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Environmental benefits of pet food obtained as a result of the valorisation of meat fraction derived from packaged food waste

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A B S T R A C T

The 2030 Agenda of the United Nations includes the objective of setting up sustainable production patterns by pursuing several Sustainable Development Goals. Among them, the "Responsible production and consumption" is a key topic in the food production and is strictly connected with the "Climate action"; the crucial point, however, is how to jointly act on all these aspects and apply them in practice.

The waste yearly produced in the food chain represent both an ethical, economic and environmental issue. In particular, as far as the recovery of packaged food waste from retailers is concerned, the valorisation of the wasted meat is an extremely relevant issue. Pet food industries could be interested in valorising this waste fraction to replace meat coming from slaughters in their product recipes.

This article evaluates the environmental impact of valorising meat fraction from packaged food waste to produce two different recipes of high quality pet food, called Natura and Pâté. A life cycle assessment of the current scenario (traditional pet food production and landfilling of packaged food waste) and of a new one (pet food production using meat fraction from packaged food waste) is carried out applying the ReCiPe 2016 method of impact assessment. Real data have been taken from retailers and pet food manufacturer.

The production of pet food using the meat fraction from packaged food waste generates on average lower environmental impacts if compared to the traditional process, in terms of GWP (-56.40%), water consumption (–22.62%), land use (-87.50%) and fossil resource scarcity (-21.78%). Benefits are interesting even if considering the production of Pâté (-14.66%), for which the traditional production process makes use of some slaughter by-products. The proposed industrial process is demonstrated to be sustainable from an environmental point of view and appears to be in line with Sustainable Development Goals (SDGs) 2, 12 and 13.

1. Introduction

The 2030 Agenda of the United Nations defines 17 Sustainable Development Goals (SDGs)[1]. None of them contrast with any others; on the contrary some of them are closely related one each other. Responsible consumption and production (SDG 12) reflects a production strategy able to do more with less; this means, for instance, reducing the environmental degradation and increasing agricultural productivity and sustainability of food production. As such, it has obvious relationships with climate actions (SDG 13) and zero hunger (SDG 2).

The responsible consumption of energy and water in food production and the reduction of food waste along the supply chain are key points in sustainable consumption and production. In the food sector the usage of energy and water is conspicuous and is expected to increase in time, due to the fact that the world population will reach about 8,6 billion in 2030 (United Nations, 2019). This context emphasises that the finished food product has not to be wasted.

Estimates of the European Commission (2017) indicate that the amount of wasted food in the EU ranges from 88 to 129 million tons per year, with associated costs estimated at 143 billion euros (Stenmarck et al. 2016; Caldeira et al. 2019). Implications of food waste for sure encompass ethical and economic aspects, but also include environmental issues that can affect the sustainability of the food chain. Food waste (FW) can be generated at different stages of a food chain, such as during raw material production, food manufacturing, storage, marketing, distribution, and consumption (Caldeira et al. 2019). In industrialized countries, however, the last stages of the food chain (e.g. retailers,

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catering industries or the final customers) are those where typically the FW could be potentially at maximum reduced (Mattsson et al. 2018). Looking at the retail stage, different data about FW in Europe can be found. Stenmarck et al. (2016) have estimated the amount of retail FW to be approximately 4.6 million tons in 2012, which would be significantly lower than the FW generated in other stages of the supply chain. From another source, according to Caldeira et al. (2019), the impact of the FW in retail and distribution phase accounted instead for 6.7 million tons in 2011. Regardless of the exact value, this amount should not be neglected because more economic and environmental impact is typically connected to the wastages in the final stages of a food chain (Eriksson et al., 2015). Moreover, super- and hyper-markets and generally all the retail stores collect food from several suppliers and concentrate in a unique place the different waste caused by expired shelf life or transport accidents (Brancoli et al., 2017). Some studies have been conducted about the estimate of food losses in retailing and supermarkets. Cicatiello et al. (2017) have presented a literature review of retail FW quantification and estimated the amount of FW produced in one retail outlet in Italy. The authors found that the store under evaluation wasted 70.6 tons of food in one year, involving an economic loss of approximately 170,000 €.

Concerning the potential reuse of retail FW, several studies suggest that the best option is through human consumption; to this end, the FW could be for example redistributed for social purposes (Falasconi et al. 2015; Segrè et al. 2009). However, most of the retail FW is no longer edible, e.g. because of a little damage on the packaging, a visual imperfection or expired shelf-life (Cicatiello et al. 2017). Under that circumstance, the residual FW should be valorized by using the best disposal option among those available (Caldeira et al., 2020). The European Commission (2014) has clearly identified the FW disposal technologies, by means of the so-called FW hierarchy, which lists the disposal options in order of preference. According to this hierarchy, governments should address their efforts for: (i) reducing FW; (ii) redistributing it (e.g. for charity purposes); (iii) recycling it as animal feed or (iv) compost; (v) recovering energy through anaerobic digestion. Only the remaining quota could be disposed of in landfill sites (Salemdeeb et al., 2017).

Several studies have shown that recycling FW to produce animal feed is the best food management option in terms of environmental impact (Lee et al. 2007; Kim and Kim 2010). Vandermeersch et al. (2014) and San et al. (2016) have also demonstrated that the valorisation of the FW for animal feed production guarantees a reduction of the environmental impact, because of the partially (or totally) avoided production of the traditional ingredients for animal feed.

As far as the composition of the FW at retail stores in concerned, fruit and vegetables were found to cover a relevant quota in terms of the amount of waste (85% of the total waste); however, in terms of the environmental impact, they contribute for 46% of the carbon footprint produced only (Scholz et al. 2015). The meat fraction (MF) shows an opposite trend, as meat only accounts for 3.5% of the total amount of FW, but generates 29% of the carbon footprint. This suggests that valorising this fraction of the FW, for instance for animal feed production, has potential to generate significant benefits in environmental terms. Despite this, however, the scientific literature has not expressively evaluated the environmental impact of valorising the MF of the food waste generated in retailing (Scholz et al. 2015). Similarly, only some studies have dealt with the treatment or valorisation of meat waste generated at stages other than retailing. The few available studies concern the valorisation of MF generated at the processing stage for some types of meat, such as pork (Noya et al. 2017; Petenuci et al. 2018), poultry feathers, swine bristles and ox hairs (Mi et al. 2019), and meat by-products (Toldrá et al., 2016). Recently Sharma et al., (2020) summarized all possible value-added products that can be obtained from meat waste used for fertilizing, animal feed production, blood meal, meat and bone meal, feather meal, lactic acid, and probiotics. To this end, valorising the meat waste is feasible only if microbiological issues related to its conservation and storage are taken into account. Indeed, specific thermal treatments are required to ensure a microbiologically stabilization of the MF coming from packaged food waste (PFW) in view of its possible usage in pet food production (Bacci et al. 2019).

In pet food production, most of the environmental impact is due to the animal husbandry stage (Lamnatou et al, 2016; Noya et al., 2017; Cesari et al, 2018). To appraise the relevance of this phase, this study will evaluate the production of two varieties of wet pet food (called "Natura" and "Pâté") with different recipes, produced by an Italian pet food manufacturer. The two recipes make use of different raw materials, such as muscle tissue (Natura) and meat by-products coming from slaughters (Pâté). In both recipes, the meat raw material will be replaced by the MF coming from PFW.

Moving from this premise, the main objective of this study is to evaluate whether the valorisation of the MF coming from FW generated at the retail phase of a food chain would be environmentally sustainable if used for producing pet food. The (possible) benefits compared to the traditional pet food production will also be evaluated.

