LIFE Project Number

LIFE15 ENV/GR/000257

LIFE PROJECT NAME or Acronym

LIFE-F4F (Food for Feed)

Action:	B6. Products' Customer Survey, Technical Scale Up, Economic and Environmental Evaluation and Replicability and Transferability of the F4F Process
Partner:	Harokopio University of Athens (HUA)
Deliverable:	B6.5. Life Cycle Analysis and Environmental Evaluation

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ACRONYMS AND ABBREVIATIONS

FU	Functional unit
GHGs	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PEF	Product Environmental Footprint
PEFCRs	Product Environmental Footprint Category Rules

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 BACKGROUND

Food waste from the hospitality sector is a key waste stream which causes policy implications in connection with the EU Landfill Directive (1999/31/EC). In order to tackle the aforementioned issue, an EU based partnership has been formed in order to implement the **Life+ Food for Feed (F4F) Project**. The main aim of the project is to evaluate, through a pilot-scale demonstration, an innovative and simple technology, and a low-emission process that enables the safe transformation of food waste, mainly from hotels (and more generally from the hospitality industry and restaurants), into animal feed.

The aim of the Life+ F4F project is to evaluate, through a pilot-scale demonstration, an innovative and simple technology, and a low-emission process that enables the safe transformation of food waste, mainly from hotels (and more generally from the hospitality industry and restaurants), into animal feed. For this project, a pilot-scale facility has been designed and constructed in Heraklion (Crete), Greece. The project targets 4- and 5-star hotels in the highly touristic areas of Heraklion and Hersonissos.

The source-separated food waste is collected from the above-mentioned sectors and transported to the facility, where the following process takes place:

- Weighing of input load
- Lifting and uploading of waste bins
- Hand sorting and removal of non-food waste
- Grinding
- Solar Drying

Finally, through this process the end product is produced, meaning the feed, will be mixed with conventional animal feed, according to the nutritional requirements of selected animals, retailers so that it will be available for consumption (Abeliotis et al, 2018).

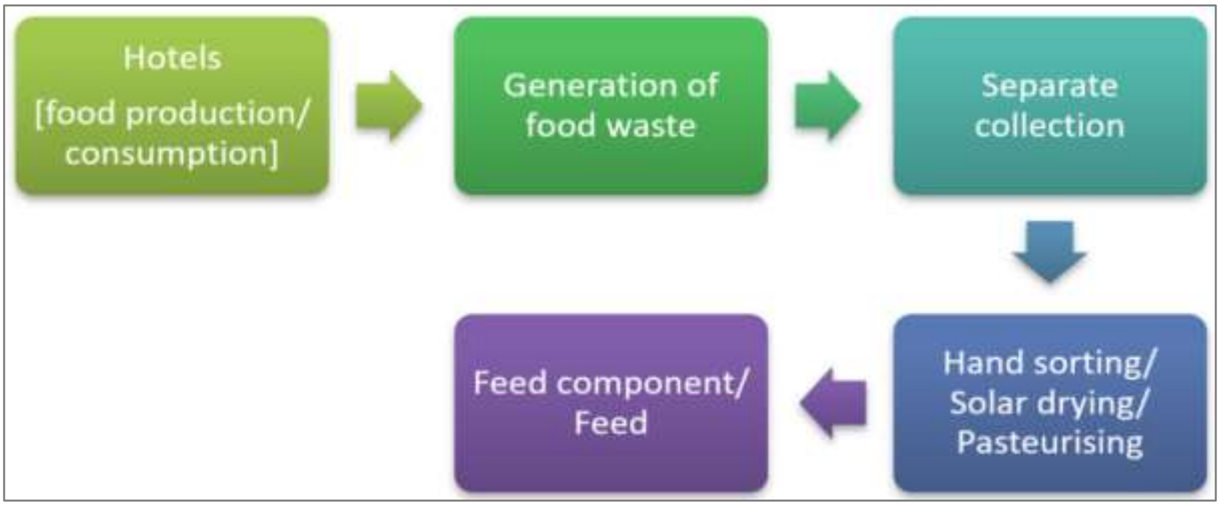


Figure 1: The Life+ Food for Feed- F4F project's process

1.2 Objective of the Study

The main objective of this deliverable is to evaluate the environmental impact of the project, performing a Life Cycle Assessment (LCA). LCA is a tool for analyzing the potential environmental impacts of products/services at all stages of their life cycle. The term 'product/service life cycle' comprises the whole raw material acquisition, production, use, end-of-life treatment, recycling, and final disposal processes. In general, assessing the environmental performance of a product or system using LCA is expected to lead to a comprehensive evaluation of the system under examination (Konstantzos et al., 2018).

For Life+ F4F project, the LCA would pay particular attention to the potential environmental impacts of the production of animal feed supplement from food waste, in relation to the conventional production of animal feed. The LCA, will take into consideration the construction and operation of the F4F pilot unit.

1.3 Life Cycle Assessment (LCA)

1.3.1 LCA Structure

As mentioned before, LCA is a reliable and widespread method to address the environmental aspects and potential environmental impacts throughout a product's lifecycle. The principles, procedures and methods of LCA are presented based on the terminology and structure of the International Organization for Standards (ISO) series ISO 14040 and ISO 14044.

According to those guidelines, LCA is composed of four phases (ISO 14040-14044:2006):

1. Goal definition and scope phase
2. Inventory analysis phase
3. Impact Assessment phase
4. Interpretation phase

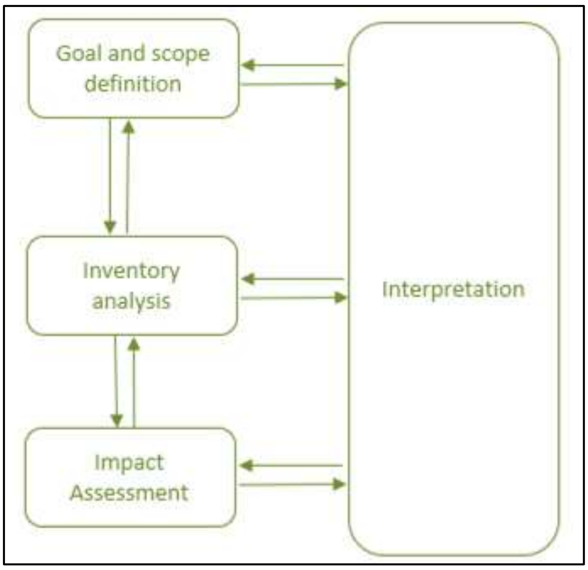


Figure 2: Life Cycle Assessment framework[1]

[1] Source: Adapted from ISO 14040:2006

As presented in Figure 2, there is an interactive relationship between the LCA phases since the evolution and results from each phase are linked directly to the other phases. A short description of each phase is described in the following sections.

LCA will be divided into two different stages, i.e., Construction & Operation

1.3.2 Phase 1: Goal and scope definition

The definition of goal and scope is the first step in LCA and there the system under study is identified, the intended results and the way the study will be directed are outlined. The determination of purpose and object is one of the most critical points of LCA because of their strong impacts on the results, so that they are agreeable with the overall objectives of the study. During the goal & scope definition, the following main facts should be considered, (ISO 14040:2006):

- the reasons for carrying out the study,
- the studied product system,
- the functional unit,
- the product system boundaries,
- LCIA methodology and types of impacts,
- data quality, assumptions and limitations.

1.3.3 Phase 2: Inventory analysis

The Life Cycle Inventory (LCI) analysis is the second phase of an LCA study and involves the compilation and quantification of input and output data for the under-study product system.

<u>The first sub-phase</u> of the LCI analysis is composed of the collection of quantitative and qualitative data for all unit processes included in the product systems boundaries. As those data play a significant role in the conclusions of the study, details about the data sources, the quality and reliability of data, the time when data have been collected shall be referenced.

In an LCI analysis the major headings under which data may be classified include:

- energy inputs, raw material inputs, ancillary inputs, other physical inputs,
- products, co-products and waste,
- releases to air, water and soil, and
- other environmental aspects.

<u>The second sub-phase</u> of the LCI analysis includes calculation procedures of the collected data, including their confirmation and the interrelation between those and the reference flow of the selected functional unit.

Moreover, during this step of LCI analysis, the initial product system boundaries may be revised and refined if necessary (exclusion of life stages, inclusion of new processes, etc). The refining process of the initial system boundaries will be based on the results of a preliminary analysis that will identify the importance of the exclusion and/or inclusion of data.

1.3.4 Phase 3: Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results, to better understand their environmental significance. This phase includes accounting, evaluating, and explanation the potential environmental impacts generated by the product through specific steps such as categorization and characterization.

According to the ISO 14044:2006 (Requirements and guidelines), the LCIA phase shall include at least the following mandatory elements:

1. Determination of impact categories, category indicators and characterization models
2. Assignment of LCI results to the selected impact categories (Classification)
3. Estimation of category indicator results (Characterization)

The selection of impact categories takes into consideration the goal and scope of the LCA, as defined in the first phase. The impact categories, which will be examined in the framework of this study, are presented in Table 1, and are based on CML2 baseline 2000 impact assessment method (Guinée et al., 2002).

Table 1. Impact category description

Impact category	Unit
Abiotic Depletion	kg Sb eq.
Global Warming (GWP100)	kg CO_2 eq.
Ozone Layer Depletion (ODP)	kg CFC-11 eq.
Human Toxicity	kg 1,4-DB eq.
Freshwater Aquatic Ecotoxicity	kg 1,4-DB eq.
Marine Aquatic Ecotoxicity	kg 1,4-DB eq.
Terrestrial Ecotoxicity	kg 1,4-DB eq.
Photochemical Oxidation	kg C_2H_2
Acidification	kg SO_2 eq.
Eutrophication	kg PO_4--- eq.

DEPLETION OF ABIOTIC RESOURCES

This impact category is concerned with protection of human welfare, human health, and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

GLOBAL WARMING

Climate change can result in adverse effects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale.

OZONE LAYER DEPLETION

Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This category is output-related and at global scale. The characterization model is developed by the World Meteorological Organization (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission). The geographic scope of this indicator is at global scale. The time span is infinity.

HUMAN TOXICITY

This category concerns effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. Characterization factors, Human Toxicity Potentials (HTP), are calculated with model USES-LCA, describing fate, exposure, and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale.

