processed food surplus as pig feed in UK

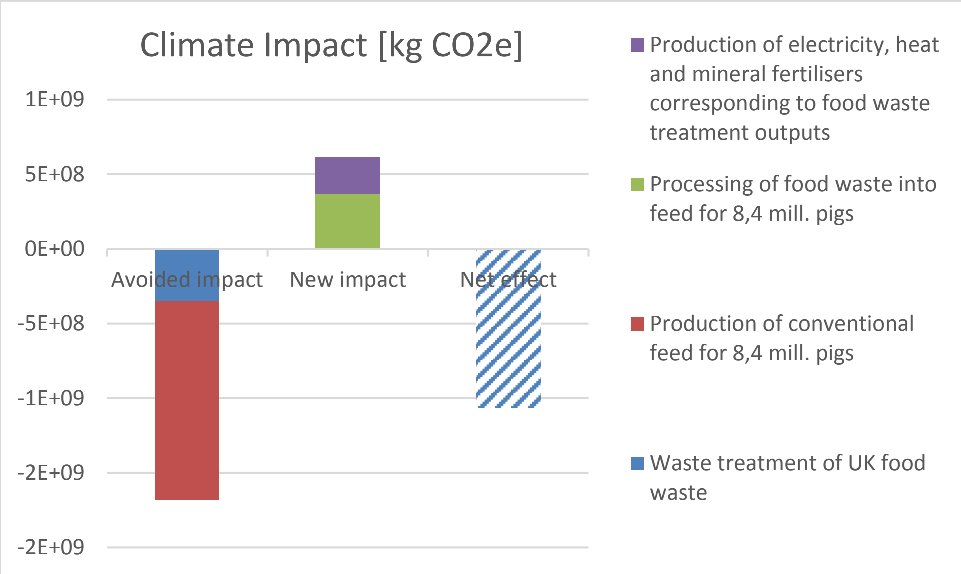
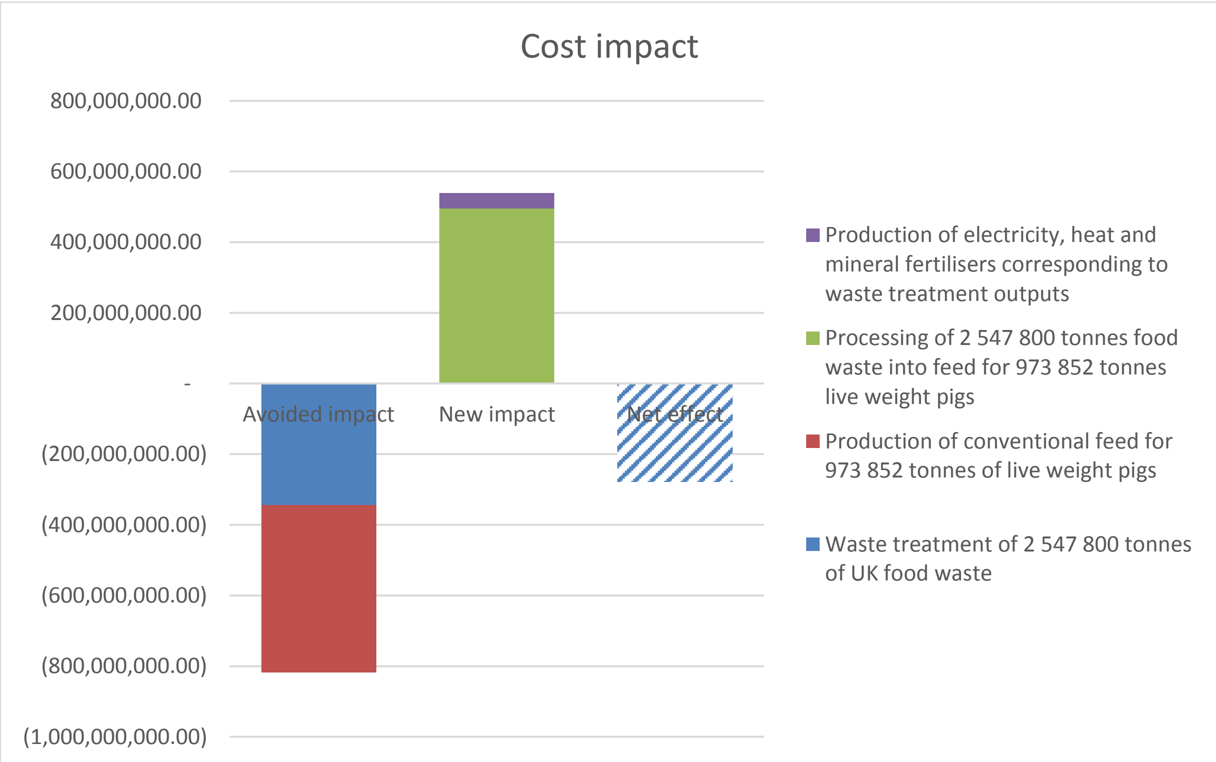


Figure 14: Net cost impact of using processed food surplus as pig feed in UK



When focusing on costs, the net effect would be an overall decrease of 278 million € per year, mostly due to the relatively low processing costs for feed (including transport costs of the feed to the farms).

Regarding other environmental impacts than climate (shown in Table 24 in Annex), the result for UK indicate that there are environmental benefits of lifting the ban for all impacts assessed except mineral, fossil and renewable resource depletion. This will be further elaborated in the interpretation.

France

The results for all impact categories studied are provided in Table 25 in Annex. In this section, the results for climate impact and costs are first shown, followed by a short description of effects on the other environmental impacts.

Figure 15 shows the climate impact of current waste treatment of food surplus that has been identified as available for valorisation into feed, from catering, retail and manufacturing in France. The single most important waste treatment contributor is the waste sent to landfill, due to emissions of methane from this treatment. The transport of food surplus from place of generation to treatment facility also contributes significantly to the overall climate impact of this stage. Note that the impact of replacing the products from the waste treatments (e.g. energy from incineration) if the waste is sent to feed production instead, is not taken into account in this figure but is shown in Figure 21.

Figure 15: Climate impact from current treatment of food surplus in France

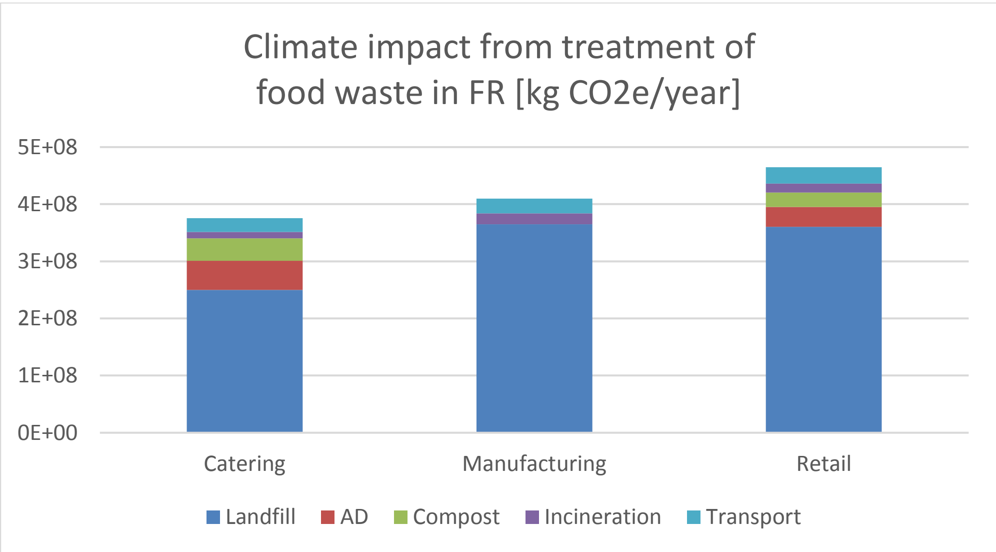


Figure 16: Cost of current treatment of food surplus in France

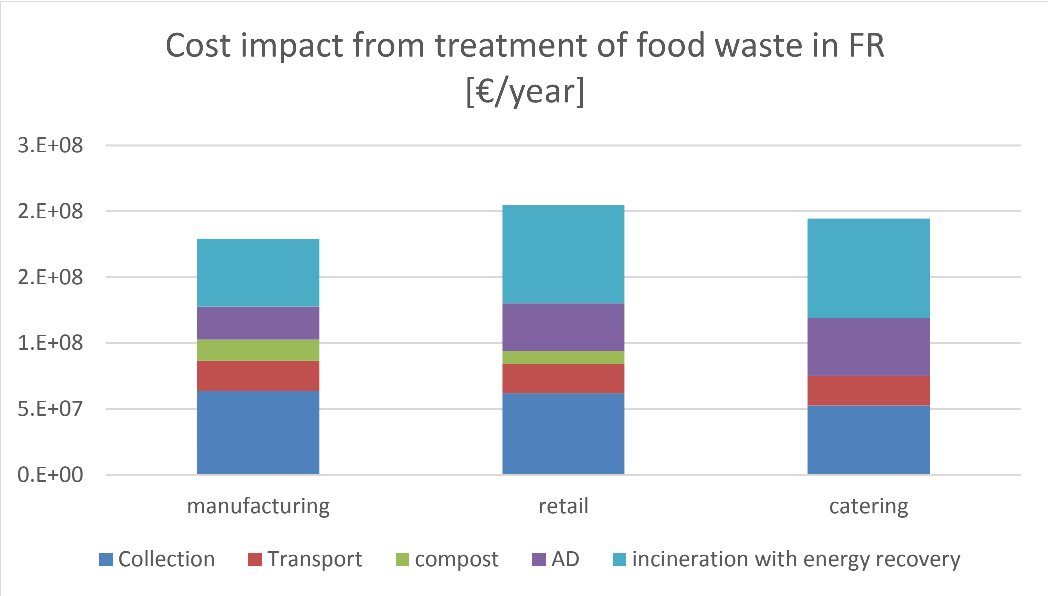


Figure 16 shows the cost of current waste treatment of food surplus that has been identified as available for valorisation into feed, from catering, retail and manufacturing in France. Incineration, followed by collection represent the items with the highest share of costs followed by anaerobic digestion. Note that the cost of replacing the products from the waste treatments (e.g. energy from incineration) if the waste is sent to feed production instead, is not taken into account in this figure, as it is shown in Figure 22.

Figure 17: Climate impact from production of conventional French pig feed

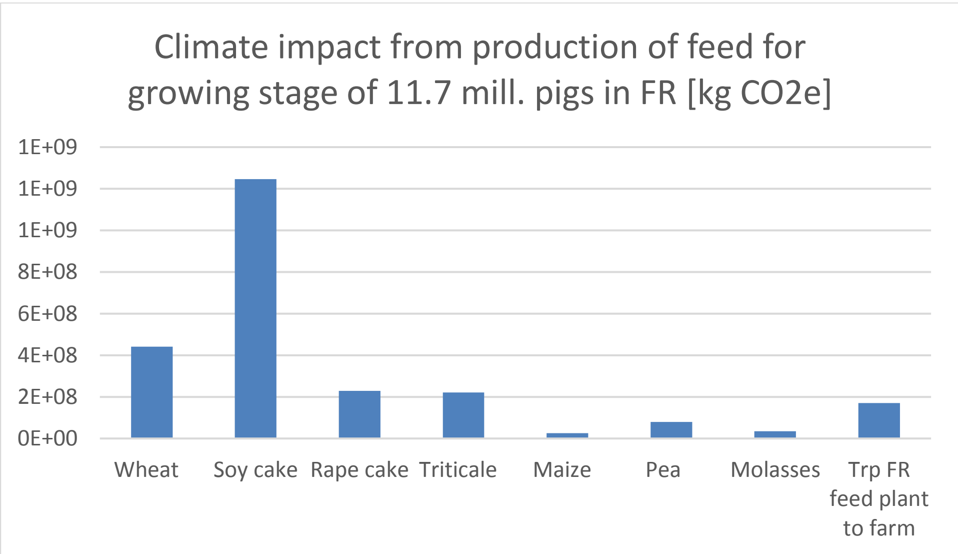


Figure 17 shows the climate impact of producing a conventional mix of growing feed for 11.7 million pigs in France. This corresponds to the number of pigs that can be bred from feeding pigs with the identified food surplus from catering, retail and manufacturing in France that today goes to waste treatment. As can be seen in the figure, the main climate impact comes from production of soy cake; the reason behind this is that the soybean cultivation has a very high climate impact due to emissions of carbon dioxide from land transformation (burning of rainforest to make land for fields). The transport of soybean from Brazil to France is not significant, nor is the transport of all feed components from the feed plant France to the farm, compared to the impact of the cultivation of the different feed ingredients.

Figure 18 shows the cost of the conventional French pig feed. Wheat feed is the largest contributor to the total feed, and due to the assumed increased average distance from feed producer to farm, transport represents the second highest share of costs, followed by rape cake, soymeal, triticale, protein pea, cane molasses and maize. As for the UK, also in France, soy cake is quite inexpensive compared to its environmental impacts.

Figure 18: Cost of conventional French pig feed

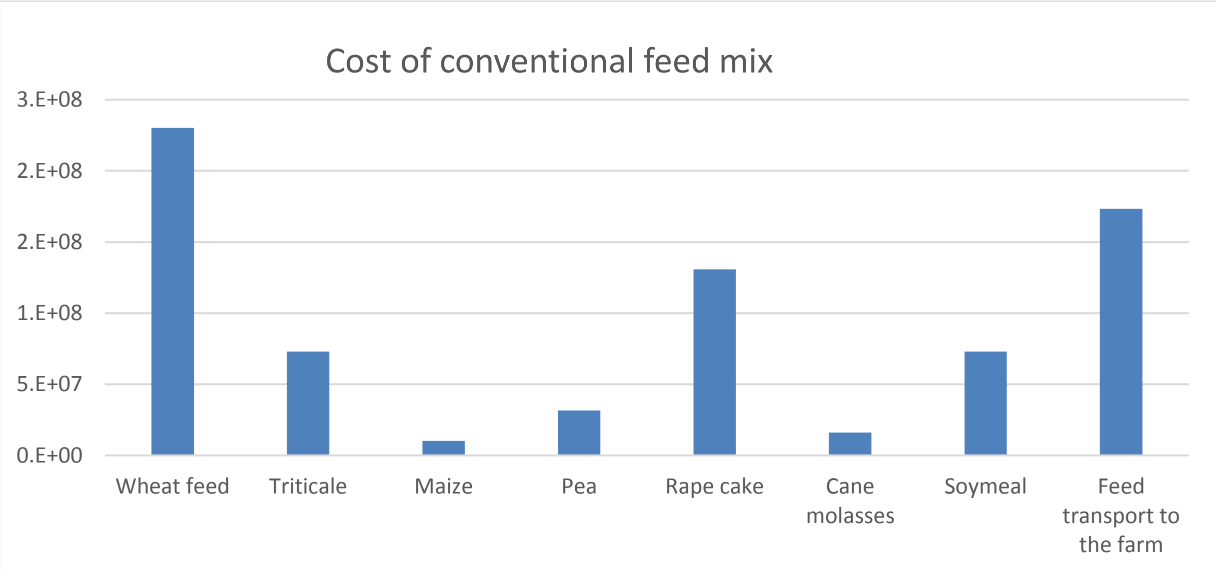


Figure 19 shows the climate impact of making feed out of the identified food surplus from catering, retail and manufacturing in France that today goes to waste treatment. The main impact comes from collecting the food surplus and distributing the heat-treated liquid feed to the farms; the collection of waste results in more climate impact than the delivery of feed. The item "rest" includes production of cleaning agents and supply of water for the processing and cleaning.

