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Opportunities for waste valorisation in the food industry – A case study with four UK food manufacturers

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ABSTRACT

Food manufacturing is comprised of a number of complex processes which generate vast amounts of food waste. Frequently, strategies for dealing with these materials are rudimentary and provide a low economic and environmental value, for instance animal feeding, anaerobic digestion, composting, incineration, landspreading and landfilling. However, food wastes contain numerous chemicals with a wide range of potential commercial applications, which makes these materials suitable feedstocks for valorisation. This paper applies a Waste Flow Modelling methodology to achieve two aims: to provide valuable food manufacturing and waste data in order to better understand current food manufacturing activities, and to analyse existing food waste management practices to lay the foundation for the implementation of alternative food waste valorisation solutions. Four UK industrial companies have been selected and assessed to represent four different food sectors where food waste valorisation could provide an economic and/or environmental advantage: a fruits supplier, a brewery, a potato supplier and a producer of peas. The production line of each of these four businesses is defined and characterised, which allows the identification of food wastes generated. Next, food wastes are categorised and quantified, and their patterns of generation and current waste management practices are described. Sankey diagrams and performance indicators are used to assess the efficiency of processes, combination of processes and the complete production line in terms of food waste generation. Finally, the results are analysed and used to obtain the main conclusions and provide recommendations for an improved food waste management system, with a focus on valorisation opportunities.

1. Introduction

In order to implement a circular economy in any industrial sector, two main strategies are needed: reducing waste levels, and finding the most sustainable solution to manage the remaining waste. Waste valorisation, which has been defined as the process of converting waste into more useful products (Arancon et al., 2013), is a useful approach to address the management of waste materials and therefore to enhance the competitiveness of biorefineries, in which wide ranges of products can be obtained by using wastes as feedstocks (Venkata Mohan et al., 2016). Food wastes have been demonstrated to be valuable bioresources that can be utilised to obtain a number of useful chemicals, materials and fuels (Lin et al., 2013; Pfaltzgraff et al., 2013). Furthermore, opportunities have already been identified to apply industrial symbiosis in valorising food wastes from the food manufacturing industry (Mirabella et al., 2014). Consequently, food waste valorisation has a great deal of potential to provide economic, social and environmental benefits (Environmental Scientist, 2017) and several countries are already promoting strategies for food waste valorisation (Fisgativa et al., 2017). These strategies go in the direction of supporting the development of a circular economy in the food sector by closing the loop and using wastes as resources, approach that is being encouraged by recent policies in Europe (European Commision, 2015; Ellen Mac Arthur Foundation, 2015).

Not only is food waste valorisation beneficial for a food manufacturing company because of the increase of economic value of the material itself, but also because these materials are usually available in vast amounts. For example, Parfitt et al. (2016) reported

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Abbreviations: WFM, Waste Flow Modelling; MFA, Material Flow Analysis; SFA, Substance Flow Analysis; MFM, Material Flow Management; FWMDT, Food Waste Management Decision Tree; N/A, Not Applicable; N/N, Not-Needed; NFHC, Not-Fit-for-Human-Consumption; OOS, Out-Of-Specification.

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that UK food manufacturers waste 1.7 million tonnes (Mt) of food yearly, of a total of 10 Mt in the UK food supply chain, to which should be added 2.8 Mt of food by-products sent to animal feeding (2.2 Mt) and rendering (0.6 Mt), and 0.7 Mt of food surplus which is either redistributed (42 kt) or sent to animal feeding (600 kt). Therefore, a total of 5.2 Mt of food surplus, by-products and waste are being generated in the UK food industry alone. For simplicity, in this paper all these materials are named 'food waste', which is defined here as any food material, either edible or inedible, not sold for human consumption as a primary food product, i.e. a food material that has lost part or all its economic value.

In Europe, industrial food waste quantities are also very significant, ranging between 19% and 39% of the total food waste in European food supply chains (Stenmarck et al. (FUSIONS), 2016; European Commission (DG ENV), 2010). Consequently, growing the economic value of a food waste, even by a small amount, may cause a significant economic advantage due to the large volumes of food currently wasted. On the other hand, food supply chains will need to adapt and sometimes significantly change in order to implement these changes, e.g. set up new biorefineries to treat food waste. Historically, stakeholders in food supply chain used to work independently. Currently the trend is towards integration of food supply chains. The next step might be the integration of food waste management, including waste valorisation, in food supply chains and even in food factories.

This paper supports this view by providing an exhaustive analysis of types and quantities of food waste arising in four food industries: a fruits supplier, a brewery, a potato supplier and a producer of peas. Only after thoroughly analysing food waste streams and current waste management practices, can alternative food waste valorisation opportunities be proposed. Therefore, the main contribution of this paper is twofold: providing detailed food waste data for the four aforementioned food sectors, and identification and discussion of opportunities for food waste valorisation.

2. Methods

The first stage of the research presented in this paper was to complete a review of relevant literature in the area of Waste Flow Modelling (WFM) with the aim of determine the state of the art of this methodology. Upon completion of this literature review, it was concluded that Waste Flow Modelling has rarely been used, and instead similar but more general methodologies have been used, such as Material Flow Analysis (MFA), Substance Flow Analysis (SFA) and Material Flow Management (MFM). Additionally, these methodologies are often applied to regions or countries, rather than to manufacturing plants (e.g. Stanisavljevic et al., 2015; Sevigné-Itoiz et al., 2015). This seems to indicate that the use of WFM to analyse industrial practices, particularly waste management practices in food manufacturing environments, is an unexplored area. The review of WFM, MFA, SFA and MFM methodologies provided the basis knowledge to undertake a WFM for each industrial partner as presented in the next sections of this paper. Nevertheless, the authors have made various additions to complement the aforementioned methodologies. The main stages in the research methodology are depicted in Fig. 1 and explained in this section.

The core of the WFM methodology used in this research is based on the MFA procedure, as explained by Brunner and Rechberger (2004). The first stage of this methodology is the definition of the system boundaries, which was determined upon consideration of the activities of the four industrial partners. In order to keep consistency amongst the four scenarios, it was decided to analyse the industrial activity of each company for a time period of one year. The following material flows were included in the assessment: raw materials, intermediate streams, final products and food wastes. Materials not forming part of any of these flows at any point of the production line were excluded of the analysis (e.g. water used for clean-in-place and packaging materials). The space scope defined included the arrival of each of the aforementioned material flows to the industrial site, its transportation and transformation through the production line, dispatch of final products for sale and treatment of food wastes generated (both on-site and off-site).

Data was collected from each industrial partner by different procedures, as summarised below. Site visits to the companies' headquarters took place for the fruits supplier, the brewery, and the potato supplier, and for the last two the visits included a tour of the industrial plant. In-person meetings with company staff were organised during which interviews were held. Questionnaires were designed and used to systematically collect data to better describe qualitatively and quantitatively the food waste problem to be tackled. These questionnaires were initially sent to the industrial partners to make them aware of the information pursued and were later used during the interviews to guide the conversations. The questionnaires included several questions regarding processes involved in the production line, raw materials used, food waste generated, current food waste management practices and logistics associated with these strategies. Data gathered included the most recent empirical information, whenever the industrial partners had collected it and it was available to be shared with the authors, and averages when the figures were moderately constant for different years. Once the initial data were collected and analysed, further communication was established to collect missing data and clarify different aspects of the information already collected, for which additional meetings and/or email exchange were used. Therefore, all information presented in this paper can be considered to have been provided by the industrial partners, unless another reference is given.

Once the food waste streams were identified, they were analysed to understand their properties, for which a nine-stage qualitative categorisation was used. The results of such categorisation were used to identify quick gains in terms of possible alternative food waste management practices, before valorisation is considered. The proposed alternative food waste management practice must have a better sustainability performance, particularly causing a lower environmental impact. A Food Waste Management Decision Tree (FWMDT) was used to undertake this analysis for each food waste identified. Both the nine-stage categorisation and the FWMDT were designed and are explained in detail by Garcia-Garcia et al. (2017).

The software e!Sankey Pro, developed by Ifu Hamburg, was used to analyse and depict with Sankey diagrams the main mass flows of the industrial activities analysed. Sankey diagrams are useful to show variability of mass flows in a manufacturing company, as the width of each arrow is proportional to the mass flow of that stream. Additionally, Microsoft Excel was used to undertake mass balances to calculate unknown values of some mass flows and ensure there were no errors in the calculations. Microsoft Visio was used to depict the production line of each industrial partner.

Once all main flows were identified, an assessment of the performance of different processes and combination of processes was undertaken. Following a review of previous WFM methodologies, four indicators were chosen as the most relevant for the present study, which were used to systematically examine the industrial practices involved:

- Eco-efficiency = quantity of sold product/quantity of raw materials used to produce the product
- Eco-intensity = quantity of raw materials used to produce a product/quantity of product sold

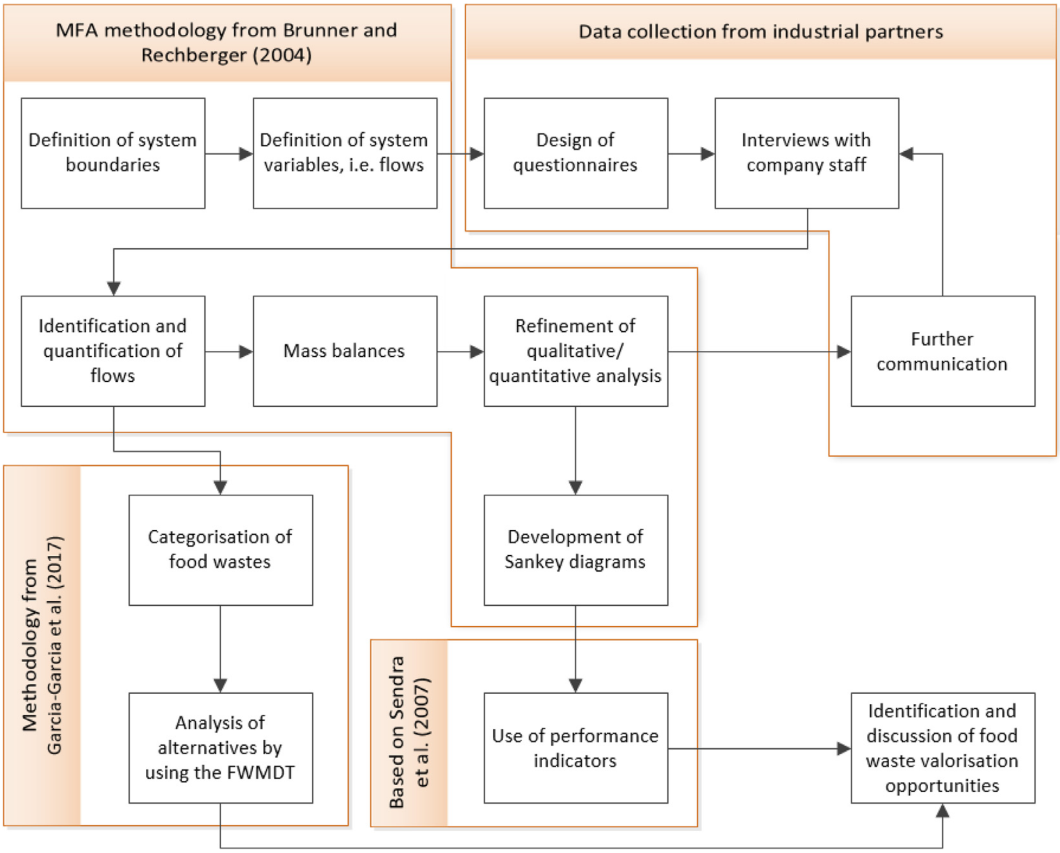

Fig. 1. Research methodology.

