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Valorisation of food waste to produce new raw materials for animal feed

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ABSTRACT

This study assesses the suitability of vegetable waste produced by food industry for use as a raw material for animal feed. It includes safety and nutritional viability, technical feasibility and environmental evaluation. Vegetable by-products were found to be nutritionally and sanitarily appropriate for use in animal feed. The drying technologies tested for making vegetable waste suitable for use in the animal feed market were pulse combustion drying, oven and microwave. The different meal prototypes obtained were found to comply with all the requirements of the animal feed market. An action plan that takes into account all the stages of the valorisation process was subsequently defined in agreement with local stakeholders. This plan was validated in a pilot-scale demonstration trial. Finally, the technical feasibility was studied and environmental improvement was performed. This project was funded by the European LIFE+ program (LIFE09 ENV/ES/000473).

1. Introduction

The fact that the Earth's population has been growing continuously over the last few hundred years, and therefore that the demand for natural sources has also increased, means that such resources are becoming increasingly scarce. As such, it is necessary to optimise their use in order to make them more sustainable. Humanity also generates thousands of tons of organic waste every day, most of which ends up as landfill, therefore the use of this waste as a raw material for feed formulation is an interesting alternative that deserves greater attention. In addition to reducing the environmental effect associated with animal feed production, valorisation of vegetable by-products for feed formulation would also maximise resource efficiency and contribute to competitiveness of feed producers by making available a more sustainable raw material which reduces the dependence on current raw materials (Myer, Brendemuhl, & Johnson, 2007; Westendorf, 2000; Westendorf, Dong, & Schoknecht, 1998). However, the use of vegetable waste as animal feed has some drawbacks that can limit its feasibility. For example, its high water content, which often exceeds 80%, makes handling more difficult and can accelerate the growth of microbiological contamination (García, Esteban, Márquez, & Ramos, 2005), thus meaning that a drying process is required. In addition, the analytical composition of such waste can vary markedly throughout the year (Westendorf, 2000), thus meaning that animal feed manufacturers have to change their feed formulations periodically depending on the composition.

Some studies in this field have indicated the feasibility of using vegetable waste in animal feed. Thus, a study of the solid organic waste generated in Salamanca (García et al., 2005) analysed different organic wastes, such as meat, fish, fruit and vegetables, restaurant and household waste, to determinate the chemical composition, microbiological characteristics and dioxin, furan, PCB and sand mineral contents for every type of waste fraction. This study concluded that it was possible to use vegetable and fruit by-products in animal feed formulations.

A subsequent study along the same lines (Esteban, García, Ramos, & Márquez, 2007) analysed these by-products as an alternative to traditional raw materials for pig feed and the influence of subsequent treatment on their digestibility. This study showed that fruit/vegetable waste had a high water content of 88.12 ± 1.84% and should thus be subjected to a drying process. The nutritional composition on a dry matter basis showed 65% nitrogen free extract, 13% crude fibre, 12% crude protein, 8% ash and 2% ether extract. To sum up, this waste mainly comprised carbohydrates (about 65%), which are the most important source of energy in swine metabolism, but had a high fibre content that reduces both the digestibility and available energy in pig diets. Although a minimum level of fibre is necessary for the digestive tract, the typical value for pig diets is about 5%. Consequently, a diet based on vegetable waste can be used but the addition of other ingredients is required.

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Taking into account these previous experiences, this study assesses the feasibility of reusing a mixture of vegetable and fruit wastes as a new raw material for animal feed.

2. Materials and methods

2.1. Characterization of vegetable waste

This study initially focused on characterization of the vegetable by-products. To this end, a full inventory of all Basque food industries that generate vegetable waste was developed with the aim of determining the amounts generated and their geographical dispersion. All the vegetable waste produced was identified by consulting previous studies and different private and public databases. The total amount of the different by-products generated by each sector, and the geographic dispersion of their production, was also quantified by contacting the associations that represent each sector and by submitting a questionnaire to the main representative companies in the Basque Country.