Figure 19: Climate impact from processing of French food surplus into pig feed

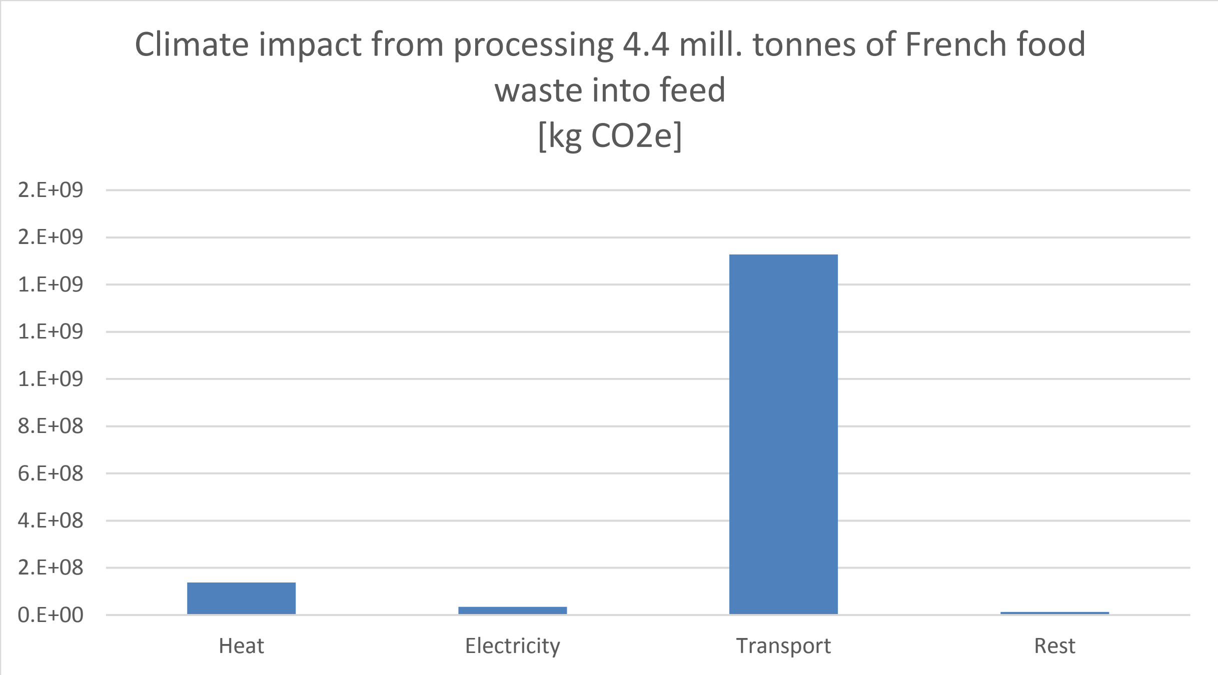
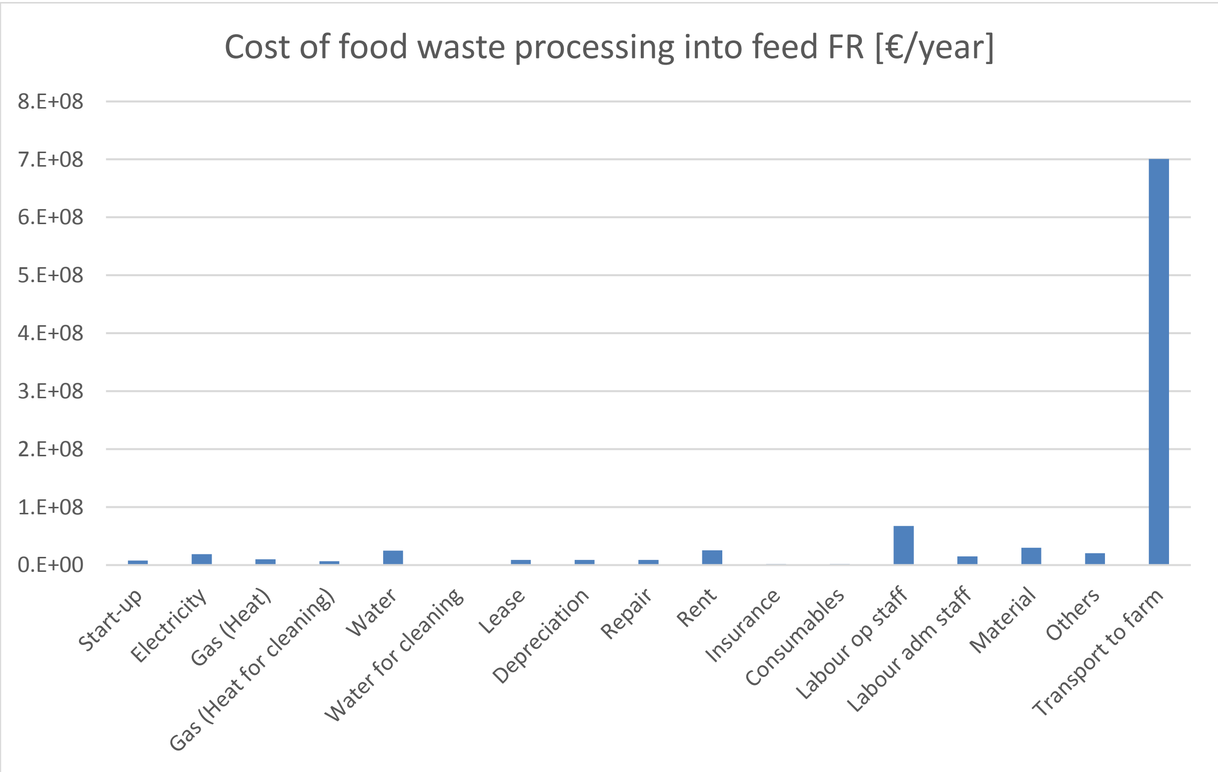


Figure 20: Cost of processing French food surplus into pig feed



As shown in Figure 20, transport represents also the major cost item with almost 700 Million €/year, followed by labour cost for operative staff, water and materials.

The current waste treatment of food surplus in France results in outputs of electricity, heat, biomethane as well as nitrogen (N), phosphorous (P) and potassium (K) in the digestate from AD that can be used instead of mineral fertilisers. If this food surplus were used as animal feed, these outputs would need to be supplied to the market in another way. The impact of producing these outputs is shown in Figure 21. All three processes contribute equally to the overall climate impact. Please note that regarding the biomethane that is produced from the AD treatment, this here replaces only *production* of natural gas; we have not taken into account the emissions from using these two fuels (biomethane as opposed to natural gas). If the use of fuel had also been included, the climate impact from natural gas would have been higher than for biomethane.

Figure 21: Climate impact of alternative production of outputs of current French waste treatment of food surplus

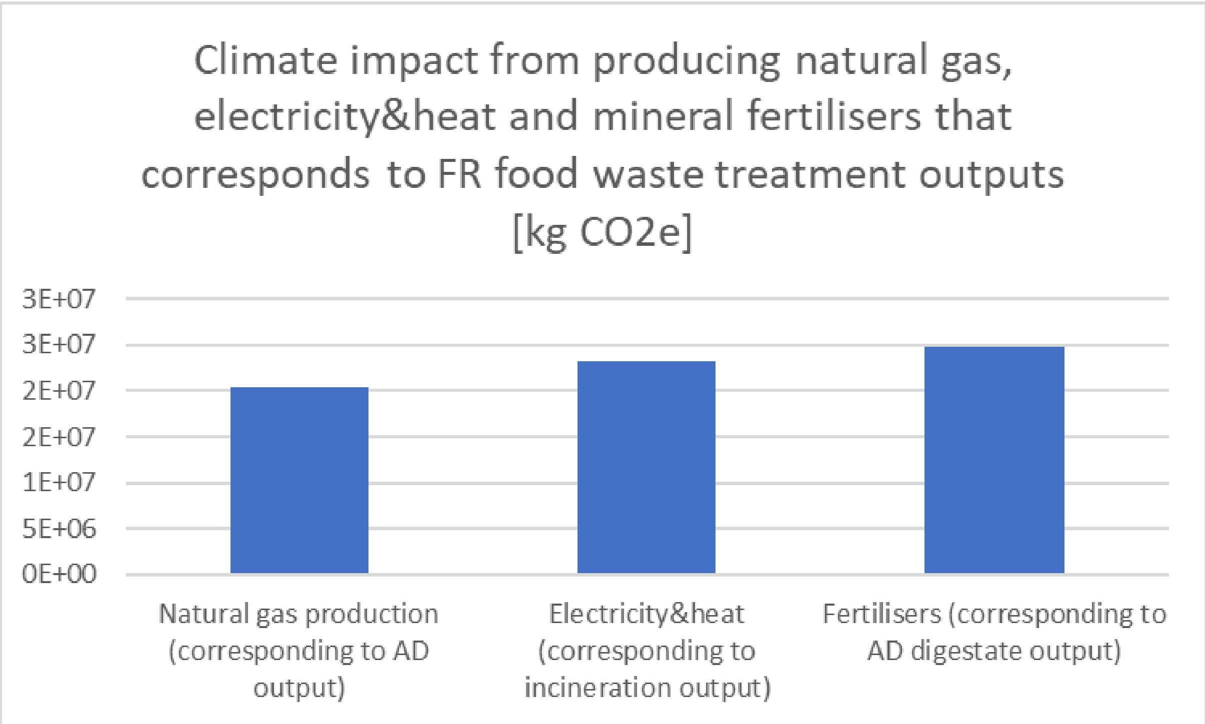
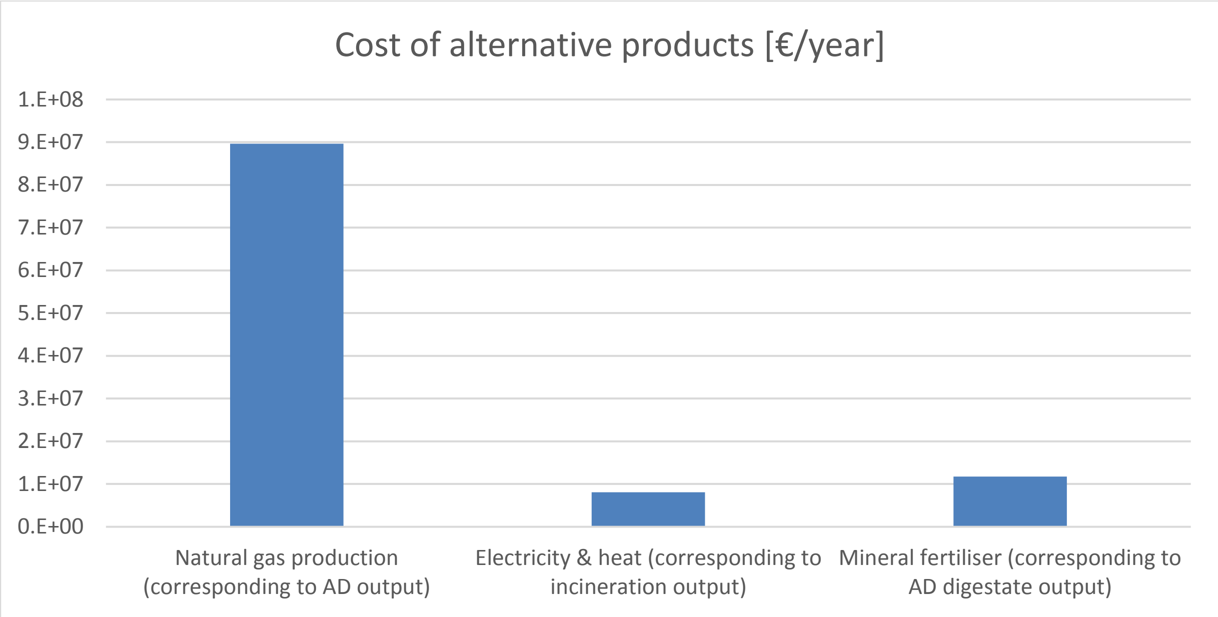


Figure 22 shows the cost of alternative outputs of the current French waste treatment. Due to its high price, compressed natural gas is the more relevant substitute product in terms of external costs.

Figure 22: Cost of alternative outputs of current French waste treatment of food surplus



In summary, Figure 23 shows the net climate impact of utilising identified food surplus in France as pig feed instead of sending it to current waste treatments. The resulting savings in greenhouse gas emissions are just under 2 million tonnes of carbon dioxide equivalents. The main benefit comes from replacing conventional feed components used in pig production. The most important aspect to limit the additional impact of valorising the food surplus into feed, is to decrease the impact of transporting the collecting the food surplus, as well as transporting the liquid feed to the farms.

