LIFE CYCLE ASSESSMENT OF A NEW FEED PRODUCTION OBTAINED BY WASTED FLOUR FOOD COLLECTED FROM THE DISTRIBUTION AND RETAIL PHASES

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ABSTRACT

Every year in Emilia Romagna more than 10000 tons of food are wasted during the retail and distribution phase. Landfill is nowadays the most adopted end of life, but working on a specific sorting system it would be possible to separate food from packaging and recover both of them in the most preferable way. In this case, Food Waste could be valorized by means of different technologies, such as anaerobic digestion, composting, and animal feed production. In this study the environmental performance of two Food Waste valorization scenarios using the Life Cycle Assessment (LCA) methodology has been analyzed. For both scenarios the Floor Food Products Fraction, like bread, pasta and biscuits, was valorized to produce animal feed. The environmental impacts of these new scenarios were compared with the impacts caused by the traditional feed production. The new scenarios lead to benefit for all the considered impact categories.

Keywords: Food waste, LCA, Waste valorization, Environmental impacts.

1. INTRODUCTION

Vermeulen et al., (2012) estimated that food production is responsible for up to 29% of the anthropogenic greenhouse gases emissions. One of the major problems related to food production is the waste generated throughout the Food Value Chain. In 2011, the Food and Agriculture Organization of the United Nations (FAO) determined that one third of the global production of food for human consumption is lost or passed out as waste, corresponding to approximately 1.3 billion tons each year (Gustavsson et al., 2011; FAO 2013a; FAO 2013b).Three main definitions of Food Waste (FW) can be found in literature. Firstly, the Food and Agriculture Organization (FAO) defines FW as wholesome edible material intended for human consumption, arising at any point in the food supply chain that is instead discarded, lost, degraded or consumed by pests (FAO 1981). Stuart (2009) adds to the FAO's definition, by stating that FW should also include edible material that is intentionally fed to animals or is a by-product of food processing diverted away from the human food chain. Finally, Smil (2004) suggests that FW covers the definitions above, but adds over-nutrition, the gap between the energy value of consumed food per capita and the energy value of food needed per capita.

Throughout the Food Value Chain, food is wasted in different stages, namely during production, food processing, distribution, and use. Several causes of this wastage exist (European Commission 2015), and they can be mainly attributed to:

- *Production*: overproduction, product and packaging damage from farmers and food processing;
- *Retail*: inefficient stock management, marketing strategies that lead to overbuying (e.g. 2 for 1, buy 1 get one for free), and aesthetic issues;
- *Catering*: the meal sizes and the difficulty to anticipate the number of clients;
- *Households*: lack of awareness towards food wastage, lack of shopping planning, misconception regarding the "best before" and "use by" date labels, and absence of knowledge/innovation to reuse and cook with the leftovers; and
- In general throughout the entire food value chain due to inappropriate storage and packaging methods.

The main reasons for food waste generated during distribution are examined in the literature, including inappropriate packaging, poor handling and transportation, failures on forecasting and storage (Kantor et al., 1997).

The management of FW should follow certain policies based on the 3R's concept, i.e., reduce, reuse, and recycle (Memon 2010; Sakai et al., 2011). In the European context, the Waste Framework Directive 2008/98/EC proposes the following waste management hierarchy: prevention, preparing for re-use, recycling, other recovery (e.g. energy recovery), and disposal (European Commission 2008). As illustrated in Figure 1, the best option is "prevention", and at the bottom of the inverted pyramid, the least favorable option is "disposal".

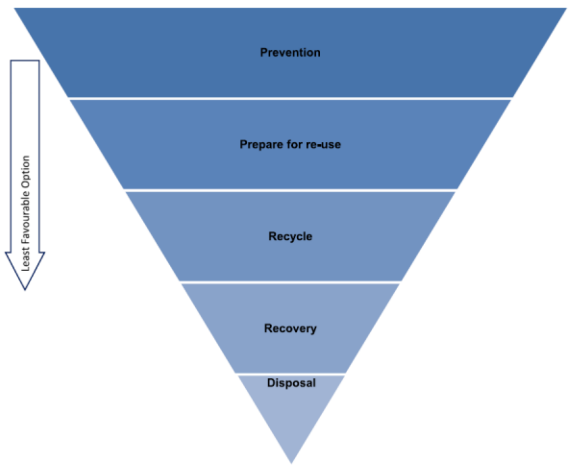

Figure 1: The waste hierarchy. (Source: European parliament council 2008)

Several studies evaluating the environmental performance of different FW management options can be found in literature. Lundie and Peters (2005) compared several FW disposal options, and showed that codisposal at landfill made a greater contribution than aerobic composting or central composting. Also Mendes et al., (2003) confirmed that the landfilling of biodegradable waste is generally the worst strategy from an environmental point of view. In addition, Güereca et al., (2006) reported that a composting based system had less impact on global warming than an incineration based system in the biowaste treatment of Barcelona, Spain. According to Khoo et al., (2009), using the FW for aerobic composting system is more environmentally sustainable than incinerators, but less compared to the anaerobic digestion process, due mainly to CO_2 and NH_3 emissions. Also in a study made in USA, anaerobic digestion had the best environmental results (Levis and Barlaz 2011). In the same study the authors showed than composting and landfill disposal with energy recovery presented lower environmental impacts than landfill disposal. Cherubini et al., (2009) showed that landfill systems is the worst alternative; the study also show that a sorting plant coupled with electricity and biogas production is the best option for waste management. Also from the study on municipal solid waste disposal by Eriksson et al. (2005) and Hong et al. (2006), landfill had more impact on global warming than incineration.