- Rate food waste/product = quantity of food waste generated/quantity of product sold
- Rate food waste/raw materials = quantity of food waste generated/quantity of raw materials used

Eco-efficiency and eco-intensity indicators are based on indicators proposed by Sendra et al. (2007) to analyse industrial areas, while the rates food waste/product and food waste/raw materials are an adaptation of them to specifically analyse food waste generation. These indicators are useful to evaluate to what extent food waste generation is a severe issue for the companies analysed, since it considers food waste amounts and purchased and sold products.

An assessment of the results obtained enabled the determination of opportunities to use food wastes as feedstocks for valorisation, which is discussed for each industrial partner. Finally, the main conclusions are presented and recommendations for food waste valorisation in each industrial context are proposed.

3. Industrial case studies

This section shows the main results of applying the WFM methodology to analyse the food waste management performance of four UK food companies: Chingford, Molson Coors, Branston and The Green Pea Company. For each of these companies, an introductory description of their manufacturing activities is firstly provided, which is followed by the identification of their food wastes. Each food waste identified is described, categorised and quantified, which allows the creation of Sankey diagrams. The performance of processes, combination of processes and the entire factory is analysed. Finally, current food waste management practices are explained and compared against alternative, more sustainable management solutions, with a focus on valorisation opportunities.

3.1. Industrial partner: Chingford Fruit Ltd

Chingford Fruit Ltd (“Chingford”) is a food business, part of A G Thames Holdings, specialised in sourcing citrus fruits, stone fruits, top fruits and kiwis. Citrus fruits, which represents around half of the products handled by Chingford, are of particular relevance for Chingford and therefore they have been chosen as a potential feedstock for valorisation. Citrus fruits include clementines, tangerines, mandarins, satsumas, oranges, grapefruits, limes and lemons. In the analysis presented in this section, clementines, tangerines, mandarins and satsumas have been grouped in a category named ‘soft citrus’, for imported streams, final product and food waste streams.

3.1.1. Production line and identification of food waste streams

Chingford is a major fruit consolidator, sourcing fruits from a number of international suppliers and supplying them to customers in the UK. Most of Chingford's citrus fruits are imported from different Spanish regions, principally from Huelva, Seville, Valencia, Castellón, Sagunto, Gandia, Alicante and Almería. Other fruits are imported from countries and regions such as Turkey, Cyprus, Florida (USA), Israel, Morocco and Egypt. Fruits are transported by container ships from their country of origin to the UK, and then by trucks to Chingford's headquarters in Dartford, east London.

When the fruits arrive to Chingford, they are firstly stored and then moved to a processing area at ambient (15–16 °C). The fruits in the processing area are transported by conveyor belts while

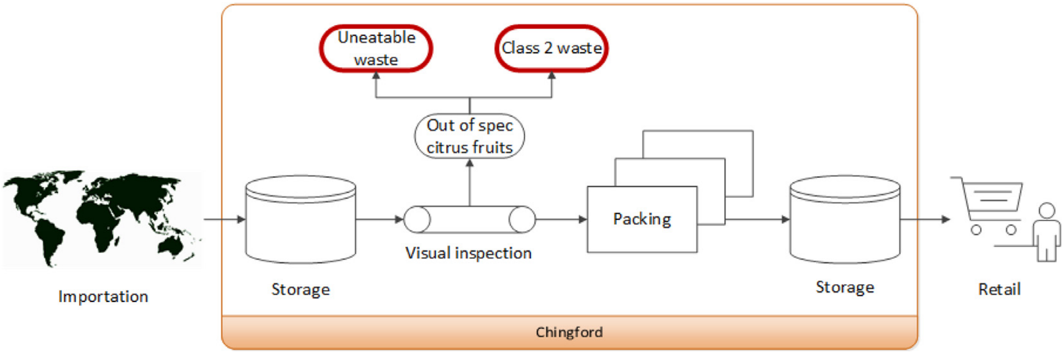

Fig. 2. Production line in Chingford. In red, the food waste streams analysed in this paper. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

company staff visually inspect the fruits to remove the products that do not meet quality standards. Finally, the fruits which are not packed in its country of origin are packed in nets or bags and moved to the warehouse, where they are maintained at 7 °C until they are dispatched.

The price per kg of final products sold by Chingford is only slightly higher than the one paid to import those products, providing a low benefit margin and therefore relying on low costs and high volumes (i.e. economy of scale).

Fig. 2 shows the main steps of the production line in Chingford. The food wastes generated at Chingford's production line are uneatable waste and class-2 products, which are described in the following sub-sections. Table 1 classifies these two food wastes according to the nine-stage categorisation and FWMDT.

3.1.1.1. Uneatable waste. Uneatable waste is the product that is not fit for human consumption because it is spoiled or seriously damaged. When this food waste is found on the conveyor belts it is placed in a large plastic bin. Different types of uneatable waste products (e.g. oranges and limes) may be placed in the same bin, but they could be easily segregated if that would help to optimise waste management. Uneatable waste is not mixed with packaging.

Regularly, uneatable waste is moved from plastic bins to larger 600-lb containers which can be placed in the warehouse or outdoors. Finally, uneatable waste is sent to an anaerobic digestion plant.

Nevertheless, citrus fruits are not the ideal substrate for anaerobic digestion. The anaerobic digestion process is very sensitive to pH, and citrus fruits provide an acid environment that affects the process (Kaparaju and Rintala, 2006). Additionally, D-limonene present in citrus fruits shows an antimicrobial action (Espina et al., 2013; Zahi et al., 2015), which reduces the metabolic activity of the microorganisms in the digester. To tackle this issue, either D-limonene should be removed (Zema et al., 2018) or citrus waste should be co-digested with other substrates, such as manure (Negro et al., 2017). Regardless, anaerobic digestion of citrus fruits also creates a high environmental impact due to eutrophication (Negro et al., 2017).

3.1.1.2. Class-2 products. Class-2 products are fit for human consumption, but they do not meet quality standards of class-1 products (i.e. final products commercialised by Chingford). They have aesthetic defects such as spots on skin and discolouring.

Class-2 products are detected in conveyor belts and then placed in 15-kg cardboard boxes where they are sent to wholesale markets. The income Chingford receives for these products is of the order of 20% of the economic value of class-1 products, with significant variation per product and month, generally ranging from £0.10 to £0.60 per kg. Therefore, although class-2 products do not create an environmental or social ramification, they entail a negative impact to Chingford due to its economic performance.

3.1.2. Quantitative analysis of food waste streams

There is a significant variability on the quantities of each food waste by product and month; similarly, the quantities of citrus fruits imported and sold to clients change for each product and month. This section analyses the mass flows for each of the aforementioned streams.

Mass flow values for imported citrus and food wastes shown in this section are values determined by Chingford's staff. Each batch of each citrus fruit from importation and food waste streams was recorded in a spreadsheet and their empirical mass values were aggregated for each month. The results encompass the period April 2016 to March 2017. It has been assumed that once all uneatable

Table 1
Categorisation of uneatable waste and class-2 products and identification of its most sustainable management solution. N/A: not applicable; N/N: not-needed.

Parameter	Uneatable waste	Class-2 products
Edibility	Edible	Edible
State	Uneatable	Eatable
Origin	Plant based	Plant based
Complexity	Single product	Single product
Animal-product presence	N/A	N/A
Treatment	N/N	Processed
Packaging	Unpackaged	Unpackaged
Packaging biodegradability	N/A	N/A
Stage of the supply chain	N/N	Non-catering waste
Current treatment	Anaerobic digestion	Redistribution
Sustainable solution according to the FWMDT	Anaerobic digestion	Redistribution

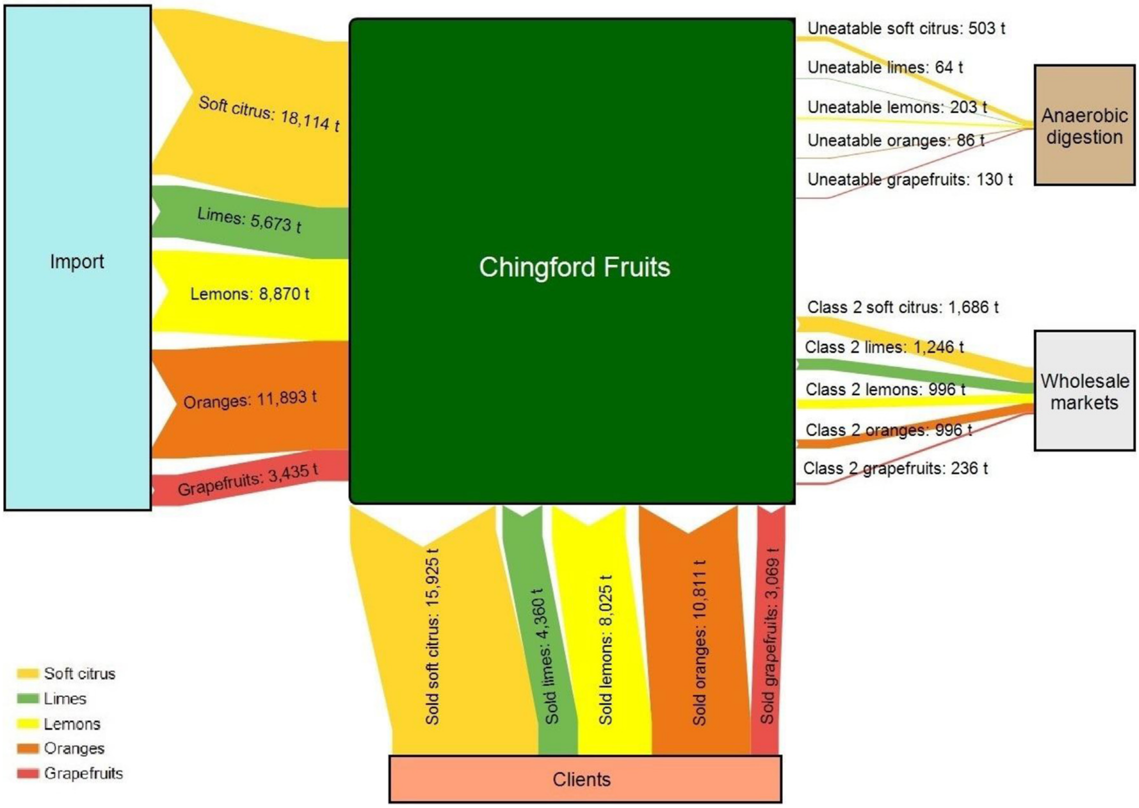

Fig. 3. Annual Sankey diagram for Chingford (from April 2016 to March 2017).

and class-2 fruits were excluded, the remainder were sold to clients. Mass balances have been used to determine these sold citrus streams and to ensure elimination of errors.

In the aforementioned time period, Chingford purchased 47,984,672 kg of citrus, and wasted 5,795,541 kg of it (12% of the purchased citrus). Fig. 3 shows a Sankey diagram of the main flows of each stream yearly, using a different colour coding for each citrus category considered: soft citrus, limes, lemons, oranges and grapefruits. Soft citrus represents the highest proportion of citrus fruit in all streams: imported fruit, sold fruit, uneatable waste and class-2 products.

Fig. 4 shows yearly values for each food waste stream classified by the citrus type and its final use. 83% of total waste is sold as class-2 fruits in wholesale markets. Soft citrus represents the largest source of such waste (37.8%), followed by limes (22.7%) and oranges (18.7%). Half of all uneatable waste corresponds to soft citrus, and over a third of class-2 products are soft citrus. Considering both citrus product type and their final use, the largest food waste streams are class-2 soft citrus and class-2 limes, which together account for half of the total food wastes at Chingford.

In Fig. 5, the variability of food waste streams per month is represented. There seems to be a correlation between seasonality and food waste generation, with February being the month with the highest quantity of food waste generated. The changes in food waste monthly values are driven mostly by a change in quantities of class-2 products.

The variability of food waste quantities has been assessed for each citrus fruit and month. The months with the largest quantity of one type of food waste are February for limes, and April and December for soft citrus. Soft citrus represents the largest source of food waste every month except oranges in August, and limes in September, February and March.