Figure 23: Net climate impact of using processed food surplus as pig feed in France

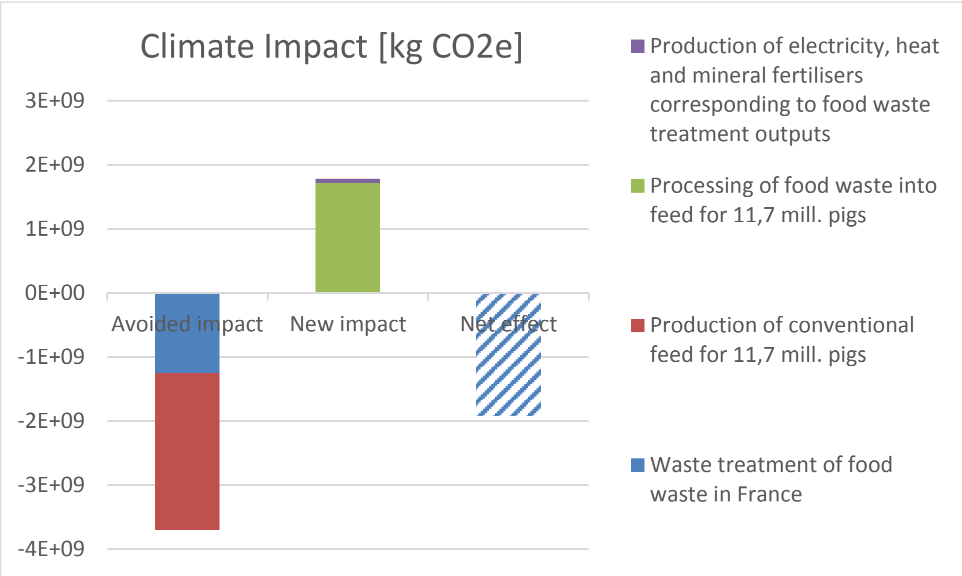
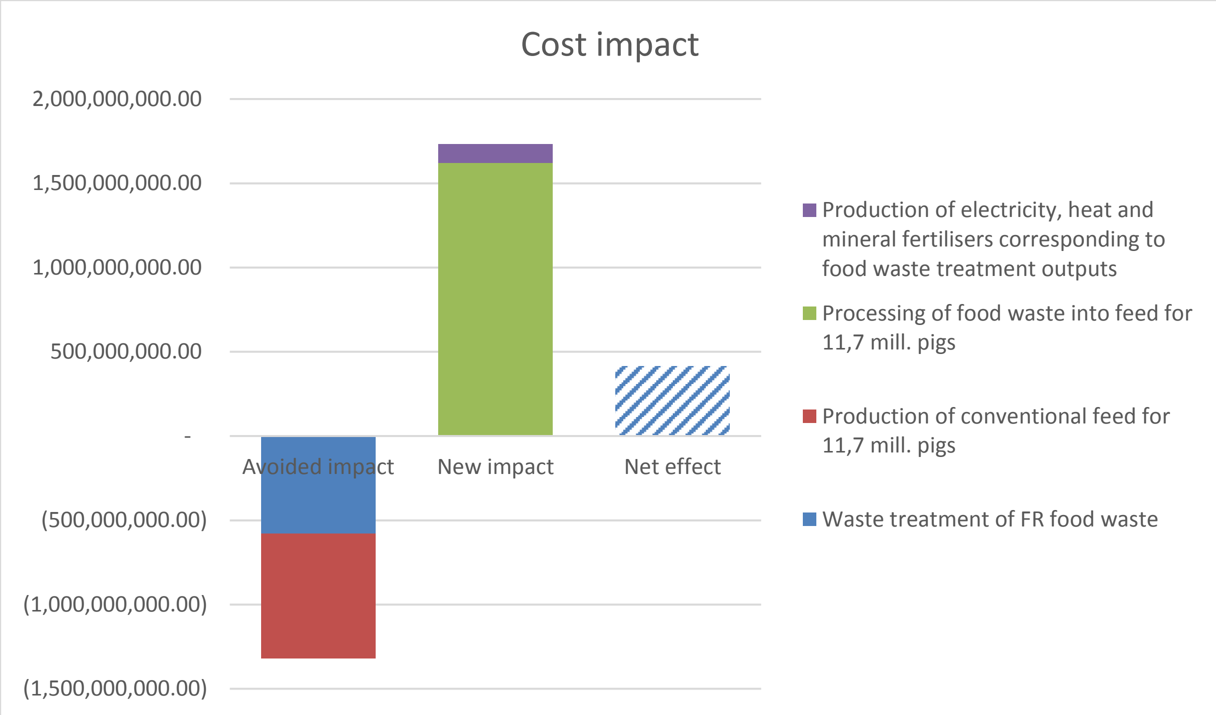


Figure 24: Net cost impact of using processed food surplus as pig feed in France



As shown in Figure 24, the net effect of using processed food surplus as animal feed would be 413 million€/year, mostly due to the increased transport cost both for food surplus collection and feed delivery to farms. Further discussions will be considered in the next chapters.

Regarding other environmental impacts than climate (shown in Table 25 in Annex), the result for France indicate that there are environmental benefits of lifting the ban for all impacts assessed except for mineral, fossil and renewable resource depletion. This will be further elaborated in the interpretation.

3.4 Interpretation

For both countries, the study shows there are climate impact benefits of allowing food surplus being fed to pigs. The scale of the reduction depends on a number of factors.

For the valorisation of the food surplus into feed, the collection of the food surplus and transporting it to the processing plant gives a significant contribution to the overall climate impact. The transport of the liquid feed to the farm is also an important contributor, even though it is proportionately smaller than the collection, mainly due to that a larger truck has been assumed in our model to be used for the transport to the farm; making it a more efficient mode of transport. Hence, to reduce the transport and to use non-fossil fuels in the collection of food surplus and the delivery of feed to the farms is an important parameter to focus on when aiming to reduce the climate impact of the food surplus valorisation into feed.

Another important parameter in the overall net effect of allowing food surplus being used as pig feed, is which conventional feed components are actually replaced. In this study we have modelled that a common mix of feed components used in each respective country is replaced. However, the type of feed component replaced, and where it has been produced, plays an important role in the net effect of environmental impacts. From a methodological perspective, this limitation should be properly addressed in a fully consequential study by appropriately modelling markets and related outlooks. In our results, the hot spot in the production of feed ingredients was soy imported from Brazil, even though it is not the most used product by mass. Potentially, the food surplus feed could replace soybeans from areas where deforestation occurs, but in cases where it would not, e.g. for farmers who instead use soy from Europe or other feed ingredients, this would mean that the reduction in climate emissions would decrease.

In Figure 25 and Figure 26 the effect of changing these two parameters, amount of conventional feed replaced and all transport distances, are shown. In the sensitivity analysis the amount of feed is increased or decreased by 30% and all transport distances in the system are increased or decreased by 30%. As can be expected the French system is more sensitive to changing the transport distances since the baseline scenario includes longer transport distances than in the UK case. Both countries are quite sensitive to the amount of conventional feed that is replaced. In the two most extreme scenarios, the ones to the right in the figure, the net saving is each respective country changes from 1.1 to either 0.6 or 1.5 million tonnes of CO^2 eq. (UK), and from 1.9 to either 0.8 or 3 million tonnes of CO^2 eq. (FR). However, even with these quite dramatic changes, both countries still show a net saving in greenhouse gas emissions. The sensitivity analysis highlights that how much might be saved, depends a lot on transport operations and which quantity of conventional feed is actually replaced.

Figure 25: Sensitivity analysis of replaced amount of feed and transport distances in UK case

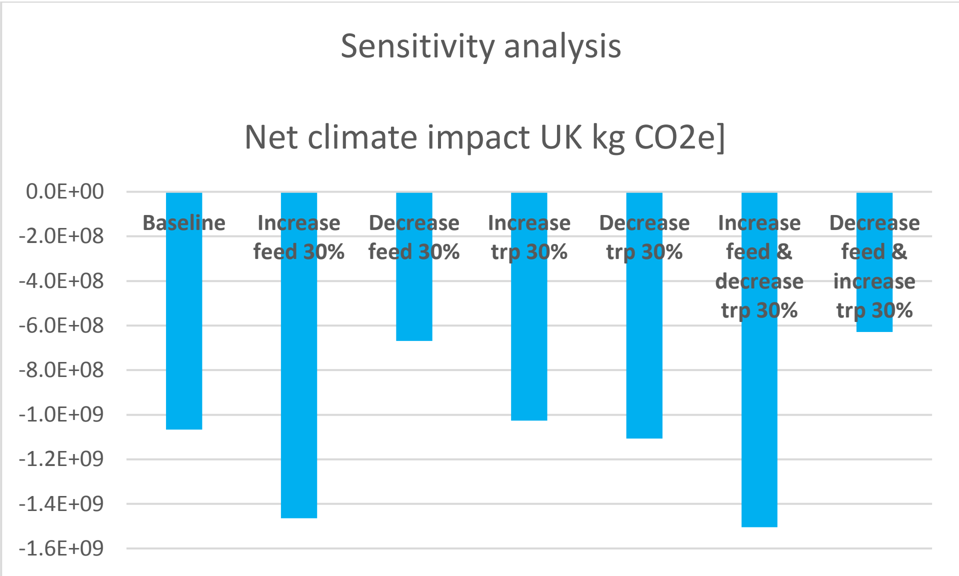
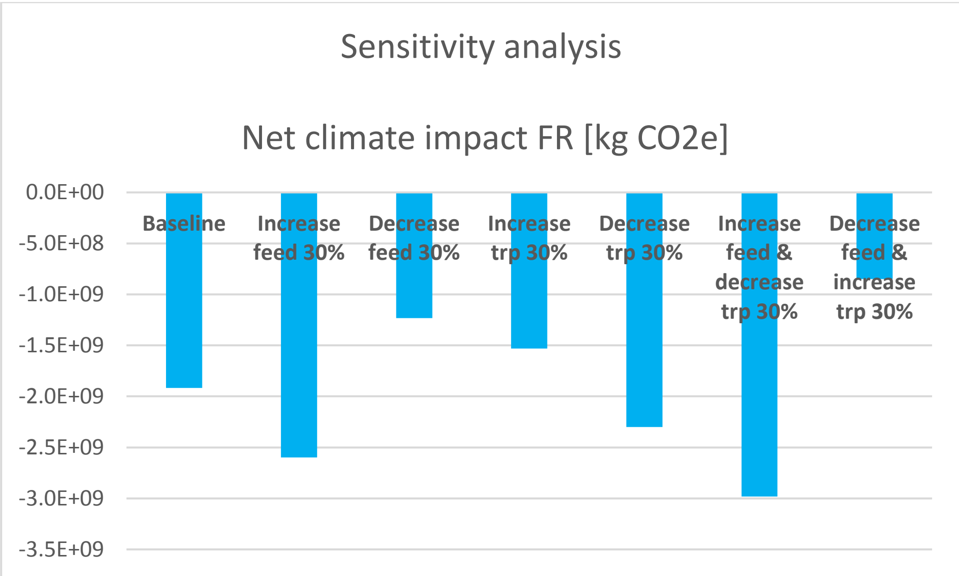


Figure 26: Sensitivity analysis of replaced amount of feed and transport distances in French case



Naturally, also the scale of change would impact on the overall climate savings that are feasible. In France, a larger mass of food surplus potentially available for valorisation into pig feed was identified; resulting in a higher overall potential for GHG savings since this could feed a larger number of pigs. In our study, we assessed that 11.7 million pigs could be grown by feed from the identified food surplus. Overall, the annual production in France is about 24 million pigs slaughtered each year (FAOSTAT, 2016), so a huge share of current conventional feed for pigs could actually be replaced. In UK, the annual production is about 11 million pigs slaughtered per year (FAO, 2016), making the share that could be potentially grown by valorised food surplus even greater (in our study assessed to be 8.7 million pigs).

Finally, what influences the net effect of making this change is the current waste treatment of food surplus. In our scenario there is still a substantial share of food surplus that is sent to landfill (e.g. catering waste in the UK), which results in methane emissions with high climate impact, and no beneficial product coming out of the treatment. This makes the benefit of instead using this food surplus as feed larger. In the future, this kind of waste treatment is likely to change, e.g. due to a policy change such as a ban of food surplus landfilling being. Consequently, the net benefit of using food surplus feed will be reduced in the future (when the negative impact of landfill will no longer be avoided).

The pattern for other environmental effects also analysed in the study is similar as for climate impact, i.e. there is a substantial benefit of allowing food surplus being fed to pigs. However, for mineral, fossil and renewable resource depletion (both countries), the result is opposite. The reason for this is the extra transport that is needed in the system. The use of resources for the transport processes in terms of production and maintenance of the trucks (which is taken into account in the data set we have used from ecoinvent), e.g. changing of tyres, is the cause of this extra environmental burden. So even though the current system also has transport operations that demand these resources, the net transport is higher in the waste to feed scenario, resulting in this net drawback in terms of resource use. This again highlights the need to focus on efficient transport when designing a system for valorising food surplus into pig feed.

Cost hotspot for the current food surplus handling scenario are identified for the UK, in the incineration. Besides, the catering sector presents other two categories not shared by the retail and the manufacturing sector for their food surplus flows, such as sink and landfill. Regarding the cost of the conventional feed mix, inputs such as barley and feed ingredients hold the highest shares in the cost, considering that there would be imported and local products but also delivery costs.

However, when it comes to the feed from food surplus processing, transport holds the highest share of cost, consistent with the expected environmental impact. In this case, calculations regarding the concentration of farms and population aid in the distance assumption for the FS processing plant location.

Further considerations should be taken into account for scaling factors used regarding the JFEC plant and its establishment in the UK, due to inputs and services availability and cost. For example, in the Japanese case, heating sources would come from different fuels than natural gas, available and cheaper in the UK (this assumption was reflected in the cost of the UK plant), and labour costs should be closely analysed even when scale economies can be reached for the variability of this type of cost.

For the net impact, incomes from electricity production (from replacing AD output) would be significant in the substitution of valorisation processes for animal feed production; however the net impact results in the saving of 278 million € per year, consistent also with environmental savings for this type of valorisation according to the UK conditions.

In contrast to the environmental impacts in the French case, costs of incineration, followed by collection represent the items with the highest share of costs followed by anaerobic digestion. This could be due to gate fees and overall costs of collection.

When assessing the cost of converting food surplus into pig feed in the French case, the hotspot is located in transport costs; however, there is still enough space for discussion, considerations and modelling required to better define the processing plant location towards the highest concentration of pig farms, and farther from the food surplus generation or population centres. Due to the transport characteristics and distances, transport bears the highest share of the production causing major influence in the cost and the environmental impact, with potential decreases depending on site selection. As in the UK case, labour costs would need further assessment as well since scaling factors from the JFEC case brought to the French case, may not capture the most realistic and efficient utilization of workers in the plant.

Although positive environmental impacts are foreseen in the French case, due to the high effect of transportation of the FS feed, the net cost impact suggests valorisation of food surplus into feed would cost more than the current scenario. However, just by better geographical allocation of the plants, potential savings in the system can be expected.

4 Case study 2: Peaches and nectarines

The REFRESH perspective

This study follows the structure proposed by the guidance Generic strategy LCA and LCC - Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain (Davis et al. 2017).

The decisions tree suggested in that publication was applied to determine which REFRESH situation was appropriate to be analysed. This research is focused on the supply chain of peaches and nectarines from farming to wholesaler gate. The answer to the guidance question: *Is the current handling about prevention/reduction of (upstream) material resources to produce a driving product?* If it is yes, this study will be focus on R1, prevention. The processes will be affected by large scale of consequences modelled as a mix; therefore, a consequential approach has been selected to capture the change produced when a prevention of FS is made.

State of the art

Fruit is typically attributed a lower environmental impact than animal-based food products. However, its production can be intensive in terms of both natural and economic resources (Torres et al. 2017). Fruit production is also characterized by relevant spoilage and overproduction, as the study of Beausang et al. (2017) highlighted. These side flows are mainly due to cosmetic specification, supply and demand changes, storage limits, weather conditions damage during harvesting, and pest and diseases. Nevertheless, surplus may occur also due to market standards, price, and unfair trade practices (Piras et al. 2018).

The implementation of prevention measures is often prioritized with the goal of achieving reduction of environmental impacts of food product (Tonini et al. 2018). Food production and indirect land use changes are highlighted as the largest contributors to the environmental burdens from FLW. This is confirmed by figures from a study analysing the environmental impact of FLW in Europe (Scherhaufer et al. 2018). This study reveals that impacts of FLW throughout the food supply chain and its management are quantifiable in 186 Mt CO2-eq, mostly due to primary production.

Findings from a study conducted in Catalonia (Spain) (Díaz-Ruiz et al, in press) mapping peaches and nectarines (PN) mass flows, reveal that between 1,3-8,6% of produce is lost due to spoilage and overproduction. Other reasons underlined were adverse climate conditions and mismanagement of production (from harvesting to wholesale storage). In Italy, approx. 220 000 t of fruit (2% of total) are not harvested (ISTAT 2018). This produce is often left in the field at farming level, while other side flows at the wholesale level are sent to processing, charity or animal feed.