A few studies evaluated the use of FW to produce animal feed. According to Kim and Kim (2010) and Lee et al., (2007) using FW for feed production presented lower environmental impact than landfill disposal. Vandermeersch et al., (2014) showed than FW can be valorized through animal feed production, reducing the environmental impact mainly due to the avoided products from traditional supply chain.

The objective of this study was to evaluate which FW valorization scenarios could bring more environmental benefit. The environmental performance was evaluated by means of LCA method.

The remainder of the paper is organized as follows. LCA methodology has been explained considering all the phases according to ISO 14044. Environmental impact assessment has been performed considering the current scenario (disposal in landfill), comparing it with the new ones and evaluating the production impacts of existing feeds in comparison with those partly originated by FW. A sensitivity analysis has been then performed showing how changes could influence the results. Finally, conclusion section is reported in order to resume the main results of this work.

2. LIFE CYCLE ASSESSMENT METHODOLOGY AND DATA

The LCA methodology was applied according to the principles and requirements provided standards. LCA consists of four main steps of analysis: goal and scope definition; inventory analysis; impact assessment; and interpretation (ISO 14044, 2006). The SimaPro 8.0.5 LCA software was used in this assessment.

2.1. Goal and scope definition

The purpose of this work is to evaluate and compare the environmental impacts of 2 FW valorization scenarios by identifying the inputs and outputs for both option and their impacts.

2.1.1. Functional unit

The functional unit provides a reference unit for which the inventory data are normalized (ISO 14040, 2006). The concept of the functional unit is key in LCA, as it facilitates the comparison of alternative products and services (ISO 14044, 2006). The functional unit of this study is 1 kg of animal feed product with 10% of FFPF. In scenario 1 we had compared the production of 1 kg corn feed with a new feed where 10% of corn was replaced with the same quantity of FFPF (Table 1). Instead in scenario 2 we compared the production of 1 kg animal feed (Table 1) with a new animal feed production where 10% of each ingredients was replaced with the same quantity of FFPF.

Table 1: Recipe for 1 kg of animal feed in 2 scenarios

Recipe for 1kg of animal feed					
Input scenario 1	Traditional animal feed	Animal feed with FFPF	Input scenario 2	Traditional animal feed	Animal feed with FFPF
Corn grains	100%	90%	Wheat grains	91.0%	81.9%
FFPF	0%	10%	Soybeans	5.0%	4.5%
			Tallow	4.0%	3.6%
			FFPF	0.0%	10.0%

We have chosen to replace only the 10%, in weight, with FFPF in the animal feed according to Prandini et al., (2007). In this study they have demonstrated that by replacing 10% of corn with the same amount of FFPF, no differences were shown for weight losses at different phases of seasoning and for the chemical analysis of seasoned hams.

2.2. System boundaries and assumptions

In order to quantify the impact of the product analyzed, system boundaries need to be determined. The case study involves the food product wasted during the retail and distribution field, located in Emilia Romagna (northern Italy). The annual generation of FW was estimated at 14,600 tons in 2013. In this study were analyzed only the FFPF, corresponding to 19% of FW (Lipinski et al., 2013).

The generation of FW happens in several supermarkets spread out through Emilia Romagna. This FW is composed by food products that were no sold to consumers, i.e., products exceeded the expiration date stated on the package, deteriorated, or that no longer seemed to be edible (Lipinski et al., 2013, HLPE 2014; BCFN 2012). Nowadays this products are disposed of in landfills (Figure 2A and Table 1).

Table 2: Summary of disposal n landfill

Current Scenario		
Input	Unit	Quantity
Transport, freight, lorry 3.5-7.5 metric ton, EURO4	km	80
Landfill of biodegradable waste EU 27	ton	1

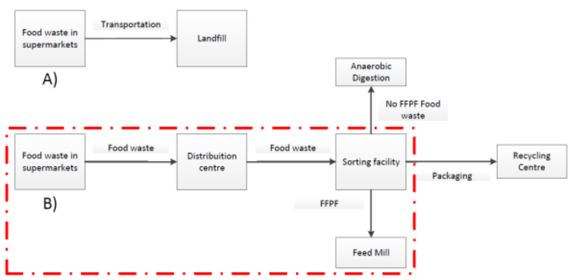

Figure 2: Graphical scheme of the A) disposal in landfill and B) new valorization scenarios

Instead in the new proposed scenarios the FW will be transported to a Distribution center and every 4 days. It will be transported from the distribution center to a centralized retort center, where a mechanical sorting will be performed, separating the organic fraction from packaging. The FFPF will be transported to a Feed mill where will be used to produce animal Feed. The other fraction of FW will be recovered in the most preferable rate such as through Anaerobic digestion (Vandermeersch et al., 2014). The sorted packaging materials will be then sent to specific recycling centres. The system boundaries can be visualized in Figure 2B, and included only the FFPF fraction.