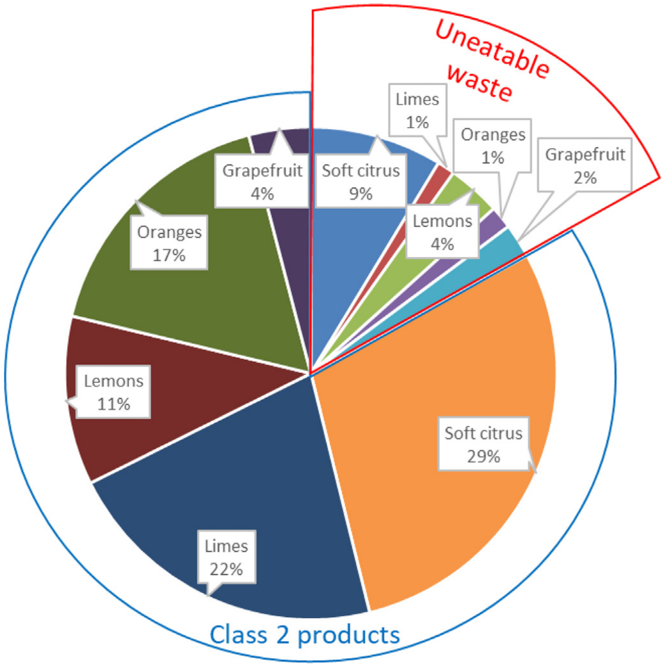

Fig. 4. Proportion of food waste streams considering their product type and final use (from April 2016 to March 2017).

Nevertheless, simply measuring the levels of food waste generation does not necessarily indicate the relative significance of the food waste, nor process efficiency at Chingford. Therefore, it was felt necessary to apply the previously described indicators of eco-

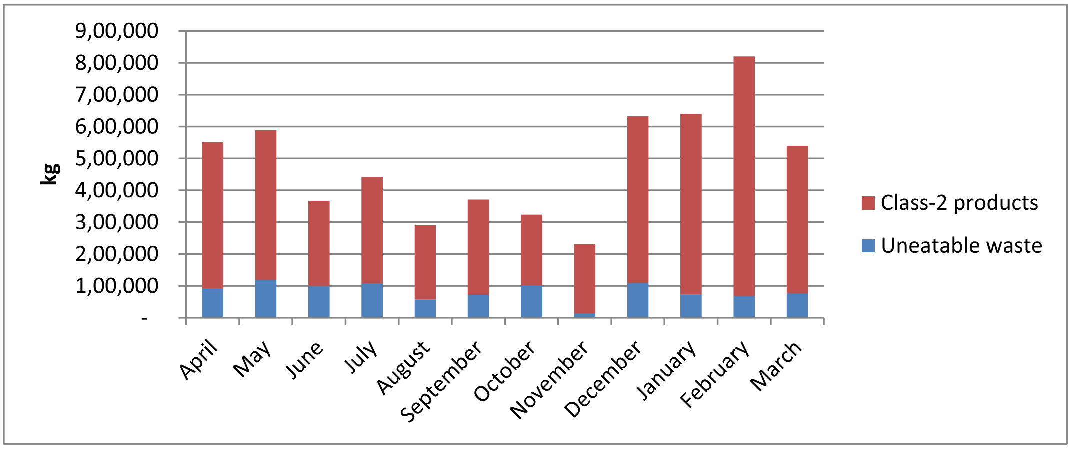

Fig. 5. Total food wastes per month classified by its final use (from April 2016 to March 2017).

efficiency, eco-intensity and waste rates to the monthly waste, sale and purchase volumes for each product, and the results can be seen in Fig. 6 (a). It can be readily seen that eco-efficiency and eco-intensity are mirror images, since their values are proportionally inverse, and consequently eco-intensity has only been analysed in Fig. 6 (a). Eco-efficiency ranges between 82.4% (February) and 92.5% (November). Eco-efficiency values indicate that during the months with more food waste generation (i.e. December to February, Fig. 5) more citrus fruits were purchased, but also other factors influenced a low eco-efficiency (and a high eco-intensity as a result). The two months with the highest rate of food wastes/citrus sold are February (21.4%) and May (19.4%). A similar trend is found for the rate of food wastes/citrus purchased, although with smaller differences between different months.

Results shown in Fig. 6 (a) seem to indicate that the quality of citrus varies for different months. The reason for this is likely to be twofold: the quality of citrus imported from the same region changes depending on the time of the season when it is harvested and the time and conditions of its storage, and Chingford imports citrus from different countries at different times of the year. It is known that food waste generation largely depends on weather conditions in regions where food is grown, e.g. heavy rain or draughts in Spain where Chingford gets a large proportion of their produce from. A more detailed analysis of the origin of each citrus imported would help to elucidate what is the weight of each of these two factors (i.e. seasonality/weather conditions vs. supplier/country of origin). Other factors that may cause low eco-efficiencies are related to storage conditions during citrus transportation and storage in Chingford and citrus demand from Chingford's clients.

Fig. 6 (b) shows the eco-efficiency of each citrus type per month. Its values fluctuate between 71.0% (limes in September) and 98.4% (grapefruit in November), except for a deep plunge for limes in winter, particularly in February (56.9%). The monthly rate of food waste/citrus sold for each product is shown in Fig. 6 (c). It ranges between 40.9% (limes in September) and 1.6% (grapefruit in November), except for a peak for limes in February (75.6%). The fluctuations for the rate of food waste/citrus purchased for each product and month, as shown in Fig. 6 (d), are flatter than for the rate of food waste/food sold, ranging between 29.0% (limes in September) and 1.6% (grapefruit in November), except for a peak for limes in February (43.1%). In conclusion, an assessment on quantities of limes wasted in February in previous years is recommended to elucidate whether this is an actual trend or an exception in the time period analysed.

3.1.3. *Conclusions and recommendations*

In the period April 2016–March 2017, Chingford generated nearly six million kg of citrus waste, which ended up either sent to anaerobic digestion or sold at discounted prices to wholesale markets. The variability of citrus waste generation is high, stemming from a complex range of factors relating to growing conditions and customer demand, and this hinders projections for citrus waste generation in future years. However, broadly speaking, it can be assumed that citrus waste generation peaks in winter. To improve projections, it is recommended to analyse the origin of each citrus imported and extend the assessment to a longer time period, although this has not been done so far due to difficulties in collecting the necessary data. Similar levels of variability in waste generation and reasons behind it are expected for other fruits and vegetables imported to the UK.

Half of all citrus waste generated corresponds to class-2 soft citrus and class-2 limes. Since 83% of all food wastes are classified as class-2 products, relaxation of cosmetic standards from retailers and customers could potentially save a significant amount of these food waste materials. Additionally, the high rate of waste from limes purchased in February makes this fruit and time point a priority target for reducing total food waste.

Since class-2 products are already used for human consumption, which is the most sustainable solution to manage food waste, it would be beneficial to use uneatable waste for valorisation processes. However, the influence of the state of the citrus (e.g. spoilage level) on the quality and quantity of the extracted materials from citrus must be assessed. If it is found that targeted materials are not affected by the state of the citrus product, soft citrus would represent the main opportunity to be used as feedstocks for valorisation, as it accounts for 50.8% of the total uneatable waste. Assessing the state of the waste to be treated and its influence in the valorisation process is key not only to valorise citrus waste but also any waste type.

Monthly variability of food waste quantities must also be considered when designing a valorisation process in which these materials are used as feedstocks. This is a key factor to design a valorisation process and adjust it to meet feedstock availability. July and December are the months with the highest generation of soft citrus uneatable waste whereas March and November are the months with the lowest generation of this type of food waste.

3.2. *Industrial partner: Molson Coors Brewing Company*

Molson Coors Brewing Company (“Molson Coors”) is a

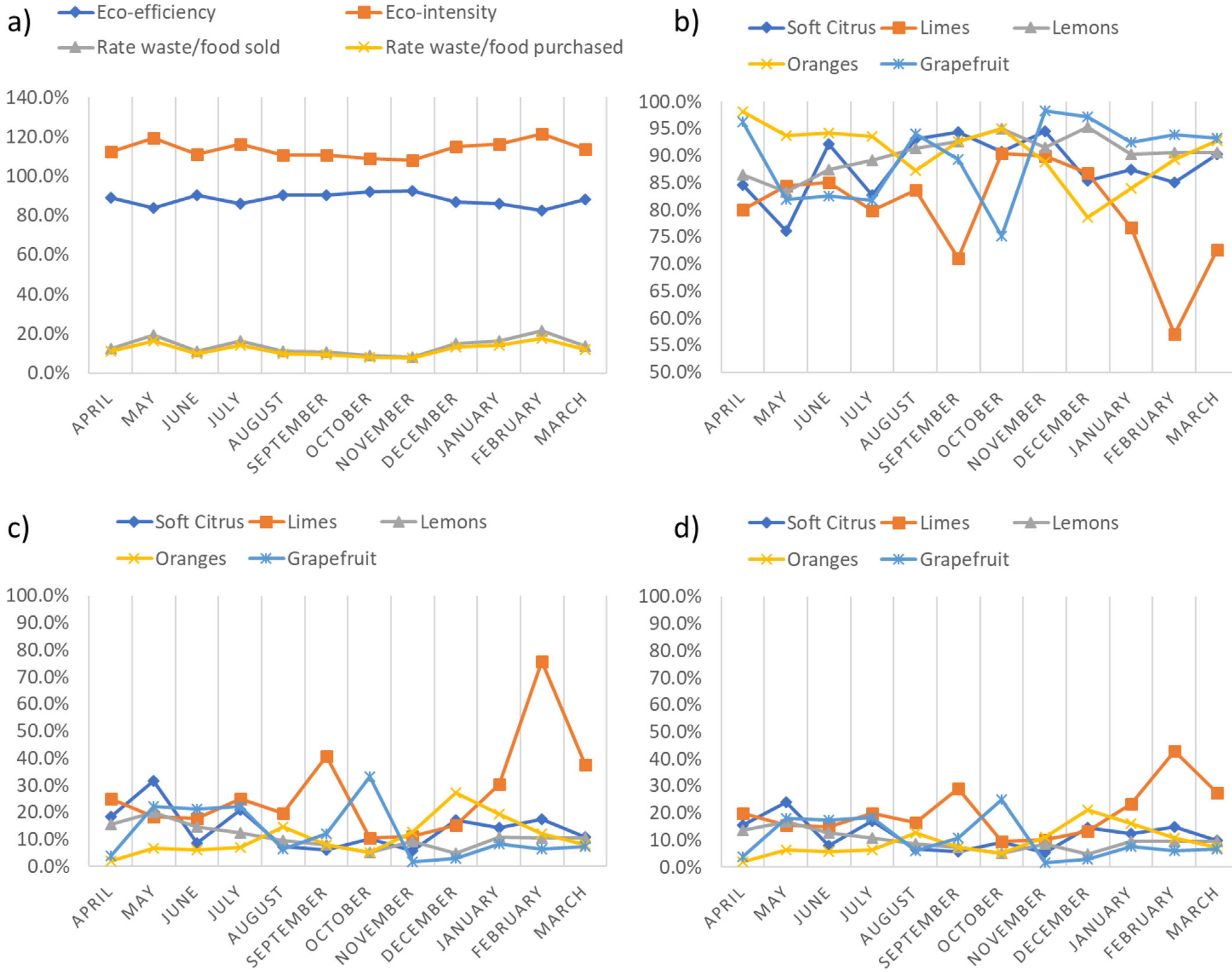

Fig. 6. Monthly values of performance indicators for the period April 2016–March 2017. (a) total values per month, (b) eco-efficiency of each product type per month, (c) rate food waste/citrus sold for each product type per month and (d) rate food waste/citrus purchased of each product type per month.

multinational brewing company that produces beer brands such as Carling, Coors Light and Cobra Beer. The headquarters of its UK arm, located in Burton upon Trent in Staffordshire, produces approximately 6.5 Mhl of beer per year. The analysis in this section refers to the manufacturing plant in Burton upon Trent, which represents around 75% of the total beer produced in the UK by Molson Coors.