While several studies analysed the environmental impact of fruit production and orchards (Milài Canals and Polo 2003; Cerutti et al. 2014) and/or their cost (Pergola et al. 2013; De Luca et al. 2014; Tamburini et al. 2015), only few studies focus on the influence of side flows, their impact, and potential reduction strategies.

This research aimed at filling this gap through a combined life cycle assessment (LCA) and costing (LCC) of peach and nectarines (PN) for fresh consumption with a focus on side flows related to spoilage and overproduction, and their prevention, in three countries: two producer countries, Italy and Spain; and one destination country, UK. Selected countries of study are a representative scenario of the European market conditions. UK is the fourth world PN importer, after Germany, Russia, and France. Spain and Italy are among the major global producer of PN (European Commission 2018).

The main questions this study wants to address are:

- What are the environmental and costing impacts of PN supply chain, from IT/SP farming to UK wholesaler considering current spoilage and overproduction?
- What are the environmental and costing impacts of PN supply chain, from IT/SP farming to UK wholesaler considering a 50% prevention of spoilage and overproduction compared with current FLW?

PN supply chain description

This study focuses on the current market of PN in Spain and Italy sold in UK. PN side flows related to spoilage and overproduction were considered in this case study. A consequential LCA was performed to calculate environmental and economic impacts considering a reduction of 50% in the current spoilage and overproduction. This will allow understanding how changes will affect the market in terms of environmental and economic impacts.

The stages considered in this research are:

- Farming: PN production in Italy and Spain.
- Transportation to wholesaler origin: Transport from farms to wholesaler at the PN origin countries, Italy and Spain.
- Wholesaler at origin: This stage includes activities related to cleaning, storage and pre-packaging of PN.
- Transport to wholesaler destination: Transport from wholesaler origin to wholesaler in UK.
- Wholesaler at destination: This stage includes the storage and packaging performed at the UK wholesaler.

Detailed information is provided in the next sections.

4.1 Goal and scope

The goal of this study was to assess the environmental impacts and cost of peach/nectarine (PN) spoilage and overproduction along the supply chain, from cradle to gate, considering Italian and Spanish PN production sold in UK. The study analysed the different valorisation routes calculating the related environmental and costing impact.

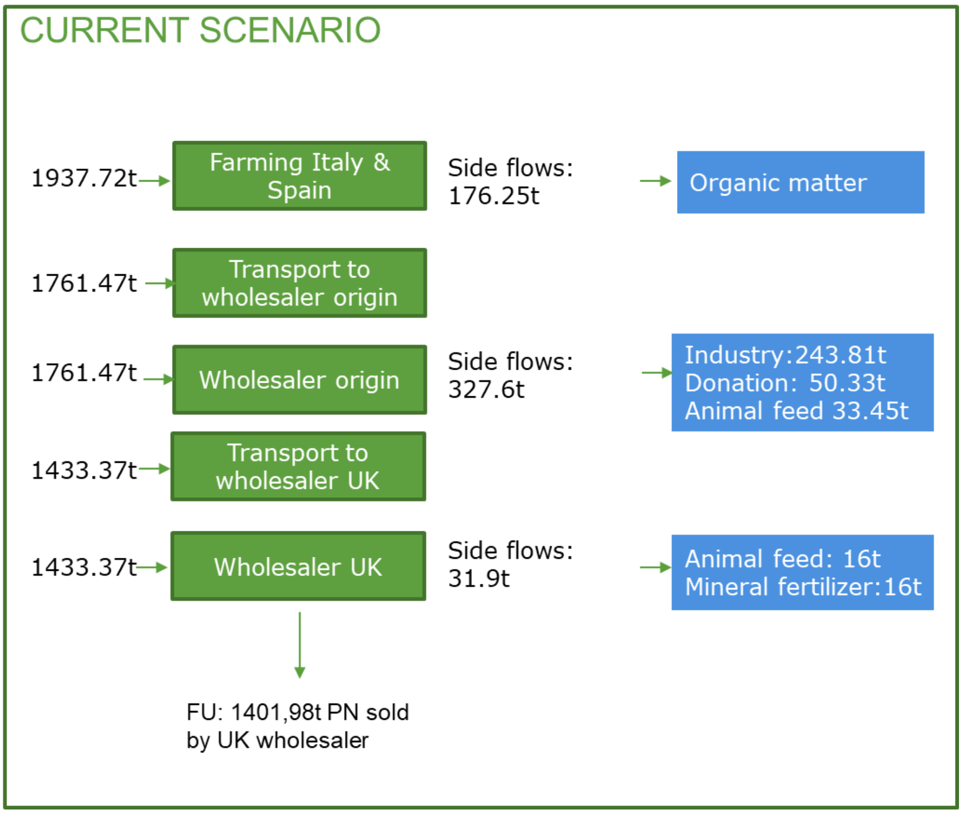
4.1.1 Functional unit

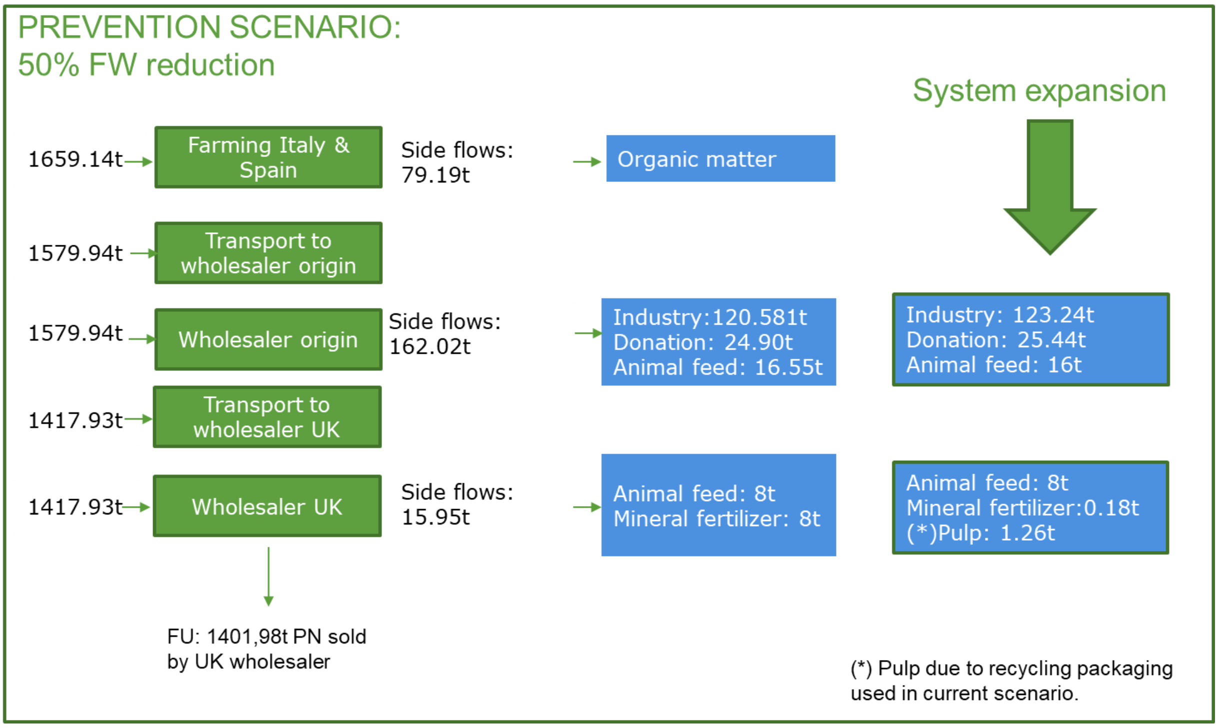
The functional unit was defined as the amount of **peaches/nectarines throughput per year at one wholesaler** in UK, from cradle to grave. Producing countries of reference are Italy and Spain, for the UK wholesale market.

4.1.2 System description and boundaries

The study follows a consequential LCA, cradle to retail gate approach. As identified, the scenario is a RS 1 (prevention of side flow); the system should thereby include all impacts/costs from the production of driving product, and then from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include this also as avoided impacts/costs. The study considers Italian and Spanish PN production sold in UK wholesaler and related spoilage and overproduction. PN in Italy and Spain are characterized by conventional agricultural practices. Once the PN are harvested, they are sent to wholesaler in the country of origin for storage and pre-packaging. After this phase, they are transported by truck to the UK wholesaler where they are packaged for sale to retailers. Consequential LCA assesses the net change in environmental impact and costs from an intervention. This intervention studied here prevents 50% of current spoilage and overproduction in the PN value chain. Figure 27 shows current and prevention scenario. The prevention scenario includes a system expansion to account for the market substitution of avoided PN side flows.

Figure 27: System boundaries of the peach/nectarine case study





As in many products, PN production can be used for other goods, such as jam and juices, animal feed, distilled products, or composting, among others. Allocation or system expansion of the environmental impacts have to be made according to this production pattern. According to the methodology outlined in D5.3, this study adopts a system expansion approach in order to account for avoided outputs of the current RS2/3 scenarios in moving towards the prevention scenario RS1. In particular, it includes substitute products of fruit for processing and donation, fruit for feed, composted fruit, and recycled packaging. System expansion at farming stage is not considered since it is assumed that spoiled produce left in the field does not generate significant environmental benefits/impacts.

4.2 Life cycle inventory

Table 20 provides an overview of the type of data collected for every stage of the supply chain investigated. The overall mass flow and the related impacts and costs were modelled starting from the abovementioned FU (the PN yearly throughput of the UK wholesaler) and moving back in the supply chain basing on primary and secondary data on food surplus, respectively in the wholesale at the origin and farming stages. Both previous studies and databases were used to model impacts and cost for PN farming in Italy and Spain. For downwards supply chain segments, the majority of inventory data needed to model the foreground processes were collected through direct interviews and questionnaires. Environmental impacts and costs of background processes were sourced from other studies or reports, and from databases. The following sections provide a detailed description of assumptions and data sources used to model the inventory of both scenarios. A full inventory of processes is provided in the annex, Table 26.

Table 20: Type of data

Stage		Primary data	Secondary data: Other studies	Secondary data: Databases
Farming	*Italy*		• PN side flows • Environmental impacts and costs	• Environmental impacts
	Spain		• PN side flows • Costs	• Environmental impacts
Transport to wholesale at origin		• Mode and distance • Cost		• Environmental impact
Wholesale at origin		• PN mass flows and waste • Energy and water use, working hours, amount and cost of packaging • Waste management scenario and cost		• Environmental impacts of background processes • Cost of other inputs
Transport to UK		• Mode and distance Cost		• Environmental impact
Wholesale at destination		• PN mass flows and waste • Energy use, working hours, amount and price of packaging • Waste management scenario		• Environmental impacts of background processes • Cost of inputs and waste disposal

4.2.1 Current practice scenario

Farming

Basing on the interviews with technical managers, the UK wholesaler is importing 17% and 83% of PN respectively from Italy and Spain. In particular, 60% of the Italian PN purchased come from the north of the country and 40% from the centre and south. Almost 62% of the Spanish PN supply are coming from North East, while the rest 38% is supplied equally from Central West and South East Spain.

Due to the impossibility to collect primary data from farmers, we relied on secondary data sources to account for the environmental and cost impact of Italian and Spanish farms. Table 21 summarizes all the sources used for the farming stage. In particular, based on literature review, it was assumed that peaches and nectarines have, on average, the same environmental impact per kg produced. The same process was used for peaches and nectarines of the same region. As mentioned, most of studies on peaches does not explicitly distinguish between the two varieties and reported results are quite similar, taking also into account the diversity of method used. In addition, due to lack of more reliable and complete data, the same database process was used for all Spanish PN, regardless of their regional origin. Costing data from De Menna et al. (2018), which are related to Emilia Romagna, were used also for central south Italy. Regional-specific data were used for Spain. Data in Italy and Spain are referred to PN production in 2016-2017.

These assumptions can have some sensible effects on results and therefore will be properly recognized in the interpretation of results.

Table 21: Farming data sources

Origin	Data Sources		
	Environmental impacts	*Costs*	*Side flows*
PN N-IT	De Menna et al. 2018		
PN S-IT	Ecoinvent 3, Peach {IT}| peach production | Alloc Def, U	De Menna et al. 2018	
PN NE-SP	Ecoinvent 3, Peach {ES}| peach production | Alloc Def, U	INE 2018	Díaz-Ruiz, R et al. 2018
PN CW-SP	Ecoinvent 3, Peach {ES}| peach production | Alloc Def, U	INE 2018	Díaz-Ruiz, R et al. 2018
PN SE-SP	Ecoinvent 3, Peach {ES}| peach production | Alloc Def, U	INE 2018	Díaz-Ruiz, R et al. 2018

Transport to wholesale at origin

Based on PN amounts from each region, total load was calculated considering the weight of reusable plastic bins (no environmental impact considered) with a capacity of 470 kg and a 28 kg weight (Socepi, 2018).

Averaged transport distances were estimated basing on the location of wholesaler at the origin, provided by the UK wholesaler, and the main PN production areas in the region:

- From Italian farmers to wholesaler at origin (North): 70 km;
- From Italian farmers to wholesaler at origin (South): 150 km;
- From Spanish farmers to wholesaler at Spain (South-East): 120 km;
- From Spanish farmers to wholesaler at origin (North-East): 250 km;
- From Spanish farmers to wholesaler at origin (Central-West): 200 km.

According to information provided by italian wholesalers, fruit is travelling mostly on small trucks with an estimated cost of 0.166€/tkm. The related environmental impact was derived from Ecoinvent 3 (process: Transport, freight, lorry 3.5-7.5 metric ton, EURO4 {GLO}| market for | Alloc Def U), considering the relatively old age on the European truck fleet (ACEA 2018).

Wholesale at origin

Modeling of this stage was carried out basing on primary data collected through interviews with italian wholesalers about: amount of energy and working hours needed for conservation and packing, water for washing (and related disposal), cardboard for packaging, amount of surplus and related disposal.

Interviews conducted in Italy revealed that wholesalers are losing between 10 and 16% of the produce. The main reasons of wasting PN are quality controls, withdraw and orders' cancellation. FLW follow the following routes in Italy:

- Farming level: PN are left in the field.
- Wholesale level: PN go to industry (for example for preparing juices, jam or alcohol), animal feed and charity donation. All those scenarios have any revenue for most of the interviewed wholesalers.

Assumptions and data sources are shown in Table 22.