The paper is structured as follows. A short introduction about the context in which this study has been carried out is first presented (sub-section 1.1). Section 2 details the technologies for the production of wet pet food, while Section 3 describes the full steps of the LCA methodology as defined by ISO 14,000 and ISO 14044. The evaluation of the environmental impact is shown in Section 4, taking into account the current scenario (i.e., disposal of in landfill of MF and use of standard ingredients to produce the two varieties of pet food), and comparing it with a new one where pet food is partly manufactured from MF. Finally, Section 5 concludes by summarizing the main results of this work and outlining possible future research activities.

1.1. The SORT project

As discussed in the introduction, the issue of food waste in retailing is relevant in the developed countries and the problem is even more important in highly populated regions. If analysing the specific context of distribution and retailing in a densely populated region of northern Italy, such as the Emilia-Romagna, the amount of food wasted yearly can be estimated to be about 14,600 tons/year (Vitale et al. 2018; Bottani et al. 2019). Valorising this waste requires the collection of PFW and the separation of meat waste from its packaging material. These considerations form the rationale behind the SORT (Italian acronym for "Technologies and models to unpack, manage inventory and track wasted food") project, whose aim is to create innovative systems for valorising PFW to obtain by-products or new goods. The SORT system is intended to support the collection of the PFW from retailers, its sorting and separation and its sustainability has already been demonstrated for the production of dried animal feed (Mosna et al. 2016), recovery and recycling of packaging materials (Vitale et al. 2018) and from a logistic and economic point of view (Bottani et al. 2019). Thanks to the use of specific machines able to process the PFW in different ways (e.g. crashing, uncorking or cutting), the sorting facility will be able to split the packaging from the food part for almost all products wasted.

2. Pet food production process

The detailed pet food production process of the Natura and Pâté production lines is described in this section to support the evaluation of the environmental impact of the current and new scenarios of pet food manufacturing. The relating process flows are proposed in Fig. 1. As far as the efficiency of these processes are concerned, it has been demonstrated that the high level of automation of the production systems allows to generate very few wastages and scraps during the production, which can last for about 8 or 16 h without specific stops (https://www.petfoodprocessing.net/articles/13488-modern-tech-innovative-approaches-for-optimizing-process-efficiencies). After the production a "cleaning in place" phase is always performed in order to clean and prepare the lines for the production of the day after.

2.1. Natura production line

2.1.1. Meat production

As a peculiarity, the Natura production line makes use only of meat muscle tissue, which typically reaches the pet food manufacturer directly from slaughterhouses producing meat for human consumption, in the form of fresh or frozen meat. Frozen meat must be defrosted at least 24 h before its usage. Depending on the MF inputs (i.e. pork, beef or poultry), three different variants of the Natura product can be manufactured.

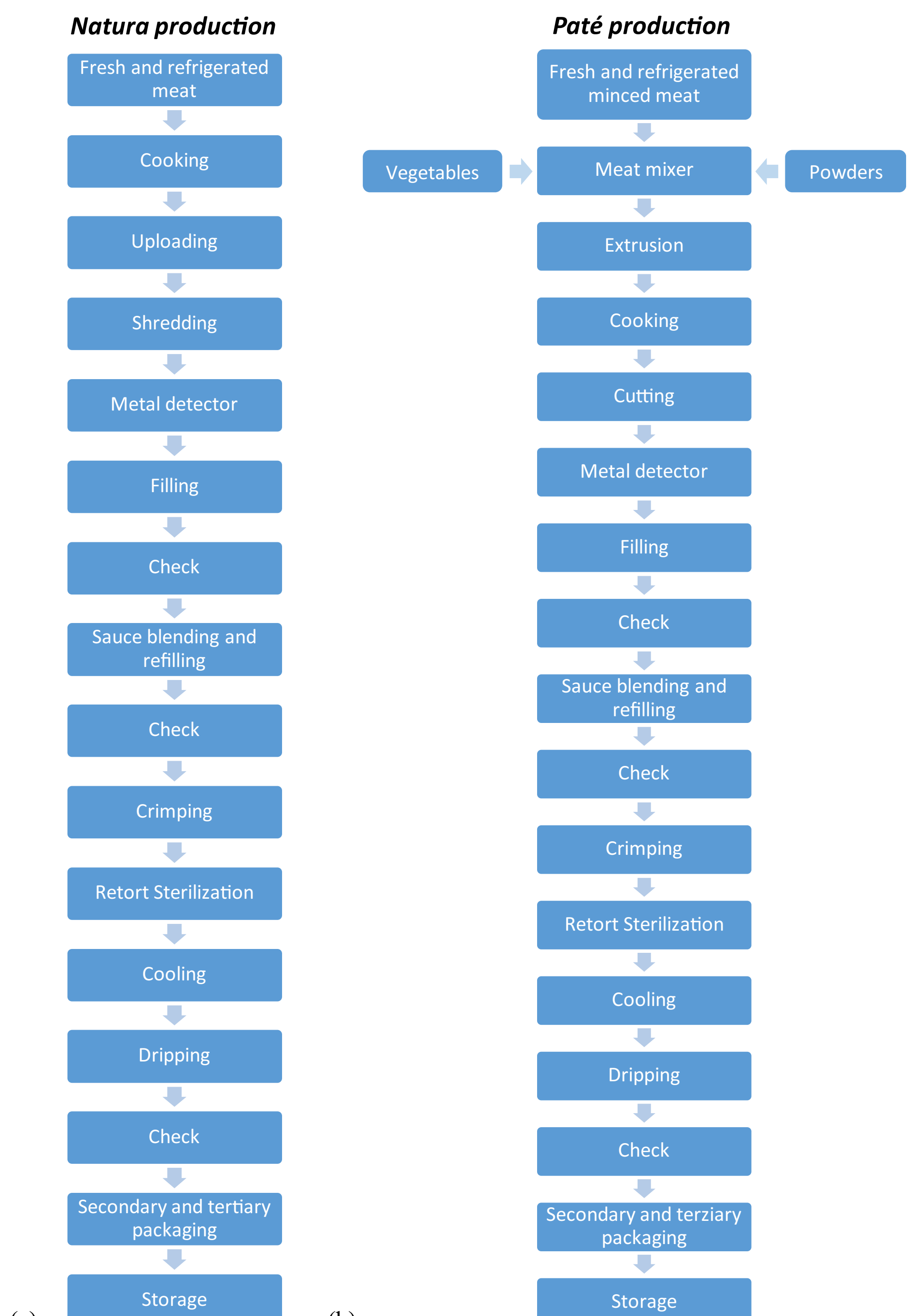

Fig. 1. Process flow of the Natura (a) and Pâté production lines (b).

2.1.2. Cooking and shredding

After defrosting, the meat enters the cooking tunnel with steam at 90 °C. There is only one tunnel for this line, located at the centre of the facility, which processes small sized containers (70–85 g). The tunnel works at minimum speed and maximum steam flow. A water spray at the end of the tunnel cools the cooked meat, which is finally cut by two cutting blades to obtained minced products.

The product is then loaded on a tape where it is checked by a metal detector for the possible presence of metal. Whenever metals are detected, the product is moved to a zone where a quick colorimetric test is carried out, and if it is found to be polluted, production stops.