3.2.1. Production line and identification of food waste streams

Beer is manufactured by the following process stages: malting the raw material (mostly barley, but other materials such as wheat can also be added to the initial mixture), milling, mashing, mixing with hops and brewing in kettles, separation of sediments, fermentation, maturation, filtration, pasteurisation and packaging (see Fig. 7). Initial processes are undertaken at farms and maltings; the production line at Molson Coors starts with the mashing process.

The food wastes generated at any beer production line are barley waste, malt waste, spent grain, spent yeast, trub, conditioning bottom, filter waste and beer waste, which are analysed in the following sub-sections. Apart from these materials, large amounts of wastewater are generated. Table 2 classifies these food wastes according to the nine-stage categorisation and FWMDT.

3.2.1.1. Barley waste. In the farms where barley is grown, there are three types of materials produced and managed in the following ways:

- Grain, used for malting
- Straw, sold for animal feeding or bedding
- Root, ploughed back to the soil

These three materials are produced in similar proportions, i.e. each represents one-third of the barley plant. Grain is the valuable, targeted material, while both straw and root are residues. The part of the barley plant which grows over the soil includes the rachis, straw and spike. The spike is formed of spikelets, which are the edible materials sent to maltings to produce malt. The rachis joins the spike with the root. This section analyses barley straw, which is commonly known as barley waste.

In England, barley is collected mostly from the east coast (Lincolnshire and Yorkshire), and usually travels in 20-t trucks around 100–150 miles to maltings, near Molson Coors' manufacturing plant, where it is stored before it is malted. During storage, chilled air may have to be blown to decrease temperature.

Barley waste is sold to farms at a rate of about £50/t and used for

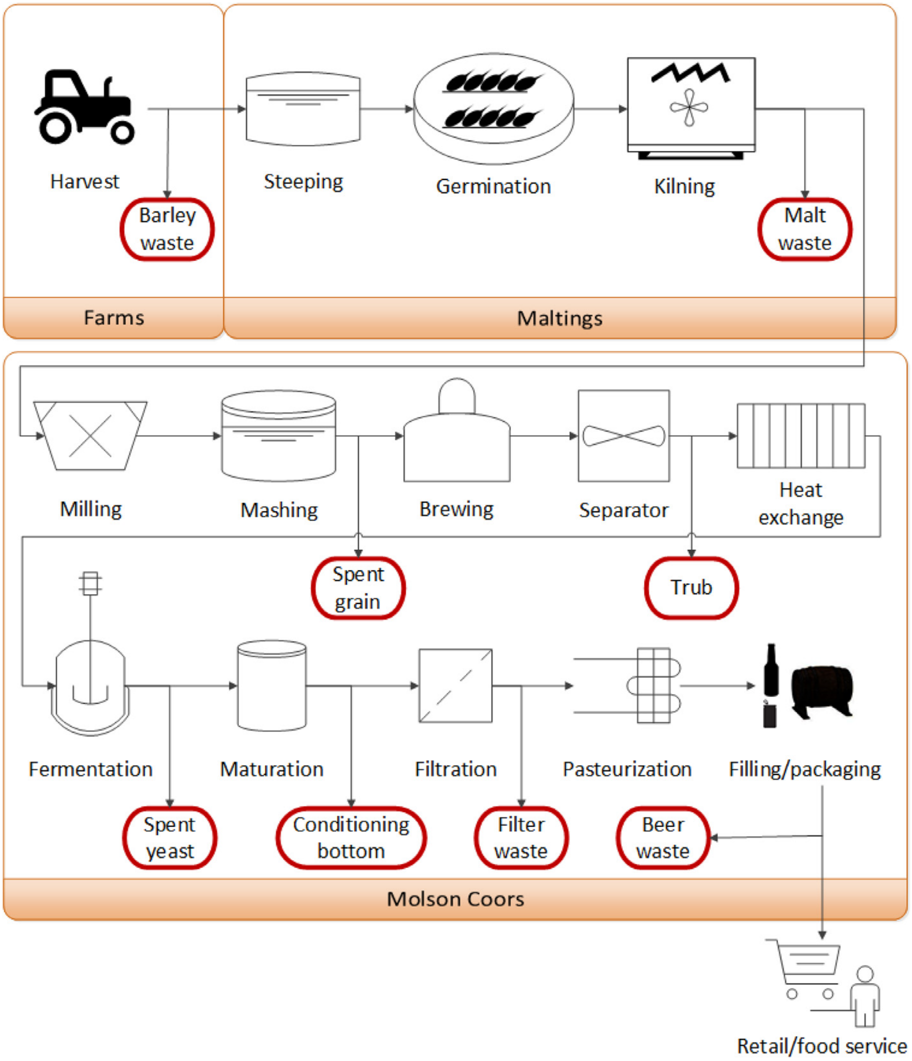

Fig. 7. Production line from farms to Molson Coors. In red, the food waste streams analysed in this paper. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

animal feeding and animal bedding. Large amounts of barley waste are produced in the east of England and sent to farms in the west.

3.2.1.2. Malt waste. Barley is malted in a process that includes three main steps: steeping, germination and kilning. In the end of the process, malt is stored in amounts of 3000–5000 t at room temperature.

For the malting process, about three times the amount of barley is added as water for steeping and germination, and a similar amount of water is removed by draining/filtering/kilning. This water cannot be reused.

Virtually all malt is used for milling and mashing, with no surplus malt that becomes waste. However, culm, the rootlets of the germinated grains, falls off when kilning. Culm is highly nutritious, thus it is pelletised and sold for animal feeding at a price of £100/t - £200/t.

The grain used as raw material in Molson Coors is composed of approximately 80% malt, 9% wheat and 11% barley without husk. Wheat and barley without husk are not malted.

3.2.1.3. Spent grain. Spent grain is a by-product discarded after the mashing process. It is composed of barley and small amounts of wheat.

Spent grain is mixed with trub (see next food waste) in a proportion of 99% spent grain, 1% trub, and sold for animal feeding (cattle). Spent grain is sold to farmers in a radius of 25–30 miles around the Molson Coors plant, providing an income for Molson Coors of about £25/t.

3.2.1.4. Trub. Trub is a by-product obtained principally in the separator after the brewing process. It is formed of hops, inactive yeast, heavy fats and proteins. Currently trub is mixed with spent grain and sent to animal feeding.

3.2.1.5. Spent yeast. Spent yeast is a by-product obtained after the fermentation process. Yeast used to produce beer is formed of fungus of the genus *Saccharomyces*. It is purchased in small quantities and then cultivated at the site to be used in the fermenters. The proportion of yeast inoculated in the fermenter against yeast waste generated at the end of the fermentation process is 1:4.

Spent yeast is sold to another company to produce Marmite®, a popular British food spread. Currently, Molson Coors cannot produce Marmite®, and for this reason animal feeding has been selected in Table 2 as the most sustainable solution within current Molson Coors' capabilities.

Table 2
Categorisation of the food wastes generated in a beer production line, and identification of its most sustainable management solution. Extended from Garcia-Garcia et al. (2017). N/A: not applicable; N/N: not-needed.

Parameter	Barley waste	Malt waste	Spent grain	Trub	Spent yeast	CT bottom	Filter waste	Beer waste
Edibility	Inedible	Inedible	Inedible	Inedible	Edible	Edible	Inedible	Edible
State	N/A	N/A	N/A	N/A	Eatable	Eatable	N/A	Eatable
Origin	Plant based	Plant based	Plant based	Plant based	Plant based	Plant based	Plant based	Plant based
Complexity	Single product	Single product	Single product	Mixed product	Single product	Single product	Mixed product	Single product
Animal-product presence	N/A	N/A	N/A	Not in contact with or containing animal-based products	N/N	N/A	Not in contact with or containing animal-based products	N/A
Treatment	N/N	N/N	N/N	N/N	Unprocessed	Unprocessed	N/N	Processed
Packaging	N/N	N/N	N/N	N/N	Unpackaged	Unpackaged	N/N	Separable from packaging
Packaging biodegradability	N/N	N/N	N/N	N/N	N/A	N/A	N/N	N/N
Stage of the supply chain	Non-catering waste	Non-catering waste	Non-catering waste	Non-catering waste	Non-catering waste	Non-catering waste	Non-catering waste	Non-catering waste
Current treatment	Animal feeding	Animal feeding	Animal feeding	Animal feeding	Production of food for human consumption	Animal feeding	50% compost +50% sewage	95% animal feeding +5% sewage
Sustainable solution according to the FWMDT	Animal feeding	Animal feeding	Animal feeding	Animal feeding	Animal feeding	Animal feeding	Anaerobic digestion	Redistribution

3.2.1.6. Conditioning bottom (CT bottom). CT bottom is a by-product obtained after the maturation process in the conditioner tanks. It is settled to the bottom of the tank as a sediment and composed principally of yeast. Currently it is send to animal feeding (swine). Alternatively, CT bottom could be filtered to separate the yeast and use it in other process, which would also enable the recovery of additional beer.

3.2.1.7. Filter waste. Filter waste is composed of diatomaceous earth, yeasts and proteins. Yeasts and proteins are edible materials and as such could be mixed with spent yeast to produce new food products (e.g. Marmite®). This food waste is currently sent to composting and sewage in similar proportions.

3.2.1.8. Beer waste. This waste corresponds to the final product which is not ultimately consumed because it belongs to one of the following streams:

- Beer remaining in casks when they are brought back from the food service sector. This causes an economic loss to the company from the food service sector which bought the beer, not to Molson Coors. Therefore, it has not been given a significant importance by the brewery.
- Beer rejected due to mislabelling.
- Spilled beer during the filling process.

Most of the beer waste corresponds to residual beer in returned casks. Currently, 95% of this food waste is sent to farms and mixed with other waste to feed animals (swine), with the remaining 5% sent to sewage.

3.2.2. *Quantitative analysis of food waste streams*

This section shows the quantification of each major stream in Molson Coors and upstream in the supply chain up to the barley farm level based on the level of beer production. Only materials that are incorporated or removed from the intermediate or final product have been considered, e.g. water needed to support some of the activities in the manufacturing plant, such as cleaning equipment, is not considered. Consequently, the following streams have been considered in the analysis:

- Raw materials: barley, wheat, barley without husk, hops and yeast.
- Waste streams: barley waste, malt waste, spent grain, trub, spent yeast, CT bottom, filter waste and beer waste.
- Intermediate streams: malt and wort.
- Water added and removed from the processes.
- Final product: beer.

Fig. 8 shows the approximate beer production at Molson Coors per month, which is driven by consumer demand and remains moderately constant for different years. The production is low in winter, and then increases during warmer months until peaking in summer. After summer, production decreases, but then in November and December it increases again due to higher demand during the festive season. This variability in beer production drives the mass flows of all streams in a beer production line.

The proportion of each raw material, product and food waste stream at Molson Coors for different months remains constant, which means that the efficiency of beer production can be assumed as unchanged throughout the year. Therefore, beer production per month, from Fig. 8, has been used as a basis for calculation to determine the value of each stream. The mass flows for each stream have been calculated based on known flow proportions, e.g. it is known that the quantity of water added for the malting process is around three times larger than the amount of barley used for malting. In order to compare mass flows between different streams, all their values have been converted in t/month, for which the following densities have been used: 1.05 kg/l for wort, 1.01 kg/l for final beer, 1 kg/l added process water. Finally, mass balances have been undertaken for each individual process and the entire production line to both calculate unknown values of some mass flows and ensure there are no errors in the calculations. After undertaking mass balances, it was needed to adjust the values of some flows to a very small extent.