2.3. Inventory analysis and data collection

The life cycle inventory analysis quantifies the resources use, energy use, and environmental releases associated with the system being evaluated (ISO 14040 2006). Ecoinvent Database 3.1 is used for secondary data by considering data related to the Italian situation (Ecoinvent 2015).

In this paragraph we have defined the incoming and avoided phases regarding the new scenarios (Figure3 and Figure 4). The considered incoming stages are: 1) Generation of FW; 2) Transportation of FW to distribution centre; 3) Storage in distribution centre; 4) Transportation of FW to Sorting facility; 5) Sorting of FW; 6) Transportation of FFPF to feed mill; 7) Feed production. While the avoided phases are: 8) Transportation of FW to the landfill, 9) Disposal product in landfill and 10) The produce of corn grain (Scenario 1) wheat grains, soybeans and tallow (Scenario 2), and 11) the relative transport.

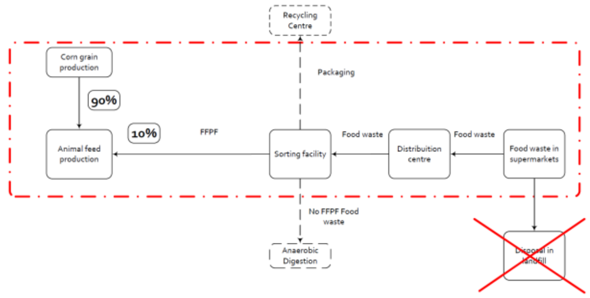

Figure 3: Graphical scheme of the scenario 1

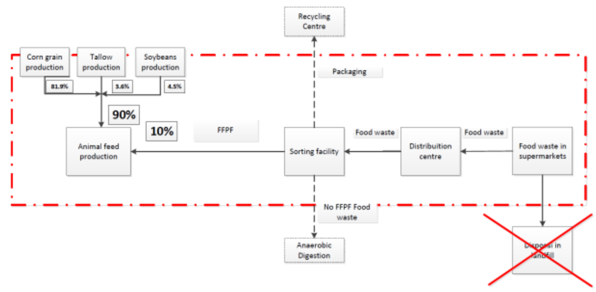

Figure 4: Graphical scheme of the scenario 2

Within the system boundary, the following assumptions and limitations are applied:

- The data from the transports was obtained based on the average distance traveled;
- Mass based allocation was used in order to account the share between FFPF, organic mass and packaging into the FW
- The average Italian electricity mix is used in this study.
- In this study, data from Italy were used when available. In case of unavailable data, relevant background data from Europe or Switzerland were used.
- Regarding the cut-off criteria applied, less than 1% of the energy and mass flows of the inputs and outputs was excluded from this analysis.

2.4. Methods of impact assessment

The data collected in the inventory analysis are the basis for the impact assessment phase whose aim is to evaluate the potential environmental impact of the system (ISO 14040 2006) caused by effluent emissions, releases into the environment and resources consumption. The impact analysis was carried out using the ReCiPe method. The hierarchic perspective has been selected in this work, as it is considered to be the most balanced of the three proposed by the method (Egalitarian, Individualist and Hierarchist). Impact values were calculated at midpoint level for 18 impact categories, i.e. (i) climate change, (ii) ozone depletion, (iii) terrestrial acidification, (iv) freshwater eutrophication, (v) marine eutrophication, (vi) human toxicity, (vii) photochemical oxidant formation, (viii) particulate matter formation, (ix) terrestrial ecotoxicity, (x) freshwater ecotoxicity, (xi) marine ecotoxicity, (xii) Ionising radiation, (xiii) agricultural land occupation, (xiv) urban land occupation, (xv) natural land occupation, (xvi) water depletion, (xvii) metal depletion and (xiii) fossil depletion.

3. LIFE CYCLE IMPACT ASSESSMENT

3.1. Current scenario: disposal in landfill

The results for the current scenario are reported in Table 2, while Figure 5 shows the relative contribution of each processing input.

Table 3: Characterization results for the overall impact of the disposal in landfill scenario.