Subsequently, all vegetable by-products identified were analysed to determine the feasibility of their inclusion in feed formulations. All study parameters were determined by identifying legal requirements, regulated by the Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed and its transposition into the legislation of the countries, and feed-market requirements that a raw material for animal feed must fulfil. Therefore, the undesirable substances studied were; nitrites, mycotoxins (aflatoxin B1, B2, G1 y G2, zearalenone, deoxynivalenol, ochratoxin A, fumonisin B1 and B2, T-2 toxin, HT-2 toxin and patuline), pesticides (aldrin, chlordane, DDT, endosulfan, endrin, HCH, hexachlorocyclohexane, heptachlor and hexachlorobenzene), heavy metals (lead, cadmium, arsenic and mercury), microbiological analyses (salmonella, listeria, Escherichia coli, Staphylococcus aureus, Clostridium perfringens, sulfite-reducing clostridia, aerobic mesophiles, enterobacteriaceae, total coliforms), molds-yeast and dioxins levels. Undesirable substances and their maximum legal limits were studied together with the ELIKA Foundation, a Basque technological for food and feed safety. Moreover, some nutritional parameters were also studied: water content, ash content, protein levels, fibre content, starch level, fat level, sugars level, caffeine and pH. The nutritional results were studied together with EPEA Association (Feed Manufacturers Association of the Basque Country), which represents 11 feed manufactures located in the Basque Country. Once all parameters were defined, the sampling plan was divided into three different periods throughout the year (spring, summer/autumn and winter), to study how the composition of these by-products varies with season and two of the most representative companies in each sector were identified as sampling points. Moreover, in order to ensure the representativeness of the samples, and therefore allow a comparison of the different samples, a sampling protocol was defined to ensure that all samples were taken in the same conditions. Thus, two samples of 1 kg were taken from each sampling point and the A samples were sent to analyse immediately to avoid degradation, without any further treatment other than grinding and homogenisation, and the B samples were frozen just in case the analysis had to be repeated. The sampling and analysis methods were carried out taking into account the Commission Regulation (EC) No 152/2009 of 27 January 2009 laying down the methods of sampling and analysis for the official control of feed.

2.2. Definition of the drying process

A drying process was defined with the aim of making the mixture of vegetable waste more stable over time. The drying process minimizes the water activity, and therefore contributes to the microbiological stability, by reducing the water content to less than 12% (Fig. 1, Eskin & Robinson, 2000). In addition, it should ensure that the nutritional composition does not undergo important changes and that no additional undesirable substances are generated.

The different drying technologies to be tested were selected by consulting previous studies and the literature in order to identify the most efficient technologies previously used to dry vegetable products: Microwave (Motevali, Minaei, & Khoshtagaza, 2010; Sharma & Prasad, 2005; Zhang, Tang, Mujumdarc, & Wang, 2006), Pulse Combustion Drying (PCD) (Zbicinski, 2002; Zbicinski, Smucerowicz, Strumillo, & Crowe, 2000), Static and Rotary Oven (McMinn & Magee, 1999; Motevali et al., 2010; Pinacho, García-Encina, Sancho, Ramos, & Márquez, 2005; Vega-Gálvez et al., 2009) and others (Besombes, Berka-Zougali, & Allaf, 2010; Lewicki, 2006; Maache-Rezzoug et al., 2008).

Once the analytical feasibility was assessed, different types of vegetable waste were taken following the sampling protocol. They were immediately mixed in a proportional way by assessing the availability and seasonality of each kind of vegetable waste throughout the year in order to ensure homogeneity in terms of meal composition. The mixture obtained was crushed and homogenised to ensure the feasibility of the drying process.

Subsequently, and in order to develop a safe and efficient drying process, initial trials were carried out with the aim of defining all parameters and conditions of the drying process: temperature, time, power consumption, etc. Once these parameters and conditions were identified, exhaustive drying trials were carried out for each technology to optimise the final drying process and to obtain different vegetable flour prototypes. Finally, the feasibility of each drying technology was assessed by analysing all the prototypes obtained in order to determine whether they fulfilled all legal and market requirements previously identified for use as a raw material for animal feed.