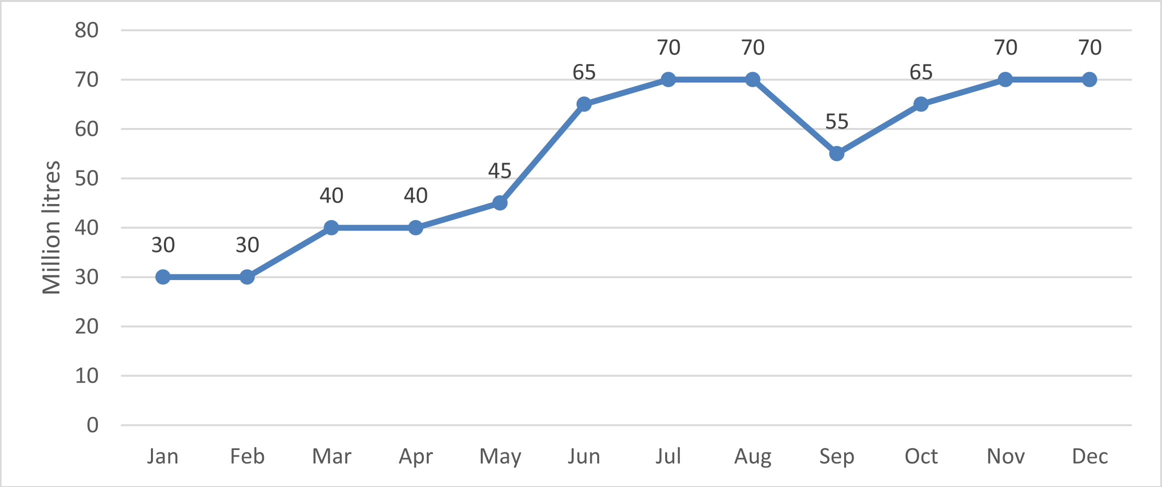

Fig. 8. Average monthly beer production at Molson Coors.

Fig. 9 shows the main results for the mass flow analysis as a Sankey diagram, using a different colour coding for raw materials, waste streams, intermediate streams, water and the final product. The main mass flows in the process correspond to water, and to wort and beer which are composed mostly of water.

The proportions of all food waste streams are shown in Fig. 10. The main streams are spent grain, which is the larger stream for most breweries, and barley waste, which is often overlooked because it is a food waste generated at farms. Due to their large amounts of these two food wastes generated, and their current use as animal feeding or bedding, both barley waste and spent grain are appropriate feedstocks for valorisation.

Since harvest and malting is not carried out at Molson Coors, it was considered useful to analyse the proportions of food waste streams generated specifically in Molson Coors' manufacturing plant, shown in Fig. 10 encircled by a blue line. Although spent grain is the largest stream, with nearly 70% of the total food wastes at the site, this value is lower than the 85% reported for other breweries (Mussatto et al., 2006; Aliyu and Bala, 2013). Trub and filter waste represents a nearly negligible amount of the total food waste, and spent yeast, 10% of the total food waste at Molson Coors, is already used to produce a food product. In conclusion, beer waste, and particularly spent grain, are the most relevant food wastes to consider in order to improve the overall waste management in the manufacturing plant.

Linking each food waste to their current management practice, the most common solution to manage food wastes from beer production is animal feeding. Spent yeast is the only food waste used for production of new food products.

Fig. 11 shows the variability of values for food wastes' mass flows, with a significant increase for the summer and festive season, following a higher beer demand. The total food waste production is 181,300 t/year.

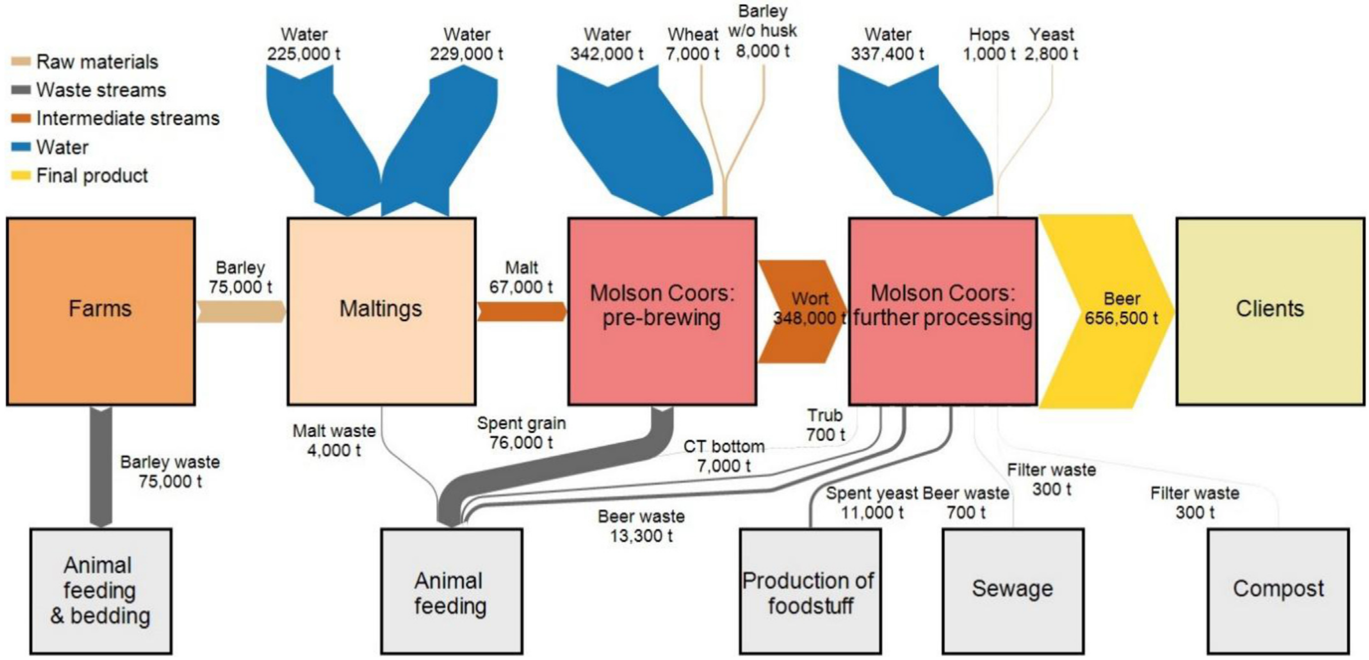

Fig. 9. Average annual Sankey diagram for Molson Coors.

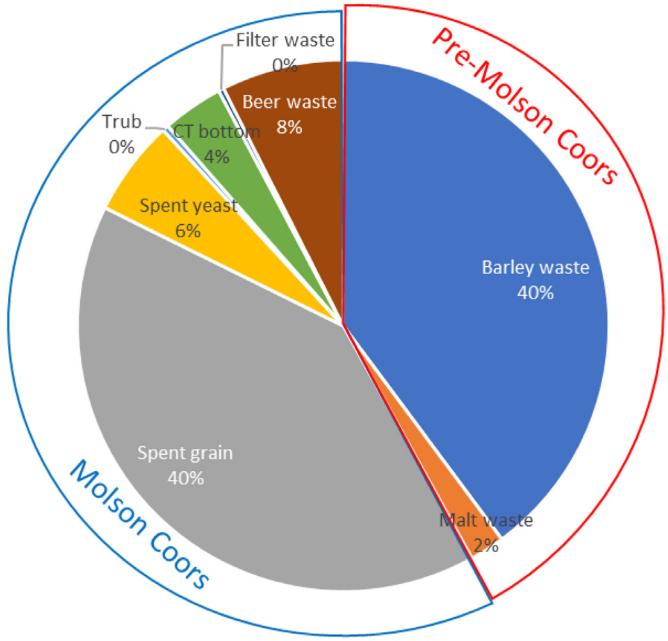

Fig. 10. Average proportions of all food waste streams generated during beer manufacturing.

The monthly tonnages of the grain food wastes are shown in Fig. 11 (a): barley waste, malt waste and spent grain. These are the only food wastes generated before the brewing process. When considering valorisation routes of these feedstocks, variability in their availabilities is a main factor. Therefore, a lower accessibility of these materials between January and March should be considered to either substitute those materials for others with similar properties, or to reduce the production level.

The mass flows values of the main food waste streams generated between the brewing and packing process are represented in Fig. 11 (b). Beer waste is the most relevant food waste due to its high quantity and because this is the final product which has completed the entire manufacturing process, and therefore it has associated a higher resource use per kg of material.

Since the processes analysed use different raw materials, and produce different products and food wastes, Table 3 shows the adapted definition of the indicators defined in Section 2 for each process or combination of processes studied, together with the values of those indicators for different process scopes. Eco-efficiency is significantly low for the malting process, due to the large amount of water used. Most of this water is removed in a subsequent step of the malting process, so when excluding water in the analysis eco-efficiency increases to a similar value than for other processes. A similar trend is observed for the rate of food waste/product, since a large amount of wastewater is obtained in the malting process. Molson Coors shows an eco-efficiency of 85.8%, significantly higher than the ‘farm to beer’ supply chain (65.8%). This is due to the significant amount of barley waste generated at farms.

3.2.3. Conclusions and recommendations

There are a number of food wastes generated in the production line of beer manufacturing, accounting for a total of over 180 kt/year in Molson Coors. In terms of their quantity, the most relevant ones are barley waste and spent grain, which account for 80% of the total food wastes generated. They are currently used for animal feeding and bedding, which are sound management practices due to their low environmental impact and the economic income that they provide. However, their use in valorisation processes for human consumption is worth exploring, due to their high availability and to the fact that valorisation may provide a more sustainable performance from both environmental and economic viewpoints compared to the current management solution.

Production of beer, and consequently waste generation, changes significantly throughout a year, peaking at summer and towards the end of the year. Although this variability is highly predictable, it should be considered when designing a valorisation process in which these materials are used as feedstocks. If spent grain is stored during periods when its production is high with the aim of valorising it when its production is low, a stabilisation method should be used to avoid microorganism growth and consequent spoilage. Drying techniques are useful to stabilise spent grain, but currently Molson Coors does not dry its spent grain due to the high energy use required. In general, when wet food waste is not treated immediately, the use of stabilisation methods is likely to be necessary to avoid spoilage.

3.3. Industrial partner: Branston Limited

Branston Limited (“Branston”) is a supplier of fresh, peeled and prepared potatoes for its retail, wholesale and food manufacturing customers. The potatoes commercialised include Branston's grown potatoes, and potatoes from a variety of suppliers, ranging from family business to large farming companies. Branston also sells seeds to some of their potato growers.

Branston has “Fresh” processing plants in three sites: Lincoln (central England), Perth (Scotland) and Ilminster (south west of England) where potatoes are sorted, graded and packaged for retail.

3.3.1. Production line and identification of food waste streams

Branston purchases potatoes from all over the UK, predominately on contract by producer groups around each site. The price of potatoes available on the UK fresh free buy market is variable depending on the season, variety and time of the year. This has an influence on the price of the final product. 70% of the final product are White and Maris Piper potatoes; the rest are Salads and other small-volume Main Crop varieties.

Branston's production line in its Fresh factory includes the following stages:

1. Potatoes are stored for up to 10 months at 3 °C and then warmed up to 10–12 °C before processing. This usually takes 3–4 days.
2. The dirty potatoes have soil removed and then are washed. Here stones and debris are removed. After washing, the potatoes are partially dried.
3. Potatoes are size graded via mechanical screens to remove very small tubers.
4. Potatoes pass under an optical grader where out of specification and not-fit-for-human-consumption potatoes are removed.
5. Potatoes go through manual sorting, i.e. a quality assurance step, to remove potatoes that have not been picked up by the optical grader.
6. Potatoes are packed and stored.
7. Potatoes are sent to supermarkets via depots that are situated around the UK.