Impact category	Unit	Total	Transport	Disposal in Landfill
Climate change	kg $CO_{2\ eq}$	1.45E+06	2.89E+04	1.42E+06
Ozone depletion	kg CFC-11 $_{eq}$	1.33E-02	5.05E-03	8.22E-03
Terrestrial acidification	kg $SO_{2\ eq}$	9.71E+02	1.11E+02	8.60E+02
Freshwater eutrophication	kg P_{eq}	1.27E+03	5.91E-01	1.27E+03
Marine eutrophication	kg N_{eq}	1.18E+03	4.75E+00	1.18E+03
Human toxicity	kg 1,4-DB $_{eq}$	6.00E+03	4.22E+03	1.78E+03
Photochemical oxidant formation	kg NMVOC	1.50E+03	1.38E+02	1.36E+03
Particulate matter formation	kg PM10 $_{eq}$	1.36E+03	5.03E+01	1.31E+03
Terrestrial ecotoxicity	kg 1,4-DB $_{eq}$	9.45E+00	7.97E+00	1.48E+00
Freshwater ecotoxicity	kg 1,4-DB $_{eq}$	3.32E+01	1.70E+01	1.62E+01
Marine ecotoxicity	kg 1,4-DB $_{eq}$	9.14E+01	6.73E+01	2.41E+01
Ionising radiation	kBq U235 $_{eq}$	1.18E+04	1.82E+03	9.95E+03
Agricultural land occupation	m^{2a}	4.32E+02	4.32E+02	0.00E+00
Urban land occupation	m^{2a}	9.71E+02	9.71E+02	0.00E+00
Natural land transformation	m^2	1.01E+01	1.01E+01	0.00E+00
Water depletion	m^3	5.85E+02	-1.42E+01	6.00E+02
Metal depletion	kg Fe $_{eq}$	5.34E+03	1.67E+03	3.67E+03
Fossil depletion	kg oil $_{eq}$	7.21E+04	1.01E+04	6.20E+04

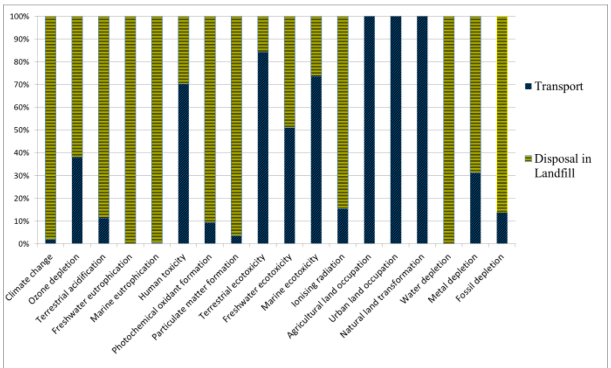

Figure 5: Relative contribution of different phases to the overall impacts for disposal in landfill

As can be seen from the total environmental impact divided according to stages (Table 1), disposal in landfill is the most important contributor to most impact categories; while, the transportation of FFPF to the landfill contributes mostly in 6 categories: Human toxicity, Terrestrial ecotoxicity, Marine ecotoxicity, Agricultural land occupation, Urban land occupation and Natural land transformation.

3.2. Scenario 1

In this case we compared the production of 1 kg corn feed with a new animal feed production where 10% of corn was replaced with the same quantity of FFPF. The results for 18 midpoint indicators can be seen in Table 4 and Figure 6.

Table 4: Characterization results for the scenario 1.

Impact category	Unit	Mais 100%	Mais 90% ; FFPF 10%	Avoided impact
Climate change	kg $CO_{2\ eq}$	5.86E-01	4.39E-01	1.47E-01
Ozone depletion	kg CFC-11 $_{eq}$	3.51E-08	3.13E-08	3.73E-09
Terrestrial acidification	kg $SO_{2\ eq}$	7.06E-03	5.70E-03	1.36E-03
Freshwater eutrophication	kg P_{eq}	8.44E-05	2.24E-05	6.20E-05
Marine eutrophication	kg N_{eq}	9.36E-03	7.45E-03	1.91E-03
Human toxicity	kg 1,4-DB $_{eq}$	6.69E-02	5.66E-02	1.03E-02
Photochemical oxidant formation	kg NMVOC	1.87E-03	1.54E-03	3.35E-04
Particulate matter formation	kg PM10 $_{eq}$	1.50E-03	1.19E-03	3.12E-04
Terrestrial ecotoxicity	kg 1,4-DB $_{eq}$	3.68E-03	2.95E-03	7.31E-04
Freshwater ecotoxicity	kg 1,4-DB $_{eq}$	2.97E-03	2.39E-03	5.80E-04
Marine ecotoxicity	kg 1,4-DB $_{eq}$	8.53E-04	7.30E-04	1.23E-04
Ionising radiation	kBq U235 $_{eq}$	1.36E-02	1.18E-02	1.85E-03
Agricultural land occupation	m^{2a}	1.35E+00	1.08E+00	2.70E-01
Urban land occupation	m^{2a}	2.45E-02	2.02E-02	4.31E-03
Natural land transformation	m^2	6.53E-05	5.87E-05	6.60E-06
Water depletion	m^3	1.71E-02	1.37E-02	3.41E-03
Metal depletion	kg Fe $_{eq}$	2.69E-02	2.30E-02	3.98E-03
Fossil depletion	kg oil $_{eq}$	9.89E-02	8.42E-02	1.47E-02

