LIFE Project Number

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LIFE PROJECT NAME or Acronym

LIFE-F4F (Food for Feed)

Data

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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+ F4F (Food for Feed) 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.

Objective

The main objective of this deliverable is to evaluate the environmental impact of the construction and operation of the F4F pilot unit, that 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).

Life Cycle Assessment

In summary, LCA is a tool for analysing 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.

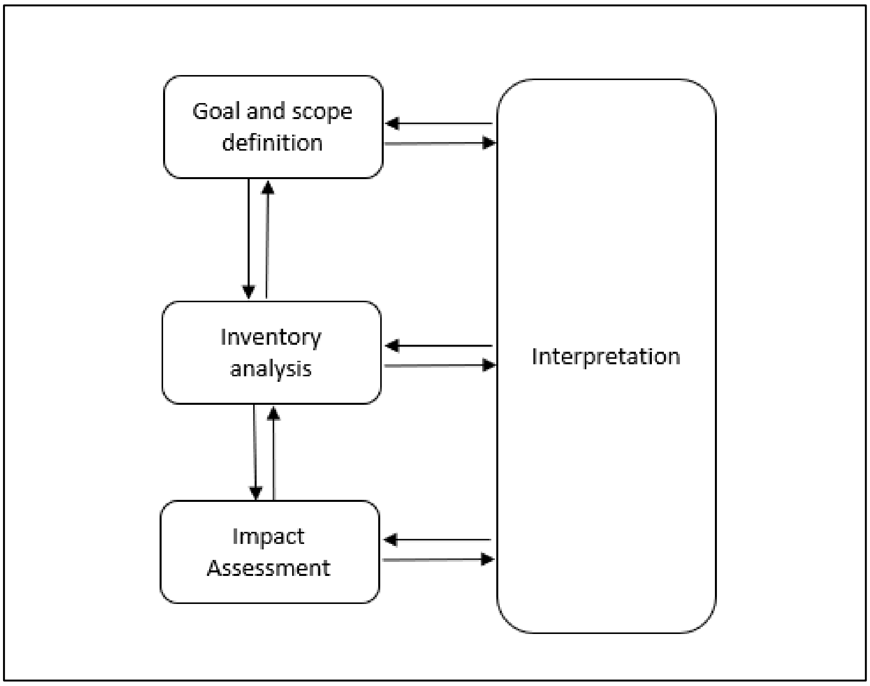


Figure 1. Life Cycle Assessment Framework (ISO 14040:2006)

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

- Goal definition and scope phase
- Inventory analysis phase
- Impact Assessment phase
- Interpretation phase

As presented in Figure 1, there is an interactive relationship between the LCA phases. 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.

Goal and scope definition

According to ISO 14040:2006, the definition of goal and scope is the first step in LCA and identifies the system under study, the intended results, and the way the study will be directed. 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.

Inventory analysis

The Life Cycle Inventory analysis (LCI) 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.

The first sub-phase of the LCI analysis is composed of the collection of qualitative and quantitative data for all unit processes included in the product systems boundaries. In an LCI analysis and modelling, the main headings under which data may be classified include:

- energy inputs, raw material inputs, ancillary material inputs,
- products, co-products, and waste,

- releases to air, water, and soil

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

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 categorization and characterization of the flows. More specifically, according to ISO 14044:2006, the LCIA phase shall include the following mandatory elements:

- **determination of impact categories**, category indicators and characterization models
- assignment of LCI results to the selected impact categories (**classification**)
- estimation of category indicator results (**characterisation**)

The **selection of impact categories** reveals a comprehensive set of environmental issues associated with the studied product system, taking into consideration the goal and scope of the LCA analysis, as defined in the first phase. According to ISO 14040 and 14044, the evaluation of the environmental impacts of products may concern midpoint or endpoint indicators. Midpoint indicators focus on a single environmental problem, such as climate change, eutrophication, acidification, ozone depletion etc. Endpoint indicators present the environmental impacts of products life cycle on three main categories:

- effect on human health
- biodiversity
- resource scarcity

During **classification**, 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 **characterisation**, 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 data inventory according to the using method

Moreover, the need to compare the results between various impacts can be set to prioritize or to resolve interactions between alternative products. The comparison between impact category indices is an optional step in LCA, as mentioned in ISO 14040:2006, and can be achieved at the **normalization** stage. The goal of normalization is twofold (Pennington et al., 2004):

- ✓ To place the results of the impact assessment in a wider context, and
- ✓ To adjust the results to have common dimensions.