Table 22: Wholesale at origin data sources

Input	Notes and assumptions	Data sources	
		Environmental impacts	*Costs*
Electricity IT		Electricity, low voltage {IT}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	EUROSTAT 2018
	North IT supplier: 30% self-produced photovoltaic electricity	Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	Free of cost
Electricity SP		Electricity, low voltage {ES}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	EUROSTAT 2018
Water IT & SP		Tap water {Europe without Switzerland}| market for | Alloc Def, U	EurEau 2017
Labour IT & SP		Not considered	EUROSTAT 2018
Cardboard	0.4kg box for 5kg packed PN; 0.4kg box for 6.3kg loose PN	Corrugated board box {GLO}| market for corrugated board box | Alloc Def, U (of project	0,75€/box (interviews)

		Ecoinvent 3 - allocation, default - unit)	
Side flows to processing	Only impact from transport (100km) and avoided cost	Transport, freight, lorry 3.5-7.5 metric ton, EURO4 {GLO}| market for | Alloc Def	Average selling price of farmed peaches for processing (De Menna et al. 2018) net of transport cost (interviews)
Side flows to donation	Only impact from transport (100km) and avoided cost	Transport, freight, lorry 3.5-7.5 metric ton, EURO4 {GLO}| market for | Alloc Def	Maximum revenue foreseen by EU CAP (RER 2018) net of transport cost (interviews)
Side flows to animal feed	Only impact from transport (100km) and avoided cost	Transport, freight, lorry 3.5-7.5 metric ton, EURO4 {GLO}| market for | Alloc Def	Maximum revenue foreseen by EU CAP (RER 2018) net of transport cost (interviews)
Waste-water		Wastewater, from residence {RoW}| treatment of, capacity 1.1E10l/year | Alloc Def, U	No cost figure available

Transport to UK

Based on PN amounts from each region shipped to UK wholesaler, total load of PN including cardboard boxes was calculated. Average distances from wholesale at origin were communicated by the UK wholesaler:

- From North Italian wholesaler: 1 242 km
- From South Italian wholesaler: 1 732 km
- From South-East wholesaler: 2 035 km
- From North-East wholesaler: 1 407 km
- From Central-West wholesaler: 1 854 km

Fruit is shipped on refrigerated trucks with an average cost of 0.834€/tkm. The related environmental impact was derived from Ecoinvent 3 (process: Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, carbon dioxide, liquid refrigerant, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, carbon dioxide, liquid refrig. | Alloc Def, U), considering the relatively old age on the European truck fleet (ACEA 2018).

Wholesale at destination

The UK wholesaler involved in the study collected all the data related to: amount of PN purchased by origin, related side flows and disposal; amount of energy and working hours needed for conservation and packing; amount, type, material and cost of packaging. In UK wholesale, most side flows are due to quality control tasks, product shelf life samples, lost-in-repack, customer & internal benchmarking, samples, extra checks, etc. Assumptions and data sources for environmental impacts and costs are shown in Table 23.

Table 23: Wholesale at destination data sources

Input	Notes and assumptions	Data sources	
		Environmental impacts	Costs
Electricity UK		Electricity, low voltage {GB}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	EUROSTAT 2018
Labour UK		Not considered	EUROSTAT 2018
White pulp tray	Tray	1 kg Sulfite pulp, bleached {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	10,08€/kg
Polyethylene film	Wrap film	1 kg Packaging film, low density polyethylene {GLO}| market for | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	
Retailer tray	returnable PP crates, assumed reuse	Not considered	Not considered
Cardboard recycling	only impacts from collection (5km from the waste management company)	5 kgkm Municipal waste collection service by 21 metric ton lorry {RoW}| market for municipal waste collection service by 21 metric ton lorry | Alloc Def, U (of project EU REFRESH)	WRAP 2018
Animal feed	only impacts from collection (5km from the waste management company)	5 kgkm Municipal waste collection service by 21 metric ton lorry {RoW}| market for municipal waste collection service by 21 metric ton lorry | Alloc Def, U (of project EU REFRESH)	WRAP 2018
Compost	collection and disposal	1 kg Biowaste {CH}| treatment of, composting | Alloc Def, U (of project Ecoinvent 3 - allocation, default - unit)	WRAP 2018

4.2.2 Side flows prevention scenario

As mentioned in the goal and scope, the future scenario is assuming the implementation of prevention measures allowing a 50% reduction of current PN spoilage and overproduction in all segments of the considered supply chain. Clearly, it represents a hypothetical situation in which more strategies are combined together to increase the overall efficiency.

The LCI of this scenario is changing from the current practice scenario in terms of material flow and external consequences. First, reduced amounts of PN, and related inputs and outputs, are needed per PN sold in each stage. Table 26 in annex shows the comparison of future scenario LCI with the current situation. Second, a system expansion was carried out to include additional functions that are displaced in the transition.

When PN side flows are partially prevented, some disposal routes (both fruit and packaging) are affected. In the farming stage, PN side flows are currently left in the fields and no benefit in terms of soil improvement and nutrient balance was considered, since farmers are not reducing fertilizers accordingly in the next year. Therefore, when spoiled produce or overproduction is prevented, it is reasonable to assume that farmers would not use more fertilizers. This assumption should be verified with further research and primary data on the effect of fruit side flows on the soil quality and nutrient balance.

In the wholesale at origin, PN side flows are currently sent to fruit processors, charities, and animal feed producer. When these flows are prevented, there are some possible consequences on related markets. In particular, the following consequences were assumed:

- Fruit processors will likely source PN from other producers, with an average environmental impact (using ecoinvent processes as above) and a lower price than PN for fresh consumption (De Menna et al. 2018);
- Charities will probably receive surplus PN from other sources, with an average environmental impact (using ecoinvent processes as above) and free of cost;
- Feed producers will substitute surplus PN with other similar by-products, and not with conventional feed products, as fruit is generally an additive; this substitution will not have an environmental burden or a value.

In the wholesale at destination, PN side flows are currently composted or sent to animal feed producers by the waste management company. It was assumed that avoided compost will be replaced by urea, using ecoinvent data (Urea, as N {GLO}| market for | Alloc Def, U), price from Indexmundi 2018, and considering a 540kg of compost per ton of PN side flow with a 0.043kg Urea to 1kg compost substitution ratio (Mondello et al. 2018). Other by-products will substitute avoided fruit for feed, as for the wholesale at origin. In addition, since less PN will be purchased, less cardboard boxes will be recycled, sulphate pulp was assumed to replace recycled pulp, using Ecoinvent data (Sulphate pulp {GLO}| market for | Alloc Def, U) and price from Indexmundi 2018.

4.3 Impact assessment

4.3.1 Methodology

The environmental impacts have been assessed using the ILCD impact assessment methodology recommended by the European commission (EC, 2012). For climate impact, the Intergovernmental Panel on Climate Change (IPCC) released new characterisation factors for greenhouse gas emissions in 2013 (IPCC, 2013); therefore, we have used these for climate impact results. The climate impact using the ILCD method are however also available in the Annex. Environmental indicators considered in this study:

- IPCC GWP 100a
- Climate change
- Water resource depletion
- Mineral, fossil and resource depletion
- Freshwater eutrophication
- Marine eutrophication
- Terrestrial eutrophication
- Acidification
- Land use

As far as cost modelling is regarded, the following type of costs were assessed along the supply chain: internal, avoided, and external. Revenues from selling PN were not considered due to the commercial sensitivity of price data. Costs were also categorized by stage and by the following typology: material, energy, labour, transport, others, avoided, external. Distribution of costs by cost bearer along the supply chain was also assessed. No evaluation of net present value or added value was carried out.

4.3.2 Results

Current practice scenario

In the current scenario, the UK wholesaler is selling 1,4 million kg of PN. In the whole supply chain, side flows amount at 0,5 million kg, mostly arising at wholesaler at the origin and farm levels. On average, spoiled produce and overproduction cause 0,38 kg per kg of PN to be disposed before retail.

Figure 28 shows the climate impact of the current PN supply chain up to wholesaler gate in UK. Total impact is about 1,37E+06 kg CO2e/year, equivalent to 0,98 kg CO2e/kg of PN. Almost one fourth of the climate impact is deriving from refrigerated transport to UK from countries of origin. The second segment in terms of impact is wholesale in UK, followed by wholesale at origin. Slightly more than 20% of the impact is caused by farming and transport from farm to packinghouses.

Figure 28: Climate impact from current PN supply chain

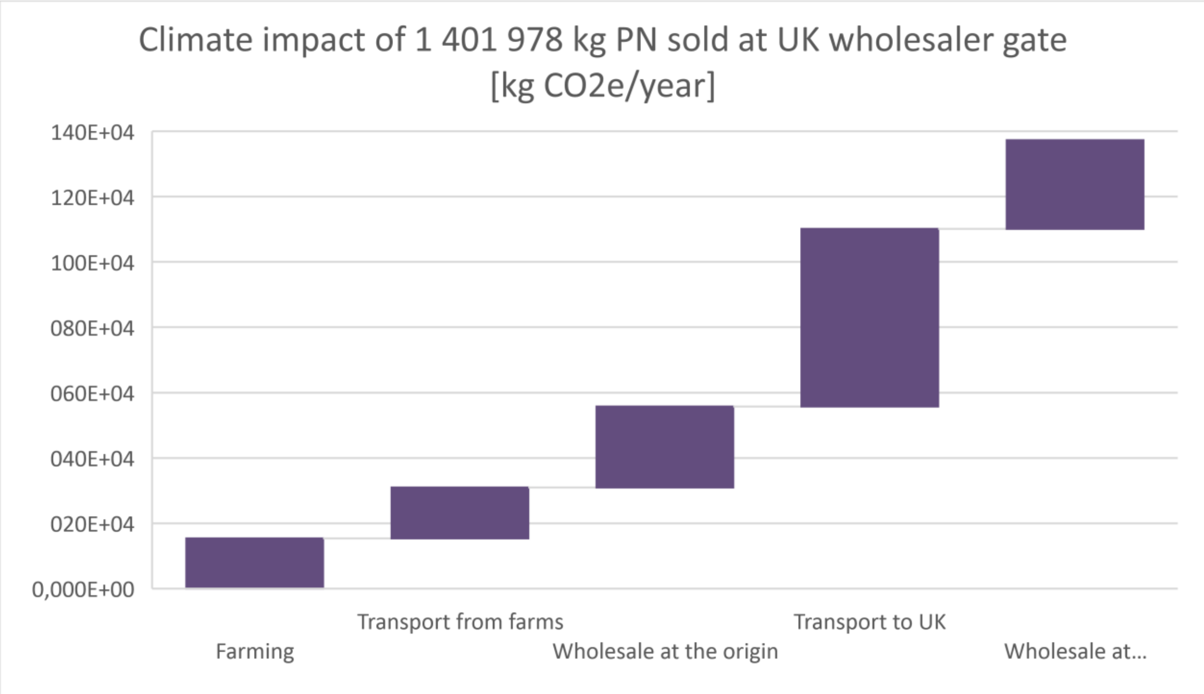
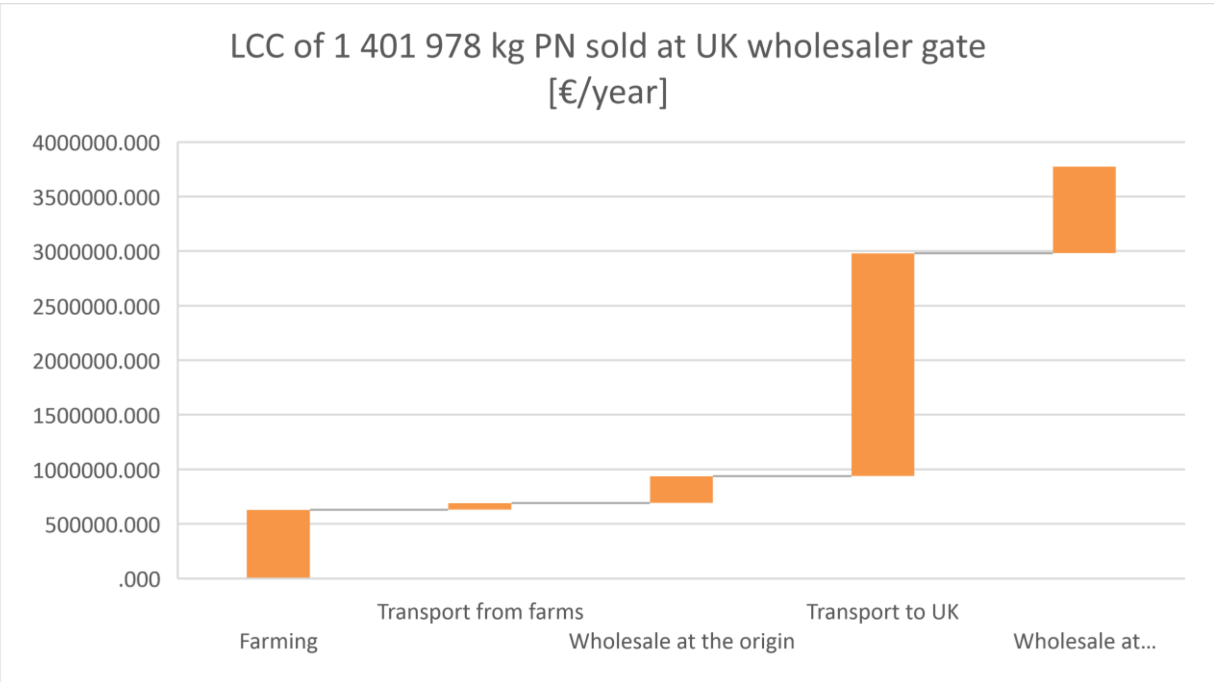


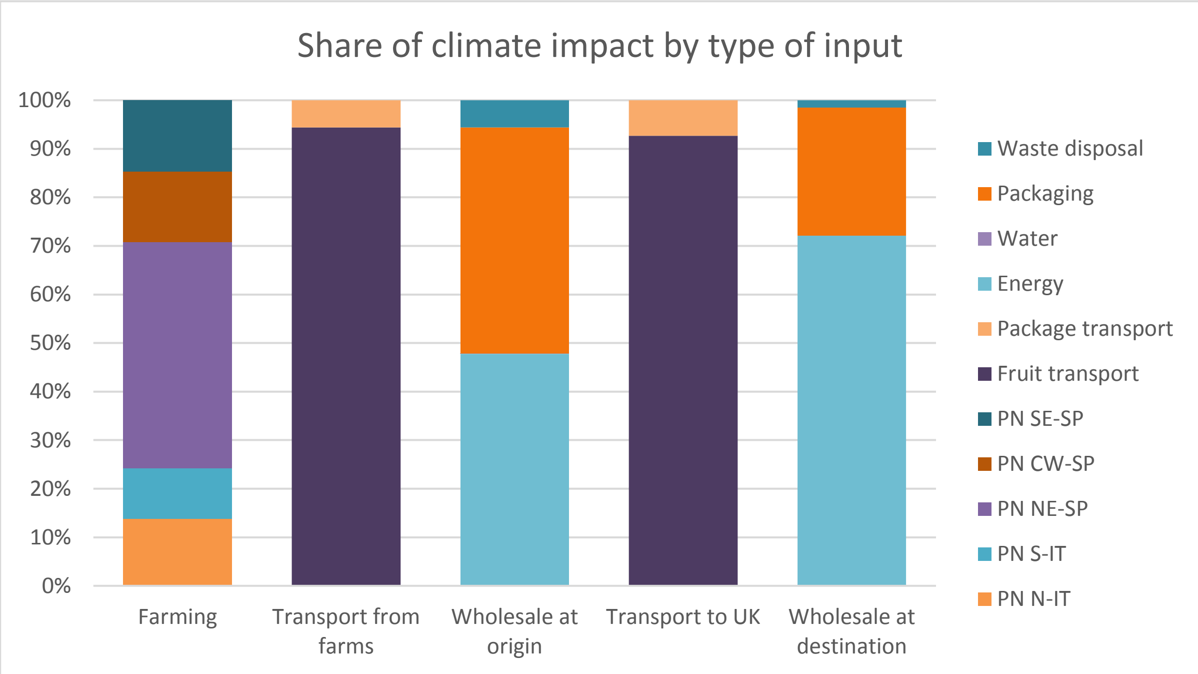
Figure 29 reports the corresponding LCC of the whole supply chain. Total cost is about 3.8 Million €, equivalent to 2.7 €/kg of PN sold. Transport to UK is even more relevant in terms of costs, since it represents the 54% of the overall amount. Wholesale at destination amounts at 20%, while farming is more relevant than wholesale at origin. Transport from farms is instead relatively inexpensive.