2.1.3. Filling and crimping

A telescopic filler is used to package the pet food into tinplate or aluminium containers (size 85 g) coming from the warehouse. As for the cans, a magnetic bridge detects possible defects in the containers and drops the defective ones. A gamma-ray machine checks the filling and if it is not satisfactory, the processed containers are removed. From here the product reaches a rotary vacuum filler equipped with valves and a tank containing the gelling sauce the cans will be filled up with. The quota of sauce in the finished product is in 45:55 ratio with the meat morsels. Once filled, the containers move to an automatic crimping machine.

2.1.4. Sterilization and cooling

The sterilization of the Natura pet food takes place in dedicated autoclaves using a static retort process. The autoclave includes 5 baskets, each containing 5,080 cans of 85 g, for a total of 25,400 cans sterilized. The sterilization process takes around 30 min at a temperature of 124–126 °C. Further 20 min of cooling must be added to decrease the cans' temperature to 30 °C, by also gradually reducing their internal pressure.

2.1.5. Packaging

Labelling, packaging in trays, a possible addition of a cardboard cluster of 3 cans and palletizing are carried out after sterilization and cooling. At present, the production of the Natura product is limited to about 200 tons per year but it is strongly growing.

2.2. Pâté production line

2.2.1. Meat production

The production line manufacturing the Pâté product is almost the same as that of the Natura product. The main difference is that Pâté consists of a mix of different meat types coming from slaughters residues, instead of muscle tissue of one animal breed only. Moreover, the meat for Pâté is preliminarily mixed with vegetables, additives and gelling substances.

2.2.2. Preliminary meat mixing and extrusion

The frozen meat in plates or blocks is ground by a special machine and arrives at the mixer where fresh meat previously minced and additives are also introduced. With different consistencies and different types of meat (frozen and fresh) the shredding process is different. These ingredients are then combined in a continuous extruder.

2.2.3. Cooking and cutting

After the extrusion, the product moves to a central cooking system, where the whole set of ingredients is cooked for about 20 min and finally cooled. After being cooled, the product is more solid than the previous one, and then it is cut to be ready for the filling machine.

2.2.4. Filling and crimping

The Pâté filling is carried out at high temperature (hot filling) in a volumetric filler. Hot filling limits the temperature difference between this phase and the sterilization, thus avoiding excessive stress of the containers. The main formats filled range from 400 to 800 g; the analysed format (85 g) is manufactured in a more limited quota. The sealing system is the same as that of the Natura line.

2.2.5. Sterilization and cooling

The sealed containers are sterilized in a retort sterilizer at a temperature of 127–130 °C. The sterilizer has an automatic controller so if the temperature drops more than half a degree, the sterilizer varies the steam entrance. At the end of the process the sealed containers are cooled.

2.2.6. Packaging

Labelling, packaging in trays, possible grouping in cardboard clusters of 3 cans and palletizing are carried out after sterilization and cooling. At present, the production of the Pâté product is greater than that of Natura and quite stable in time. Overall, the production plant can manufacture about 5,000 tons in 48 working weeks per year when producing the 85 g format, although productivity can be affected by format changes.

3. Materials and methods

3.1. Methodological approach

The LCA methodology was applied according to the principles and requirements provided by ISO 14,044 (ISO, 2006) standards. All the steps required by the standard have been followed in order to be easily replicable also by other researchers or interested industries (Takahashi et al., 2012). SimaPro 8.5 software (https://simapro.com/) with the support of Ecoinvent 3.4 (Moreno et al., 2017) and Agri-footprint 2.0 databases (Agri-footprint 2.0 part 1, 2015) have been used to support the assessment. Ecoinvent and Agri-footprint make use of different methodologies and use different activity data; however, according with the description reported in agri-footprint Report (Agri-footprint, 2017), there is consistency between the two databases and since databases provide background datasets, there are no problems in using datasets from both databases.

3.1.1. Goal and scope definition

The purpose of this work is to evaluate and compare the environmental impacts of a valorisation scenario for two recipes of pet food products (i.e. Natura and Pâté) obtained using three types of MF from PFW, by identifying the inputs and outputs of all the related processes and assessing their impacts. Two main scenarios are taken into account for the comparison. The first one is the current ("benchmark") situation, in which the MF of the PFW is disposed of in landfill sites and the pet food is manufactured following the typical stages of animal husbandry, slaughter and production. The second scenario depicts a new situation, where the PFW is collected from the retail channel and the MF is recovered and valorised by becoming the input of the pet food production chain. In this new scenario, the PFW is gathered from the retail stores with a special collection system, separated from the packaging materials in a sorting facility, then shipped to the pet food manufacturer for its final valorisation. All these phases require a cold chain.

Overall, the two pet food products described previously will be analysed in four different variants. To be more precise, three variants will be taken into account for the Natura product, manufactured using muscle tissues either from pork (Natura-pork), beef (Natura-beef) or poultry (Natura-poultry) meat. Only one variant will be instead evaluated for the Pâté, which is obtained from a mix of the previously indicated MF plus other type of meat waste (entrails), powder and vegetables.

3.1.2. Functional unit

The functional unit provides a reference unit for which the inventory data are normalized. The concept of functional unit is key in LCA analyses, as it facilitates the comparison of alternative products and services (McAuliffe et al., 2018). For the purpose of this study, 1 kg of finished pet food was taken as functional unit. For the Natura production, according to the possible product variants, 1 kg of pet food can be produced using three different types of muscle tissue as raw material; for the Pâté product instead, 1 kg of pet food is always produced with a mix of meat. As the pet food obtained from the PFW has the same nutritional and economic value as the benchmark one, no implications for the Functional unit definition have been derived.

Based on the interviews carried out at the retail stores, it was appraised that retailers of the Emilia-Romagna region wasted 14,600 tons of PFW in 2015. A quota of 300 tons/year has been removed from this amount, as it corresponds to the quantity of FW donated for charity purposes in the region. The PFW at retail stores can be categorized in different groups, such as bakery, coffee, drinks, fish, meat, etc. For the case under examination, it is important to estimate the amount of meat that could be obtained from the food wasted at the retail stage. Segrè & Falasconi (2011) estimated the meat waste generated in the whole food supply chain to account for 9% of the total food waste of Italy. More recent data of Caldeira et al. (2019), who focused expressively on the retail chain, lead to a greater percentage (25.3%), as the MF is estimated to account for 1.7 million tons/year out of 6.7 million tons/year of food waste in retailing. This percentage is more similar to other published data (e.g. Albizzati et al. 2019, Xue et al. 2017); Albizzati et al. (2019) in particular found 17% of MF by evaluating food waste in 20 French retail outlets. Hence, the data reported by Caldeira et al. (2019) will be used to estimate the MF in PFW, determine the feasibility of the new pet food production and evaluate the impact of the transport relating to the chosen functional unit. On the basis of this assumption, the MF obtained from the PFW collected in Emilia-Romagna would be sufficient to cover the whole market demand for the analysed pet food products manufactured by the company under examination.

To better understand the composition of the MF of PFW and evaluate its usability for pet food production, a survey was carried out between 2015 and 2016 in four big retail stores located in the area of Parma (a city in Emilia Romagna Region with a population 200,000 inhabitants). Based on this survey, processed meat accounts for the 31.21%, pig meat for the 18.50%, beef meat for the 5.72%, poultry meat for the 40.00%, sheep-goat for the 2.57% and finally rabbit for the 2.00%.