FRESH-WATER AQUATIC ECOTOXICITY

This category indicator refers to the impact on freshwater ecosystems, as a result of emissions of toxic substances to air, water and soil. Eco-toxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure, and effects of toxic substances. The time horizon is infinite Characterization factors are expressed as 1,4-dichlorobenzene equivalents/kg emission. The indicator applies at global/continental/ regional and local scale.

MARINE AQUATIC ECOTOXICITY

Marine eco-toxicity refers to impacts of toxic substances on marine ecosystems (see description freshwater toxicity).

TERRESTRIAL ECOTOXICITY

This category refers to impacts of toxic substances on terrestrial ecosystems (see description freshwater toxicity).

PHOTOCHEMICAL OXIDATION

Photo-oxidant formation is the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems, and which also may damage crops. This problem is also indicated with "summer smog". Winter smog is outside the scope of this category. Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate) and expressed in kg ethylene equivalents/kg emission. The time span is 5 days, and the geographical scale varies between local and continental scale.

ACIDIFICATION

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems, and materials (buildings). Acidification Potential (AP) for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO_2 equivalents/ kg emission. The time span is eternity, and the geographical scale varies between local scale and continental scale. Characterization factors including fate were used when available. When not available, the factors excluding fate were used (In the CML baseline version only factors including fate were used). The method was extended for Nitric Acid, soil, water and air; Sulphuric acid, water; Sulphur trioxide, air; Hydrogen chloride, water, soil; Hydrogen fluoride, water, soil; Phosphoric acid, water, soil; Hydrogen sulphide, soil, all not including fate. Nitric oxide, air (is nitrogen monoxide) was added including fate.

EUTROPHICATION

Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water, and soil. Nutrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992) and expressed as kg PO_4 equivalents per kg emission. Fate and exposure are not included, time span is eternity, and the geographical scale varies between local and continental scale.

During the classification step, information from the data inventory map to the impact categories, depending on the chosen method. For the most part, the calculated emissions contribute to more than one impact category.

During the characterization, the analysis, quantification and aggregation of environmental burdens and impacts belonging to the various individual categories are carried out. The characterization can be accessed by associating the information from the data inventory according to the using method. For example, the indicator unit of the 'climate change' category is kilograms of CO_2 equivalent. Therefore, CH_4 emissions that affect 'climate change' as well must be multiplied by a characterization indicator to be converted into equivalent CO_2 emissions. This multiplier is sourced from various methodologies, but in general, represents the mass with the same effect between emissions.

Also, ISO 14040:2006 provides an optional process to compare several impact category indicators. This option, called normalization stage, and is a process to calculate the magnitude of the results of impact category indicators, in relation to some reference information (Pennington et al, 2004). The characterized results of each impact category are divided by a selected reference value, and the results of normalization can be used directly to highlight the relative importance of the different impact categories (Aymard & Botta-Genoulaz, 2017).

1.3.5 Phase 4: Interpretation

During Life Cycle Interpretation, the results of LCI and LCIA analysis are reviewed and evaluated as a basis for conclusions, recommendations and decision-making following the goal and scope definition. According to ISO 14040-14044:2006, Mousiopoulos, 1999 & Koronaios, 2008, three main categories of activities have been identified for the interpretation phase:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA
- evaluation that considers completeness.
- conclusions, limitations, and recommendations

The goal of life cycle interpretation is to define the level of reliance on the final results and deliver them in a clear manner (SETAC, 2002).

2 LIFE CYCLE ASSESSMENT

2.1 GOAL & SCOPE DEFINITION

2.1.1 Goal of the study

The goal of the present study is the environmental impact assessment via means of LCA of the construction and operation of the solar drying unit designed, constructed, and operating in the framework of the LIFE+ F4F project.

More specifically, the objectives of the present LCA of Life+ F4F project is to assess the environmental impact assessment via means of LCA of the construction and operation of the solar drying unit.

2.1.2 Scope of the study

2.1.2.1 System Boundaries

Infrastructure

The scope of the present study includes all infrastructure of the pilot solar drying unit. More specifically, it includes the landscaping of the surrounding space, the necessary excavations for the construction of the pilot unit, the construction of the flooring and the underground wastewater collection tank, the construction of the pre-sorting unit (within the pre-sorting unit, hand sorting of the collected food waste from the hotels is taking place).

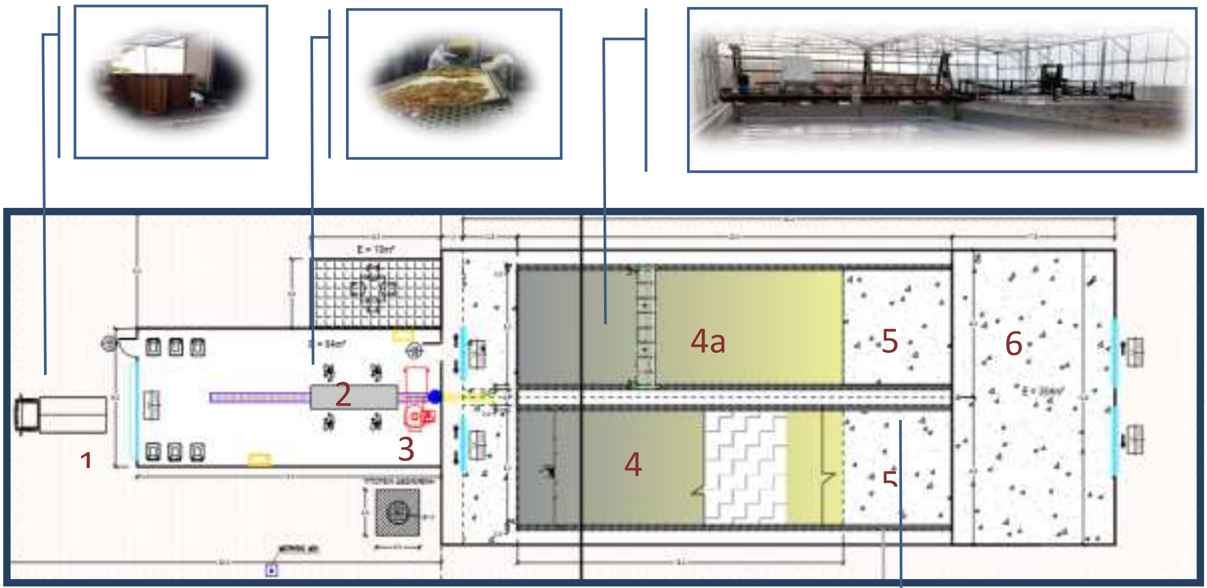
The infrastructure of the pilot unit includes the metallic solar drying greenhouse with its doors and windows. Moreover, it includes the metallic structure, the electromechanical equipment of the pre-sorting unit (a PVC curtain, a conveyor belt for waste sorting, a chipper/crusher, an INOX bowl and a feeding pump, a submerged wastewater pump and the electrical equipment control panel).

It also includes the polycarbonic sheets for the covering of the greenhouse, the underfloor heating system of the greenhouse, the feeding system pipeline, two inverter units for the cooling of the pre-sorting unit, the insect-proof net of the greenhouse, the hydraulic and electrical infrastructure of the solar drying unit.

In summary, the F4F pilot unit, consists of a prefabricated building (14m x 6m) where food waste pre-treatment takes place and a solar drying unit (30m x 12.8m). A series of air-conditions and air extraction and recirculation units (for health and safety issues) have been installed into the prefabricated building. The solar drying unit is essentially a greenhouse, covered by polycarbonate, windows are covered with insects' net and there is a concrete floor for pest control. Roof based fans are used to extract moisture from the sun drying hall, connected with the operation of the turners. It consists of two drying halls, covered by stainless steel. Each drying hall (20m long and 5m wide, with 0.80m high reinforced concrete side walls), is covered with an extensive network of pipelines connected with solar thermal collectors and a heat pump in order hot water to accelerate the drying rate.

On the top of the pipelines, a high-quality stainless still cover is covering the drying hall surface, where the food waste is in contact with. Each corridor floor has a different type of drying turner (a horizontal

and a vertical turner are being used). The turners are a prototype system custom-made for the process. They have several motors and sensors for a variety of moves:
a) moving in the drying hall corridor using wheels rolling on the sidewalls, in various speeds and both directions,
b) increasing and decreasing the height of the turner's drum,
c) turning the drum both directions and in various and control speeds,
e) estimating its position from the ends of the corridor at all times, and
f) including a series of safety operation mechanisms (e.g., emergency stop).



1. Entrance in the F4F pilot unit of the collected food waste from hotels with a refrigerator truck
2. Hand sorting of the collected food waste
3. Shredder, pulverizer & feeding pump
4. 4a. Solar drying tank with a horizontal drying turner
   4b. Solar drying tank with a vertical drying turner
5. Free space for emptying the drying cells after the completion of the drying process. The final product is placed in big bags.
6. Temporary storage of the final product

Figure 3. The operation process of F4F project

Operation

Separated food waste is collected daily (except Sundays), from hotels and catering services, into plastic bags. These bags and removed into brown bins (240lt) and then transferred into the refrigerator truck. As the refrigerator truck has a weighting system, the daily collected quantity by each facility should be estimated. After the collection, the contractor from the collection service transfers the bins into the pilot unit.

Figure 4: Food waste collection process from hotels

The next stage is the lifting and unloading of each bin, using a manual elevation mechanism, on the installed conveyor system, where personnel was hand sorting foreign objects from the food wastes, such as metal, glass, paper, etc.

Figure 5: Import and hand-sorting of the source-separated food waste in the pilot scale facility

At this stage, the waste impurities are removed and driven to a treatment facility nearby. Impurities are mainly plastic (straws, bottles, and bags), paper and metal (food cans), and are excluded from the production process of dry pet food supplement. The average percentage is less than 1% of the feedstock and is considered negligible.

Figure 6: Impurities during hand shorting stage

At the end of the belt and after the hand sorting, there is a shredder for the grinding of food waste. The pulp after shredding is being collected into an inox hopper and then this pulp is being disposed into a worn which supplies the pump. This pump is being connected with a pipe proper to be used for food. The pulp through this pipe is being transferred into the solar drying halls.

Figure 7: The pulp after the shredding process

Next, there is the solar drying process. At this stage, the food waste after hand sorting and shredding are forwarded through a pipeline into the solar drying halls. In the pictures below it is presenting the drying process into the drying halls.

Figure 8: Solar drying unit

The final product, after the solar drying process, is presented below.