Figure 29: LCC of current PN supply chain



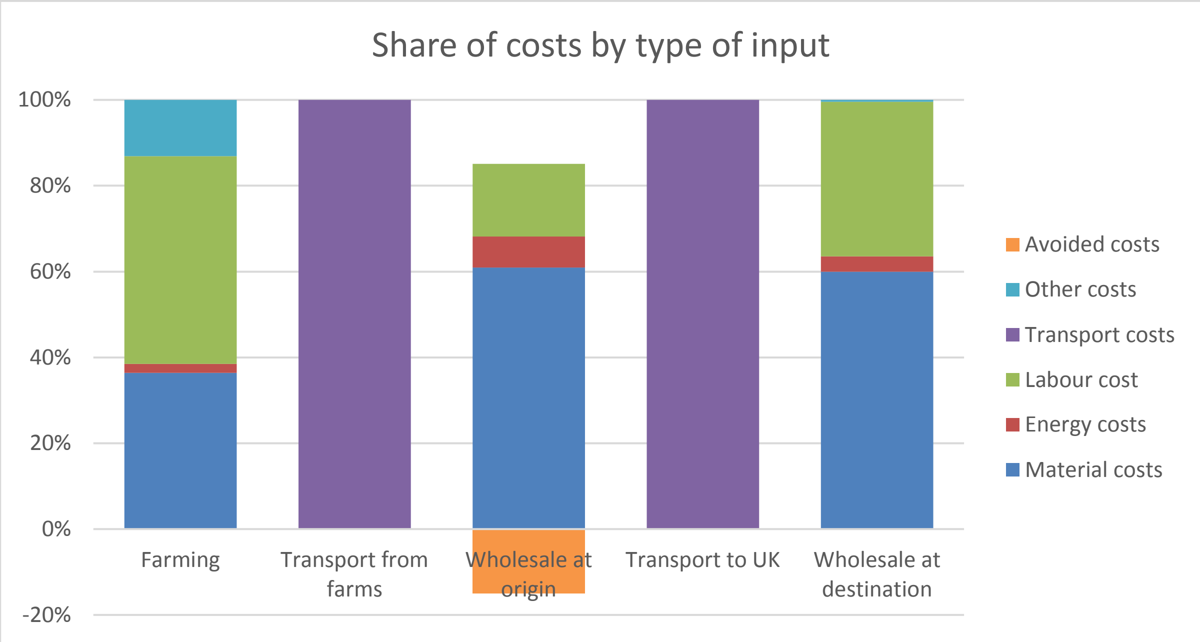
By analysing the shares of impacts (Figure 30) and costs (Figure 31) in each segment, it is possible to identify the main hotspots. In farming, most of the impact (77%) is coming from Spanish PN, due to the larger mass sourced from that country. However, Italian PN have a comparatively higher impact and cost (Figure 32) related to a greater specific intensity of production.

Figure 30: Share of climate impact by type of input



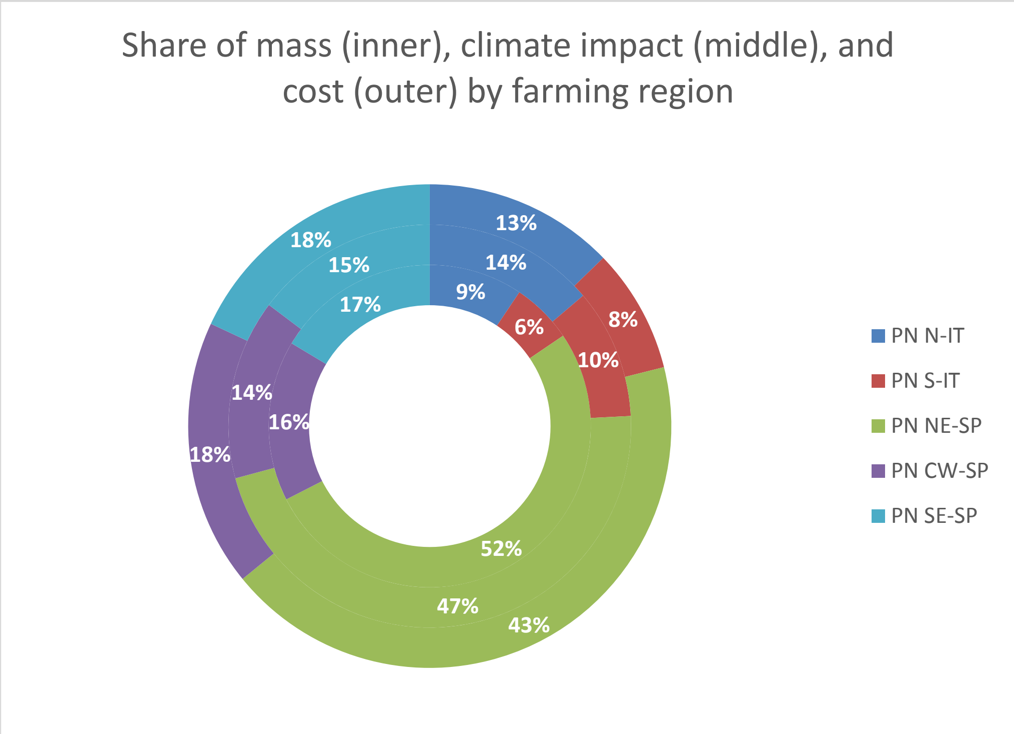
Both in transport from farms and to UK, mass of fruit is more relevant than packaging (bins and cardboard) respectively. Considering the role of transport-related damages, potential savings from side flows prevention might compensate the additional impact from the weight of more protective package, if using recycled/recyclable material. Wholesalers at origin and in UK have a similar environmental profile, with energy and packaging as main contributors. White pulp trays used during wholesale at destination are however less impacting than cardboard due to the reduced weight. Waste disposal (transport of fruit to processors or charities) is more relevant in the first case due to the larger distance travelled by surplus.

Figure 31: Share of costs by type of input



When costs are considered, transport and materials (from fertilizers and chemicals to packaging) are the most relevant costs in the supply chain. However, labour is quite relevant especially at farms (average of 48% of costs) and in the wholesale at destination (38%), while energy and other costs (e.g. waste disposal) are residual. The only segment with some avoided costs is wholesale at the origin, where some revenues, equivalent to 17% of the segment costs, are generated by PN side flowsx management (e.g. processing and product withdrawals).

Figure 32: Share of PN mass, climate impact, and costs by region



Prevention scenario and net effect

In the prevention scenario, the functional unit remains the same (1.4 million kg of PN sold to retail), but 50% of current side flows is prevented throughout the supply chain with a mix of measures (e.g. relaxation of market standards, improved crop management, etc.). Figures related to PN side flows are reduced to 0.26 million kg per year and 0.18kg per every kg sold.

Direct effects on the climate and cost impact of the supply chain are represented in Figure 33 and Figure 34 respectively. The impact on climate change decreases to 1.32E+06 kg CO2e/year, equivalent to a 4% reduction. The overall cost decreases to 3.7 Million €/year, with a 2.6% reduction. In fact, the reduction of side flows in the wholesale at the origin leads to reduced avoided costs from related management (processing, charities, and feed). It must be noted how, assuming a constant purchase and selling price per kg, the wholesaler would register a substantial increase in the profits, since he would need to buy less PN per PN sold, overcompensating the reduced avoided costs.

Figure 33: Climate impact from PN supply chain - prevention scenario

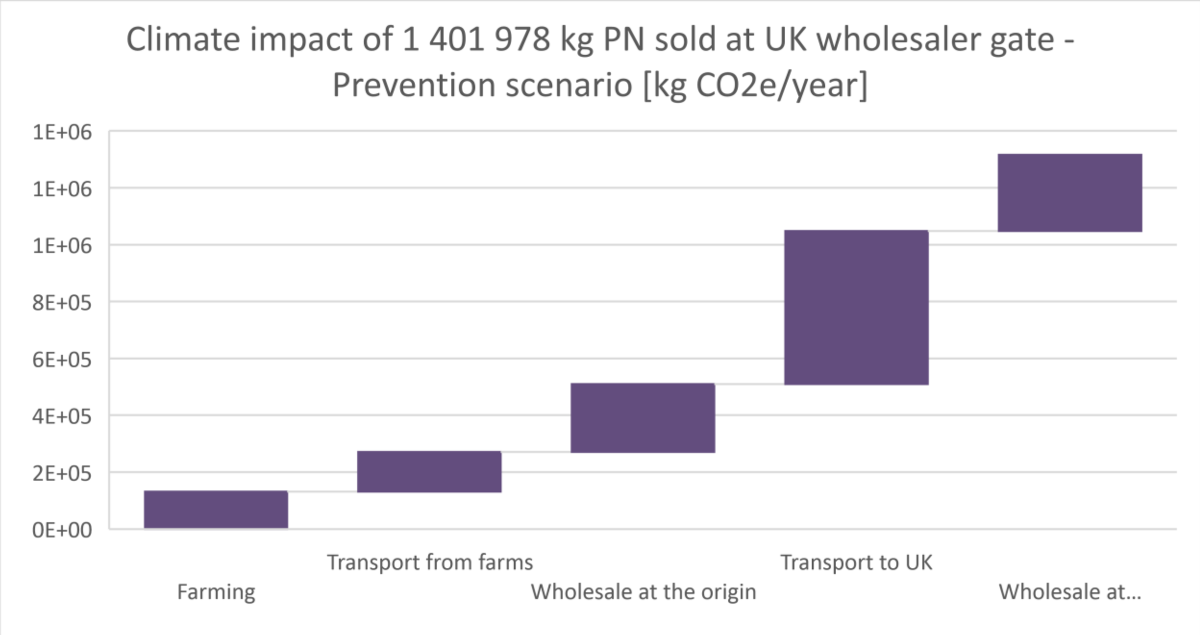


Figure 34: LCC of PN supply chain - prevention scenario

In addition to the changes in the supply chain, also external consequences must be accounted for. Figure 35 shows the added impact deriving from system expansion, respectively for climate change and costs. Further 15E+03 kg CO2e/year and 5300 €/y should be added to the overall impact of the change. Most added impact would derive from the need to substitute for avoided fruit for processing (both LCA and LCC) and donations (only LCA), while the impact of additional mineral fertilizer and virgin pulp is limited.

Figure 35: Added impacts from system expansion

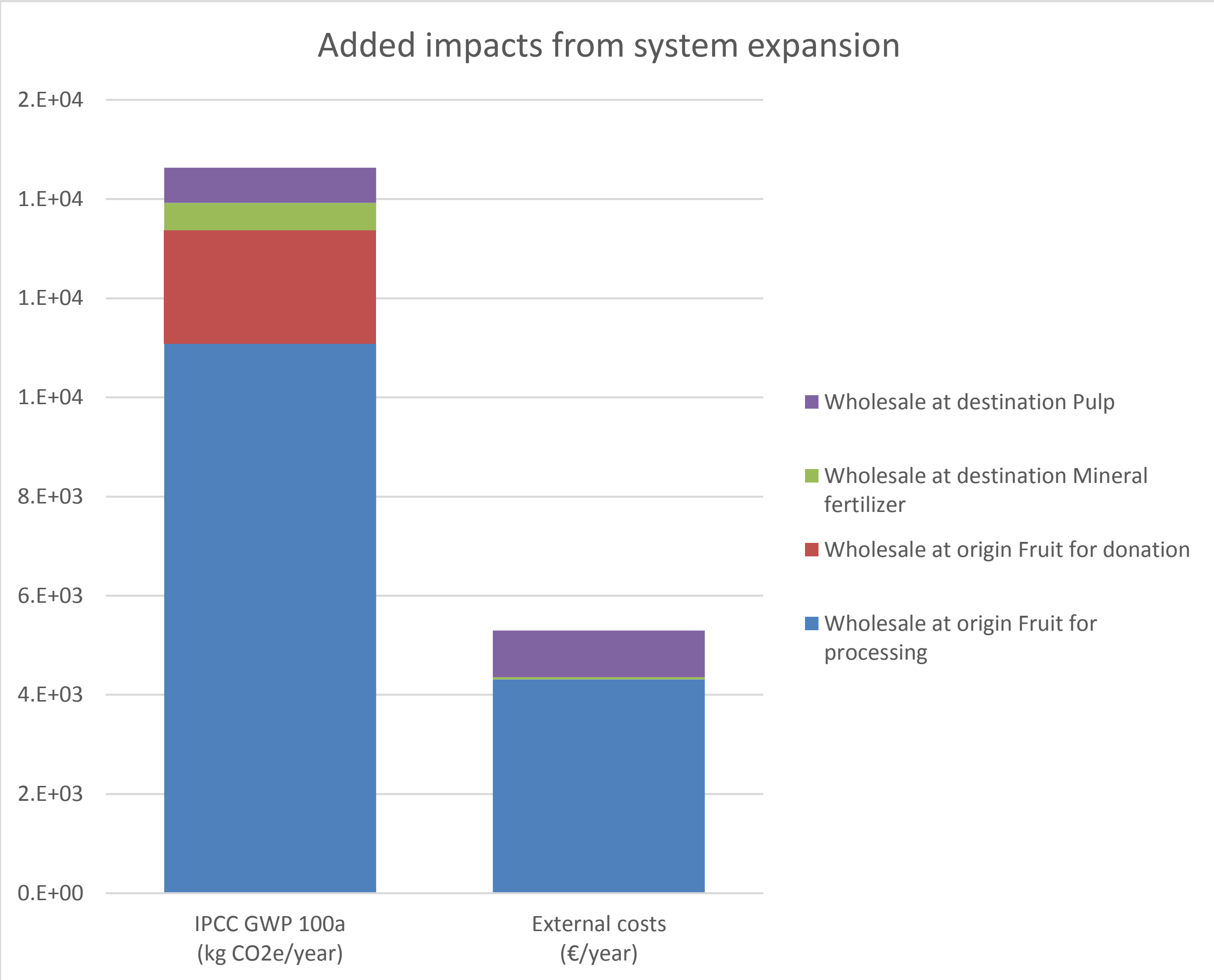


Figure 36 and Figure 37 show the comparison of current scenario, future prevention, the added impact, and the net effect on climate change and costs respectively. In both cases, there would be a net benefit in preventing spoilage and overproduction for the overall supply chain. When considering each segment, it is possible to see how farming would capture most of the benefit, along with transport, while wholesaler at the origin would see an increase in both the environmental impact (including indirect effects) and costs (including external costs).