In addition, to the “Fresh” operations described above, the site at Lincoln has an “Ingredients” factory where potatoes are peeled and sent to other businesses for use in ready meals, and a “Retail” factory, where out-of-specification potatoes are processed into added value products. The products of the Retail factory go directly to supermarkets whilst those of the Ingredients factory go to another

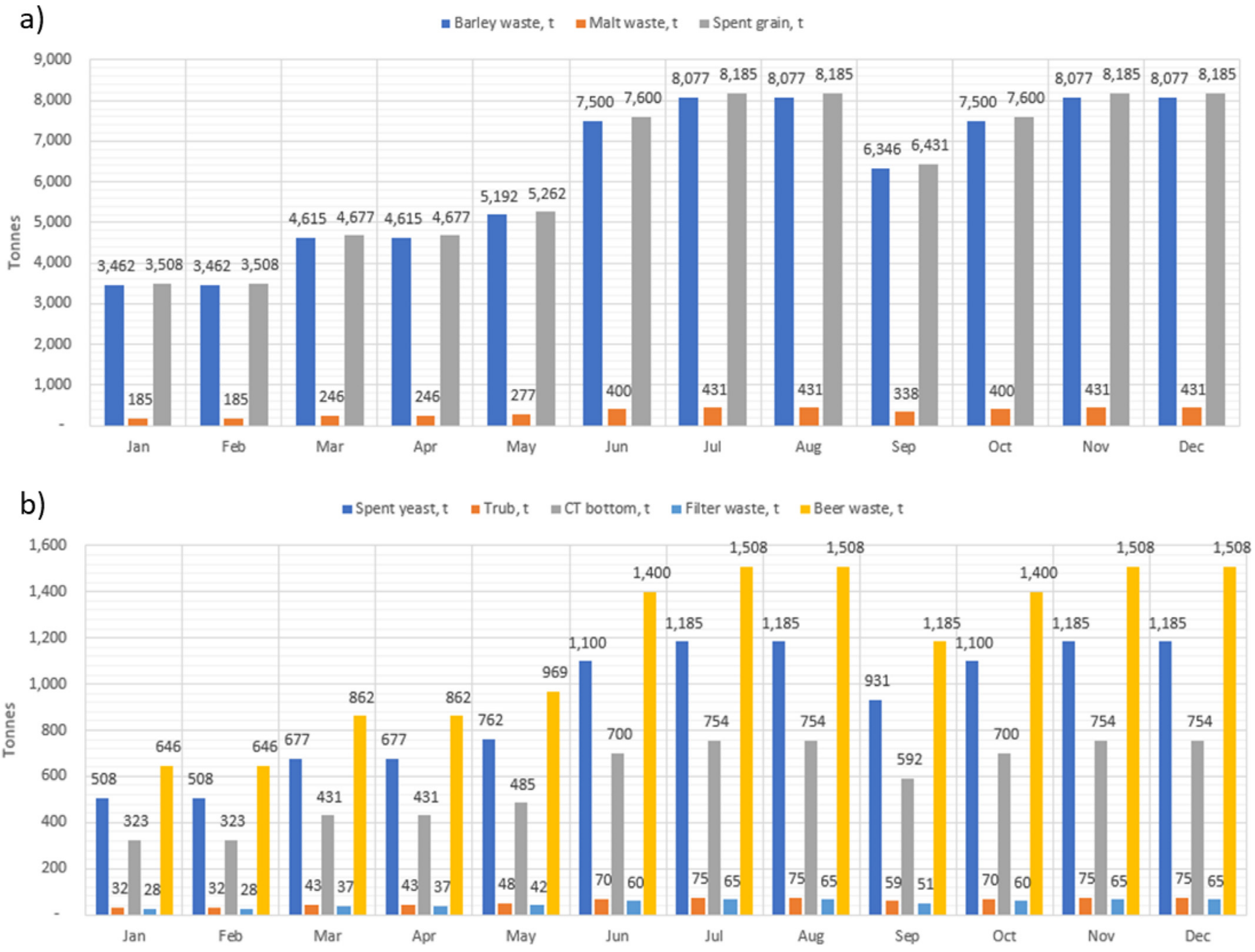

Fig. 11. Total tonnage of food wastes associated with beer production in Molson Coors in an average year. (a) tonnage of pre-brewing food wastes and (b) tonnage of further-processing food wastes.

business for additional processing and usage before going to supermarkets. These considerations are summarised in Fig. 12 which shows the production line for Branston, including the three factories in Lincoln.

The three food waste streams identified in Fig. 12, i.e. not-fit-for-human-consumption potatoes, out-of-specification potatoes and potato peelings are analysed in the following sub-sections. Table 4 classifies these three food wastes according to the nine-stage categorisation and FWMDT.

3.3.1.1. Not-fit-for-human-consumption potatoes.

Not-fit-for-human-consumption potatoes (NFHC potatoes) include potatoes with green-colour areas, bruises, halves and waste material from quality analyses and trials. They are sent to an anaerobic digestion plant located at Branston's site in Lincoln, which supplies 40% of the manufacturing site's electricity. They can also be sold for animal feeding for a marginal value. Potatoes sold for animal feeding can sometimes be stored a maximum of 24 h before they are sent away.

3.3.1.2. Out-of-specification potatoes. Out-of-specification potatoes (OOS potatoes) are fit for human consumption, but aesthetically they do not meet quality standards to be sold to customers because they have a wrong size or shape, skin defects or are not suitable from a quality point of view to go into a retail pack.

Certain potato varieties that have been approved by the customer have the OOS potatoes utilised in the Ingredients factory, where they are peeled by abrasion and sent to other businesses for use in ready meals (e.g. fishcakes and mashed potato on fish pies). Potato peelings are stored in silos (see next food waste).

Some OOS potatoes are sent to the Retail factory, where they are processed into added value products, such as unpeeled potatoes with herbs and butter added, or peeled potatoes which are either made into wedges, chips and diced potato products or sold as a whole peeled potato in a bag. Added-value potatoes from the Retail factory are then sold to supermarkets.

The rest OOS potatoes are sold to secondary markets, including animal feeding. The price received by secondary markets is below the price of the UK fresh free buy market but shows a similar variability throughout the season.

3.3.1.3. Potato peelings. Potato peelings are the food waste stream obtained in the Ingredients factory after abrasive peeling of OOS potatoes. Water is used to assist in the process of removing potato peelings in the abrasive peeler. The product is then transported to a chilled storage area. Branston's staff estimated an approximate

Table 3
Definition of indicators for each process combination.

Process scope	Eco-efficiency	Eco-intensity	Rate waste/product	Rate waste/raw materials
Farm to beer	beer/(barley + water for malting + water for mashing + wheat + barley w/o husk + water for brewing & fermenting + hops + yeast) = 65.80%	(barley + water for malting + water for mashing + wheat + barley w/o husk + water for brewing & fermenting + hops + yeast)/beer = 152.00%	(barley waste + malt waste + spent grain + spent yeast + trub + CT bottom + filter waste + beer waste)/beer = 28.70%	(barley waste + malt waste + spent grain + spent yeast + trub + CT bottom + filter waste + beer waste)/(barley + water for malting + water for mashing + wheat + barley w/o husk + water for brewing & fermenting + hops + yeast) = 18.9%
Malting (incl. water)	malt/(barley + water for malting) = 22.30%	(barley + water for malting)/malt = 447.80%	(removed water from malting + malt waste)/malt = 347.80%	(removed water from malting + malt waste)/(barley + water for malting) = 77.7%
Malting (excl. water)	malt/barley = 89.30%	barley/malt = 111.90%	malt waste/malt = 6.00%	malt waste/barley = 5.3%
Pre-brewing	wort/(malt + water for mashing + wheat + barley w/o husk) = 82.10%	(malt + water for mashing + wheat + barley w/o husk)/wort = 121.80%	spent grain/wort = 21.80%	spent grain/(malt + water for mashing + wheat + barley w/o husk) = 17.9%
Further processing	beer/(wort + water for brewing & fermenting + hops + yeast) = 95.30%	(wort + water for brewing & fermenting + hops + yeast)/beer = 105.00%	(trub + spent yeast + CT bottom + filter waste + beer waste)/beer = 5.10%	(trub + spent yeast + CT bottom + filter waste + beer waste)/(wort + water for brewing & fermenting) = 4.9%
Molson Coors	beer/(malt + water for mashing + wheat + barley w/o husk + water for brewing & fermenting + hops + yeast) = 85.80%	(malt + water for mashing + wheat + barley w/o husk + water for brewing & fermenting + hops + yeast)/beer = 116.60%	(spent grain + spent yeast + trub + CT bottom + filter waste + beer waste)/beer = 16.60%	(spent grain + spent yeast + trub + CT bottom + filter waste + beer waste)/(malt + water for mashing + wheat + barley w/o husk + water for brewing & fermenting + hops + yeast) = 14.3%

proportion for this food waste stream of 60% solids and 40% water, however this is variable.

Potato peelings are stored in silos, from where they are removed 4–5 times per week. Potatoes are peeled at the factory in Lincoln only.

3.3.2. *Quantitative analysis of food waste streams*

This section quantifies the food waste streams from the three Branston's sites: Lincoln, Perth and Ilminster. Branston handles an average of 300,000 t of potatoes per year, of which in the region of 230,000 t of final product are sold every year. This quantity of final product is evenly distributed throughout the year with a weekly average of around 4400 t. Minor variation between different weeks are explained due to the need to adapt to customer requirements.

Similarly, there is a small variation in the food waste generation rate, with a slight increase throughout the potato season. Food waste generation can increase to a maximum of 15% throughout the year, depending on the individual season. Because of the significantly small variation in food waste generation rate and the difficulty to predict its exact variability for different years, it has been agreed with Branston's company staff to assume constant monthly values.

The quality of food waste is constant throughout the year, however dry matter increases as the season progresses.

Proportions of each output flow for one year from Branston and their final destination can be seen in Fig. 13: sold for human consumption, sold for animal feeding and sent to anaerobic digestion.

Fig. 14 shows the quantification of the main mass flows for one year in Branston: 300,000 t of raw potatoes arrived to Branston, of which 230,000 t were sold as fresh final potatoes whilst 70,000 t of potatoes were sent to other destinations. These numbers vary depending on the season.

15,000 t of NFHC potatoes are obtained every year. 7000 t of this is sent to the anaerobic digestion plant at Branston, which is the requirement to get it to full capacity, whilst the rest, approximately 8000 t/year, is sent to animal feeding.

55,000 t of potatoes fit for human consumption which do not meet quality standards are discarded every year as OOS potatoes. This food waste stream is split in different proportions which are sent to the Retail factory, the Ingredients factory, or are directly sold, as explained below.

6000 t/year of the OOS potatoes are sent to the Retail factory, where they are processed into added value products and sold to supermarkets.

22,000 t/year of the OOS potatoes are sent to the Ingredients factory to be peeled and sold for use in ready meals. Currently, the only estimated quantification for this stream is a volumetric flow of 6500 m^3/year for the peeling process, with a proportion of 60% solids and 40% water in the potato peelings. Following a review of abrasive and mechanical potato peeling processes, it can be estimated that of the order of 25% of the potato mass is wasted, leaving a 75% of potato flesh as peeled potato (Lisińska and Leszczyński, 1989; Arapoglou et al., 2009; Liang and McDonald, 2014). This provides an estimate of 5500 t/year of potato peelings and 16,500 t/year of peeled potato.