The impacts categories considered in the CML2 baseline 2000 impact assessment method, and their respective units of measurement, are the following (Guinée et al., 2002):

Table 1. CML2 baseline 2000 impact assessment categories.

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.

(Stratospheric) 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 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 PO4 equivalents per kg emission. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale.

Interpretation

The Life Cycle Interpretation is the final phase of the LCA procedure, in which 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. A key purpose of performing life cycle interpretation is to define the level of reliance on the results and deliver them in a clear, exhaustive, and precise manner (SETAC, 2002). Three main categories of activities have been identified (ISO 14040-14044:2006) 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, sensitivity, and consistency checks
- conclusions, limitations, and recommendations

The 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.

The scope of the study

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.

Functional unit

The functional unit is defined as "processing of 1 tn of collected food waste annually". The lifespan of the pilot unit is estimated to be 20 years. All quantitative input and output data that will be collected during the study shall be calculated in relation to this reference flow.

Figure 2. Outline of the solar drying pilot plant process.

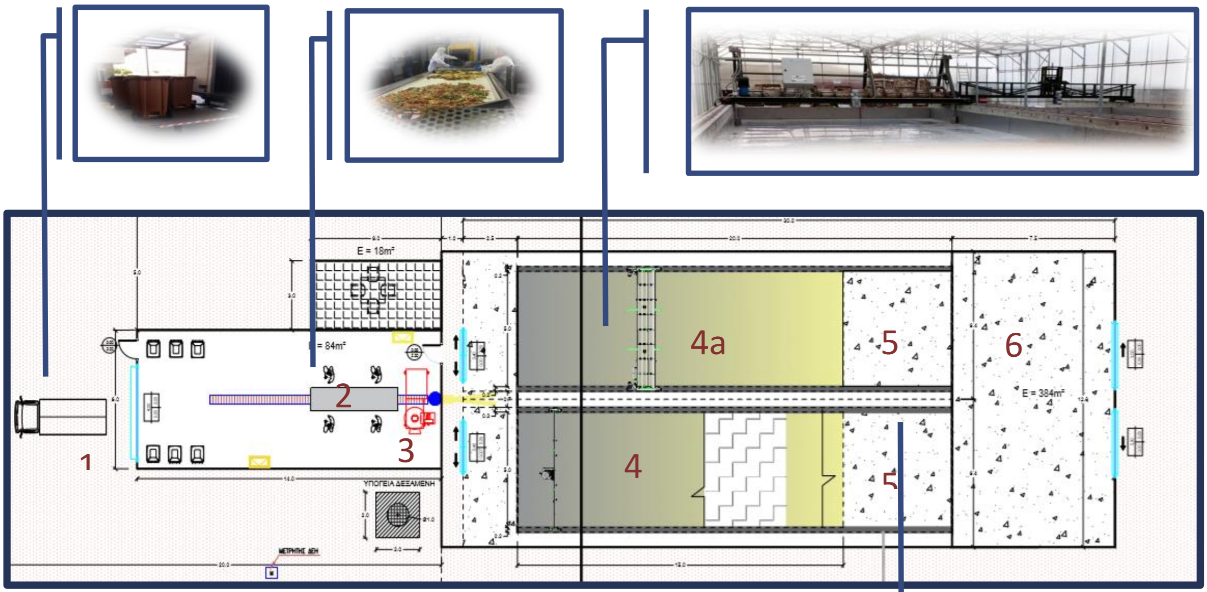
Life cycle inventory

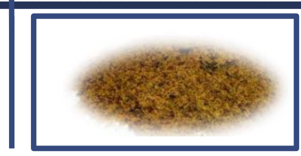
The key components of the inventory of the pilot plant infrastructure are presented in Table 2. The key components were extracted from the master plan of the pilot plant. These are:

- 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	Measure
Landscaping		
Excavation	m³	129.3
Floor construction		
Reinforced concrete	m³	39.2
Lightly reinforced concrete	m³	65.2
Cover concrete	m³	15
Lightly reinforced concrete floor	m³	8.4
Industrial floor (epoxy resin)	m³	8.4
Gravel	m³	0.4
Excavation	m³	0.8
Reinforce concrete for tank	m³	1.8
Asphalt, bitumen	m³	20.6
Metallic structures		
Stainless steel	kg	1500
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	m³	7
Drainage pipes (PVC-U) (125 mm diameter)	m	45
Drainage pipes (PVC-U) (100 mm diameter)	m	10
Electrical infrastructure		
Excavation	m³	11
Pipes (PVC)	m	500
Cables	m	500
Electricity consumption during operation		
Food waste shredder	kW	8.2
Feeding pump	kW	1.1
Submerged wastewater pump	kW	1.1
Greenhouse openings motor	kW	1.5
Air conditioning units	kW	14.2





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 F4F production process.

Impact assessment of the construction and operation of the solar drying unit

The scope of the study includes the construction and operation of the solar drying unit. The impact assessment results are presented in Table 3. The % contribution of each one of the materials utilised in the infrastructure are presented in Table 4. The % contribution of each material utilised in the infrastructure is presented in Figure 4.

The results of Figure 4 indicate the % contribution of each component that participates to the infrastructure. Floor construction is the life cycle stage that contributes the most to all impact categories.

Table 3. Total characterisation impact assessment results for the infrastructure of the solar drying unit.

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat pump
Abiotic depletion	kg Sb eq	75.92774	0.023017	72.06537	0.10040	0.15206	3.17997	0.00147	0.21451	0.05106	0.13987
Acidification	kg SO_2 eq	42.63512	0.025831	40.17372	0.05069	0.04596	1.93382	0.00013	0.21610	0.01343	0.17455
Eutrophication	kg PO_4--- eq	8.08568	0.006152	7.868641	0.00422	0.00602	0.16510	1.2E-05	0.01768	0.00221	0.01564
Global warming (GWP100)	kg CO_2 eq	12302.43	3.44741	11667.35	11.0639	11.1132	526.410	0.24639	37.2325	3.42430	42.0481
Ozone layer depletion (ODP)	kg CFC-11 eq	0.00199	4.18E-07	0.000716	1.35E-07	6.66E-08	1.12E-07	2.73E-07	4.05E-06	2.52E-08	0.00127
Human toxicity	kg 1,4-DB eq	4365.376	2.324267	4247.325	19.5007	8.98072	58.2397	0.07373	13.8869	1.53962	13.5049
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	2306.256	0.23042	2288.502	3.57009	2.794438	7.866069	0.003804	0.983139	0.855428	1.450706
Marine aquatic ecotoxicity	kg 1,4-DB eq	3012148	553.0872	2991508	36.8185	1822.70	10152.9	9.33633	3329.39	896.857	3838.66
Terrestrial ecotoxicity	kg 1,4-DB eq	34.35792	0.005059	32.46255	0.02964	0.07631	1.62419	0.00081	0.07163	0.03405	0.05368
Photochemical oxidation	kg C_2H_4 eq	1.94676	0.000699	1.820529	0.00249	0.00364	0.10143	4.83E-05	0.00856	0.00127	0.00809

Table 4. % contribution of the various infrastructure materials to the total impact assessment results of the solar drying unit.

Impact category	Unit	Total	Landscaping	Floor construction	Electrical cabling	Drainage	Metallic structure	Pumps	Solar collector	Water supply	Heat Pump
Abiotic depletion	%	100	0.03	94.91	0.13	0.20	4.19	0.00	0.28	0.07	0.18
Acidification	%	100	0.06	94.23	0.12	0.11	4.54	0.00	0.51	0.03	0.41
Eutrophication	%	100	0.08	97.32	0.05	0.07	2.04	0.00	0.22	0.03	0.19
Global warming (GWP100)	%	100	0.03	94.84	0.09	0.09	4.28	0.00	0.30	0.03	0.34
Ozone layer depletion (ODP)	%	100	0.02	35.98	0.01	0.00	0.01	0.01	0.20	0.00	63.76
Human toxicity	%	100	0.05	97.30	0.45	0.21	1.33	0.00	0.32	0.04	0.31
Fresh water aquatic ecotoxicity	%	100	0.01	99.23	0.15	0.12	0.34	0.00	0.04	0.04	0.06
Marine aquatic ecotoxicity	%	100	0.02	99.31	0.00	0.06	0.34	0.00	0.11	0.03	0.13
Terrestrial ecotoxicity	%	100	0.01	94.48	0.09	0.22	4.73	0.00	0.21	0.10	0.16
Photochemical oxidation	%	100	0.04	93.52	0.13	0.19	5.21	0.00	0.44	0.07	0.42