Regarding other environmental impacts than climate (shown in Table 27 and 28 in Annex), the results indicate that there are overall environmental benefits for the prevention scenario for all impacts assessed. In terms of hotspots, there would be an increase of the wholesale at origin deriving from the added impacts of external effects.

Figure 36: Comparison of climate change

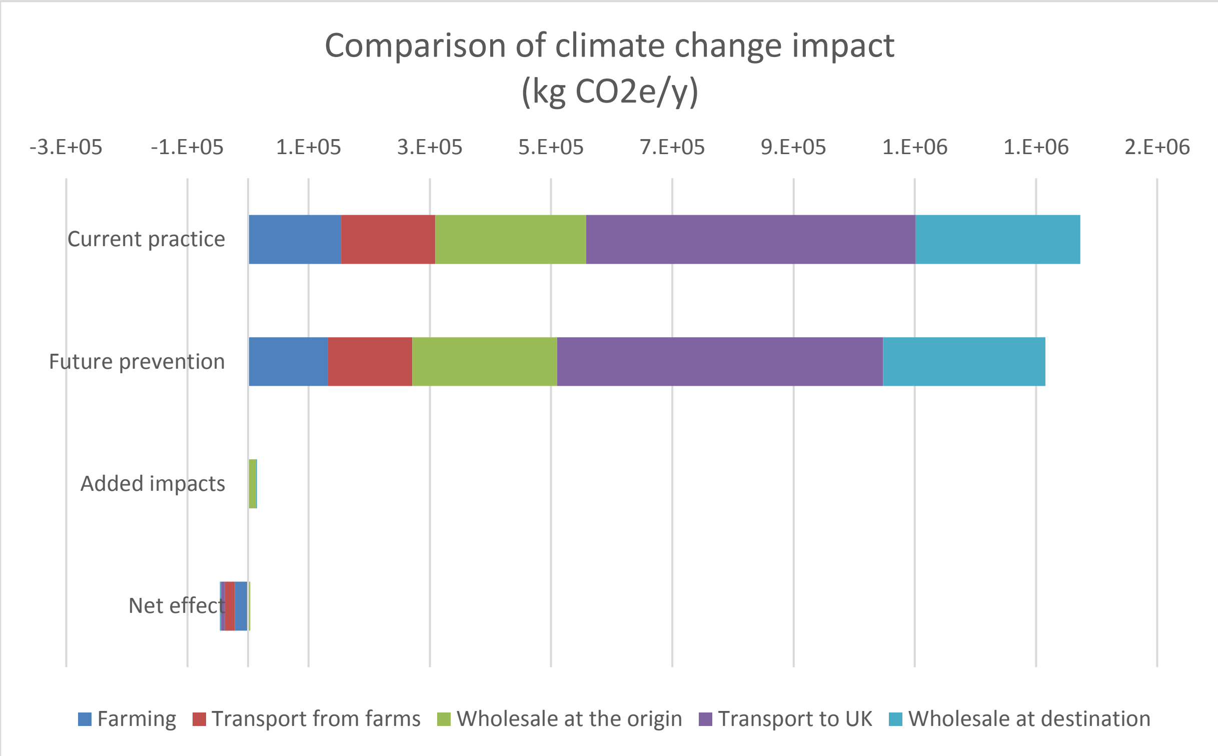
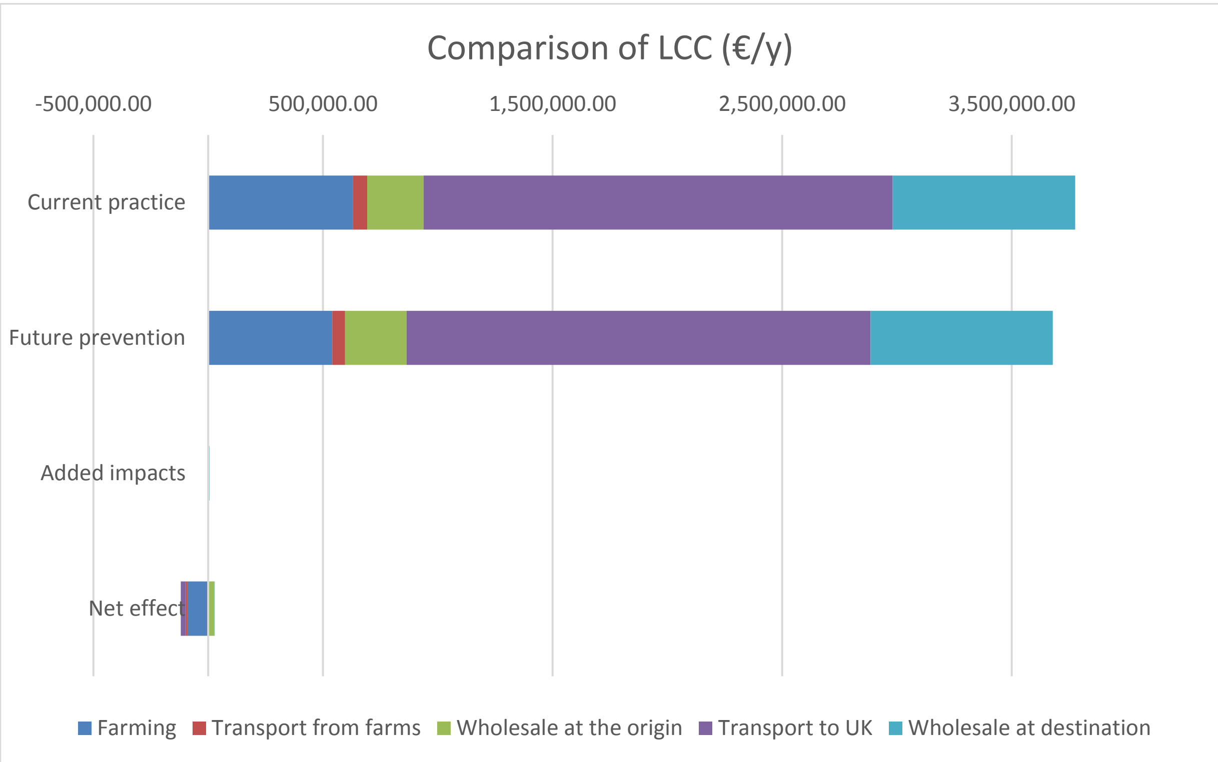


Figure 37: Comparison of LCC



4.4 Interpretation

Hotspots

From an environmental perspective, more than 1/3 of the climate change impacts are due to the PN transportation from producing countries to UK. Climate controlled trucks is causing larger climate change impact than non-refrigerated trucks. Nevertheless, they might avoid some food surplus by prolonging the product shelf life. EURO4 was considered as emission standard, considering the average age of heavy-duty vehicles in EU. The optimization of logistic routes and truck storage plays a key role in the environmental impacts as well as the costing. Investments in more efficient trucks, alternative transporting fuels, could improve the current situation generating less environmental impacts. Packaging used for transportation accounts for about 10% of the climate change impact of this stage. As for the refrigeration, on one side packaging increases the climate change impact of PNs, due to its production and end of life, but on the other side it avoids product damages from transport, extending PN shelf life.

About 40% of the environmental impact is caused by the wholesaler stages (origin and destination). It is mostly due to the energy required for storage and packing, and the impact of packaging itself. Wholesaler at origin requires more energy for storage and ripening, while wholesaler at destination requires more energy related to packaging process. The impacts from the cardboard trays are the most relevant; therefore this aspect could be improved if they were reusable, produced out of recycled material, or if current trays were more efficient (in terms of weight) than current ones.

About 22% of the environmental impact is related to farming and transport from farm to origin wholesaler. Farming stage includes fertilizers and agrochemical products as inputs, and those are the biggest contributors to climate change. Secondary data used in this study are quite in line with other research but some variations can be found. For example, a research performed in Spain reveals a carbon footprint value of peach of 0.381 kgCO_2e up to consumption, with a 36% attributable to the farming stage (Vinyes et al. 2017). Another study from the same author confirms a range between 0.16 kg CO2eqkg and 0.37 kg CO2e per 1kg of peach produced, depending on the orchard year (Vinyes et al. 2015). For this reason a sensitivity analysis was carried out on this parameter (see following section).

Focusing on other impact indicators: water depletion has the largest value at farming stage while at transport levels is very low (less than 100 m3 water eq. compared with more than 518 580 m3 water eq. at farming stage); MFRD has the biggest value at wholesaler at origin, while transport to UK is very low (0.23 kg Sb eq.). Regarding eutrophication effects, FE is more affected at farming and wholesaler level while ME and TE are being more affected at transport to UK stage. AC has also its biggest value at wholesaler stage (the sum of origin and destination); while LU kg C deficit has the greatest value at wholesaler stage due to cardboard and white pulp production for packaging.

The costing analysis followed the same distribution as the environmental impacts. Therefore, the biggest costing impact occurs at transportation from wholesaler at origin to destination stage. It accounts for more than the 50% of the total costs at the studied supply chain. After that stage, the next cost is related to wholesaler at destination due to the packaging involved and the amount of labour requested for packaging and storage management. After wholesaler UK, farming has the biggest cost. It is mainly due to labour force (about 67% in Italy and 50% in Spain of the stage cost), followed by farming materials.

The 50% prevention scenario simulated in the study provided some interesting results. The general effect would a potential net reduction of impacts. Only at the wholesale level in the origin countries, there would be a net increase in both the environmental impact and costs, deriving from the external effects of fruit surplus prevention. In particular, since current destination of PN side flows is including some valorisation as donations and fruit processing, other fruit (with related impacts) would be needed for charities and fruit processor.

Since most of the impact occurs late in the chain, the reduction of spoilage and overproduction at the wholesaler at destination would have a larger effect on the reduction of overall impacts and costs (e.g. less fruit shipped per kg of fruit sold). So, actions to prevent side flows at this stages of the supply chain should be prioritized, including measures to be taken earlier in the chain, as an increased quality sorting before shipping in order to transport only fruit with a longer expected shelf life. On the other hand, cosmetic standards not related with shelf life (e.g. size) could be relaxed to counterbalance the increased quality sorting. In addition, these measures should be coupled with a further promotion of secondary markets (e.g. fruit for processing) for overproduction at the earlier stages, in order to not penalize wholesalers at the origin.

Sensitivity analysis

In order to measure the influence of the different parameters utilized, a sensitivity analysis was performed for the following inputs.

At farming stage, a variation of +/-30% of the GWP at this stage causes a variation of 3% in the GWP total per FU. This means that if the GWP at farming stage increases a 30%, the total GWP impact by FU will increase by 3%. Correspondingly, a decrease of 30% in the GWP at farming level will result in an overall impact reduction of the FU by 3%. When net effect is calculated, an increase in the farming impact of PN causes an increase in the benefit from prevention and vice versa.

Electricity use is another parameter that has been tested. An increment by 30% of GWP in the electricity input will cause an increment of GWP per FU by 6.8%, meaning that FU is more sensitive to electricity variations than by farming stage variations. A decrease of GWP in the electricity input by 30% will cause an overall GWP decrease per FU.

When net effect is addressed, a 30% increment in the GWP at electricity level will benefit the prevention scenario by causing a reduction of 3% in the GWP per FU.

As expected, sensitivity of results to transport is higher. An increment by 30% of the GWP due to transport activities will increase the GWP overall emissions per FU of about 15,6%. A decrease by 30% at transport stage will decrease by 15,6% the GWP emissions per FU. Focused on the net effect, there is a strong relation between transport and prevention scenario. When transport increases its GWP emissions by

30%, prevention scenario increases its benefit effects (less emissions). On the other hand, a decrease by in the GWP at transport level will decrease the difference in GWP between current and prevention scenario.

Limitations

This study has some limitations. The first identified regards data availability. Whenever possible primary data was utilized, as in the case of transportation (origin and destination) and process at the wholesaler at origin and destination. At farming stage, the study was built from other scientific studies, mainly focused in the countries of analysis (Italy and Spain). Environmental impacts and background processes where obtained in the case of all stages of the supply chain from reliable databases, and when available for farming, it was as well collected from other scientific studies.

Other assumption made in this study concerns the costing side. Excluding transport to wholesaler destination and wholesaler destination stage, costs were collected from secondary resources such as scientific studies but mainly national statistics resources. This might affect some regional differences, when

Due to its scope, this study excludes retail and consumption stages, where most surplus is created. These stages should be included to embrace the whole PN supply chain and consequently, the whole impact. Lastly, this research focus on conventional agriculture, which is the most representative. However, from an environmental, costing, and side flows perspective, organic agriculture should be considered as well.

5 Conclusions

This report aims to contribute to one of the sustainability objectives of the REFRESH project, namely: *Addressing environmental impacts and lifecycle costs of possible policy and consumption changes*. Furthermore, the method that was developed previously (Davis et al., 2017) in line with the objective *Supply consistent LCA and LCC approaches by developing measures and methodologies*, was in this study applied and thereby tested.

In this study, two case studies were conducted: one exploring the effect of utilising food surplus from catering, food manufacturing and retail as pig feed in UK and France, and the other exploring the effect of reducing food surplus in the supply of peach and nectarines from Spain and Italy, to a UK wholesaler. First conclusions from each case study are summarised, followed by general conclusions about testing of the methodology.

5.1 Feed case

The study shows that there are environmental gains of feeding pigs with heat-treated food surplus, in both countries investigated. For the economic part however, the French case showed an increase in costs, due to transport to farms. For UK the change would result also in cost savings. There was a clear benefit in terms of climate impact, and for many other environmental impacts. The only exception was found for water depletion (UK case) and mineral, fossil and renewable resource use (both cases) which showed an increase with the change. The water use stems from the processing of food surplus into feed, which was in the French case outweighed by the saved water use for avoided production of conventional feed, which was not the case for the UK. The other extra resource use in the food surplus to feed scenario stems from the increased need for transport (collection of food surplus and delivery to processing plant). Hence, important parameters to focus on to optimise environmental and economic gains from utilising the food surplus as feed are:

- Efficient transport during collection of food surplus and delivery of feed to the farms, both in terms of short distances, but also efficient modes of transport (non-fossil fuels, high utility rate);
- Efficient use of water during processing of food surplus into feed;
- Potential reduction of labour costs through increased productivity.

The importance of the potential reduction of environmental impacts and costs depends primarily on the following factors:

- The distance between the origin of food surplus and the processing plant (the longer the distance, the less savings);

- Which feed products are replaced: the higher the impact of replaced feed (e.g. soy from deforestation areas has high climate impact, and sugar cultivation often requires high water use), the larger environmental gains;
- Current waste treatment of food surplus: lower amount of food surplus being sent to treatments that don't generate products (e.g. landfill), will result in less savings;
- The amount of food surplus available for processing into feed: in the future food surplus arisings could decrease, and thereby the potential for utilisation as pig feed will naturally decrease accordingly.

5.2 Peach and nectarine case

The study shows that the spoiled produce and overproduction in the whole supply chain to the UK wholesaler amount to 0.5 million kg per year, mostly arising at wholesaler at the origin and farm levels. On average, this corresponds to 0.38 kg per kg of PN lost before retail.