2.3. Definition of the action plan

The action plan for a sustainable, efficient and innovative recovery of vegetable wastes for animal feed describes in detail all the stages that are necessary for the feasible recovery of the mixture of vegetable by-products as a raw material for animal feed. It must guarantee the safety of the animal feed and compliance with the

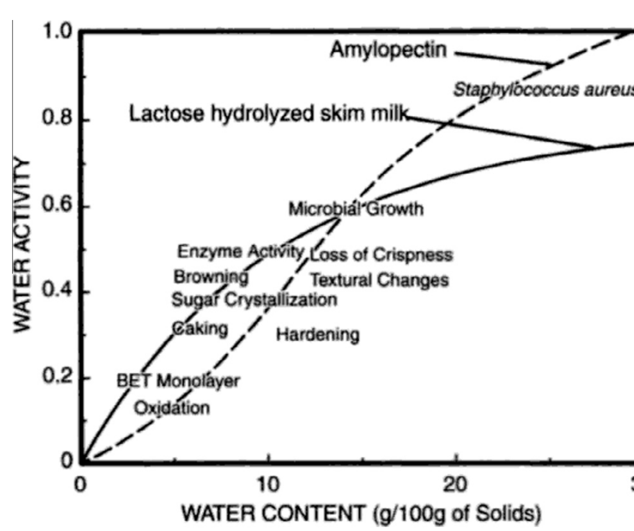

Fig. 1. Critical water activity and water content ranges for various changes and microbial growth occurring in food materials (Eskin et al., 2000).

requirements of the animal feed market. Thus, once the drying process had been defined, technical and administrative actions for each stage in which the action plan is divided were defined: (i) how to manage vegetable waste: minimum personal hygienic conditions to avoid external contamination and responsibilities of each stage of the recovery, (ii) under what conditions they must be stored: type of containers, cleaning or replacement protocol, appropriate storage area, equipment and facilities sizing for different scenarios, for how long and under which conditions, (iii) how it should be transported: collection frequency, minimal-maximum quantity per collection and per logistics route, collecting maximum radius, type and size of trucks, quality control protocol and minimum hygienic and technical conditions for transportation, and (iv) the most appropriate process for transforming it into an appropriate raw material for animal feed: type of containers for by-products storage, % of each vegetable waste in the final mixture formulation, equipment for the required milling and dehydration process, process parameters, type of packaging, labelling including the technical specifications of obtained meals and HACCP of the process. As part of this process, all the documents that are necessary to guaranty the traceability and forms to fill in order to fulfil legislation were identified, as well as all the facilities that are needed at each stage in the valorisation process. In addition, all the logistical limitations of the food industries, such as space problems or availability of facilities, were identified by visiting the most representative companies in each sector.

2.4. Assessment of the technical feasibility

The proposed action plan was technically assessed by performing a pilot-scale demonstration test. Thus, the following variables were defined: by-products sampling procedure, traceability data, transport conditions, types and quantities of vegetable wastes, control parameters, sampling procedures, delivery conditions and responsibilities.

The duration of this test was established by taking into account weekly variations in the of generated waste. In addition, 2 or 3 of the most representative companies in each sector were selected as interested agents in the demonstration. Waste manager responsible for collecting, transporting and processing vegetable waste was selected taking into account his ability to adapt to the requirements of the demonstration test. All the agents involved in the demonstration were trained in how to correctly follow the specifications of the action plan, such as managing vegetable waste under conditions suitable for obtaining a raw material for animal feed.

The trial results were fully evaluated and all the improvement measures identified included in a new version of the action plan.

2.5. Assessment of the environmental benefit

According to Article 4 of the Framework Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives: Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste.

In order to assess the environmental impact of the new treatment alternatives with respect to the current management of food by-products, a Life Cycle Assessment (LCA) was carried out to provide reliable and scientifically rigorous information for use in the waste-management decision-making processes and to identify the most sustainable management option. The LCA is an internationally standardized approach which quantifies all material, water and energy inputs and emissions, effluents and waste outputs of any product or service throughout its life cycle, from extraction of raw materials to the end of product life. During the LCA, these inputs and outputs are quantified in the form of environmental impact or damage. According to ISO 14040 in order to carry out a standardized assessment following step has been considered:

2.5.1. Goal and scope definition

The functional unit of this assessment is the management of 1 tonne of vegetable wastes. From the production place (supermarkets, etc.) to the production of established and dehydrated vegetable meal ready for including in animal feed (Fig. 2). None of the agricultural processes involved in the production of this vegetables are taken into account due to the fact that this is a recovery process for a current waste, and thus no impact from the previous stages is included.