Figure 9: Project's final product

Evaluation of the produced feed as pet food

To assess the suitability of the F4F pilot plant's final product as a pet feed, feeding trials with various small animals took place. During these trials, diets with varying amounts of dried food residues (DFR) (0%, 5%, 10% and 15%) were produced. In summary the following conclusions were reached:

- Final Humidity: Less than 14% (around 12%)
- Calorie value: 2.676- 3324 kcal /kg (3.000 kcal /kg on average)
- Average weight reduction: 80% w/w[2] (including impurities diversion)

Taking into consideration that on average the calorific value of pet food is around 3.600 kcal / kg pet food (FEDIAF, 2018), the replacement ratio is app. 120%[3] in terms of weight. In other words, 1 kg of conventionally produced pet food, should be replaced by 1,2 kg of F4F animal feed. Furthermore, according to the studies that took place, for various reasons, the maximum suggested percentage of food replacement was 10% on kcal basis, i.e., 12% on weight basis. The complete evaluation of the produces feed for pets is presented in Deliverable B 5.2.

Finally, the system boundaries and the main processes to produce animal feed from food waste, are shown in Figure below.

[2] weight / weight
[3] 3600 / 3000 = 1,2

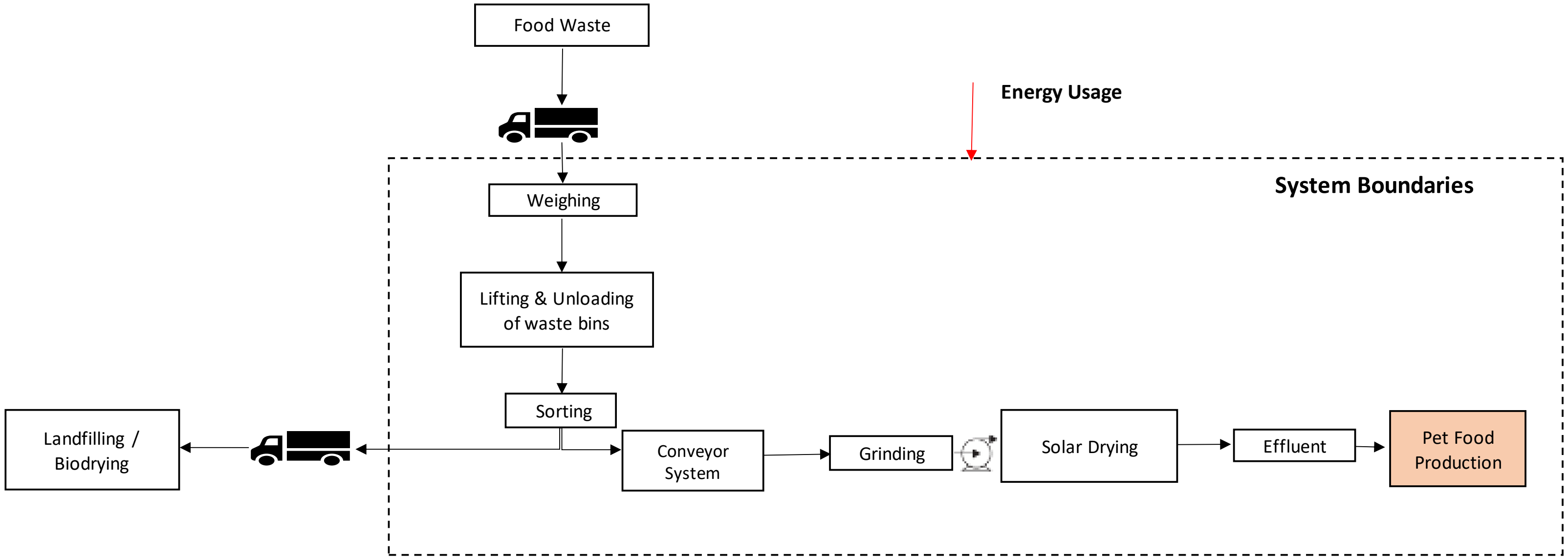


Figure 10: System Boundaries

As presented in the figure above the shorting and transportation process of food waste from hotels and catering services, as well as the transportation of the final product to the end-users are out of the scope of the present LCA study, for the results to be easily comparable. Moreover, since animal food will be used locally, the expected contribution to the environmental impacts will be negligible. Additionally, the transportation and further treatment of the impurities are not included in the present LCA study since the percentage is negligible. Nevertheless, the addition of all the aforementioned excluded stages can be easily added at a later stage, if deemed necessary for the purposes of an LCA with a more case specific scope.

Furthermore, one major offset benefit was identified, i.e. the environmental benefits due to the replacement of pet food production.

The potential environmental benefits due to the diversion of food waste from other treatment alternatives could be also considered; however, since there is a plethora of alternatives with a very wide range of impacts (e.g., landfill or composting), it was decided to be excluded of the system boundaries, for the results to be easily comparable.

Finally, the following are mentioned:

- The lifespan of the pilot unit is estimated to be 20 years.
- The pilot unit is expected to treat around 500 t of food waste per year and produced around 100 t of animal feed.

2.1.2.2 Functional Unit

Since the expected pet food replacement ratio is based on calories and nutrients, the functional unit was selected to be "the production of 1.000 kcal animal feed". According to the results of the produced feed evaluation, we calculate that on average 1.000 kcal animal feed equals to around 334 g of produced food[4]. Taking into consideration that the average weight reduction is 80% w/w, that equals to 1,67 kg of food waste[5].

Based on the above, the following equivalencies are calculated:

Production of 1.000 kcal pet food = Production of 334 g pet food = Treatment or 1,67 kg of food waste

2.1.2.3 Methodological approach

The main steps of the methodology that will be followed, are presented next:

1. First, the **data from the operation of F4F pilot plant will be analyzed**, to be used in the LCA. Data includes:
    - average incoming food waste to pilot plant
    - average production of final product
    - average energy consumption

[4] 1 kg of produced food has a 3.000 kcal calorific value, hence 1.000 kcal equals to 1/3 kg (~0,334 kg)
[5] 1,67 kg X 0,2 = 0,334 kg

2. **Average environmental impacts** will be presented, to acquire a basic knowledge of that to expect in terms of impacts and their allocation in the lifecycle of the product. Data will be based on literature review, environmental product declarations and published databases.

3. The following step will be the **LCI modeling**, based on all the above-mentioned data. The modeling will be performed using SimaPro software 9.2 (PRé Consultants, 2011) and MS excel. As previously mentioned, for the products under examination, the following will be analyzed:
   a) the material use (resources) from production,
   b) the energy/emissions (impacts) from production,
   c) the offset benefits of the system

4. Next, the **LCIA** will be performed, covering all objectives as presented in the goal and scope definition section.

5. Finally, all the **results will be analyzed and evaluated**, possible impacts and/or benefits will be assessed, and specific strategies for the maximization of the environmental benefits will be proposed.

2.1.2.4 Data requirements

Data were sourced from primary qualitative and quantitative data derived from F4F pilot plant. Average energy consumption of the plant is based on primary data.

As the product is produced in Greece, thus impacts from electricity production were sourced from Ecoinvent databases using Greek data. Ecoinvent is a database developed by the Swiss Centre for Life Cycle Inventories, which accommodates more than 4.000 datasets for products, services and processes (SCLCI, 2016). Furthermore, electricity losses during low-voltage transmission and transformation from medium-voltage are also considered in the analysis.
Furthermore, as previously mentioned, data regarding pet/animal feed production, will be sourced from PEFCRs: Prepared pet food for cats and dogs report (FEDIAF, 2018) and meat-based Animal Feed production from SimaPro 9.2 (PRé Consultants, 2011). Finally, the LCA software SimaPro 9.2 was used for modelling the product systems, while MS excel for calculating the inventory, and also performing the impact assessment.

In general, the overall quality of the data is considered to be adequate for scope and the requirements of this study.

2.1.2.5 LCIA methodology and types of impacts

As previously mentioned, the LCIA will be performed based on the CML2 baseline 2000 impact assessment method (Guinée et al., 2002). LCIA will include the following steps:
- Selection of impact categories
- Classification
- Characterization
- Normalization

2.1.2.6 Basic assumptions & limitations

Based on the goal & scope of the LCA, project team tried to balance the use of general / average data with specific information where existing, without compromising the credibility of the results. Finally, as previously presented, shorting and transportation process of food waste from hotels and catering services, transportation of the final product to the end-users as well as transportation and further treatment of the impurities are not included in the present LCA study. Nevertheless, the addition of all these stages can be easily added at a later stage, if deemed necessary.

2.2 Inventory Analysis

2.2.1 Construction

The key components of the inventory of the pilot plant infrastructure are presented in Table 2. The key components were extracted from the master plan of the pilot plant. These are (Abeliotis et al, 2018):

- materials (e.g., reinforced concrete and asphalt) and operations (e.g., excavation) for landscaping and floor construction.
- metallic structures (pre-sorting unit and solar drying greenhouse).
- water supply and drainage infrastructure (e.g., excavation and pipes).
- and electrical infrastructure (e.g., cables).

Table 2: Life cycle inventory of the solar drying unit.

Infrastructure component	Unit	Value
Landscaping		
Excavation	m^3	129.3
Floor construction		
Reinforced concrete	m^3	39.2
Lightly reinforced concrete	m^3	65.2
Cover concrete	m^3	15
Lightly reinforced concrete floor	m^3	8.4
Industrial floor (epoxy resin)	m^3	8.4
Gravel	m^3	0.4
Excavation	m^3	0.8
Reinforce concrete for tank	m^3	1.8
Asphalt, bitumen	m^3	20.6
Metallic structures		
Stainless steel	kg	1.500
Water supply and drainage infrastructure		
Cast iron covers	kg	20
HDPE pipe (25 mm diameter)	m	70
HDPE pipe (32 mm diameter)	m	50
Excavation	m^3	7
Drainage pipes (PVC-U) (125 mm diameter)	m	45
Drainage pipes (PVC-U) (100 mm diameter)	m	10
Electrical infrastructure		
Excavation	m^3	11
Pipes (PVC)	m	500
Cables	m	500

2.2.2 Operation

Feed production

The first full scale operational period started on 3rd of June 2019 and concluded on 31st of October, 2019. Within 126 days, about 144 t of food waste have been collected from hotels and a catering service and managed into the F4F pilot unit. From this input quantity of food waste, finally produced about 30 t of feed (average weight reduction: 80% w/w).