Chicken and turkey are the major components of the total meat waste, probably because of the greater quantities sold and to the fact that chicken and turkey are delicate products, which could be subject to alterations due to the thin muscle fibres. These data were further refined to identify the cuts of meat containing muscle tissue only, which are to be used when producing the Natura product. The resulting details are summarized in Table 1, which also shows the usage of the MF to produce either the Natura or Pâté products. In addition, percentages of the other ingredients used in the different recipes have been reported in the same table.

3.2. System boundaries and assumptions

To quantify the impact of the products analysed, system boundaries need to be defined. As mentioned, the present case study involves the food product wasted at the retail and distribution stages in the Emilia-Romagna region of northern Italy and takes into account two scenarios, which are evaluated following a "cradle to gate" approach.

The benchmark scenario consists of two macro-processes, such as PFW disposal and traditional pet food production. This scenario assumes that the PFW collected from the retail stores is disposed of in landfill and the pet food is manufactured through the normal stages of husbandry, slaughter, refrigerated storage and production (listed as sub-processes of meat production in Fig. 2-A). The first three sub-processes, although not performed at the pet food manufacturer's site, are nonetheless taken into account in the environmental assessment. Overall, the following processes are taken into account when evaluating the traditional pet food production in the current scenario: 1) meat production (husbandry and slaughter, transport and refrigeration); 2) pet food production (including transformation and packaging activities); 3) packaging materials; and 4) additional pet food ingredients. The phase of disposing the PFW of in landfill sites completes this scenario.

The new scenario assumes instead the valorisation of the MF of PFW received from the sorting facility to produce pet food. As the MF comes from the PFW recovery, the phases of husbandry, slaughter and refrigeration are no longer required (Fig. 2-B), and will be replaced by: 1) the collection of PFW at retail stores using appropriate devices (trolleys and boxes); 2) the logistics processes required to move the PFW in the logistics system (from the retail stores to the distribution centres up to the SORT facility); 3) the unpacking and sorting of PFW; and 4) its transport to the pet food manufacturer. Process 3) is required because the MF comes from food waste which is packaged; hence, it is always necessary to separate it from its packaging (unpacking) and, after separation, collect the packaging material at one side and the meat fraction at another side (sorting), so that they can be treated and valorised by means of appropriate processes.

Landfilling of FW will also be avoided in this scenario, as the recovered meat is used for pet food production according with some studies that compare the benefits of products obtained by

Table 1
Detailed data of meat muscle tissues waste in the area of Parma 2015–2016 and their use in pet food.

Classification	Waste (%)	Pet food destination	Pet food recipe [%]			
			Meat waste	Water	Corn starch	Vegetables (carrots, spinaches, potatoes, onions)
Processed meat	31.21	–	–	–	–	–
Beef meat	0.61	*Pâté*	15.00%	32.75%	2.25%	10.00%
Pig meat	6.35	*Pâté*	15.00%	32.75%	2.25%	10.00%
Poultry meat	20.00	*Pâté*	15.00%	32.75%	2.25%	10.00%
Other meat	4.57	*Pâté*	10.00%	32.75%	2.25%	10.00%
Boneless pig meat	12.15	*Natura-pig*	55.00%	42.75%	2.25%	–
Boneless beef meat	5.11	*Natura-beef*	55.00%	42.75%	2.25%	–
Boneless poultry meat	20.00	*Natura-poultry*	55.00%	42.75%	2.25%	–

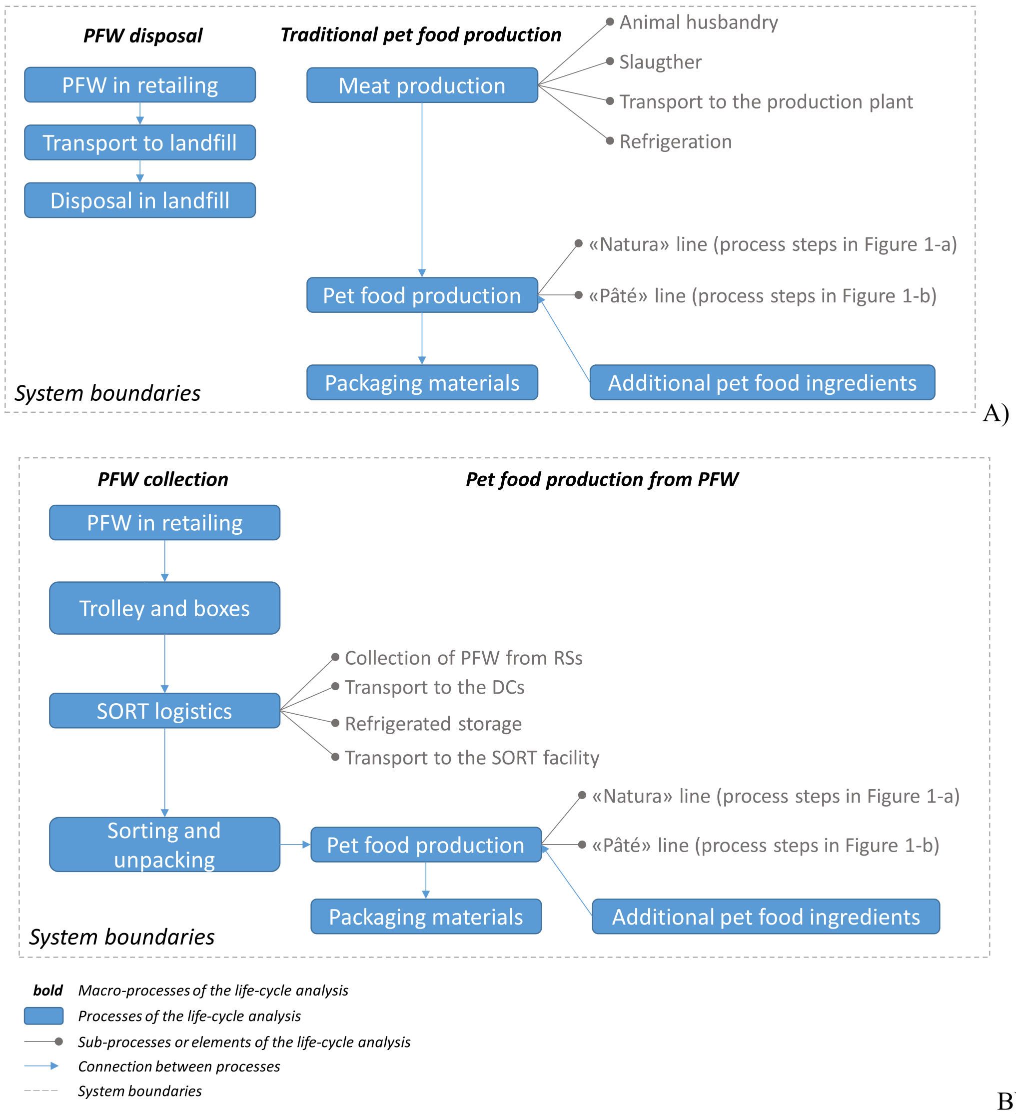

Fig. 2. System boundaries of the benchmark (A) and new (B) scenarios.

a circular economy (Albizzati et al., 2019; Tonini et al., 2019). A system expansion approach has been used in order to avoid allocation of sub processes and by-products (Cederberg and Stadig, 2003).

This study focuses on the MF of the food waste only, as this represents a prominent part of the actual PFW in terms of weight and can be used as raw material for pet food production; also, the edible part of PFW is known to contribute to the environmental impact to the greatest extent. The remaining fractions of PFW, in terms of food or packaging waste, could be valorised as well, but their valorisation process would be different from that taken into account in this study (i.e. pet food production) and therefore goes beyond the scope of the present study. In addition, the valorisation of some other fractions of PFW has already been dealt with in different studies; for example, Vitale et al. (2018) focused expressively on the valorisation of the packaging fraction of the PFW, while Mosna et al. (2016) have evaluated the environmental impact of valorising the waste of bakery products for producing animal feed.