For the impact characterization climate change, human toxicity, eutrophication, abiotic resource depletion and water depletion potential methods has been selected according to ILCD (EC & Institute for Environment, 2012). SimaPro 8.0. software was used for the impact assessment.

2.5.2. Life cycle inventory

Main inputs and outputs taken into account in the LCA are shown in Table 1. For primary data direct measurements has been taken from the pilot study. However, for the background data Ecoinvent 2.2 commercial dataset was selected.

3. Results

3.1. Characterization of vegetable waste

The different vegetable by-products identified as being produced in the Basque Country are derived from fruit/vegetables, potatoes, apple pressing, grape pressing/grapes, agriculture, bread and coffee husks, with these by-products being generated in the retail, potato, cider, wine, horticulture, baking and coffee-grinding sectors. The total amount of the different by-products generated by each sector is shown in Table 2.

Although production is relatively stable throughout the year in most sectors, there are two sectors in which this production is limited to a few months per year (Table 3), namely the cider sector (September to December) and the wine sector (September to October), thus making these by-products only available at that time.

Analysis of the undesirable substances found in these by-products showed that nitrite levels were above the maximum legal limit of 15 mg/kg for raw materials for animal feed formulations in two cases, namely coffee husk (33.3 mg/kg) and grape pressing/grapes (28 mg/kg). For the remaining sectors, all nitrite levels were below the maximum legal limit. The mycotoxins analysed were aflatoxin B1, B2, G1 y G2; zearalenone; deoxynivalenol; ochratoxin A; fumonisin B1 and B2; T-2 toxin; HT-2 toxin and patuline. All values obtained were well below the maximum permitted limits. The pesticides analysed were aldrin, chlordane, DDT, endosulfan, endrin, HCH, hexachlorocyclohexane, heptachlor and hexachlorobenzene. All values obtained were well below the maximum permitted limits. The heavy metals analysed were lead, cadmium, arsenic and mercury and, as in the previous cases, all values obtained were well below the maximum permitted limits. Microbiological analyses showed that salmonella and listeria were absent and that *Escherichia coli*, *Staphylococcus aureus*, *Clostridium perfringens*, sulfite-reducing clostridia, aerobic mesophiles, enterobacteriaceae, total coliforms and molds-yeast were present below the maximum permitted levels. Dioxins were analysed in a sample comprising a mixture of all by-products and all results were well below the maximum permitted limits.

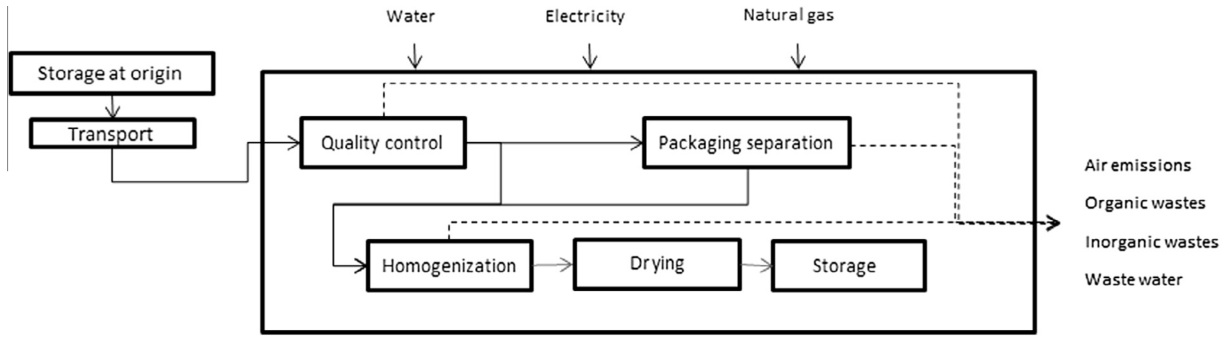

Fig. 2. System boundaries of the studied system.

Table 1
Life cycle inventory for the selected functional unit, treatment of 1 tonne of vegetable waste.