The initial moisture of the food waste was about 75% (average) and the moisture of the final product was about 10-12%.

Moreover, according to the pilot plant's operator the energy consumption during the first full scale operational period is about 28.882 kWh that equals to 0,20 kWh per kg of food waste or 0,96 kWh per kg of final product or 0,32 kWh per functional unit[6].

Offset benefit

As previously mentioned, the major environmental benefits that is expected is due to the replacement of pet food production. Potential environmental impacts were calculated based on the PEFCRs: Prepared pet food for cats and dogs report (FEDIAF, 2018) and meat-based Animal Feed production from SimaPro 9.2 (PRé Consultants, 2011).

[6] 0,96 kWh per kg X 0,334 kg per FU = 0,32 kWh per FU

2.3 LIFE CYCLE IMPACT ASSESSMENT

2.3.1 Characterization

Construction

The impact assessment results and the percentage contribution of each one of the materials utilised in the infrastructure are presented are presented in the following tables. Moreover, the percentage contribution of each material utilised in the infrastructure is presented in the following figure. As presented in the Tables, floor construction is the life cycle stage that contributes the most to all impact categories (Abeliotis et al, 2018).

Table 3: Characterization impact assessment results for the infrastructure of the unit (total).

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat pump
Abiotic depletion	kg Sb eq	1.518,555	0,460	1.441,307	2,008	3,041	63,599	0,029	4,290	1,021	2,797
Acidification	kg SO_2 eq	852,685	0,517	803,474	1,014	0,919	38,676	0,003	4,322	0,269	3,491
Eutrophication	kg PO_4--- eq	161,714	0,123	157,373	0,084	0,120	3,302	0,000	0,354	0,044	0,313
Global warming (GWP100)	kg CO_2 eq	246.046,716	68,948	233.347,000	221,278	222,264	10.528,200	4,928	744,650	68,486	840,962
Ozone layer depletion (ODP)	kg CFC-11 eq	0,040	8,36E-06	1,43E-02	2,70E-06	1,33E-06	2,24E-06	5,46E-06	8,10E-05	5,04E-07	2,54E-02
Human toxicity	kg 1,4-DB eq	87.307,511	46,485	84.946,500	390,014	179,614	1.164,794	1,475	277,738	30,792	270,098
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	46.125,122	4,608	45.770,040	71,402	55,889	157,321	0,076	19,663	17,109	29,014
Marine aquatic ecotoxicity	kg 1,4-DB eq	6,02E+07	1,11E+04	5,98E+07	7,36E+02	3,65E+04	2,03E+05	1,87E+02	6,66E+04	1,79E+04	7,68E+04
Terrestrial ecotoxicity	kg 1,4-DB eq	687,158	0,101	649,251	0,593	1,526	32,484	0,016	1,433	0,681	1,074
Photochemical oxidation	kg C_2H_4 eq	38,935	0,014	36,411	0,050	0,073	2,029	0,001	0,171	0,025	0,162

Table 4: Characterization impact assessment results for the infrastructure of the unit (per t of food waste).

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat pump
Abiotic depletion	kg Sb eq	0,152	4,60E-05	1,44E-01	2,01E-04	3,04E-04	6,36E-03	2,94E-06	4,29E-04	1,02E-04	2,80E-04
Acidification	kg SO_2 eq	0,085	5,17E-05	8,03E-02	1,01E-04	9,19E-05	3,87E-03	2,60E-07	4,32E-04	2,69E-05	3,49E-04
Eutrophication	kg PO_4--- eq	0,016	1,23E-05	1,57E-02	8,44E-06	1,20E-05	3,30E-04	2,40E-08	3,54E-05	4,42E-06	3,13E-05
Global warming (GWP100)	kg CO_2 eq	24,605	6,89E-03	2,33E+01	2,21E-02	2,22E-02	1,05E+00	4,93E-04	7,45E-02	6,85E-03	8,41E-02
Ozone layer depletion (ODP)	kg CFC-11 eq	0,000	8,36E-10	1,43E-06	2,70E-10	1,33E-10	2,24E-10	5,46E-10	8,10E-09	5,04E-11	2,54E-06
Human toxicity	kg 1,4-DB eq	8,731	4,65E-03	8,49E+00	3,90E-02	1,80E-02	1,16E-01	1,47E-04	2,78E-02	3,08E-03	2,70E-02
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	4,613	4,61E-04	4,58E+00	7,14E-03	5,59E-03	1,57E-02	7,61E-06	1,97E-03	1,71E-03	2,90E-03
Marine aquatic ecotoxicity	kg 1,4-DB eq	6.024,295	1,106	5.983,016	0,074	3,645	20,306	0,019	6,659	1,794	7,677
Terrestrial ecotoxicity	kg 1,4-DB eq	0,069	1,01E-05	6,49E-02	5,93E-05	1,53E-04	3,25E-03	1,62E-06	1,43E-04	6,81E-05	1,07E-04
Photochemical oxidation	kg C_2H_4 eq	0,004	1,40E-06	3,64E-03	4,98E-06	7,28E-06	2,03E-04	9,66E-08	1,71E-05	2,54E-06	1,62E-05

Table 5: Characterization impact assessment results for the infrastructure of the unit (per FU).

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat pump
Abiotic depletion	kg Sb eq	2,54E-04	7,69E-08	2,41E-04	3,35E-07	5,08E-07	1,06E-05	4,91E-09	7,16E-07	1,71E-07	4,67E-07
Acidification	kg SO_2 eq	1,42E-04	8,63E-08	1,34E-04	1,69E-07	1,54E-07	6,46E-06	4,34E-10	7,22E-07	4,49E-08	5,83E-07
Eutrophication	kg PO_4--- eq	2,70E-05	2,05E-08	2,63E-05	1,41E-08	2,01E-08	5,51E-07	4,01E-11	5,91E-08	7,38E-09	5,22E-08
Global warming (GWP100)	kg CO_2 eq	4,11E-02	1,15E-05	3,90E-02	3,70E-05	3,71E-05	1,76E-03	8,23E-07	1,24E-04	1,14E-05	1,40E-04
Ozone layer depletion (ODP)	kg CFC-11 eq	6,65E-09	1,40E-12	2,39E-09	4,51E-13	2,22E-13	3,74E-13	9,12E-13	1,35E-11	8,42E-14	4,24E-09
Human toxicity	kg 1,4-DB eq	1,46E-02	7,76E-06	1,42E-02	6,51E-05	3,00E-05	1,95E-04	2,46E-07	4,64E-05	5,14E-06	4,51E-05
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	7,70E-03	7,70E-07	7,64E-03	1,19E-05	9,33E-06	2,63E-05	1,27E-08	3,28E-06	2,86E-06	4,85E-06
Marine aquatic ecotoxicity	kg 1,4-DB eq	10,061	0,002	9,992	0,000	0,006	0,034	0,000	0,011	0,003	0,013
Terrestrial ecotoxicity	kg 1,4-DB eq	1,15E-04	1,69E-08	1,08E-04	9,90E-08	2,55E-07	5,42E-06	2,71E-09	2,39E-07	1,14E-07	1,79E-07
Photochemical oxidation	kg C_2H_4 eq	6,50E-06	2,33E-09	6,08E-06	8,32E-09	1,22E-08	3,39E-07	1,61E-10	2,86E-08	4,24E-09	2,70E-08

Table 6: Contribution of the various infrastructure materials to the total impact assessment results of the unit.

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat Pump
Abiotic depletion	%	100,00%	0,03%	94,91%	0,13%	0,20%	4,19%	0,00%	0,28%	0,07%	0,18%
Acidification	%	100,00%	0,06%	94,23%	0,12%	0,11%	4,54%	0,00%	0,51%	0,03%	0,41%
Eutrophication	%	100,00%	0,08%	97,32%	0,05%	0,07%	2,04%	0,00%	0,22%	0,03%	0,19%
Global warming (GWP100)	%	100,00%	0,03%	94,84%	0,09%	0,09%	4,28%	0,00%	0,30%	0,03%	0,34%
Ozone layer depletion (ODP)	%	100,00%	0,02%	35,96%	0,01%	0,00%	0,01%	0,01%	0,20%	0,00%	63,78%
Human toxicity	%	100,00%	0,05%	97,30%	0,45%	0,21%	1,33%	0,00%	0,32%	0,04%	0,31%
Fresh water aquatic ecotoxicity	%	100,00%	0,01%	99,23%	0,15%	0,12%	0,34%	0,00%	0,04%	0,04%	0,06%
Marine aquatic ecotoxicity	%	100,00%	0,02%	99,31%	0,00%	0,06%	0,34%	0,00%	0,11%	0,03%	0,13%
Terrestrial ecotoxicity	%	100,00%	0,01%	94,48%	0,09%	0,22%	4,73%	0,00%	0,21%	0,10%	0,16%
Photochemical oxidation	%	100,00%	0,04%	93,52%	0,13%	0,19%	5,21%	0,00%	0,44%	0,07%	0,42%