Finally, to be consistent with the evaluation of the impact of a food product, the impact of MF in FW landfilling was charged to the benchmark scenario as a separate source of impact; on the other hand, it was not inserted as avoided impact in the new scenario, by considering as null the contribute of meat coming from PFW. Again, this choice is in line with similar studies in the field (Mosna et al., 2016; Brunklaus et al., 2018, Lam et al., 2018; Albizzati et al., 2019).

3.3. Life-cycle inventory analysis

The inventory analysis of the benchmark and new scenarios is reported in TABLE 2. This table also lists the whole set of phases relating to the two scenarios, and, for each phase, details the data used as input. These data refer to the functional unit (1 kg of pet food product). The data in TABLE 2 also distinguish, where appropriate, the specific type of pet food product they refer to; to this end, the numerical values have been computed taking into account the recipes in TABLE 1.

The new scenario considers sorting and unpacking machines (see Vitale et al. 2018) which, in the case under examination, are required to process MF packaged in trays only; related data refer to conveyor belts and a trays cutting machine. As far as the logis-

Table 2
inventory analysis of the benchmark and new scenario (data per Functional Unit).

Scenario **Benchmark**	New	Process	Description	Pet food product	Input	Unit	Amount
x		Transport to landfill	Transport of the PFW to landfill sites	all	Truck (3.5 tons)	kg*km	0.55*80
x		Disposal in landfill	Disposal of PFW in landfill sites	all	Landfill of municipal solid waste EU-27	kg	0.55
	x	SORT logistics	Collection of the PFW from the retail stores and transport to the distribution centres	all	Refrigerated Truck (3.5 tons)	kg*km	0.55*103
	x	SORT logistics	Refrigerated storage of PFW at the distribution centres	all	Electricity for refrigerator	kWh	2.20E-02
	x	SORT logistics	Transport of the PFW to the sorting and unpacking plant	all	Refrigerated Truck (7.5–16 tons)	kg*km	0.55*95
	x	SORT logistics	Transport of the MF of PFW to the pet food processing plant	all	Refrigerated Truck (7.5–16 tons)	kg*km	0.55*204
	x	Sorting and unpacking	Sorting and unpacking of the PFW for MF recovery. Total consumption for 1ton of MF from PFW in electricity for equipment and compressed air. A lifetime of 20 years is assumed for equipment materials	all	Electricity	kWh	1.28E-02
				all	Equipment materials – PE	kg	4.00E-03
				all	Equipment materials - stainless steel	kg	3.10E-02
x		Meat production	Animal husbandry, slaughter, transport and conservation	Natura - chicken	Chicken meat, fresh, at slaughterhouse	kg	5.50E-01
				Natura - beef	Beef meat, fresh, from dairy cattle, at slaughterhouse	kg	5.50E-01
				Natura - pig	Pig meat, fresh, at slaughterhouse	Kg	5.50E-01
				Pâté	Chicken co-product, feed grade, at slaughterhouse	kg	1.83E-01
				Pâté	Beef co-product, feed grade, at slaughterhouse	kg	1.83E-01
				Pâté	Pig co-product, feed grade, at slaughterhouse	kg	1.83E-01
				all	Electricity for refrigerator	kWh	1.76E-02
				all	Refrigerated Truck	kg*km	55
x	x	Additional pet food ingredients	Ingredients for the sauce in the finished product - Pâté line	Pâté	Maize starch	kg	2.25E-02
				Pâté	Water (for Pâté)	kg	3.28E-01
				Pâté	Vegetables (for Pâté)	kg	0.1
			Ingredients for the sauce in the finished product - Natura line	Natura - all variants	Maize starch	kg	2.25E-02
				Natura - all variants	Water	kg	4.28E-01
x	x	PET food production	Mixing phase	Pâté	Electricity	kWh	9.53E-03
			Extrusion phase	Pâté	Electricity	kWh	5.50E-02
			Cooking	all	Steam	kg	1.37E-01
				all	Electricity	kWh	1.03E-01
			Preparation - cutting and metal detector	all	Electricity	kWh	1.32E-01
			Sauce blending and re-filling	all	Electricity	kWh	4.08E-02
				all	Electricity	kWh	1.47E-02
			Filling and crimping	all	Electricity	kWh	6.33E-02
				all	Electricity for compressed air production	kWh	1.01E-02
			Sterilization	all	Electricity	kWh	1.53E-02
				all	Steam	kg	1.60E-01
				all	Electricity for compressor	kWh	3.00E-03
				all	Water	Mc	7.30E-03
			Packaging machine	all	Electricity	kWh	5.53E-02
			Clean in place process	all	Electricity	kWh	1.27E-01
				all	Tap water	L	1
				all	Foaming agent	kg	3.00E-02
x	x	Packaging materials	Primary packaging materials	all	Aluminium can	kg	1.18E-01
				all	Metal working	kg	0.117.64
				all	PVC film	kg	1.54E-03
			Secondary packaging materials	all	Folding boxboard	kg	5.55E-02
				all	Printed paper label	kg	6.09E-03

tics data are concerned, they were taken from the scenario evaluated in Bottani et al. (2019) for the collection of PFW from retailers, its shipment to distribution centres for storage and its final delivery to the SORT facility. The distance covered in the last transport phase, i.e. from the SORT facility to the pet food manufacturer, was determined taking into account the real locations of the targeted pet food manufacturing company and of the SORT facility.

As far as the landfill of MF of PFW is concerned, the "Landfill of municipal solid waste EU-27" process has been chosen; an average transport distance of 80 km from retailers to municipal landfill, covered by a non-refrigerated truck (3.5–7.5 tons), has also been set.

Finally, looking at the meat production macro-process, different inputs have been considered in the AS IS process according to the product variants previously described for Natura and Pâté; for this latter, in particular, a mix of by-products coming from industrial slaughterers have been used. Related data were taken from the Agri-footprint 2.0 database (Agri-footprint part 2, 2015) and refer to the Netherlands industries. All the data used are referring to a European context, and they are considered as valid in the year of the analysis (2019).

3.4. Methods of impact assessment

Several life cycle impact assessment (LCIA) methods can be used when carrying out an LCA analysis and choosing one of these methods over another one could change the results of the evaluation and the related discussion. Previous studies (Vitale et al., 2018; Bottani et al., 2019) highlighted that the new ReCiPe 2016 method (Huijbregts et al., 2016) could be a good choice to highlight the most interesting impact categories for food waste valorisation scenarios. Recently also Brancoli et al. (2020) highlighted as ReCiPe midpoint method allows to analyse some interesting aspects in the food waste issues. A survey on the Scopus database (on 12th May 2020) was carried out to identify the impact categories most frequently used when evaluating the environmental benefit of a food waste valorisation scenario. That survey returned 570 papers dealing with "LCA food waste", 112 of which adopted the GWP or climate change indicator, 114 the land use one, 28 the water consumption or depletion, while only 5 the fossil depletion or resource scarcity. According to these findings, GWP, land use, fossil resource scarcity and water consumption were selected as impact categories in this study. Furthermore, among the Egalitarian, Individualist and Hierarchist approaches, the hierarchic perspective was chosen in this study as one of the most used in the food sector (Dekker et al., 2020). Other methods such as EPD and ILCD were not taken into account, for several reasons. EPD, indeed, does not consider the "land use" impact category; while in the case of ILCD method, its particular approach in the evaluation of the biogenic carbon dioxide could change the results if compared with studies using other LCIA methods.