Potato peelings include a thin layer of potato skin and a significant amount of potato flesh, since the abrasive peeling process tends to over peel the potatoes to ensure there is no skin left on the peeled potato. Therefore, the density of potato peelings has been estimated to be similar to that of whole potatoes, i.e. 0.59 t/m^3 for English raw potatoes (Charrondiere et al., 2012). Machine and Process Design (2015) provides a slightly higher estimation for whole unpeeled potatoes of 0.657 t/m^3, but also confirms a very similar density for both potato and potato peelings, as estimated above, since the densities of whole, peeled and unpeeled potatoes are 0.657 t/m^3 and 0.641 t/m^3 respectively. Therefore, the 5500 t/year of potato peelings with an estimated density 0.59 t/m^3 would occupy a volume of 9322 m^3/year. Adding to the calculations the 6500 m^3/year of water used in the abrasive peeling process reported by Branston, a final volumetric proportion of 59% of potato peelings and 41% of water is obtained, similar to the 60% solids and 40% water estimated by Branston. In conclusion, it has been estimated that the mass flow of potato peelings is equal to 5500 t/year of dry potato peelings or 12,000 t/year of both potato peelings and water. A precise measurement of both the mass flows for this stream and composition of potato peelings is recommended to

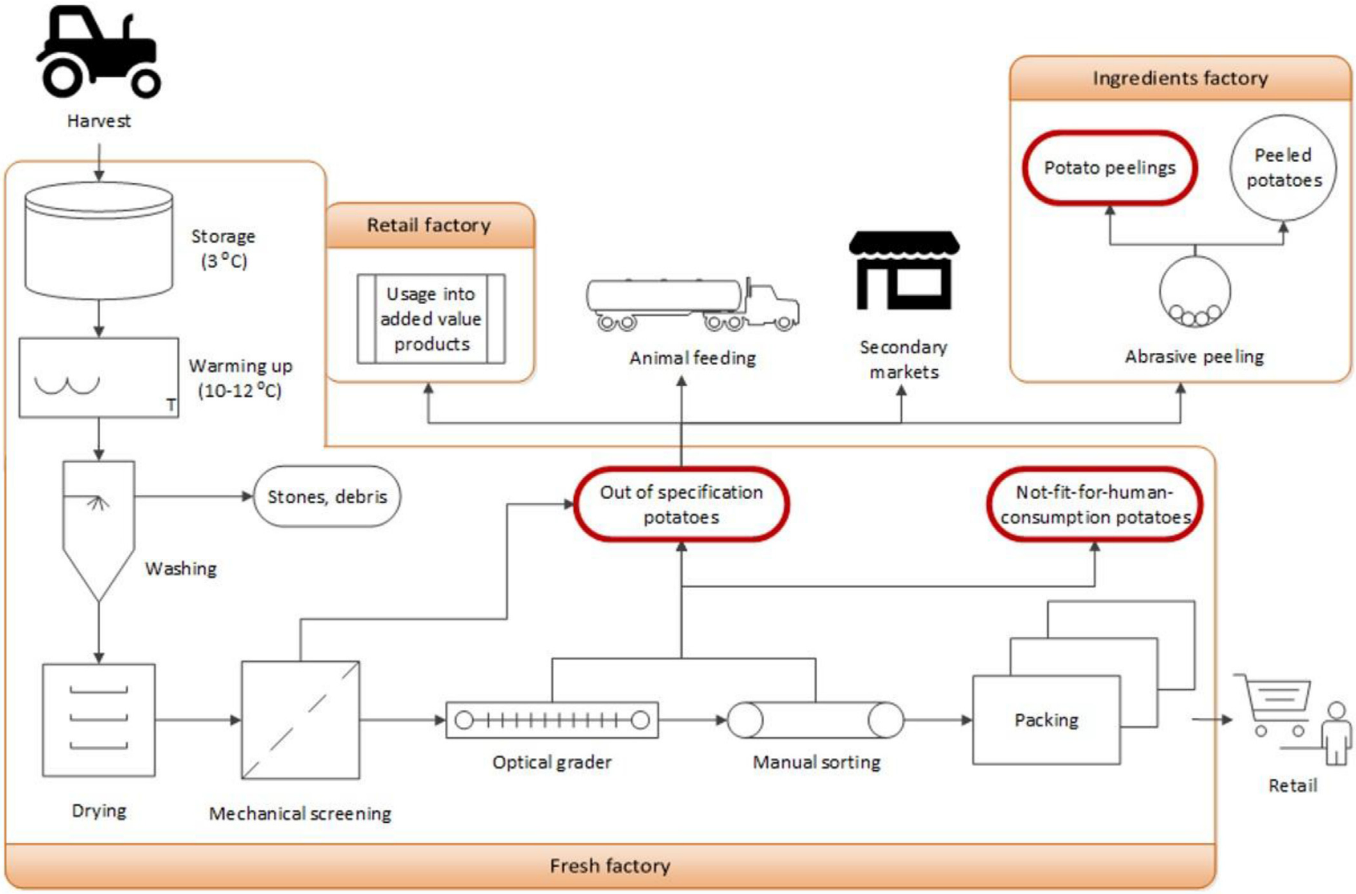

Fig. 12. Production line in Branston. In red, the food waste streams analysed in this paper. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Categorisation of NFHC potatoes, OOS potatoes and potato peelings, and identification of its most sustainable management solution. N/A: not applicable; N/N: not-needed.

Parameter	NFHC potatoes	OOS potatoes	Potato peelings
Edibility	Edible	Edible	Inedible
State	Uneatable for humans, eatable for animals	Eatable	N/A
Origin	Plant based	Plant based	Plant based
Complexity	Single product	Single product	Single product
Animal-product presence	N/A	N/A	N/A
Treatment	N/N	Processed	N/N
Packaging	Unpackaged	Unpackaged	N/N
Packaging biodegradability	N/A	N/A	N/N
Stage of the supply chain	Non-catering waste	Non-catering waste	Non-catering waste
Current treatment	Animal feeding	Redistribution/stockfeed	Animal feeding
Sustainable solution according to the FWMDT	Animal feeding	Redistribution	Animal feeding

obtain a more accurate quantification for this stream, which is expected to rise in the following years as demand for peeled potatoes is projected to increase.

Finally, 14,000 t/year of OOS potatoes are sold in secondary markets, whilst 13,000 t/year are sent to animal feeding (stockfeed). OOS potatoes sent to animal feeding accounts for the remaining OOS potatoes that cannot go to other destination because of a lack of supply outlet. Considering both NFHC and OOS potatoes, a total of 21,000 t of food wastes are sent to animal feeding per year, of which only 5500 t are sent from Lincoln site.

The values for the performance indicators explained in Section 2 can be found in Table 5. Although food wastes have been defined as any output other than fresh final potatoes (first row in Table 5), an alternative set of the indicators have been defined to include potatoes used for human consumption in the final-product category (second row in Table 5).

3.3.3. *Conclusions and recommendations*

Branston generates 70,000 t of food wastes per year, of which 33,500 t are not used for human consumption and are sent to animal feeding or anaerobic digestion. This includes all NFHC potatoes (15,000 t/year), OOS potatoes sold for animal feeding (13,000 t/year) and potato peelings (5500 t/year). These three food waste streams would be ideal feedstocks for valorisation.

The food waste generation rate of these streams is relatively constant, with a maximum increase of 15% throughout the year.

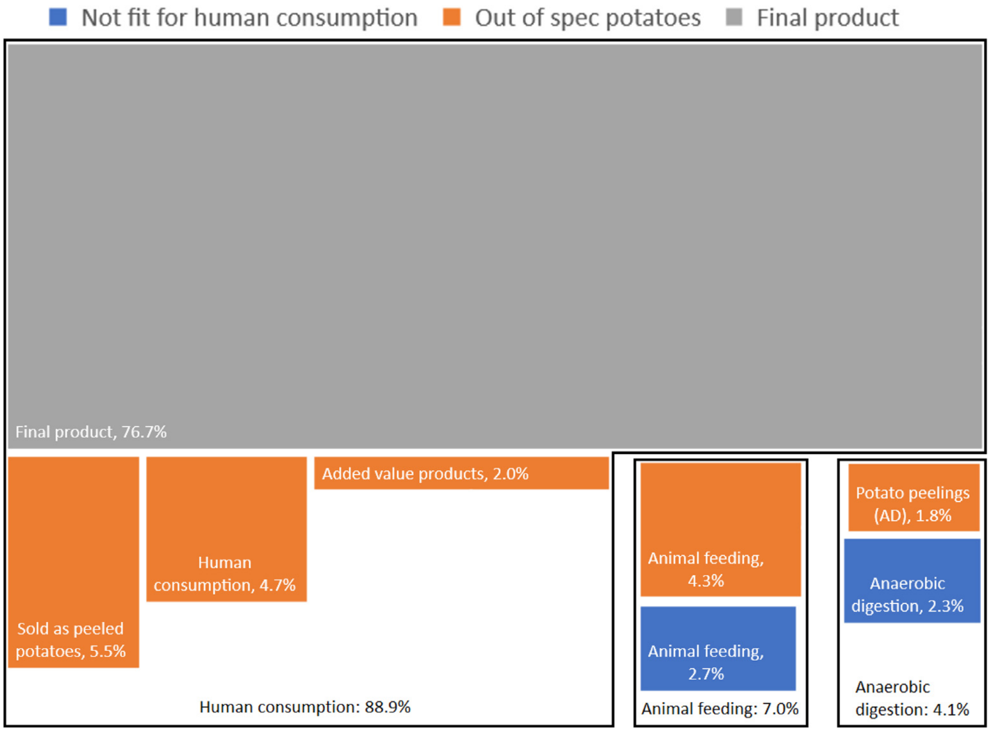

Fig. 13. Average percentage of each output flow in Branston. Streams have been grouped into two categories: their stream type (background colour) and their final destination (from left to right: sold for human consumption, sold for animal feeding and sent to anaerobic digestion). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

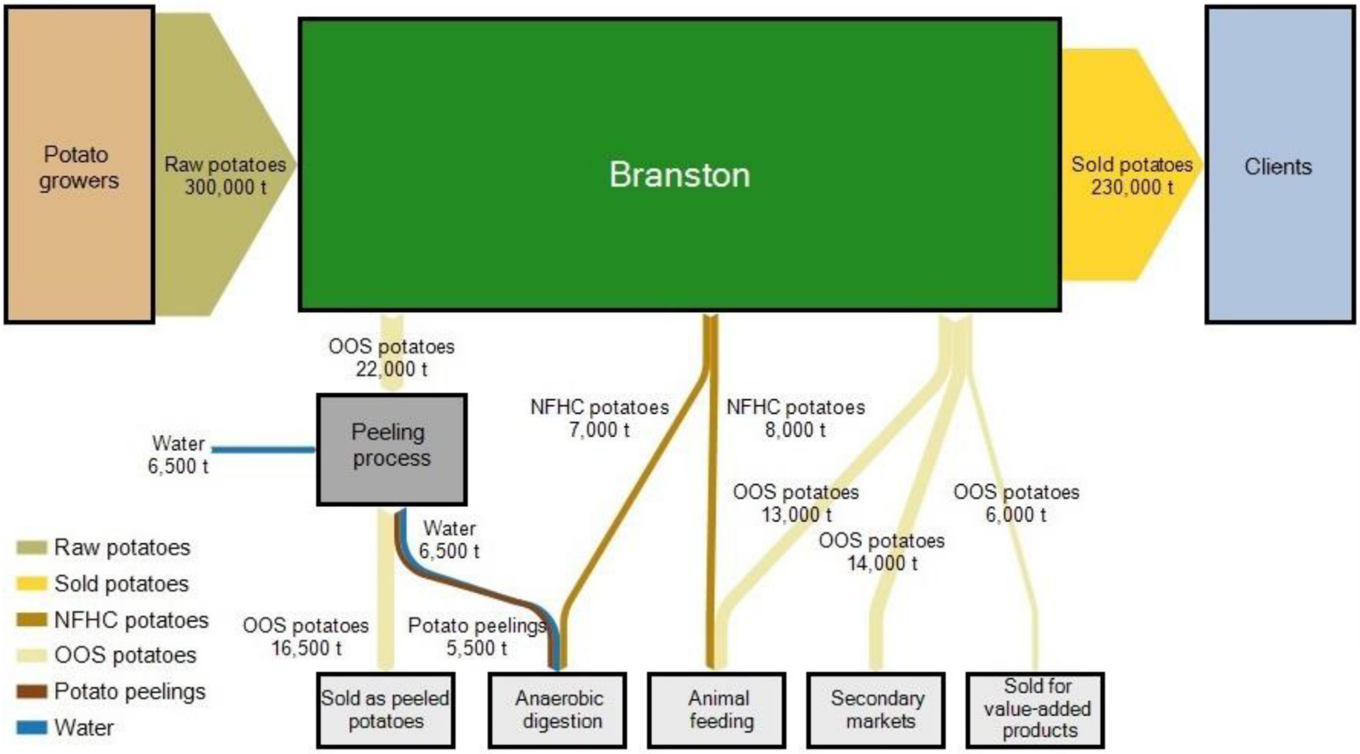

Fig. 14. Average annual Sankey diagram for Branston.