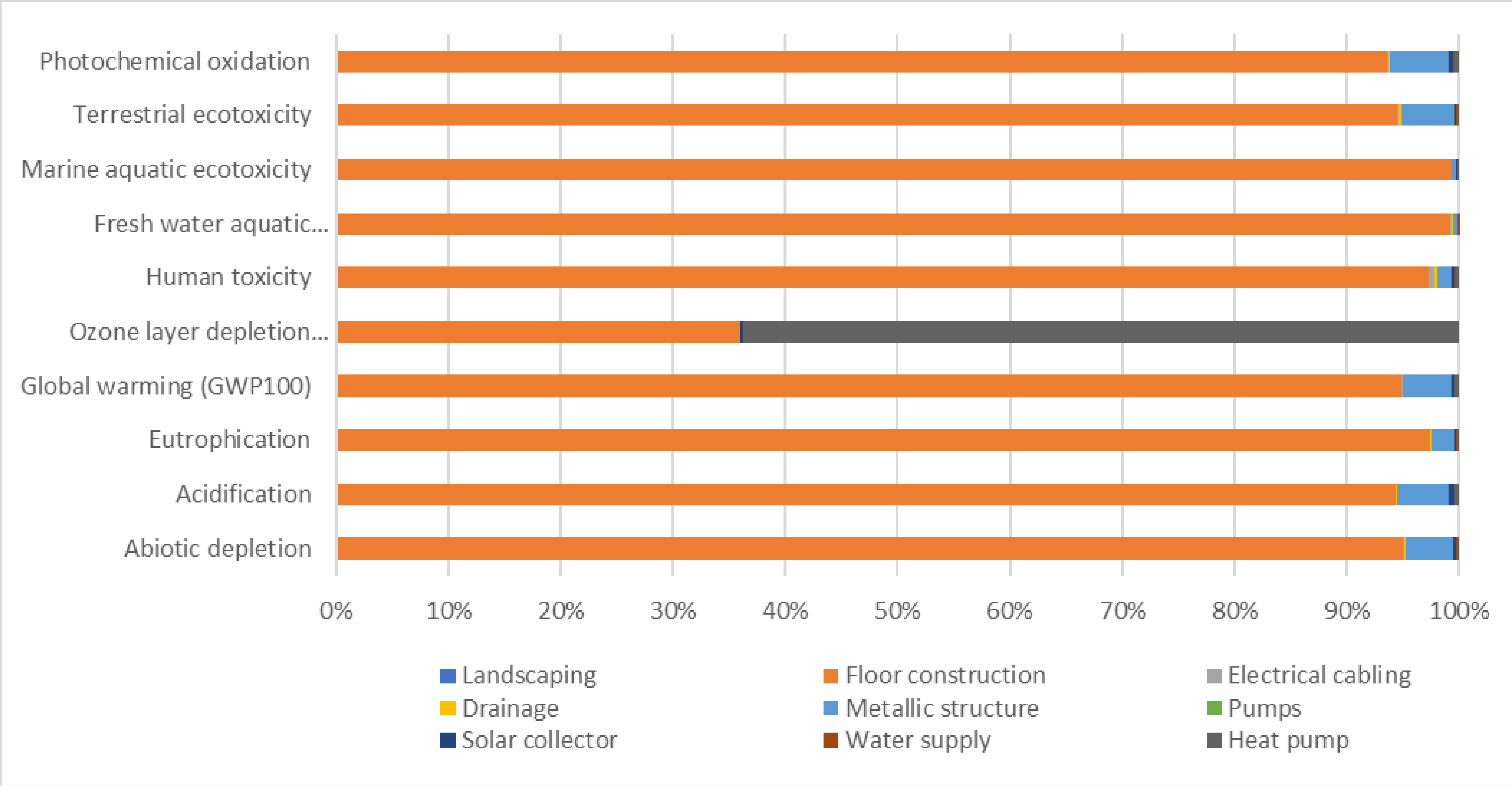


Figure 11. Contribution (%) to the impact categories of different materials used in the infrastructure of the unit.

Operation

The impact assessment results & the percentage contribution of each one (energy consumption and offset benefit) are presented are presented in the following Tables. Moreover, the percentage contribution of each stage is presented in the following Figure.

Table 7: Characterization impact assessment results for the operation of the unit (per FU).

Impact category	Unit	Total	Operation (Energy Consumption)	Pet Food Replacement
Abiotic depletion	kg Sb eq	3,77E-04	3,77E-04	-1,98E-08
Acidification	kg SO_2 eq	2,25E-03	2,26E-03	-6,35E-06
Eutrophication	kg PO_4--- eq	3,28E-03	3,29E-03	-1,04E-06
Global warming (GWP100)	kg CO_2 eq	3,07E-01	3,73E-01	-6,58E-02
Ozone layer depletion (ODP)	kg CFC-11 eq	1,10E-08	1,10E-08	-6,85E-11
Human toxicity	kg 1,4-DB eq	3,07E-01	3,07E-01	-2,25E-04
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	2,08E-01	2,08E-01	-3,26E-05
Marine aquatic ecotoxicity	kg 1,4-DB eq	1,31E+03	1,31E+03	-1,10E-01
Terrestrial ecotoxicity	kg 1,4-DB eq	8,39E-04	8,39E-04	-6,40E-07
Photochemical oxidation	kg C_2H_4 eq	8,95E-05	8,96E-05	-1,61E-07

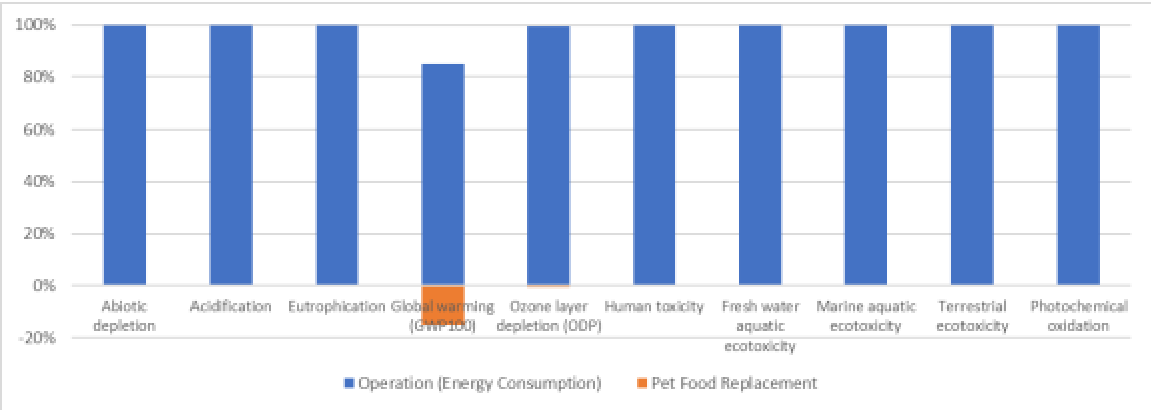


Figure 12: Contribution (%) to the impact categories for the operation of the unit (per FU).

As shown in the Figure above, the potential environmental benefit is substantial in the category of Global Warming. Furthermore, as presented in the next Figure, in case the maximum replacement percentage increased from 12% (on weight basis) to 40%, the offset benefit in Global Warming category increases significantly.

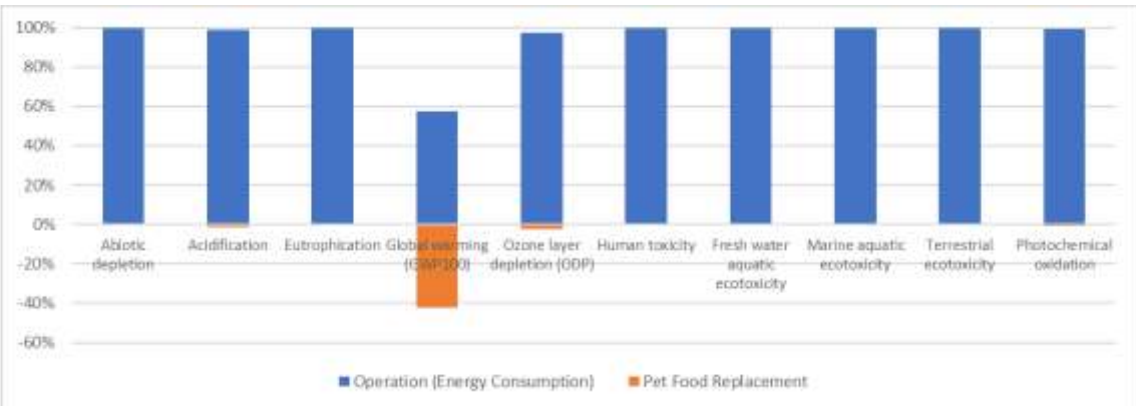


Figure 13: Contribution (%) to the impact categories for the operation of the unit (increased replacement percentage)

Summary

The impact assessment results & the percentage contribution of each stage (construction, operation & offset benefit from use) are presented are presented in the following Tables. Moreover, the percentage contribution of each stage is presented in the following Figure.

Table 8: Characterization impact assessment results for all life cycle stages of the unit (per FU).

Impact category	Unit	Total	Construction	Operation (Energy Consumption)	Pet Food Replacement
Abiotic depletion	kg Sb eq	6,31E-04	2,54E-04	3,77E-04	-1,98E-08
Acidification	kg SO_2 eq	2,39E-03	1,42E-04	2,26E-03	-6,35E-06
Eutrophication	kg PO_4--- eq	3,31E-03	2,70E-05	3,29E-03	-1,04E-06
Global warming (GWP100)	kg CO_2 eq	3,48E-01	4,11E-02	3,73E-01	-6,58E-02
Ozone layer depletion (ODP)	kg CFC-11 eq	1,76E-08	6,65E-09	1,10E-08	-6,85E-11
Human toxicity	kg 1,4-DB eq	3,22E-01	1,46E-02	3,07E-01	-2,25E-04
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	2,16E-01	7,70E-03	2,08E-01	-3,26E-05
Marine aquatic ecotoxicity	kg 1,4-DB eq	1.320,745	10,061	1.310,794	-0,110
Terrestrial ecotoxicity	kg 1,4-DB eq	9,54E-04	1,15E-04	8,39E-04	-6,40E-07
Photochemical oxidation	kg C_2H_4 eq	9,60E-05	6,50E-06	8,96E-05	-1,61E-07

Table 9: Contribution (%) to the impact categories for all the life cycle stages of the unit.