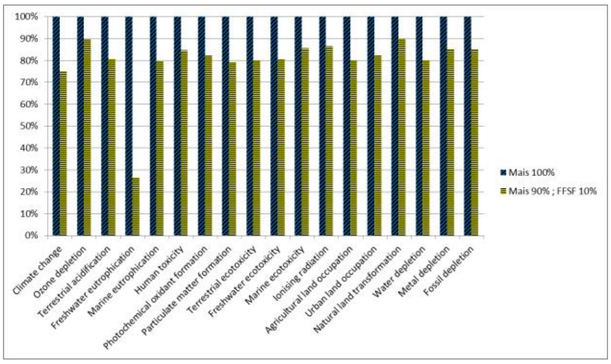

Figure 6: Results of the LCA for the Scenario 1

The new scenario showed better results in each impact categories analyzed; in almost all the categories the impact were resulted less than 10-20%, while for the Freshwater eutrophication the impact was resulted less than 73 %, mainly due to the avoided disposal in landfill of FFPF. For the other categories, the main reason for these results are the same; by valorizing the FFPF with feed production, avoids partly the production of animal feed from corn, avoiding the environmental impact that are directly related to agriculture activities, such as land occupation. The Relative contribution of each processing input for the new scenario can be seen in Appendix A.

3.3. Scenario 2

In scenario 2 we compared the production of 1 kg animal feed (Table 1) with a new animal feed where 10% of each ingredients was replaced with the same quantity of FFPF. The results for 18 midpoint indicators can be seen in Table 4 and Figure 7.

Table 5: Characterization results for the scenario 2

Impact category	Unit	0% FFPF	10% FFPF	Benefit
Climate change	kg $CO_{2\,eq}$	6.04E-01	4.54E-01	1.51E-01
Ozone depletion	kg CFC-11 $_{eq}$	5.30E-08	4.57E-08	7.32E-09
Terrestrial acidification	kg SO2 $_{eq}$	6.32E-03	5.11E-03	1.21E-03
Freshwater eutrophication	kg P $_{eq}$	1.05E-04	3.87E-05	6.61E-05
Marine eutrophication	kg N $_{eq}$	1.11E-02	8.88E-03	2.27E-03
Human toxicity	kg 1,4-DB $_{eq}$	9.31E-02	7.75E-02	1.55E-02
Photochemical oxidant formation	kg NMVOC	2.23E-03	1.83E-03	4.07E-04
Particulate matter formation	kg PM10 $_{eq}$	1.48E-03	1.17E-03	3.07E-04
Terrestrial ecotoxicity	kg 1,4-DB $_{eq}$	4.96E-03	3.97E-03	9.87E-04
Freshwater ecotoxicity	kg 1,4-DB $_{eq}$	2.38E-03	1.91E-03	4.63E-04
Marine ecotoxicity	kg 1,4-DB $_{eq}$	7.86E-04	6.77E-04	1.10E-04
Ionising radiation	kBq U235 $_{eq}$	1.81E-02	1.54E-02	2.75E-03
Agricultural land occupation	m^{2a}	1.40E+00	1.12E+00	2.79E-01
Urban land occupation	m^{2a}	1.40E-02	1.18E-02	2.22E-03
Natural land transformation	m^2	9.47E-05	8.22E-05	1.25E-05
Water depletion	m^3	3.26E-02	2.61E-02	6.51E-03
Metal depletion	kg Fe $_{eq}$	4.01E-02	3.35E-02	6.62E-03
Fossil depletion	kg oil $_{eq}$	1.11E-01	9.35E-02	1.70E-02

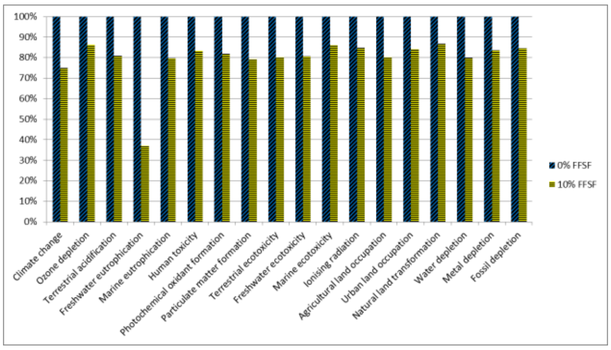

Figure 7: Results of the LCA for the Scenario 2

Also this scenario showed better results in each impact categories analyzed; in almost all the categories the impact were resulted less than 14-25%, while for the Freshwater eutrophication the impact was resulted less than 63%. The reasons are the same as already discussed in the previous sections.
The Relative contribution of each processing input for the new scenario can be seen in Appendix B.