The total climate impact is 0.98 kg CO_2e/kg of PN. More than one third of the climate impact derives from the refrigerated transport to UK from Spain and Italy. Total cost is 2.7 €/kg of PN sold. Transport to UK is even more relevant in terms of costs, since it represents 54% of the overall cost in the system.

Preventing side flows related to spoilage and overproduction by 50% at all instances would reduce the climate impact and cost by 4% and 2,6% respectively. The reduction of side flows in the wholesale at the origin leads to reduced avoided costs from current waste management (processing, charities, and feed). It must be noted that, assuming a constant purchase and selling price per kg, the wholesaler would register a substantial increase in the profits, since he would need to buy less PN per PN sold, and overcompensating the reduced avoided costs.

5.3 General conclusions on the application of REFRESH LCA/LCC methodology

The methodology framework applied in both case studies proved to be easy to follow and could be replicated into different countries and different food supply chains. However, it was found that even though the recommendations helped to frame the two case studies in a consistent way, it was difficult to follow all recommendations regarding LCI and cost data for processes in the systems. It is recommended that marginal long-term data should be used to model effects of large-scale changes, which was the case in the feed study. However, it is in practice difficult to pinpoint exactly which products that would be affected by a change, this is ideally done by modelling of the economic market dynamics for each affected market (e.g. market for soybeans, rapeseed, electricity etc), as well as available datasets for production of all products delivered to each specific market, which is often lacking. Even though we have in this study not used this due to absence of readily available economic models and sufficient LCI data, this study still highlights the most important parameters that affects the overall net gain or drawback of implementing a change. Hence, the results from these studies can still be used to indicate expected effects of a change, by highlighting which parameters that are most significant for the overall net result of impacts and costs.

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7 Annex

Table 24: Summary of environmental impacts for UK feed case

		Avoided impact		Added impact		
		Waste treatment of food waste	Production of conventional growing feed for 8,4 mill. pigs	Processing of food waste into growing feed for 8,4 mill. pigs	Production of electricity, heat and mineral fertilisers corresponding to waste treatment outputs	Net effect UK
IPCC GWP 100a	kg CO2 eq	-4,7E+08	-1,3E+09	6,2E+08	2,5E+08	-9,4E+08
Climate change	kg CO2 eq	-1,4E+09	-1,4E+09	6,1E+08	2,5E+08	-1,9E+09
Acidification	molc H+ eq	-1,9E+06	-2,2E+07	3,2E+06	1,5E+06	-1,9E+07
Terrestrial eutrophication	molc N eq	-8,5E+06	-9,5E+07	1,1E+07	2,0E+06	-9,1E+07
Freshwater eutrophication	kg P eq	-6,0E+04	-1,1E+06	5,8E+04	7,4E+04	-1,0E+06
Marine eutrophication	kg N eq	-1,1E+06	-1,9E+07	9,7E+05	1,8E+05	-1,9E+07
Land use	kg C deficit	-5,1E+08	-3,2E+10	1,3E+09	1,9E+08	-3,1E+10
Water resource depletion	m3 water eq	-2,2E+05	-1,8E+06	1,5E+06	1,2E+05	-4,0E+05
Mineral, fossil & ren resource depletion	kg Sb eq	-3,6E+03	-1,1E+03	1,7E+04	6,0E+03	1,9E+04
Land occupation	m2	-6,2E+06	-2,8E+09	2,2E+07	2,3E+07	-2,7E+09

Table 25: Summary of environmental impacts for France feed case

		Avoided impact		Added impact		
		Waste treatment of UK food waste	Production of conventional feed for 11,7 mill. pigs	Processing of food waste into feed for 11,7 mill. pigs	Production of electricity, heat and mineral fertilisers corresponding to food waste treatment outputs	Net effect FR
IPCC GWP 100a	kg CO2 eq	-1,6E+09	-2,4E+09	2,1E+09	6,8E+07	-1,9E+09
Climate change	kg CO2 eq	-2,6E+09	-2,5E+09	2,1E+09	6,8E+07	-2,9E+09
Acidification	molc H+ eq	-3,9E+06	-2,8E+07	9,1E+06	3,9E+05	-2,2E+07
Terrestrial eutrophication	molc N eq	-1,7E+07	-1,2E+08	3,0E+07	6,8E+05	-1,1E+08
Freshwater eutrophication	kg P eq	-7,9E+04	-1,1E+06	1,3E+05	1,8E+04	-1,1E+06
Marine eutrophication	kg N eq	-4,2E+06	-2,5E+07	2,8E+06	5,5E+04	-2,6E+07
Land use	kg C deficit	-1,4E+09	-5,4E+10	6,3E+09	1,1E+08	-4,9E+10
Water resource depletion	m3 water eq	-2,4E+05	-1,4E+08	2,7E+06	1,8E+05	-1,3E+08
Mineral, fossil & ren resource depletion	kg Sb eq	-8,9E+03	-1,4E+04	1,1E+05	6,1E+03	9,1E+04
Land occupation	m2	-1,5E+07	-4,1E+09	9,9E+07	4,0E+06	-4,1E+09

Table 26: LCI for PN study referring to current and prevention scenario

Supply chain	Item		Unit	Current scenario	Prevention scenario
Farming	PN sold	PN N-IT sold	Kg	1.66E+05	1.53E+05
		PN S -IT sold	Kg	1.08E+05	1.00E+05
		PN N-SP sold	Kg	9.15E+05	8.16E+05
		PN CW-SP sold	Kg	2.84E+05	2.53E+05
		PN SE-SP sold	Kg	2.89E+05	2.58E+05
	PN side flows	PN N-IT loss	Kg	2.19E+04	1.01E+04
		PN S -IT loss	Kg	1.43E+04	6.63E+03
		PN N-SP loss	Kg	8.61E+04	3.84E+04
		PN CW-SP loss	Kg	2.67E+04	1.19E+04
		PN SE-SP loss	Kg	2.72E+04	1.21E+04
Transport to wholesaler at origin		PN transport	tkm	3.48E+05	3.11E+05
		Bin transport	tkm	2.07E+04	1.85E+04
Wholesaler at origin	PN sold	PN N-IT sold	Kg	1.45E+05	1.43E+05
		PN S -IT sold	Kg	9.49E+04	9.36E+04
		PN N-SP sold	Kg	7.34E+05	7.27E+05
		PN CW-SP sold	Kg	2.27E+05	2.25E+05
		PN SE-SP sold	Kg	2.32E+05	2.30E+05
	PN side flows	PN N-IT loss	Kg	2.01E+04	9.91E+03
		PN S -IT loss	Kg	1.31E+04	6.47E+03
		PN N-SP loss	Kg	1.81E+05	8.96E+04
		PN CW-SP loss	Kg	5.61E+04	2.77E+04
		PN SE-SP loss	Kg	5.72E+04	2.83E+04
	Inputs	Energy conservation	kWh	2.38E+05	2.35E+05
		Energy packaging	kWh	2.64E+04	2.61E+04
		Water	m^3	2.72E+02	2.69E+02
		Cardboard	Kg	1.13E+05	1.12E+05
	Waste disposal	Fruit processing	Kg	2.44E+05	1.21E+05
		Donation	Kg	5.03E+04	2.49E+04
		Animal feed	Kg	3.35E+04	1.65E+04
	System expansion	Food processing	Kg	0	1.23E+05
		Donation	Kg	0	2.54E+04
		Animal feed	Kg	0	1.69E+04
Transport to UK		PN transport	tkm	2.27E+06	2.25E+06
		Package transport	tkm	1.79E+05	1.77E+05
Wholesaler destination	PN sold	PN N-IT sold	Kg	1.41E+05	
		PN S -IT sold	Kg	9.23E+04	
		PN N-SP sold	Kg	7.19E+05	
		PN CW-SP sold	Kg	2.23E+05	
		PN SE-SP sold	Kg	2.27E+05	
	PN side flows	PN N-IT loss	Kg	4.27E+03	2.14E+03
		PN S -IT loss	Kg	2.62E+03	1.31E+03
		PN N-SP loss	Kg	1.52E+04	7.61E+03

	PN CW-SP loss	Kg	4.93E+03	2.47E+03
	PN SE-SP loss	Kg	4.85E+03	2.43E+03
Inputs	Energy conservation	kWh	8.14E+04	8.05E+04
	Energy packaging	kWh	2.22E+05	2.19E+05
	Packaging	Kg	4.73E+01	4.73E+01
Waste disposal	Cardboard disposal	Kg	1.13E+05	111.864.971
	Compost	Kg	1.59E+04	7.97E+03
	Animal feed	Kg	1.59E+04	7.97E+03
System expansion	Mineral fertilizer	Kg	0	1.85E+02
	Conventional feed	Kg	0	7.97E+03
	Pulp	Kg	0	1.26E+03

Table 27: Environmental impacts related to PN current scenario

Supply chain	Produce sold	Produce wasted	IPCC GWP 100a	WRD	MFRD	FE	ME	TE	AC	LU	Land occ.
	kg	*kg*	*kg CO2 eq*	*m3 water eq*	*kg Sb eq*	*kg P eq*	*kg N eq*	*molc N eq*	*molc H+ eq*	*kg C deficit*	*m2a*
Farming	1.76E+06	1.76E+05	1.54E+05	5.19E+05	2.11E+01	8.34E+01	7.55E+02	5.79E+03	1.86E+03	2.20E+06	1,73E+05
Transport from farms	1.76E+06		1.55E+05	2.42E+01	5.37E-02	2.83E+00	2.43E+02	2.67E+03	7.00E+02	7.89E+04	4,70E+03
Wholesale at the origin	1.43E+06	3.28E+05	2.49E+05	5.14E+02	3.78E+01	8.81E+01	3.48E+02	2.89E+03	1.61E+03	5.76E+05	1,26E+05
Transport to UK	1.43E+06		5.44E+05	7.29E+01	2.26E-01	1.17E+01	8.92E+02	9.77E+03	2.55E+03	4.05E+05	2,37E+04
Wholesale at destination	1.40E+06	3.19E+04	2,72E+05	4,97E+02	1,89E+00	9,18E+01	2,60E+02	2,52E+03	1,96E+03	3,24E+05	2,72E+05
Total impact			1,37E+06	5,20E+05	6,11E+01	2,78E+02	2,50E+03	2,36E+04	8,69E+03	6,52E+05	1,37E+06
	per kg sold	3.82E-01	9,80E-01	3,71E-01	4,36E-05	1,98E-04	1,78E-03	1,69E-02	6,20E-03	4,65E-01	9,80E-01

GWP (Global warming potential); CC (Climate change); WRD (Water resource depletion); MFRD (Mineral fossil and resource depletion); FE (Freshwater eutrophication); ME (Marine eutrophication); TE (Terrestrial eutrophication); AC (Acidification) and LU (Land use).

Table 28: Environmental impacts related to PN prevention scenario

Supply chain	Produce sold	Produce wasted	IPCC GWP 100a	WRD	MFRD	FE	ME	TE	AC	LU	Land occ.
	kg	*kg*	*kg CO2 eq*	*m3 water eq*	*kg Sb eq*	*kg P eq*	*kg N eq*	*molc N eq*	*molc H+ eq*	*kg C deficit*	*m2a*
Farming	1.58E+06	7.92E+04	1.32E+05	4.42E+05	1.82E+01	7.15E+01	6.52E+02	4.97E+03	1.60E+03	1.88E+06	1,49E+05
Transport from farms	1.58E+06		1.39E+05	2.16E+01	4.81E-02	2.53E+00	2.17E+02	2.39E+03	6.26E+02	7.06E+04	4,20E+03
Wholesale at the origin	1.42E+06	1.62E+05	2.39E+05	5.10E+02	3.74E+01	8.69E+01	3.33E+02	2.74E+03	1.56E+03	5.66E+05	1,25E+05
Transport to UK	1.42E+06		5.38E+05	7.21E+01	2.24E-01	1.16E+01	8.82E+02	9.66E+03	2.52E+03	4.01E+05	2,34E+04
Wholesale at destination	1.40E+06	1.59E+04	2,68E+05	4,96E+02	1,88E+00	9,12E+01	2,57E+02	2,44E+03	1,93E+03	3,23E+05	2,68E+05
Added impacts			1.46E+04	4.27E+04	1.56E+00	7.74E+00	3.69E+01	5.59E+02	1.80E+02	2.32E+05	1,71E+04
	per kg sold		1.04E-02	3.05E-02	1.11E-06	5.52E-06	2.63E-05	3.99E-04	1.28E-04	1.65E-01	1,22E-02
Total impact			1,33E+06	4,86E+05	5,92E+01	2,71E+02	2,38E+03	2,28E+04	8,42E+03	6,42E+05	1,33E+06
	per kg sold	1.83E-01	9,49E-01	3,47E-01	4,23E-05	1,94E-04	1,70E-03	1,62E-02	6,01E-03	4,58E-01	9,49E-01

GWP (Global warming potential); CC (Climate change); WRD (Water resource depletion); MFRD (Mineral fossil and resource depletion); FE (Freshwater eutrophication); ME (Marine eutrophication); TE (Terrestrial eutrophication); AC (Acidification). LU (Land use).

Table 29: Costing impacts related to PN current scenario

Supply chain	Produce sold	Produce wasted	Material costs	Energy costs	Labour cost	Transport costs	Other costs	Avoided costs
	kg	*kg*	*€*	*€*	*€*	*€*	*€*	*€*
Farming	1.76E+06	1.76E+05	229,815.92	12,940.44	305,212.67		82,930.22	
Transport from farms	1.76E+06					61,331.92		
Wholesale at the origin	1.43E+06	3.28E+05	212,616.96	25,332.41	59,190.75			-51,908.64
Transport to UK	1.43E+06					2,043,741.81		
Wholesale at destination	1.40E+06	3.19E+04	476,413.48	28,291.05	286,270.72		3,627.21	
Total impact			918,846.37	66,563.90	650,674.14	2105073.73	86,557.43	-51,908.64
	per kg sold	3.82E-01	0.66	0.05	0,46	1.50	0.06	-0.04

Table 30: Costing impacts related to PN prevention scenario

Supply chain	Produce sold	Produce wasted	Material costs	Energy costs	Labour cost	Transport costs	Other costs	Avoided costs	External effects
	kg	*kg*	*€*	*€*	*€*	*€*	*€*	*€*	*€*
Farming	1.58E+06	7.92E+04	196,669.16	11,080.92	262,068.65	0.00	70,933.87		
Transport from farms	1.58E+06					54,855.23			
Wholesale at the origin	1.42E+06	1.62E+05	210,252.76	25,012.47	58,528.07			-25,673.70	
Transport to UK	1.42E+06					2,021,125.89			
Wholesale at destination	1.40E+06	1.59E+04	476,413.48	27,976.40	28,6240.60		2,992.21		
Added impacts									5,296.95
Total impact			883,335.40	64,069.78	606,837.32	2,075,981.12	73,926.08	-25,673.70	5,296.95
	per kg sold	1.83E-01	0.63	0.05	0.43	1.48	0.05	-0.02	0.003