All the analyses have been performed using Simapro release 8.5, with the availability of their associated databases; outcomes are detailed in section 4.

3.5. Data quality and uncertainty analysis

A check on the data quality was carried out with the purpose of ensuring that the input data are as accurate as possible. To this extent: (i) data related to the meat production and meat by-products used in the benchmark scenario of meat production, including husbandry and slaughter processes, were retrieved from the Agri-footprint database version 2.0 (Agri-footprint part 2, 2015); (ii) data about the SORT transports have been retrieved from Bottani et al. (2019), using the scenario where all the PFW is collected from retailers, while data about the sorting and unpacking of PFW have been taken from Vitale et al. (2018); (iii) data used to evaluate the avoided end-of-life of MF of PFW were retrieved by ELCD Database version 3 (European Commission JRC, 2015), setting "Landfill of municipal solid waste EU-27"; (iv) finally, for the processes of pet food production and relating packaging materials, primary data have been obtained from an Italian pet food company. All the processes have been detailed in terms of specific input and output values (electricity, water, steam, etc…) retrieved from Ecoinvent 3.4 (Moreno et al., 2017).

For the data retrieved from the Ecoinvent databases, the system model of "Allocation at the Point of Substitution (APOS)" has been set; accordingly, burdens are attributed proportionally to specific processes (Saade et al. 2019). The choice of APOS provides really small differences in terms of LCIA results, but it has been selected because recyclable materials and wastes that are allocated in the APOS version would receive zero impact on the Cut-off version (Steubing et al., 2016). The datasets were chosen taking into account the location of the study (Italy); if Italian data were not available, the data related to the closest area from a geographical point of view or the average in a wider region have been used (e.g. the European data). Overall the study has considered>99% of the possible impacts generated by the benchmark and new scenarios. The use of different datasets has been made considering the need for having the most accurate data about the field of application, being aware of the problems that it could generate (Lesage et al., 2018). Based on this issue, uncertainty analyses on inventory and modelling have been performed.

As far as the uncertainty analysis is concerned, it has been carried out using the Montecarlo simulation model present in Simapro v.8.5, by running 1,000 iterations at a significance level $\alpha = 0.05$. The results returned show that in the worst case (i.e. the new scenario), 76.4% of the inventory data follow a log-normal distribution while 23.3% only are undefined. As far as the model uncertainty is concerned (Guo and Murphy, 2012; Scrucca et al., 2020), typical indicators used for its evaluation are the Coefficient of Variation (CV), i.e. the ratio between the standard deviation and the mean, or a normalized indicator for the dispersion of the results in the category indicator. Based on the ReCiPe 2016 (H) midpoint method, the results show that, looking again at the worst case (which is always the new scenario), high level of uncertainty is reached in the water consumption category only (CV = 233%); for GWP, land use and fossil resource scarcity, instead, CV is significantly lower and scores 10.2%, 11.7% and 16.5% respectively.

4. Life cycle impact assessment

4.1. Benchmark scenario: Packaged meat disposed in landfill and traditional pet food production

To evaluate the different impacts associated to the benchmark scenario, two separate sets of results are reported in the following subsections according to the two macro-processes that compose the scenario; first, the impact of packaged meat disposed of in landfill will be evaluated, then the impact of the traditional pet food production.

4.1.1. Environmental impact of packaged meat disposed in landfill

The results related to the disposal of the quantity of packaged meat waste (0.55 kg) required for the production of 1 kg of pet food are shown in the last columns of TABLE 3, which details the relative contribution of process.

As far as the environmental impact of the MF of PFW divided according to stages is concerned, disposal of the packaged meat in landfill represents the main contribution for global warming, fossil resource scarcity and water consumption. Conversely, for

Table 3
Contribution analysis of the environmental impact of the benchmark scenario (per functional unit).

Impact category	Product	Traditional pet food production					Packaged meat disposal		
		Meat production	Pet food production	Additional pet food ingredients	Packaging materials	Total	Meat disposal in landfill	Transport of meat waste	Total meat waste
Global Warming (kg CO_2 eq)	Natura beef	3.37E + 00	8.13E-01	4.24E-02	1.61E + 00	5.83E + 00	8.68E-01	4.20E-02	9.10E-01
	Natura-pig	2.19E + 00	8.13E-01	4.24E-02	1.61E + 00	4.65E + 00			
	Natura-poultry	1.96E + 00	8.13E-01	4.24E-02	1.61E + 00	4.43E + 00			
	Pâté	1.56E-01	8.43E-01	7.26E-02	1.61E + 00	2.69E + 00			
Land Use (m^2a crop eq)	Natura beef	1.39E + 00	1.24E-01	3.97E-02	5.39E-02	1.61E + 00	0.00E + 00	1.19E-03	1.19E-03
	Natura-pig	1.84E + 00	1.24E-01	3.97E-02	5.39E-02	2.06E + 00			
	Natura-poultry	1.40E + 00	1.24E-01	3.97E-02	5.39E-02	1.62E + 00			
	Pâté	9.55E-02	1.25E-01	6.78E-02	5.40E-02	3.42E-01			
Fossil resource scarcity (kg oil eq)	Natura beef	1.61E-01	2.24E-01	1.12E-02	3.03E-01	6.99E-01	1.62E-02	1.38E-02	3.00E-02
	Natura-pig	1.68E-01	2.24E-01	1.12E-02	3.03E-01	7.06E-01			
	Natura-poultry	1.43E-01	2.24E-01	1.12E-02	3.03E-01	6.81E-01			
	Pâté	1.35E-02	2.32E-01	1.76E-02	3.03E-01	5.66E-01			
Water consumption (m^3)	Natura beef	1.85E-02	1.96E-02	1.12E-03	2.99E-02	6.91E-02	2.39E-04	1.21E-04	3.60E-04
	Natura-pig	1.23E-02	1.96E-02	1.12E-03	2.99E-02	6.29E-02			
	Natura-poultry	1.41E-02	1.96E-02	1.12E-03	2.99E-02	6.47E-02			
	Pâté	9.47E-04	2.01E-02	6.33E-03	2.99E-02	5.74E-02			

land use the transport to the landfill is the only contributor. Transport activities are also impactful on fossil resource scarcity due to the emissions relating to fossil fuel consumption.

4.1.2. Environmental impact of traditional pet food production

The benchmark scenario takes into account the production of 1 kg of pet food manufactured using the recipes detailed in TABLE 1, without the contributions of MF deriving from PFW collection and sorting. The results of the environmental impact for the three variants of the Natura products and for the Pâté product are reported in TABLE 3; their comparison is shown in Fig. 3.

Looking at the environmental impacts divided according to stages, meat production is the most impactful phase for global warming and land use for all the Natura product variants. To be more precise, its contribution ranges from 44.12% to 57.73% for global warming and from 86.25% to 89.71% for land use. This result is mainly due to the relevant methane emissions caused by enteric fermentation, manure management and chemical and organic fertilizers use for feed production, respectively. In the pet food production process, lighting, refrigeration, cutting, filling and packaging all require electricity, while cooking and sterilization also require steam. Thus, a significant amount of energy is required in the pet food plant, which further contributes to the global warming potential.