3.4. Comparison between Scenario 1 and scenario 2

In this paragraph we compared the environmental benefits (avoided impacts thanks to using FFPF in the animal feed) between scenario 1 and 2 (Figure 8).

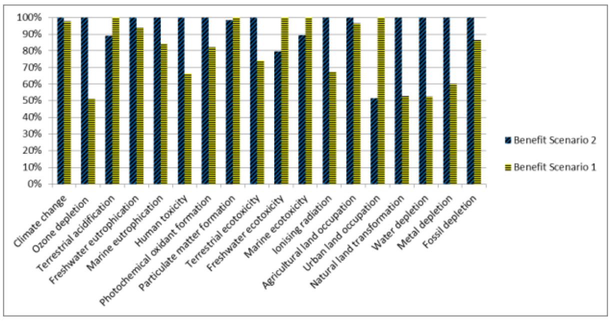

Figure 8: Comparison results between 2 scenarios

Scenario 2 showed better results in 13 categories (Climate change, Ozone depletion, Freshwater eutrophication, Marine eutrophication, Human toxicity, Photochemical oxidant formation, Particulate matter formation, Terrestrial ecotoxicity, Ionising radiation and Natural land transformation), while scenario 1 had better results in 5 categories (Terrestrial acidification, Freshwater ecotoxicity, Marine ecotoxicity, Agricultural land occupation and Urban land occupation).
Summarizing scenario 2 can bring more environmental gains than scenario 1 because the FFPF is valorized for producing Animal feed containing soybeans and wheat grain that they have most environmental impactful than producing corn grain (Figure 9).

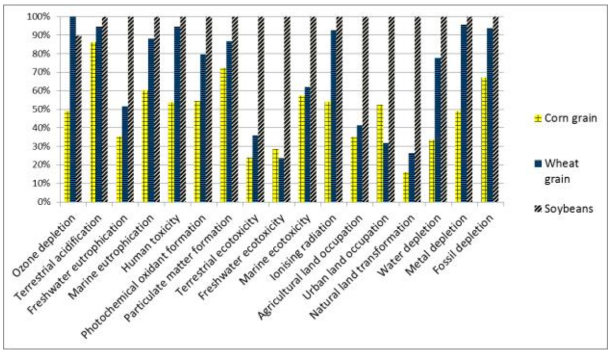

Figure 9: Total impact of vegetable productions

Table 6: Comparison results between 2 scenarios

Impact category	Unit	Benefit Scenario 2	Benefit Scenario 1
Climate change	kg $CO_{2\ eq}$	1.51E-01	1.47E-01
Ozone depletion	kg CFC-11 $_{eq}$	7.32E-09	3.73E-09
Terrestrial acidification	kg $SO_{2\ eq}$	1.21E-03	1.36E-03
Freshwater eutrophication	kg P $_{eq}$	6.61E-05	6.20E-05
Marine eutrophication	kg N $_{eq}$	2.27E-03	1.91E-03
Human toxicity	kg 1,4-DB $_{eq}$	1.55E-02	1.03E-02
Photochemical oxidant formation	kg NMVOC	4.07E-04	3.35E-04
Particulate matter formation	kg PM10 $_{eq}$	3.07E-04	3.12E-04
Terrestrial ecotoxicity	kg 1,4-DB $_{eq}$	9.87E-04	7.31E-04
Freshwater ecotoxicity	kg 1,4-DB $_{eq}$	4.63E-04	5.80E-04
Marine ecotoxicity	kg 1,4-DB $_{eq}$	1.10E-04	1.23E-04
Ionising radiation	kBq U235 $_{eq}$	2.75E-03	1.85E-03
Agricultural land occupation	m^{2a}	2.79E-01	2.70E-01
Urban land occupation	m^{2a}	2.22E-03	4.31E-03
Natural land transformation	m^2	1.25E-05	6.60E-06
Water depletion	m^3	6.51E-03	3.41E-03
Metal depletion	kg Fe $_{eq}$	6.62E-03	3.98E-03
Fossil depletion	kg oil $_{eq}$	1.70E-02	1.47E-02

Table 6 shows the comparison of the avoided environmental impact of the two scenarios; considering the whole use of the FFPF (2774 ton) to produce Animal feed (2774,000 ton).

4. SENSITIVITY ANALYSIS

Sensitivity analysis is a systematic procedure for estimating the effects of the choices made regarding methods and data on the outcome of a study (ISO 14040, 2006). A sensitivity assessment was performed to evaluate the environmental performance when the transport phase (Transportation of FW to distribution center, transportation of FW to Sorting facility; and transportation of FFPS to feed mill) varies. We assume that no variations occur in the other processing phases when changing the transport phase. This sensitivity analysis considers different distances; in particular they were increased by 2-3-4-5-10 times to see the influence on the whole process.