Product		
Vegetable meal	159.19	kg
Avoided product		
Oat meal	159.19	kg
Input		
Vegetable wastes	1	tn
PP plastic (reception)	480	g
Transport	91.42	Tkm
Electricity (storage)	3.36	Kwh
Refrigerants (storage)	0.028	g R134a
Electricity (homogenisation)	5.28	Kwh
Electricity (crushing)	6.76	Kwh
Electricity (drying)	6.76	Kwh
Natural gas (drying)	261.6	Kwh
Output		
Refrigerant (R134a)	0.028	g
Waste water	137.62	L

Table 2
Vegetable waste production.

Sector	No of centres	Vegetable wastes tonnes
Markets	857	4.201
Potato	27	7.500
Cider	133	3.626
Wine	209	6.981
Horticulture	64	200
Bread	305	3.275
Coffee	24	37

Table 3
Seasonal variability of cider and wine sector wastes production.

Sector	September	October	November	December
Cider	880.6	1215.6	1215.6	314
Wine	3650	3331	–	–

The nutritional analysis showed that retail and horticultural by-products had the highest water content (>85%), followed by cider and potatoes (approx. 75%) and wine (>65%). In contrast, bread and coffee by-products had lower levels of about 20% and 3.5%, respectively. The ash contents for all vegetable by-products were less than 0.7%, except for bread and coffee, with an ash content of more than 2%, and wine by-products (1.5%). The protein levels in coffee and bread by-products were the most interesting (17% and 10%, respectively), followed by wine by-products (3%). Protein contents for by-products from the other sectors were less than 1.5%. The fibre contents for coffee, wine and cider by-products were 37.68%, 11.12% and 7.31%, respectively, with the values for other by-products being lower than 1.5%. The starch level in potato by-products is 12.6%, whereas fat levels in wine and cider by-products are around 2%, followed by bread with 1.2%. Fat levels for other by-products are below 0.7%. The sugars levels in retail and cider by-products are about 5%, followed by wine and bread by-products with 3.5% and 1.7%, respectively. Sugar levels in other by-products are below 1%. The caffeine level in coffee by-products is about 1.21%. The pH of bread, coffee and potato by-products is about 5.5, which contrasts with the value of 3.5 for retail and cider by-products and 4.5 for horticultural and wine by-products.

3.2. Definition of the drying process

Three different technologies, namely microwave, PCD and both a static and rotary oven, were identified as the most appropriate technologies for drying vegetable wastes. As such, different tests were carried out to optimise the operating conditions (essentially temperature and power consumption) for each of these technologies. The optimal values were 85 °C for a static oven, 110 °C for a rotary oven, 140 °C for PCD, and 1000 W for microwave drying.

The different prototypes obtained with each technology under these operating conditions were analysed to ensure that they fulfilled all requirements for use as raw materials in animal feed. The analytical results for the different vegetable meals obtained are shown in Table 4.

3.3. Definition of the action plan

The action plan was divided into phases of storage, collection, transport and centralization of all vegetable by-products in a treatment plant, with each stage involving the following:

- The by-products should be stored at the sites where they are generated under hygienic conditions that slow possible degradation processes and prevent possible external contamination. Storage containers should be of limited capacity and can be stacked, with the aim of avoiding an undergoing self-heating related to partially processed by-products heaps. They must be preferable stored under refrigeration conditions, or alternatively in the coolest possible site at the facilities. For example, closed containers of 1 m^3 capacity, located at the coolest possible site at the facilities, are proposed.
- Once the vegetable waste has been generated, daily collection is proposed in order to avoid any change in the nutritional composition or the production of undesirable substances. Otherwise, the fast degradation of these by-products due to their high water content would make them unsuitable for use as raw materials for animal feed. Due to its lower water content, some vegetable waste, such as bread by-products, could be stored for longer periods with no decrease in quality.

Table 4
Analytical characterization of different vegetal waste flours.