On the contrary, for the Pâté product, the highest contribution (≈60.07%) to the global warming comes from the packaging material; this result is to be related to the production process of primary packaging for this product. The pet food production process is the second most important impactful phase for global warming and contributes for 31.42% to this impact category.

For the remaining impact categories (water consumption and fossil resource scarcity), the Natura product variants all show a similar behaviour. In particular, for all variants, the highest contribution (>40%) to these impact categories come from the packaging material, followed by the pet food production process (from 28.30% to 32.84%) and by meat production (always around 20%, with a peak of 26.71% impact on water consumption in the case of Natura-beef product). As far as the Pâté product is concerned, the highest contribution to water consumption and fossil resource scarcity (>50%) comes, once again, from the packaging material, followed by pet food production. The relevant impact of the aluminium can on water consumption is due to the amount of water used in aluminium coil manufacturing and can production by means of drawing and ironing. In addition, the impact is relevant also because of the small quantity of pet food (85 g) contained in the can.

4.2. New scenario: Pet food production from meat waste

The environmental impact of the new scenario, in which meat muscle or meat by-products are completely substituted by the meat fraction of the PFW, are reported in TABLE 4. As mentioned earlier, in evaluating the new scenario, no impacts were allocated for the production of meat coming from PFW. As the process of meat production does not fall into the systems boundaries of this scenario, the impact of MF from PFW (either in the form of packaged beef, poultry or pig) is null; therefore, all products are equivalent in terms of impact. Accordingly, one evaluation only has been performed for the three variants of the Natura product.

Looking at the relative impacts of each stage, for both products the packaging materials (once again, strictly connected to the production of the aluminium can) represents a major contribution in global warming (>60%), fossil resource scarcity (>50%) and water consumption (52.85% for Pâté and 58.79% for Natura). In the last impact category (land use), the pet food production process represents the major source of impact (49.99% for Pâté and 56.17% for Natura). The remaining processes contribute to the total impact to a significantly lower extent. To be more precise, the average contribution of the SORT logistics process to the total impact is less than 2.50% (a peak of 4.79% is observed for fossil resource scarcity in the case of the Natura product), while for unpacking and sorting and trolley and boxes it always is less than 1%.

4.3. From the benchmark to the new scenario: Benefits evaluation

The benefits of moving from the benchmark scenario to the new one have been evaluated and are shown in graph in Fig. 4. The landfilling of PFW has been taken into account in this evaluation and in particular, it has been ascribed to the benchmark scenario (to be consistent with Fig. 2), although it has been left as a separate macro-process and not charged to the traditional pet food production macro-process. In the new scenario, indeed, the PFW is used as input for pet food production instead of being disposed of in landfill sites.

Fig. 4 demonstrates that for both products, the new scenario involves better values in all the impact categories analysed if compared to the benchmark scenario. Basically, the lower impact of the new scenario is due to the avoided animal husbandry phase; this is

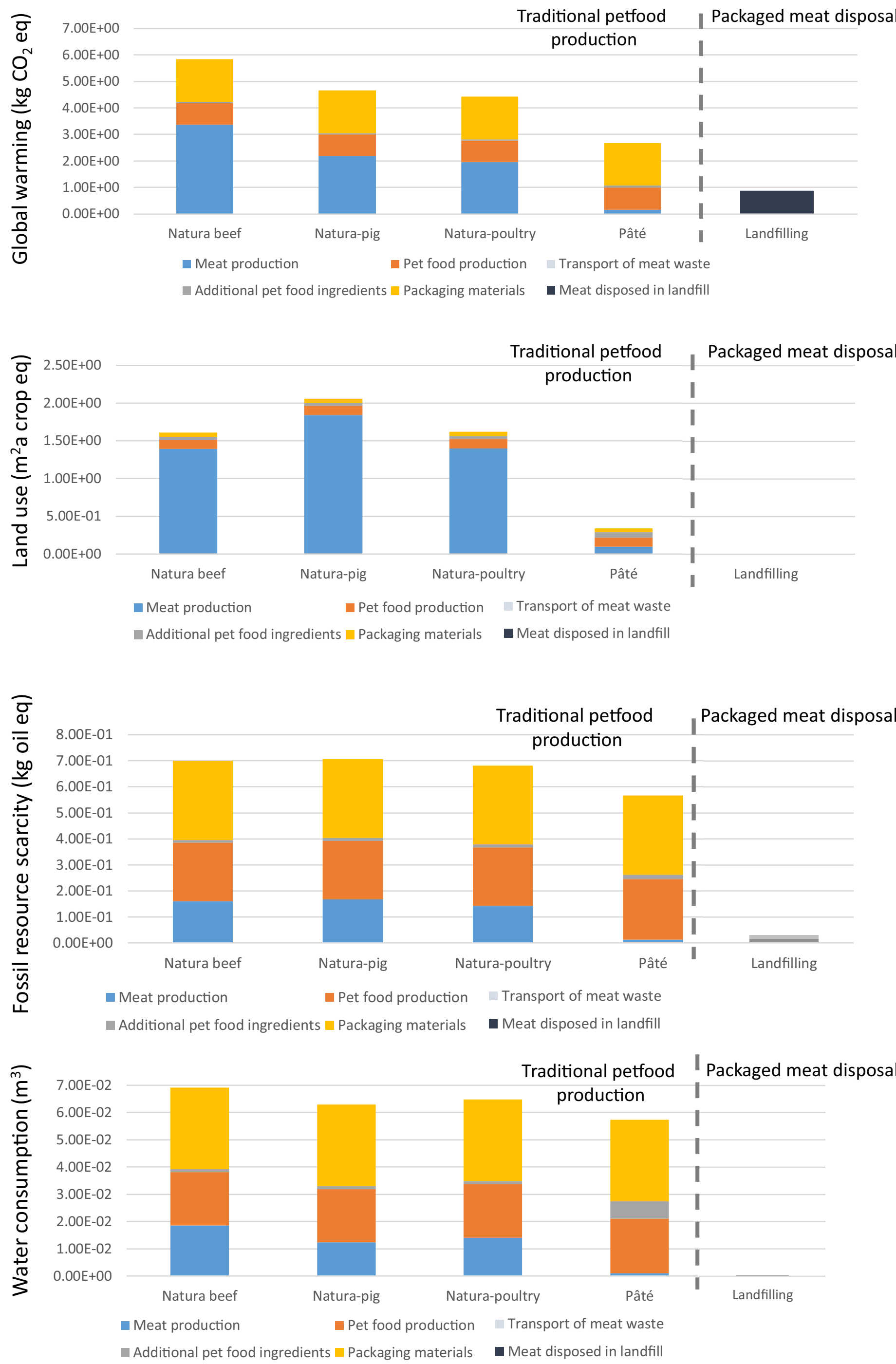

Fig. 3. Environmental impacts of the Natura and Pâté production - benchmark scenario (per functional unit).

demonstrated by the fact that those categories where the husbandry represented a major contribution in the benchmark scenario (primarily global warming, cf. Fig. 3) now benefit from a significant reduction of the environmental impact.

If comparing the two products, it is easy to see that benefits of the new scenario are slightly lower for the Pâté product than for the Natura product. This is particularly the case for fossil resource scarcity and water consumption impact categories, for which the impacts observed in the benchmark scenario and in the new one are almost the same, although the new scenario shows a small environmental benefit. The lower benefit is due to the fact that the Pâté production in the benchmark scenario already makes use of meat by-products coming from slaughters instead of meat muscle.