Impact category	Unit	Total	Construction	Operation (Energy Consumption)	Pet Food Replacement
Abiotic depletion	kg Sb eq	100%	40%	60%	0%
Acidification	kg SO_2 eq	100%	6%	94%	0%
Eutrophication	kg PO_4--- eq	100%	1%	99%	0%
Global warming (GWP100)	kg CO_2 eq	100%	12%	88%	
Ozone layer depletion (ODP)	kg CFC-11 eq	100%	38%	63%	0%
Human toxicity	kg 1,4-DB eq	100%	5%	96%	0%
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	100%	4%	96%	0%
Marine aquatic ecotoxicity	kg 1,4-DB eq	100%	1%	99%	0%
Terrestrial ecotoxicity	kg 1,4-DB eq	100%	12%	88%	0%
Photochemical oxidation	kg C_2H_4 eq	100%	7%	93%	0%

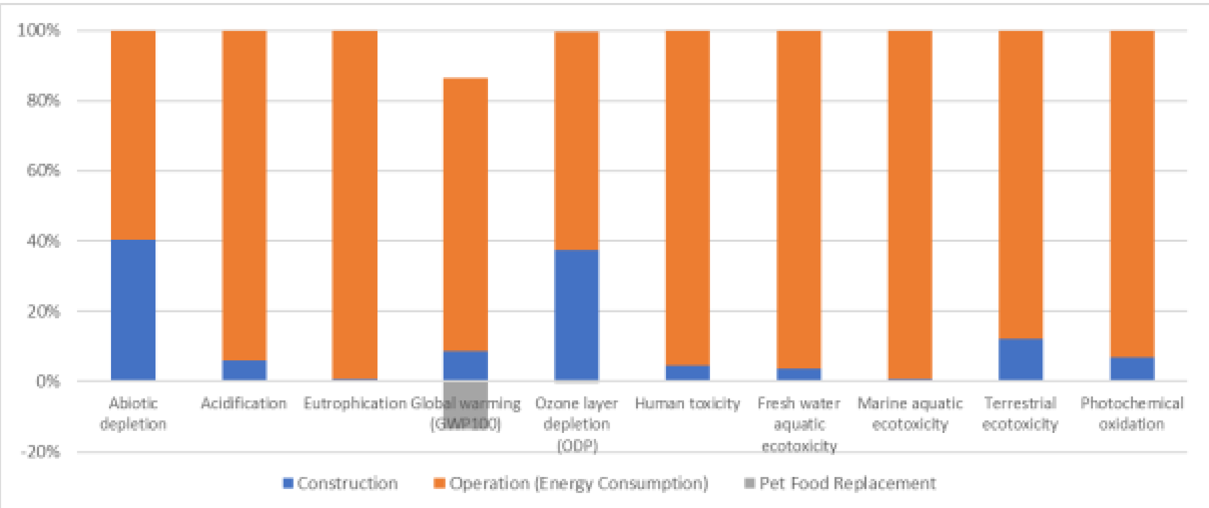


Figure 14: Contribution (%) to the impact categories for all the life cycle stages of the unit.

From the Table and Figure above, it is apparent that the operation (orange colour) contributes the most to all impact categories, except from abiotic depletion and Ozone layer depletion, where both floor construction and heat pump manufacturing play a significant role.

2.3.2 Normalization

Next, are presented the normalisation results for the infrastructure and equipment of the unit, as well as the operation (including the offset benefit of use).

Table 10: Normalized results for the construction phase of the unit (per FU).

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat pump
Abiotic depletion	kg Sb eq	4,20E-14	1,27E-17	3,99E-14	5,55E-17	8,41E-17	1,76E-15	8,13E-19	1,19E-16	2,82E-17	7,73E-17
Acidification	kg SO_2 eq	8,48E-15	5,14E-18	7,99E-15	1,01E-17	9,14E-18	3,84E-16	2,58E-20	4,30E-17	2,67E-18	3,47E-17
Eutrophication	kg PO_4--- eq	1,77E-15	1,34E-18	1,72E-15	9,21E-19	1,31E-18	3,60E-17	2,62E-21	3,86E-18	4,82E-19	3,41E-18
Global warming (GWP100)	kg CO_2 eq	7,90E-15	2,21E-18	7,49E-15	7,11E-18	7,14E-18	3,38E-16	1,58E-19	2,39E-17	2,20E-18	2,70E-17
Ozone layer depletion (ODP)	kg CFC-11 eq	6,65E-16	1,40E-19	2,39E-16	4,51E-20	2,22E-20	3,74E-20	9,12E-20	1,35E-18	8,42E-21	4,24E-16
Human toxicity	kg 1,4-DB eq	2,92E-14	1,55E-17	2,84E-14	1,30E-16	6,00E-17	3,89E-16	4,93E-19	9,28E-17	1,03E-17	9,02E-17
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	3,69E-14	3,68E-18	3,66E-14	5,71E-17	4,47E-17	1,26E-16	6,08E-20	1,57E-17	1,37E-17	2,32E-17
Marine aquatic ecotoxicity	kg 1,4-DB eq	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Terrestrial ecotoxicity	kg 1,4-DB eq	9,89E-16	1,46E-19	9,35E-16	8,53E-19	2,20E-18	4,68E-17	2,33E-20	2,06E-18	9,80E-19	1,55E-18
Photochemical oxidation	kg C_2H_4 eq	3,76E-15	1,35E-18	3,51E-15	4,81E-18	7,03E-18	1,96E-16	9,32E-20	1,65E-17	2,45E-18	1,56E-17

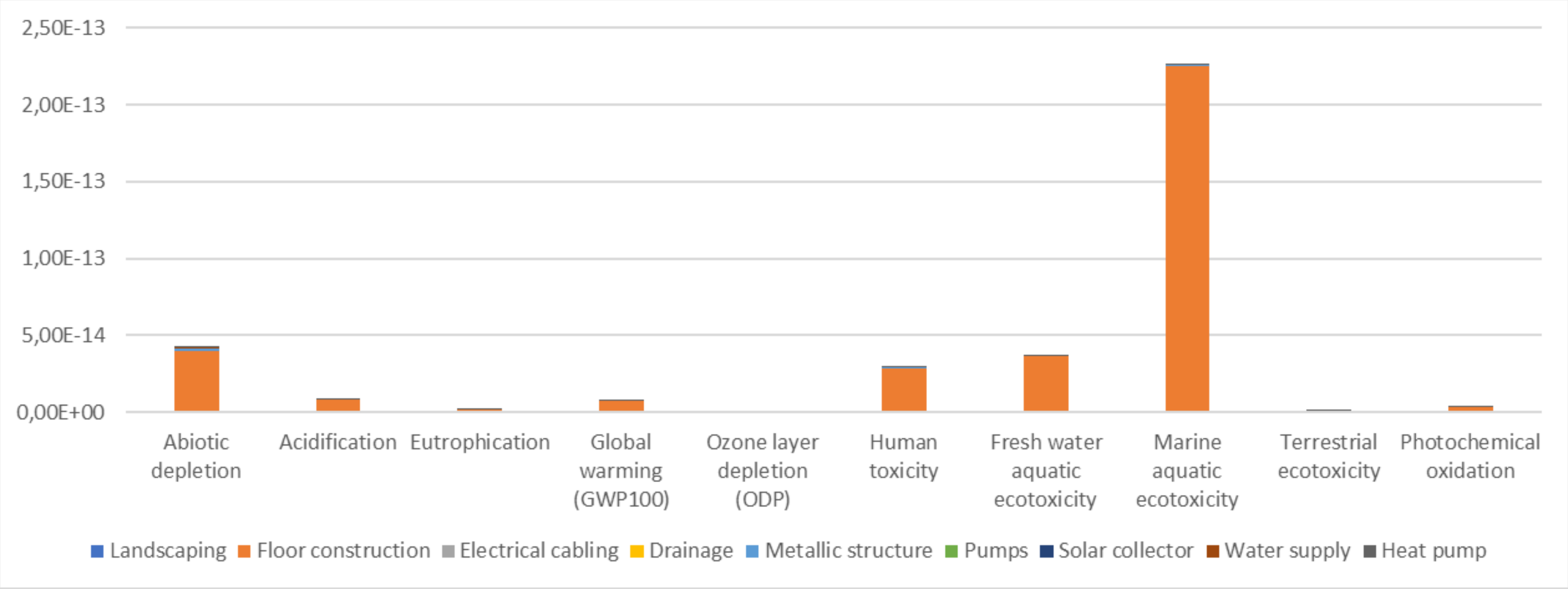


Figure 15: Normalized results for the construction phase of the unit.

Table 11: Normalized results for all the life cycle stages of the unit (per FU).

Impact category	Unit	Total	Construction	Operation (Energy Consumption)	Pet Food Replacement
Abiotic depletion	kg Sb eq	1,04E-13	4,20E-14	6,24E-14	-3,28E-18
Acidification	kg SO_2 eq	1,43E-13	8,48E-15	1,34E-13	-3,78E-16
Eutrophication	kg PO_4--- eq	2,16E-13	1,77E-15	2,15E-13	-6,79E-17
Global warming (GWP100)	kg CO_2 eq	6,69E-14	7,90E-15	7,17E-14	-1,26E-14
Ozone layer depletion (ODP)	kg CFC-11 eq	1,76E-15	6,65E-16	1,10E-15	-6,85E-18
Human toxicity	kg 1,4-DB eq	6,43E-13	2,92E-14	6,14E-13	-4,50E-16
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	1,03E-12	3,69E-14	9,95E-13	-1,56E-16
Marine aquatic ecotoxicity	kg 1,4-DB eq	2,97E-11	2,27E-13	2,95E-11	-2,48E-15
Terrestrial ecotoxicity	kg 1,4-DB eq	8,22E-15	9,89E-16	7,24E-15	-5,52E-18
Photochemical oxidation	kg C_2H_4 eq	5,55E-14	3,76E-15	5,18E-14	-9,33E-17

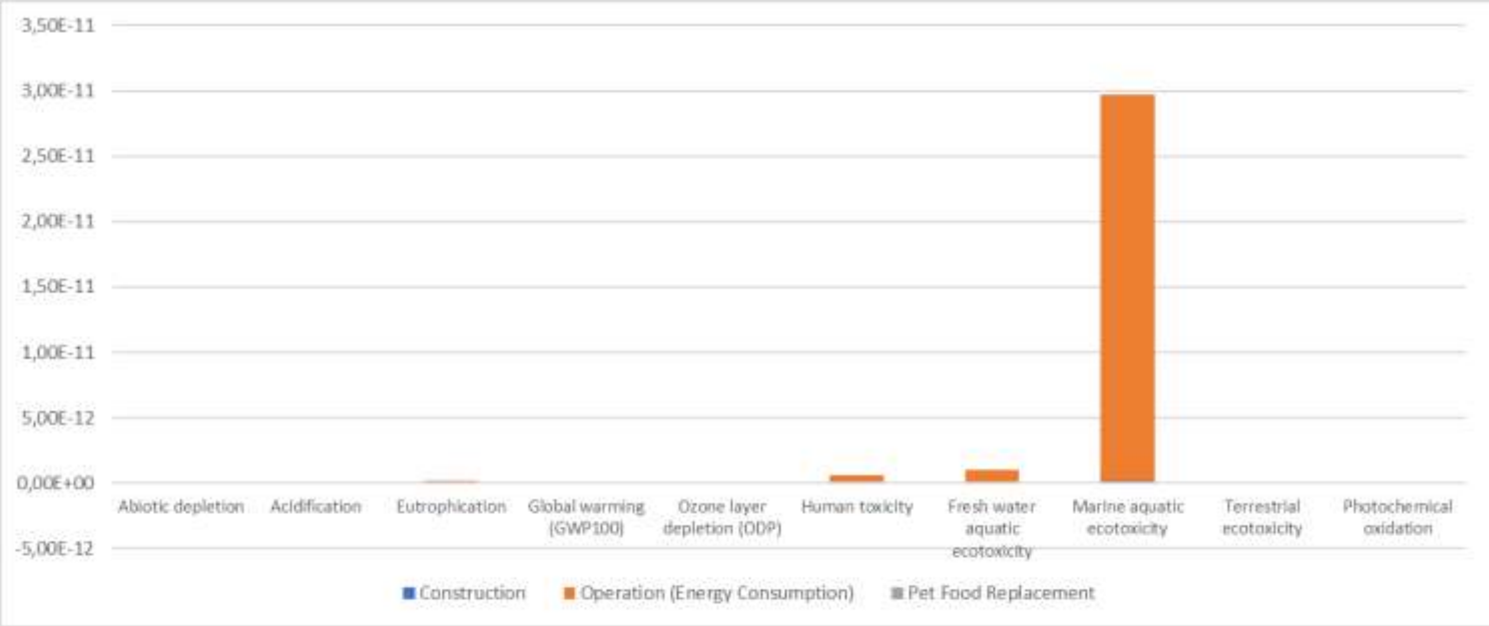


Figure 16: Normalized results for all the life cycle stages of the unit.