Table 7: Summary of transport phase

Transport Phase

Phase	Means of transport	Unit	Quantity
Transportation of FW to distribution centre	Lorry 3.5-7.5 metric ton, EURO4	km	250
Transportation of FW to Sorting facility	Lorry 16-32 metric ton, EURO4	km	80
Transportation of FFSF to feed mill	Lorry 3.5-7.5 metric ton, EURO4	km	40

The results of the sensitivity analysis show that the variation in the transport phase (Table 7) has a limited influence on the environmental impacts (Figure 10 and Figure 11). In fact, increasing by 3 times the transport phase in scenario 1, only in 2 categories (Ozone depletion and Ionising radiation) the impact of the new scenario is higher the impact of the scenario where animal feed is produced only with corn. Instead in scenario 2 solely increasing by 4 times the transport phase, the new scenario showed a higher impact in one unique category (Natural land occupation) compared to the original scenario (Table 4).

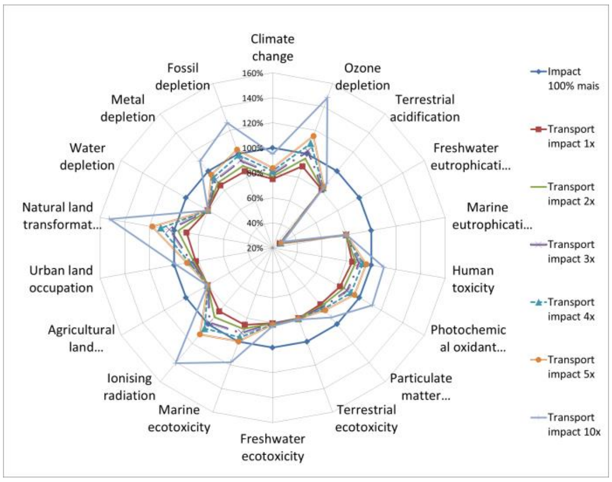

Figure 10: Graphical results of the sensitivity analysis for the variation in transport phase, scenario 1

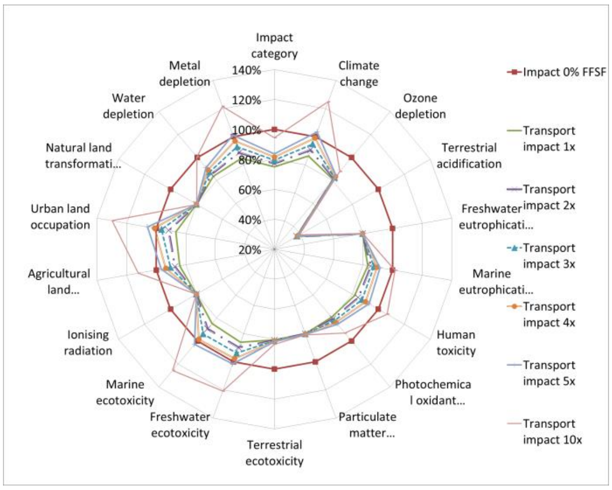

Figure 11: Graphical results of the sensitivity analysis for the variation in transport phase, scenario 2

5. CONCLUSIONS

The purpose of this work is to evaluate and compare the environmental impacts of 2 FW valorization scenarios by identifying the inputs and outputs for both option and their impacts. Both scenarios ensure a reduction of the environmental impact in all categories considered as compared to the current scenario (landfill). The LCA study showed than scenario 2 can bring more environmental gains than scenario 1 (in particular in 13 categories such as Climate change, Ozone depletion, Freshwater eutrophication and Terrestrial ecotoxicity).The results showed that about 4E+6 kg CO_2-eq. of greenhouse gases would be avoided valorizing the FFPS through both scenarios This study prove clearly that the method of manufacturing feed from FW for animals can be an environment friendlier method than landfilling.

Further studies could investigate the environmental performance of other FW treatment scenarios, for instance, separating the meat and fish fractions of FW for pet food production.