5. Conclusions

To start solving issues relating to the huge amount of food produced and wasted worldwide, acting in line with the SDGs, it is appropriate to focus on a specific part of the food supply chain. The problem of food waste in retailing can no longer be underestimated, as approximately 6.6 million tons are wasted yearly in this channel, based on the most recent European data. Out of the total

Table 4
Contribution analysis of the environmental impact of the Natura and Pâté products – new scenario (per functional unit).

Impact category	Product	Pet food production	Additional pet food ingredients	Packaging materials	SORT logistics	Unpacking and sorting	Trolley and boxes	Total
Global warming (kg CO2 eq)	Natura	8.13E-01	4.24E-02	1.61E + 00	9.01E-02	4.48E-03	1.03E-03	2.56E + 00
	Pâté	8.43E-01	7.26E-02	1.61E + 00	9.01E-02	4.48E-03	1.03E-03	2.62E + 00
Land use (m2a crop eq)	Natura	1.24E-01	3.97E-02	5.39E-02	2.36E-03	7.66E-05	2.48E-05	2.20E-01
	Pâté	1.25E-01	6.78E-02	5.39E-02	2.36E-03	7.66E-05	2.48E-05	2.49E-01
Fossil resource scarcity (kg oil eq)	Natura	2.24E-01	1.12E-02	3.03E-01	2.71E-02	1.33E-03	3.08E-04	5.67E-01
	Pâté	2.32E-01	1.76E-02	3.03E-01	2.71E-02	1.33E-03	3.08E-04	5.81E-01
Water consumption (m3)	Natura	1.96E-02	1.12E-03	2.99E-02	3.13E-04	3.03E-05	8.75E-06	5.10E-02
	Pâté	2.01E-02	6.33E-03	2.99E-02	3.13E-04	3.03E-05	8.75E-06	5.67E-02

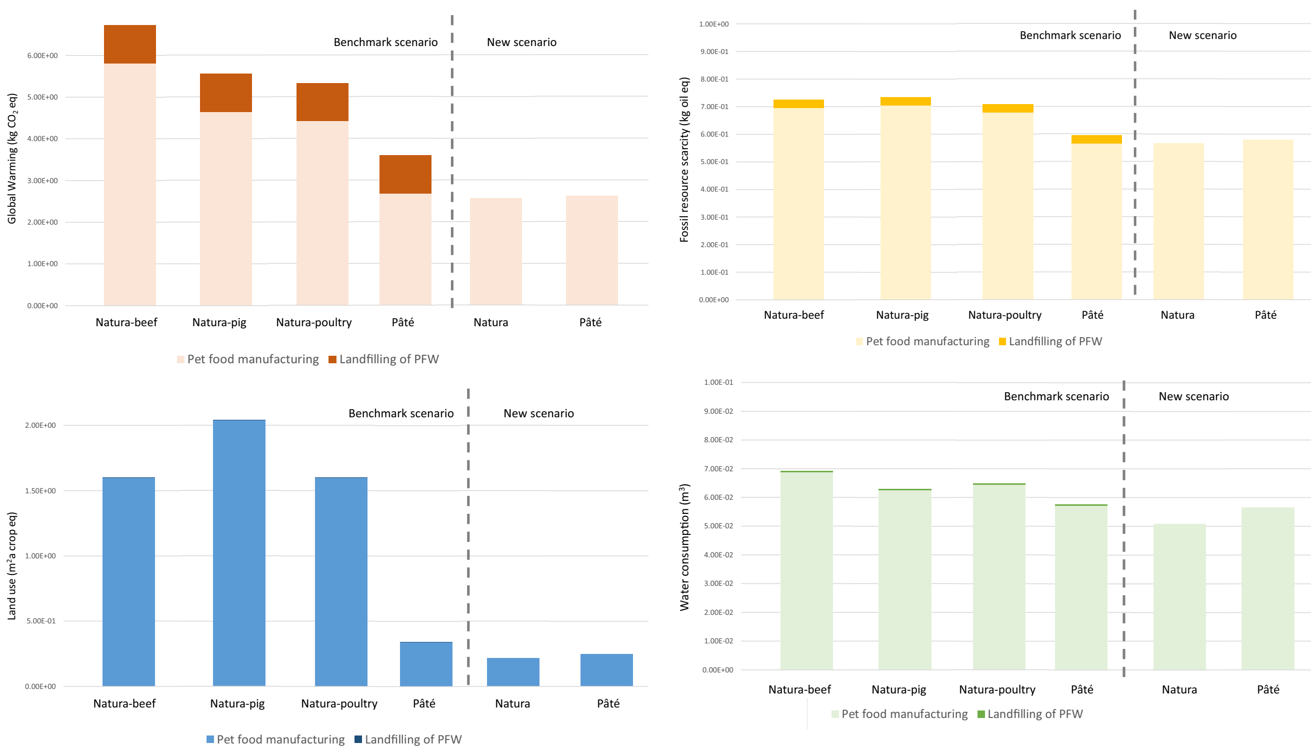

Fig. 4. AS IS vs. TO BE scenario – comparison for Natura and Pâté products (per functional unit).

waste, meat products represent a relevant quota; this implies relevant economic and environmental issues. Meat products in fact have a significant environmental impact (due, in particular, to the phases of husbandry and slaughter) and wasting these food products is a huge problem from an environmental but also economic point of view. The problem is exacerbated by the fact that the shelf life of meat products is often limited, as most of these products are fresh and not processed.

A contribution on this specific topic is almost absent in the scientific literature dealing with the UN 2030 Agenda in the food sector and this is why this article has proposed an evaluation of the extent to which the recovery of packaged food waste from retailers is virtuous. Such an evaluation is not easy, as several the aspects have to be take into account.

In line with these considerations, this article has evaluated, from a quantitative point of view, the environmental benefits of using the meat fraction coming from food waste to replace meat in the recipe of some pet food products. Two lines of products have been evaluated to this end: the Natura product, which makes use of muscle tissue only, and the Pâté product, which includes a mix of various types of meat fractions coming from residues of slaughter. The results show that replacing muscle tissue in the Natura products reduces the environmental impact from a minimum of 21.78% (in fossil resource scarcity) to a maximum of 87.50% (in land use) compared to the benchmark scenario. Because of the differences in the recipes, the usage of meat coming from food waste for the Pâté production generates lower environmental benefits, accounting for 14.66% on average across the impact categories analysed.

The main conclusion from these outcomes is that the additional phases of food waste collection, storage, sorting and unpacking, have a limited impact on the environment compared to the impact caused by the husbandry and slaughter of muscle tissue, which is particularly relevant in the case of beef meat required for the Natura product. In the case of Pâté, the current use of by-products coming from slaughters generates a limited environmental impact of this product even in the benchmark scenario.

The outcomes of this study are particularly interesting from a practical point of view. More precisely, as the additional phases of PFW collection, storage, sorting and unpacking, have a limited impact on the environment, the valorisation of the MF from PFW to produce high quality pet food seems to be a virtuous process, suitable for large-scale implementation. This valorisation scenario of food waste in retailing complements previous studies by

Brancoli et al. (2017) and Mosna et al. (2016), which focused on the production of animal feed from wasted bread and bakery products.

It is finally important to remark that the economic profitability of the process has not been treated in this article, but, in the light of the previous considerations, it would represent an important future research activity. Additional future research directions could be oriented toward evaluating the environmental impact and in particular the impact on water and energy consumption of collecting, storing, sorting and unpacking the whole amount of PFW coming from retailers, thus aggregating the different aspects evaluated by the authors in the last years.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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