Parameter	Unit	Crude sample	Pulse combustion 140 °C	Microwave 1000 W	Static oven 85 °C	Rotatory oven 110 °C
Moisture	%	66.06	25.20	9.51	9.5	4.46
Energy	kcal/100 g	133	248	325	243	164
Crude protein (PB)	%	4.37	9.62	10.25	8.87	9.37
Crude fibre (FB)	%	<0.5	2	4.5	<0.5	3.2
Starch	%	25.64	44.28	57.94	41.6	29.02
Fat gross	%	0.85	1.66	1.7	1.57	1.59
Total sugars	%	3.11	7.58	13.8	9.92	0.87
Ash	%	1.55	3.6	2.92	2.84	28.6
Sodium	mg/kg	2023.2	3418.2	5142.5	3203.6	3452.4
Calcium	mg/kg	363.4	689	746.6	510	498.3
Phosphorus	ppm	938.7	1548.4	1827	1150.5	1563.2
Caffeine	%	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrites	mg/kg	<10	<10	<10	<10	60.8
Nitrates	mg/kg	75.2	477.7	377.1	288.2	90.8
Hg	mg/kg	<0.050	<0.050	<0.050	<0.050	<0.050
Pb	mg/kg	<0.040	<0.040	<0.040	<0.040	<0.040
Cd	mg/kg	0.23	0.08	0.09	0.09	<0.01
As	mg/kg	<0.05	<0.05	<0.05	<0.05	<0.05
Cu	mg/kg	8.89	10.57	8.8	10.21	2.28
Aflatoxin B1	µg/kg	<0.5	<0.5	<0.5	<0.5	<0.5
Patuline	µg/kg	<5	<5	<5	<5	<5
Pesticides*	ng/g	<D.L.	<D.L.	<D.L.	<D.L.	<D.L.

* See more details in Supplementary Material 1.

- The different vegetable wastes should be collected using different collection routes on the kind of by-product concerned, for example one for retail by-products, another for potato by-products and another for cider and wine by-products, etc. Before collection, the truck driver should perform a preliminary visual quality control of the vegetable by-products based on a quality-control protocol defined by the animal feed sector. Subsequently, depending on the result of this quality control, the waste will be transported to the treatment plant if it is of sufficiently high quality for animal feed, or sent to a landfill site if not. The transport vehicle should comply with EC Regulation 183/2005 of the European Parliament.
- Once at the treatment plant, the operator should perform a second visual quality control, similar to the first control. Subsequently, if the waste is of sufficient quality for animal feed, it should be stored in a large vertical silo, depending on the kind of by-product, while awaiting treatment to make it suitable for use in animal feed.
- Before processing, the different types of vegetable waste should be mixed in a proportional way to ensure homogeneity in terms of meal composition. The mixture obtained should subsequently be crushed and homogenised to ensure the feasibility of the drying process.
- The final step of the process is to dry the mixed waste to reduce its water content to less than 12% and then store it in large vertical silos, under appropriate conditions, to maintain its quality over time.

3.4. Assessment of the technical feasibility

The demonstration test took place from 3rd to 18th October 2013, during which two weekly cycles were conducted. Six food industries, one waste manager and one technology centre took part in this process.

The vegetable waste was stored in containers with a capacity of 1000 l, under conditions guaranteeing its safety and quality. Vegetable waste was collected three times a week, or every two days. Less than 20% of the samples show degradation symptoms. The time required to collect the different vegetable wastes from each industry was about 15 min. During this period, the truck driver had sufficient time to perform the preliminary visual control and to load the vegetable waste onto the truck.

The transport vehicle fulfilled all the requirements of EC Regulation 183/2005 of the European Parliament, such as the completion of all documents with information regarding the load. Reception of vegetable waste at the treatment plant started with a visual inspection. The aim of this control is to establish if the by-products satisfy minimum requirements determined by the market (degradation symptoms or undesirable materials such as packaging). The wastes were then stored in containers with a capacity of 1000 l.

Before drying, the different types of vegetable waste were mixed in a proportional way in order to ensure homogeneity in terms of meal composition. The mixture of wastes used in producing the final dried flour was: 40% of potato residue, 30% of fruit and vegetable by-products from retail sector, 10% of vegetable by-products from horticulture sector and 20% of apple pomace from cider sector. Bread, wine and coffee wastes were not considered because they were already valorised for other applications. Once mixture, vegetable wastes were crushed and homogenised with the aim of obtaining a homogeneous particle size of about 100 µm. This particle size ensures the functionality of the drying by PCD. The mixed vegetable waste was then dried by PCD at 140 °C. The vegetable meal obtained (about 500 kg) was stored in bags of 25 kg.