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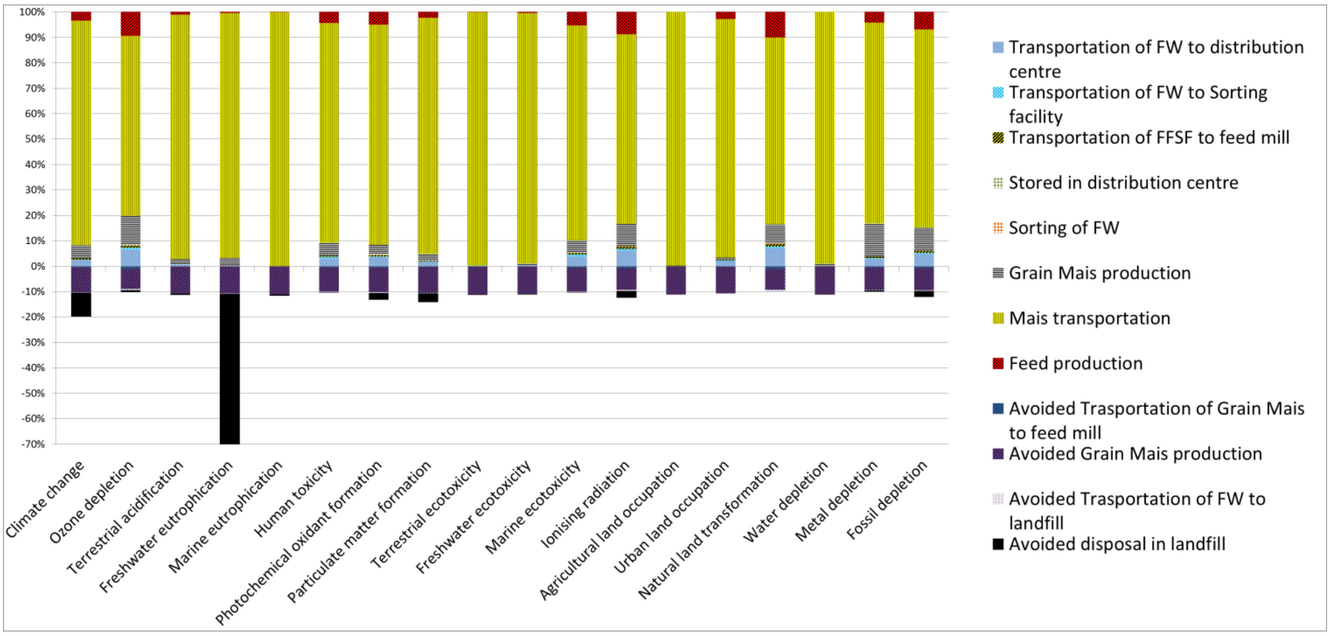
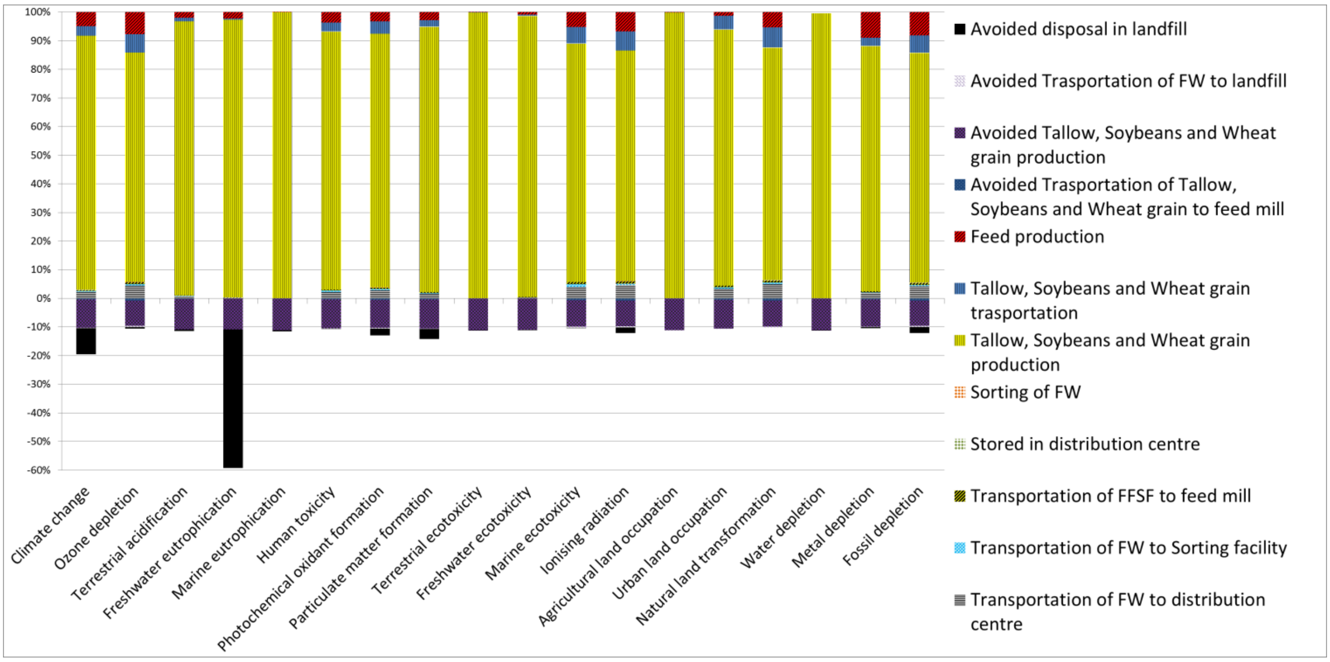
APPENDIX



Appendix A: Relative contribution of different phases to the overall impacts for scenario 1



Appendix B: Relative contribution of different phases to the overall impacts for scenario 2