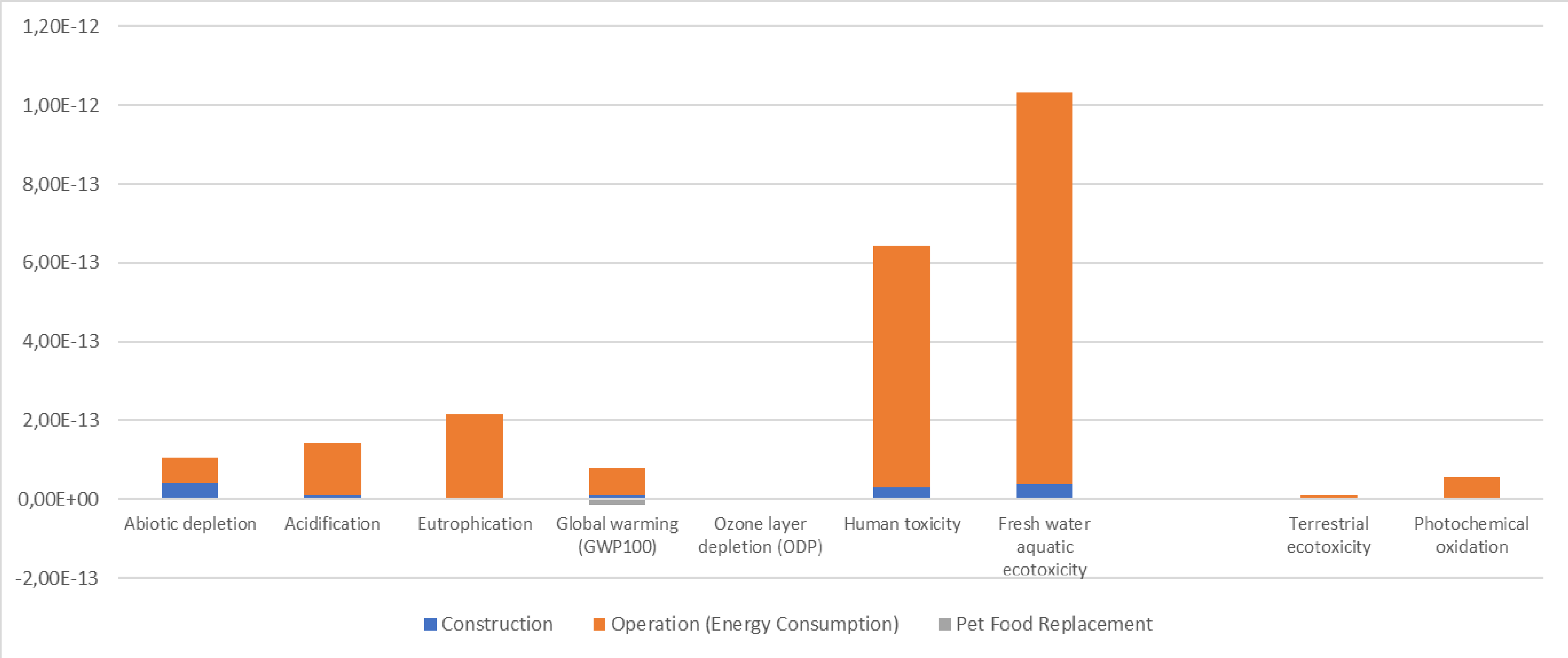


Figure 17: Normalized results for all the life cycle stages of the unit (marine aquatic ecotoxicity excluded for visual purposes)

2.4 LIFE CYCLE INTERPRETATION

2.4.1 Results Evaluation

Analysing the normalised results, the following are identified:

- ✓ Regarding construction, the results indicate that the most important impact categories are the marine aquatic ecotoxicity, the abiotic depletion, the freshwater aquatic ecotoxicity and human toxicity. In each one of the above-mentioned impact categories the main contribution results from the floor construction.

- ✓ Regarding operation, the results indicate that the most important impact category, in order of magnitude, is marine aquatic ecotoxicity, while relatively significant seem to be the categories freshwater aquatic ecotoxicity and human toxicity.

At this point, it should be noted that uncertainty issues relating to ecotoxicity are very common mainly due to the lack of spatial differentiation (Konstantzos et al., 2018). Furthermore, values of ecotoxicity categories, depend on the country's electricity generation mix. In cases heavy metals such as chromium VI emissions are limited, the ecotoxicity potential impacts of the system under examination could be significantly decreased.

2.4.2 Conclusions & Recommendations

Next, the main conclusions & recommendations from the LCA are presented in bullet points:

- ✓ LCA results showed that operation contributes the most to all impact categories, except from abiotic depletion and ozone layer depletion, where construction of the unit (especially floor construction and heat pump manufacturing) plays a significant role.

- ✓ Furthermore, the most important impact category, in order of magnitude, is marine aquatic ecotoxicity, while relatively significant seem to be the categories freshwater aquatic ecotoxicity and human toxicity. However, values of ecotoxicity categories, depend on the country's electricity generation mix. Hence electricity production from sources with limited heavy metals emissions, is expected to lead to significantly decreased ecotoxicity potential impacts.

- ✓ Moreover, one major offset benefit was identified, i.e., the environmental benefits due to the replacement of pet food production, with significant results.

- ✓ Finally, it is important to mentioned that the potential environmental benefits due to the diversion of food waste from other treatment alternatives was not included in the scope of the study, since there is a plethora of alternatives with a very wide range of impacts (e.g. landfill or composting), In case of alternatives with high environmental impacts (e.g. landfill), the total offset environmental benefits could be increased.

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4 ANNEXES

4.1 CHARACTERIZED RESULTS FROM SIMAPRO 9.2 / ECOINVENT 3

Acidification

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Ammonia	Air	kg SO_2 eq	0,000622	2,89E-07
2	Nitrogen oxides	Air	kg SO_2 eq	0,046606	1,21E-05
3	Nitrogen oxides	Air	kg SO_2 eq	0,037664	0,000506
4	Sulfur dioxide	Air	kg SO_2 eq	0,007311	6,09E-07
5	Sulfur dioxide	Air	kg SO_2 eq	0,000776	0,001176
6	Sulfur dioxide	Air	kg SO_2 eq	0,064971	0,005234

Abiotic depletion

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Copper	Raw	kg Sb eq	Sourced from PEFCRS	2,07E-07
2	Gold	Raw	kg Sb eq		6,57E-06
3	Lead	Raw	kg Sb eq		7,54E-08
4	Palladium	Raw	kg Sb eq		2,03E-08
5	Platinum	Raw	kg Sb eq		1,17E-07
6	Silver	Raw	kg Sb eq		4,49E-08
7	Zinc	Raw	kg Sb eq		2,94E-08

Eutrophication

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Phosphate	Water	kg PO4--- eq	0,01083	0,002065
2	Phosphate	Water	kg PO4--- eq	0,00128	0,000265
3	Nitrogen oxides	Air	kg PO4--- eq	0,009924	0,009793
4	Nitrogen oxides	Air	kg PO4--- eq	7,63E-05	4,3E-05
5	Nitrogen oxides	Air	kg PO4--- eq	0,012121	0,012118
6	Nitrate	Water	kg PO4--- eq	0,000357	6,89E-05
7	Dinitrogen monoxide	Air	kg PO4--- eq	8,56E-05	8,39E-05
8	COD, Chemical Oxygen Demand	Water	kg PO4--- eq	0,001047	0,001036
9	COD, Chemical Oxygen Demand	Water	kg PO4--- eq	0,000156	0,000154
10	Ammonia	Air	kg PO4--- eq	0,000136	0,000136

Fresh water aquatic ecotoxicity

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Zinc	Soil	kg 1,4-DB eq	0,006827	0,006827
2	Zinc	Water	kg 1,4-DB eq	0,007491	0,007491
3	Zinc	Water	kg 1,4-DB eq	0,013141	0,013141
4	Vanadium	Water	kg 1,4-DB eq	0,132356	0,132356
5	Thallium	Water	kg 1,4-DB eq	0,006239	0,004569
6	Selenium	Water	kg 1,4-DB eq	0,031909	0,007043
7	Phenol	Water	kg 1,4-DB eq	0,004993	0,004959
8	Nickel	Water	kg 1,4-DB eq	0,208244	0,208244
9	Nickel	Air	kg 1,4-DB eq	0,013051	0,012986
10	Nickel	Air	kg 1,4-DB eq	0,006372	0,006371
11	Molybdenum	Water	kg 1,4-DB eq	0,006762	0,001585
12	Molybdenum	Air	kg 1,4-DB eq	0,003258	0,003258
13	Copper	Water	kg 1,4-DB eq	0,061374	0,061374
14	Copper	Water	kg 1,4-DB eq	0,003913	0,003913
15	Copper	Air	kg 1,4-DB eq	0,03853	0,03853
16	Cobalt	Water	kg 1,4-DB eq	0,26612	0,049735
17	Beryllium	Water	kg 1,4-DB eq	0,50854	0,140423
18	Barium	Water	kg 1,4-DB eq	0,052223	0,051869
19	Barium	Water	kg 1,4-DB eq	0,034236	0,008609
20	Barium	Air	kg 1,4-DB eq	0,005546	0,005546
21	Acrolein	Air	kg 1,4-DB eq	0,015903	0,015903