Table 5
Values of indicators for different food waste scopes.

Food waste scope	Eco-efficiency	Eco-intensity	Rate food waste/final product	Rate food waste/raw material
Outputs not sold as fresh final product	76.7%	130.4%	30.4%	23.3%
Outputs not sold for human consumption	88.8%	112.6%	12.6%	11.2%

This gives a weekly average food waste generation rate of 644 t/week. A constant food waste generation rate facilitates the design of a valorisation process since it provides a constant feedstock to be used as raw material. Furthermore, potato food wastes can be stored for a period of time at 3 °C, therefore if the food waste generation rate increases during a specific time period, these materials can be preserved and used when the food waste generation rate decreases.

In terms of food waste reduction, relaxation of cosmetic standards from retailers and customers could potentially save a significant amount of OOS potatoes being wasted. Additionally, 13,000 t/year of OOS potatoes are sold for animal feeding but could be used for human consumption instead. It is recommended to find alternative process routes of markets to use these OOS potatoes for human consumption.

NFHC potato generation rate is difficult to reduce. Possible options to explore to minimise this quantity are optimisation of the cold chain, improvement of storage conditions (e.g. temperature, level of humidity, cleanness of air, improved isolation) and reduction of potato movements. These possibilities to reduce waste levels are also applicable for most wastes from other food industries.

Finally, a more precise measurement of the mass flow rate and composition of potato peelings is recommended to obtain a more accurate quantification of this stream.

3.4. *Industrial partner: The Green Pea Company Ltd*

The Green Pea Company Ltd (“The Green Pea Company”) is a farmer co-operative with around 240 members who grow peas for Birds Eye's freezing operation at Hull. This factory accounts for the majority of Birds Eye's pea production in the UK and is the world's largest pea factory, processing around 61 t of peas per hour during the harvest season. Birds Eye supplies around half of the frozen peas sold in the UK. The Green Pea Company's peas are also sold internationally as Findus, particularly in Italy.

The harvesting area is located in East Yorkshire and North Lincolnshire and occupies about 10,000 ha.

3.4.1. *Production line and identification of food waste streams*

The Green Pea Company produces 45,000 t of peas per harvest, with an average of 900 t of peas per harvest day, although significant harvesting variability means that harvesting rate can vary from 0 to 1200 t per day. Harvest starts in the end of June or beginning of July for around seven weeks; in 2017, the harvest season started on 1st July and finished on 18th August.

The Green Pea Company uses the following raw materials:

- Seed, which is primarily brought from the south coast of England, whereas smaller quantities are imported from France and Belgium. 165 kg of seed are needed per hectare, which gives a total of 1650 t of seed needed per harvest. It is purchased at a price of £240/t.
- Fertiliser, which is mostly phosphorus and potassium based. Phosphate is mostly imported, whereas potash is sourced from the UK. Fertiliser is needed in small amounts, with an expenditure of about £15/ha.
- Pesticides, which is likely to be mostly imported. The quantity needed varies between different seasons, but an expenditure of about £100/ha can be assumed.

The Green Pea Company's production line is shown in Fig. 15. Peas are grown as part of a crop rotation: the pea crop is grown a maximum of one time every six years in a given field. When peas are ready to harvest, the harvester takes the crops from the soil and separates the peas and the vine. The vine is ploughed back to the soil, and peas are moved to a holding tank and then to trailers pulled by tractors, which transport them to Birds Eye's factory at Hull. Peas travel an average of 15 miles to reach Birds Eye's factory at Hull, which is located in a central position amongst pea fields, with a maximum distance between a farm and the factory of 40 miles. The Green Pea Company receives a price of around 30 p/kg.

The Green Pea Company uses about 800,000 L of diesel per year. Out of this, 180,000 L are used to sow and seed the crop in the spring, and the rest for harvest, both in harvesters and tractors.

In Birds Eye's factory, peas are blanched in water at 90 °C for 60 s and then cooled. Finally, they are transported by a conveyor belt with bouncing motion in a tunnel at −25 °C, where they are blast-frozen. The entire process, between harvest and freezing, takes up to 2.5 h for every pea, which ensures maximum nutrient and taste retention.

The food waste of interest generated during pea harvest and processing is the pea vine field residue, also known as pea vine or pea haulm. This material includes stems, pods, leaves and a small amount of peas. The proportion of each of these elements has not been determined.

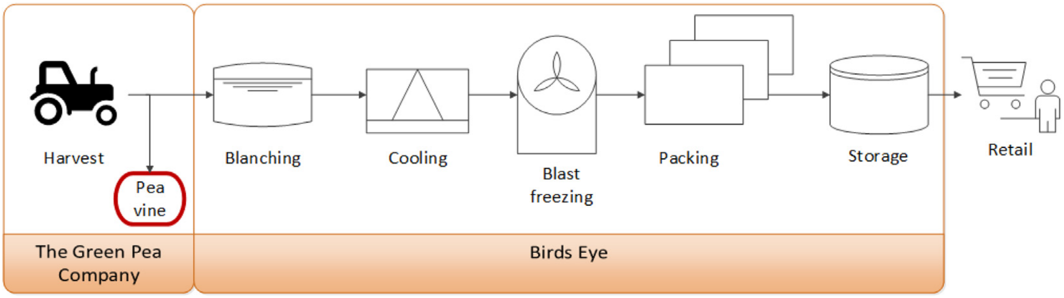

Fig. 15. Production line for peas produced by The Green Pea Company. In red, the food waste stream analysed in this paper. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 6
Categorisation of pea vine and identification of its most sustainable management solution. N/A: not applicable; N/N: not-needed.

Parameter	Pea vine
Edibility	Inedible
State	N/A
Origin	Plant based
Complexity	Single product
Animal-product presence	N/A
Treatment	N/N
Packaging	N/N
Packaging biodegradability	N/N
Stage of the supply chain	Non-catering waste
Current treatment	Landspreading
Sustainable solution according to the FWMDT	Animal feeding

Pea vine is left on the soil after the peas have been removed, bringing organic matter and nutrients, such as nitrogen, back to the soil, which not only improves soil structure, but also reduces the need for later fertiliser application. The root nodules provide the largest contribution to nitrogen-fixing properties of the pea plant because of the presence of rhizobia bacteria (The Andersons Centre, 2015). Pea plants can fix between 70 and over 200 kg N/ha (Cuttle et al., 2003). However, not all nitrogen from the pea vine is utilised in the next crop. Some nitrogen is volatilised to atmosphere and some is leached, which causes eutrophication (Askegaard et al., 2011).

Table 6 classifies pea vine according to the nine-stage categorisation and FWMDT. Currently, pea vine is used for landspreading as a fertiliser, but as explained above the soil may need a lower amount of pea vine to maintain its physical, chemical and biological characteristics under some circumstances. According to the FWMDT, the surplus pea vine could be distributed for use as in animal feed. Alternatively, pea vine can also be used for anaerobic digestion, to obtain bioenergy, or to produce compost, which could give an additional economic benefit to The Green Pea Company.

3.4.2. *Quantitative analysis of food waste streams*

The Green Pea Company generates approximately 153,000 t of pea vine per harvest, which means that less than a quarter of the crop mass is the edible pea. Harvesting rate varies significantly for different days of the same harvest, but as an average over 3000 t of pea vine are obtained per day, of which a large proportion could be used for valorisation purposes.

Table 7 shows the adapted definition of the indicators defined in Section 2 for The Green Pea Company's activities and the value of each indicator. As raw materials, only seeds have been considered, because they represent most of the raw material use by mass, the quantity used is accurately known and they have a constant value. Therefore, fertiliser and pesticide use have not been included in the calculations.

As can be seen in Table 7, the values of eco-efficiency, eco-intensity and rate food waste/raw materials is very high. This is explained by the fact that only the seeds have been considered as raw materials, and the amount of seed used is very low compared to the quantity of peas and pea vine generated. In order to determine the exact raw material used to produce peas, not only fertiliser and pesticides could be included into the calculations, but also the quantity of organic matter and nutrient present in the soil and used by the pea plant to grow.

3.4.3. *Conclusions and recommendations*

The Green Pea Company generates approximately 153,000 t of pea vine per harvest, which is around three times the amount of pea obtained. Currently this is left on the soil to use its nutrient content for future harvests, but a portion of it could be used as a feedstock for valorisation. Simple, alternative ways to manage pea vine and obtain an economic benefit would be selling it for animal feeding, using it for anaerobic digestion, or composting. Other, potentially more sustainable solutions include the recovery of such nutrients and use them in new food products. As stated in the introduction section of this paper, valorising food waste by extracting its valuable compounds, and potentially using them in new food products, is a promising option to manage these materials sustainably.

It must be considered that pea vine is generated only during the harvest season, in July and August. Therefore, a pea vine process valorisation should only be used during these months, or alternatively pea vine should be stabilised and stored in a way that its nutrient content is maintained (e.g. by freezing).

4. Conclusions

This paper has demonstrated that there are vast quantities of food wastes generated in the UK food industry by examining food waste generation in four different industrial food sectors. After analysing current management practices, evidence suggests that there are significant opportunities to valorise a number of the food wastes identified, and in doing so, improve the sustainability performance of current treatment methods. Key aspects to consider when designing food waste valorisation processes include quantities and types of material available, patterns of generation of these materials, qualitative and quantitative characteristics of food waste, and variability of food waste generation and quality. These aspects have been analysed for each food waste from each industrial site studied, which allowed the identification of optimal food waste valorisation opportunities: uneatable citrus fruits for Chingford; barley waste and spent grain for Molson Coors; NFHC potatoes, OOS potatoes sold for animal feeding and potato peelings for Branston; and pea vine for The Green Pea Company. Recommendations have also been given to support the implementation of valorisation alternatives for the aforementioned feedstocks. For instance, the state of uneatable citrus fruits should be assessed to evaluate if it can be valorised, spent grain and pea vine should be stabilised prior to its valorisation, and opportunities to reduce potato waste generation should be explored before analysing the feasibility of different waste treatments. It is expected that the issues to valorise food waste identified in this paper will also arise when other food wastes are considered as feedstocks. Generally, it is recommended to explore the viability of extracting valuable compounds from these food waste materials and assess the potential uses of such compounds, for example to manufacture new food products for human consumption.

Table 7
Definition of indicators and their values.

Indicator	Definition	Value
Eco-efficiency	Quantity of peas produced/quantity of seed used to produce it	2727%
Eco-intensity	Quantity of seed used to produce peas/quantity of peas produced	3.7%
Rate waste/product	Quantity of pea vine generated/quantity of peas produced	340%
Rate waste/raw materials	Quantity of pea vine generated/quantity of seed used to produce peas	9723%

The methodology used in this paper could be easily applied to other agri-food companies. Furthermore, as the food industry of a majority of developed countries tend to generate significant quantities of food wastes, it is expected that numerous valorisation opportunities can be found in most food manufacturing environments. When valorisation opportunities are identified, exhaustive analyses should be undertaken to compare the sustainability performance of current and proposed alternative practices. Integrating food waste valorisation in the food supply chain, and even in the food company that generates the waste, may present a significant advantage to improve the sustainability of the food system. In the next stages of the research project presented in this paper, both environmental and socio-economic assessments are going to be used to justify the implementation of alternative, novel food waste valorisation processes.

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Appendix A. Supplementary data

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