3.5. Life cycle impact assessment

As can be seen from Fig. 3, the drying process is the aspect of the proposed action plan with the greatest environmental impact. Thus, this stage is responsible for more than 80% of the potential impact on climate change and abiotic resource depletion, 50% of human toxicity and about 60% of eutrophication and water depletion. The transportation and homogenisation processes have the second and third highest environmental impacts.

However, as this is a recovery treatment in which a raw material is obtained, it is necessary to take into account the products that do not need to be manufactured. In this case, the vegetable meal obtained is very similar to oatmeal; therefore the overall analysis must take this “avoided production” into account as a positive impact.

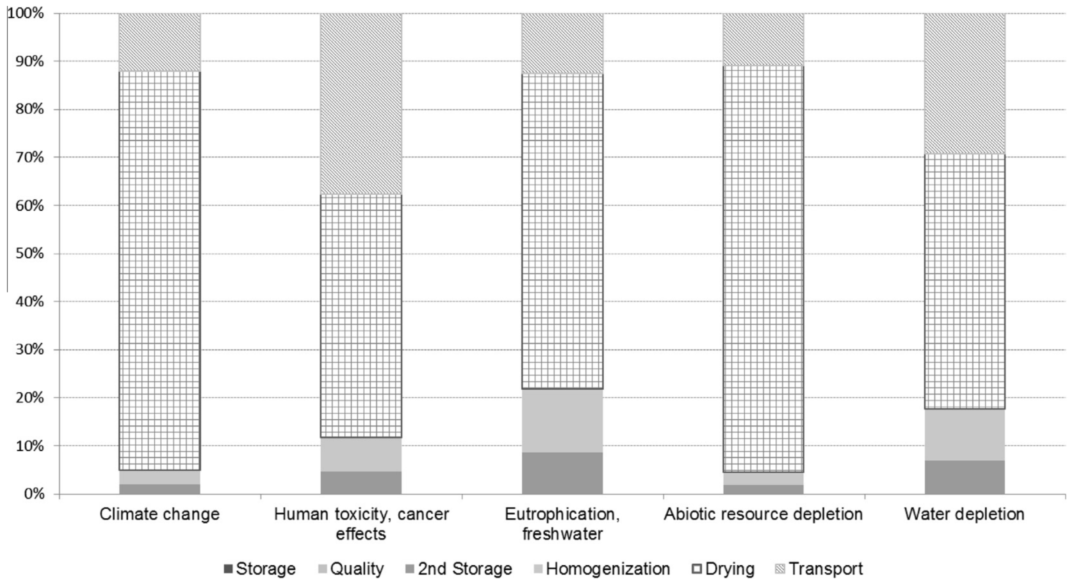

Fig. 3. Relative contribution of the steps involved in the valorisation alternative proposed to the climate change, human toxicity, eutrophication, abiotic resource depletion and water depletion potential environmental impact categories.

Overall, as can be seen from Fig. 4, and as regards human toxicity, eutrophication and water depletion, the new alternative has a negative impact, thus indicating an "improvement" for the environment. With regard to climate change or depletion of abiotic resources, the new process prevents the production of oatmeal, thereby reducing these two impacts by 40% and 20% respectively.

4. Discussion

According to the analytical results, despite the fact that almost all vegetable by-products are currently stored for several days in containers outdoors without any refrigeration, almost all undesirable substances are present below the maximum permitted limits. However, as high nitrite levels are found in coffee and wine by-products, nitrite levels in these by-products must be monitored. Despite this, it can be concluded that it is feasible to use these vegetable by-products as raw materials for animal feed provided that they are present below the maximum permitted limit.