Global warming / Climate change

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Carbon dioxide, fossil	Air	kg CO2 eq	Sourced from PEFCRS	13,74553
2	Carbon dioxide, fossil	Air	kg CO2 eq		0,130562
3	Carbon dioxide, fossil	Air	kg CO2 eq		4,336434
4	Dinitrogen monoxide	Air	kg CO2 eq		0,082395
5	Dinitrogen monoxide	Air	kg CO2 eq		0,045302
6	Methane, fossil	Air	kg CO2 eq		0,196255

Human toxicity

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Antimony	Air	kg 1,4-DB eq	2,246063	2,246063
2	Antimony	Water	kg 1,4-DB eq	0,01588	0,003404
3	Barium	Air	kg 1,4-DB eq	0,097965	0,097965
4	Barium	Water	kg 1,4-DB eq	0,094599	0,023789
5	Barium	Water	kg 1,4-DB eq	0,1443	0,143323
6	Benzene	Air	kg 1,4-DB eq	0,141274	0,141272
7	Benzene	Water	kg 1,4-DB eq	0,029206	0,029001
8	Beryllium	Water	kg 1,4-DB eq	0,07798	0,021533
9	Cadmium	Air	kg 1,4-DB eq	0,047003	0,047002
10	Chromium VI	Air	kg 1,4-DB eq	0,025231	0,015014
11	Copper	Air	kg 1,4-DB eq	0,746301	0,746296
12	Hydrogen fluoride	Air	kg 1,4-DB eq	0,130579	0,041894
13	Molybdenum	Air	kg 1,4-DB eq	0,181804	0,181804
14	Molybdenum	Water	kg 1,4-DB eq	0,027244	0,001868
15	Molybdenum	Water	kg 1,4-DB eq	0,078271	0,01835
16	Nickel	Air	kg 1,4-DB eq	0,354536	0,354535
17	Nickel	Air	kg 1,4-DB eq	0,045897	0,007255
18	Nickel	Air	kg 1,4-DB eq	0,726198	0,722576
19	Nickel	Water	kg 1,4-DB eq	0,021274	0,021274
20	Nitrogen oxides	Air	kg 1,4-DB eq	0,111884	0,111855
21	Nitrogen oxides	Air	kg 1,4-DB eq	0,091607	0,090394
22	Selenium	Air	kg 1,4-DB eq	0,018833	0,018833
23	Selenium	Air	kg 1,4-DB eq	0,02962	0,018588
24	Selenium	Water	kg 1,4-DB eq	0,048217	0,023383
25	Selenium	Water	kg 1,4-DB eq	0,611952	0,135081
26	Thallium	Air	kg 1,4-DB eq	0,025267	0,025267
27	Thallium	Water	kg 1,4-DB eq	0,17525	0,128342
28	Vanadium	Water	kg 1,4-DB eq	0,046627	0,046627

Marine aquatic ecotoxicity

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Vanadium	Water	kg 1,4-DB eq	126,6012	126,6012
2	Thallium	Water	kg 1,4-DB eq	20,71847	15,17288
3	Selenium	Water	kg 1,4-DB eq	276,4713	61,02753
4	Selenium	Water	kg 1,4-DB eq	21,78379	10,56393
5	Nickel	Water	kg 1,4-DB eq	144,6137	144,6137
6	Nickel	Air	kg 1,4-DB eq	78,01442	77,62526
7	Nickel	Air	kg 1,4-DB eq	38,08729	38,08714
8	Molybdenum	Water	kg 1,4-DB eq	29,68893	6,960328
9	Molybdenum	Air	kg 1,4-DB eq	65,28883	65,28883
10	Hydrogen fluoride	Air	kg 1,4-DB eq	1864,762	598,2768
11	Hydrogen fluoride	Air	kg 1,4-DB eq	41,91386	39,72661
12	Hydrogen fluoride	Air	kg 1,4-DB eq	90,82658	90,81702
13	Copper	Air	kg 1,4-DB eq	154,9876	154,9866
14	Cobalt	Water	kg 1,4-DB eq	341,8197	63,88255
15	Beryllium	Water	kg 1,4-DB eq	3002,224	829,0016
16	Barium	Water	kg 1,4-DB eq	190,7967	189,5044
17	Barium	Water	kg 1,4-DB eq	125,0805	31,45461
18	Barium	Air	kg 1,4-DB eq	101,0745	101,0745

Ozone layer depletion

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	kg CFC-11 eq	Sourced from PEFCRS	1,42E-08
2	Methane, bromochlorodifluoro-, Halon 1211	Air	kg CFC-11 eq		1,04E-08
3	Methane, bromotrifluoro-, Halon 1301	Air	kg CFC-11 eq		3,17E-06

Photochemical oxidation

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Toluene	Air	kg C2H4 eq	1,94E-05	1,94E-05
2	Sulfur dioxide	Air	kg C2H4 eq	0,002808	0,002599
3	Sulfur dioxide	Air	kg C2H4 eq	7,81E-05	3,1E-05
4	Sulfur dioxide	Air	kg C2H4 eq	0,000292	0,000292
5	Pentane	Air	kg C2H4 eq	1,41E-05	1,21E-05
6	Methane, fossil	Air	kg C2H4 eq	4,61E-05	4,21E-05
7	m-Xylene	Air	kg C2H4 eq	1,88E-05	1,88E-05
8	Formaldehyde	Air	kg C2H4 eq	7,81E-05	7,81E-05
9	Carbon monoxide, fossil	Air	kg C2H4 eq	0,000109	0,000105
10	Carbon monoxide, fossil	Air	kg C2H4 eq	3,42E-05	3,07E-05
11	Carbon monoxide, fossil	Air	kg C2H4 eq	0,000675	0,000675
12	Butane	Air	kg C2H4 eq	9,03E-06	7,62E-06
13	Benzene	Air	kg C2H4 eq	1,62E-05	1,62E-05
14	Acetaldehyde	Air	kg C2H4 eq	5,09E-05	5,09E-05

Terrestrial ecotoxicity

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
1	Zinc	Soil	kg 1,4-DB eq	0,003521	0,003521
2	Zinc	Air	kg 1,4-DB eq	0,000994	0,000994
3	Tin	Air	kg 1,4-DB eq	0,00034	0,00034
4	Selenium	Soil	kg 1,4-DB eq	4,23E-05	4,23E-05
5	Nickel	Soil	kg 1,4-DB eq	0,000138	0,000138
6	Nickel	Air	kg 1,4-DB eq	0,002407	0,002395
7	Nickel	Air	kg 1,4-DB eq	0,000152	2,4E-05
8	Nickel	Air	kg 1,4-DB eq	0,001175	0,001175
9	Molybdenum	Air	kg 1,4-DB eq	0,000586	0,000586
10	Mercury	Water	kg 1,4-DB eq	0,000883	0,00018
11	Mercury	Air	kg 1,4-DB eq	0,0038	0,002094
12	Mercury	Air	kg 1,4-DB eq	8,6E-05	7,31E-05

No	Substance	Compartment	Unit	Meat – based Animal Feed (1 t)	Electricity, low voltage, production GR (1 kwh)
13	Mercury	Air	kg 1,4-DB eq	0,000846	0,000846
14	Lead	Soil	kg 1,4-DB eq	0,00011	0,00011
15	Lead	Air	kg 1,4-DB eq	0,000351	0,000351
16	Formaldehyde	Air	kg 1,4-DB eq	0,000141	0,000141
17	Copper	Soil	kg 1,4-DB eq	4,81E-05	4,81E-05
18	Copper	Air	kg 1,4-DB eq	0,001213	0,001213
19	Cobalt	Soil	kg 1,4-DB eq	5,5E-05	5,5E-05
20	Cobalt	Air	kg 1,4-DB eq	5,76E-05	5,76E-05
21	Barium	Air	kg 1,4-DB eq	0,00063	0,00063
22	Antimony	Air	kg 1,4-DB eq	0,000205	0,000205
23	Acrolein	Air	kg 1,4-DB eq	0,000499	0,000499

4.2 Data form Product Environmental Footprint Category Rules (PEFCRs)

A Product Environmental Footprint (PEF) is a methodology by the European Commission's Joint Research Center (JRC) which is based on LCA. Various PEF guides have been developed in the context of one of the building blocks of the Flagship initiative of the Europe 2020 Strategy – "A Resource-Efficient Europe[7]", in an effort to increase resource productivity and to decouple economic growth from both resource use and environmental impacts, taking a life-cycle perspective. In that sense, PEF's goal is to provide "a common way of measuring environmental performance" for companies within in EU wishing to market their product.

More specifically, the "Product Environmental Footprint Category Rules (PEFCRs): Prepared pet food for cats and dogs" report[8] aims to develop a reliable set of rules to estimate the environmental impacts of prepared pet food products for cats and dogs. The results obtained through the PEFCR analysis, may be used for supply chain management, product design, development, and comparative allegations among pet food products.

The estimation of the relevant impacts is based on the full life cycle, including raw materials extraction, processing, distribution, storage, use, and disposal or recycling stages, for complete meals for cats and dogs sold in the EU market for the following four sub-categories:

- wet cat food
- dry cat food
- wet dog food
- dry dog food

[7] European Commission 2011: COM (2011) 571 final: Communication from the Commission to the EP, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe.
[8]The report is available here: https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm

The composition of each pet food sub-category was based on an average bill of ingredients BIO). The average BIO was derived from primary data received from pet food manufacturers. Hence, the examined pet food products could be described as average pet food products sold/consumed in the EU member states. For the purposes of this LCA, study, the characterized results from dog food where used, for the following categories:

- ✓ Abiotic Depletion.
- ✓ Global Warming / Climate change.
- ✓ Ozone depletion.

Characterized results per kg of dog pet food

Impact category	Units	Characterized results	
		Life cycle excl. use	Use stage
Global Warming / Climate change	kg C02 eq	**1,64**	3,60E-02
Ozone depletion	kg CFC-11 eq	**1,71E-09**	8,38E-11
Abiotic Depletion	kg Sb eq	**4,94E-07**	2,23E-07

Use stage, that includes the impacts related to the dishwashing of the dishes and utensils used to serve pet food, the refrigeration of unused portions of the pet food as well as the waste of pet food, was excluded, in order for the results to align with the scope of the LCA study.

LIFE-F4F (Food for Feed)

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