In addition, it has been concluded, together with the EPEA Technical Committee, that there are no important differences in the composition of the different by-products, thus meaning that they can be managed as a single by-product, although their high content as regards the recommended percentage of the most important nutritional parameters, such as protein, limits their inclusion in

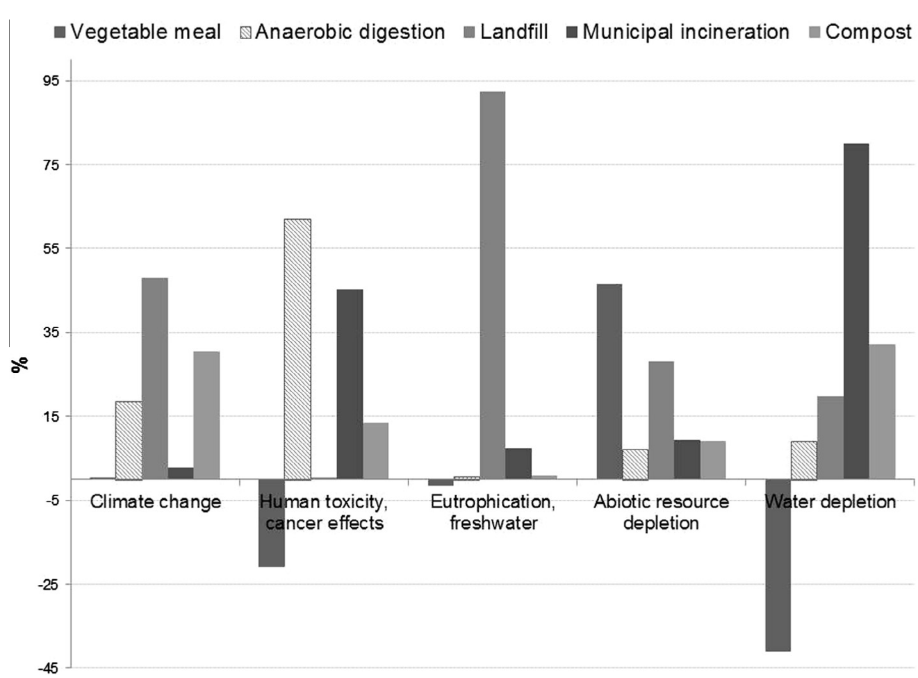

Fig. 4. Comparative LCA of the vegetable bio waste management alternatives analysed: vegetable meal for animal feed, anaerobic digestion, landfill, incineration and compost production.

feed formulations to between 3% and 6%. Moreover, in general, the water content of the vegetable waste studied herein is too high for inclusion in feed formulations without prior treatment; therefore a drying process must be developed to reduce this variable.

With regard to the drying process, all the different vegetable meal prototypes produced in this study fulfil the nutritional requirements of animal feed manufacturing companies and legal requirements with respect to undesirable substances. As such, and regardless of economic aspects, all technologies tested are useful for drying vegetable waste for subsequent use as a raw material for animal feed.

The action plan proposed was technically validated by conducting a pilot-scale demonstration trial, thus allowing us to conclude that, from a technical point of view, it is possible to recover vegetable by-products.

According to the environmental improvement assessment, landfill is the option with the greatest impact from a climate change and aquatic eutrophication point of view due to emissions to air and water from the decomposition of bio waste, which is in accordance with previous studies: Cherubini, Bargigli, & Ulgiati, 2009 or Güereca, Gassó, Baldasano, & Jiménez-Guerrero, 2006. These emissions are abundant in greenhouse gases such as methane and some nitrogen compounds, which have a greenhouse potential 24 times higher than that of CO_2. Furthermore, the alternative of anaerobic digestion has the highest impact on human toxicity as our analysis showed that the release of metals from the sludge resulting from digestion is a major problem for human toxicity. Finally, incineration has a marked impact on water depletion due to the need to use water to stabilize the ash after burning. Even when considering the avoided products, the recovery of by-products such as vegetable meals has a high impact on abiotic resource depletion due to the high energy demands of the drying process. In this regard, it should be noted that this impact likely reflects the dependence on fossil resources in the Spanish electricity mix. Furthermore, the data entered into the tool are not likely to be representative of a large-scale operating environment since they are obtained from tests on a pilot scale. As such, this value could be reduced significantly if drying data that take efficiency ratios into account are used. Moreover, as pointed out by Bernstad and Jansen (2012) there are a lot of variables (regional and global) involved in the food waste management system and it is difficult to establish a comparison between different studies and management options since the guidelines for the correct measurements are still under development.

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The Feed Manufacturers Association of the Basque Country (EPEA) helped with the assessment of the nutritional value of vegetable meal.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodchem.2015.11.035.

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