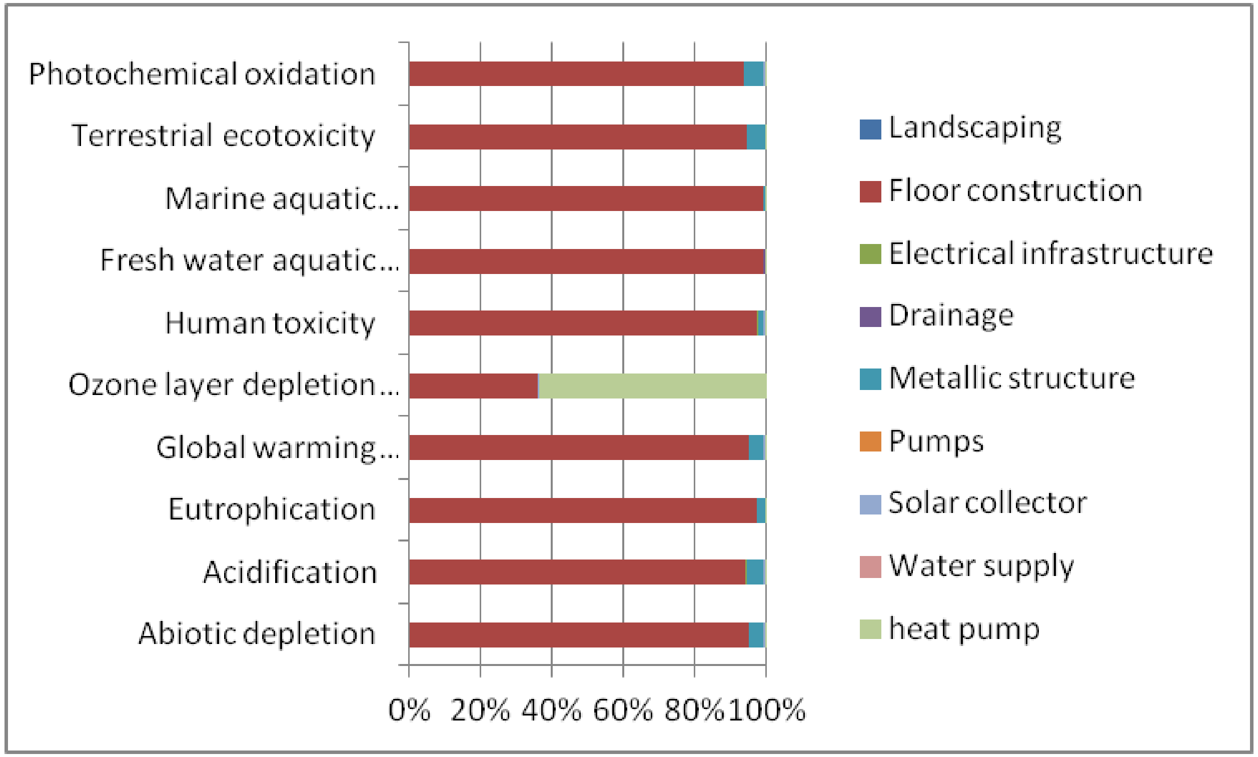


Figure 4. Contribution (%) to the impact categories of different materials used in the infrastructure of the solar drying unit.

So far, the results of the impact assessment of the infrastructure have been presented. In the next lines the contribution of the operation of the solar drying unit will be examined. The characterisation results of the impact assessment for both the construction and operation of the solar drying unit are presented in Table 5. The % contribution of the infrastructure and the operation component of the solar drying unit is presented in Table 6. The % contribution of the infrastructure and operation components are also presented in Figure 5.
The results presented in Figure 5 indicate that the operation (red colour) contributes the most to all impact categories, except freshwater aquatic ecotoxicity and eutrophication.

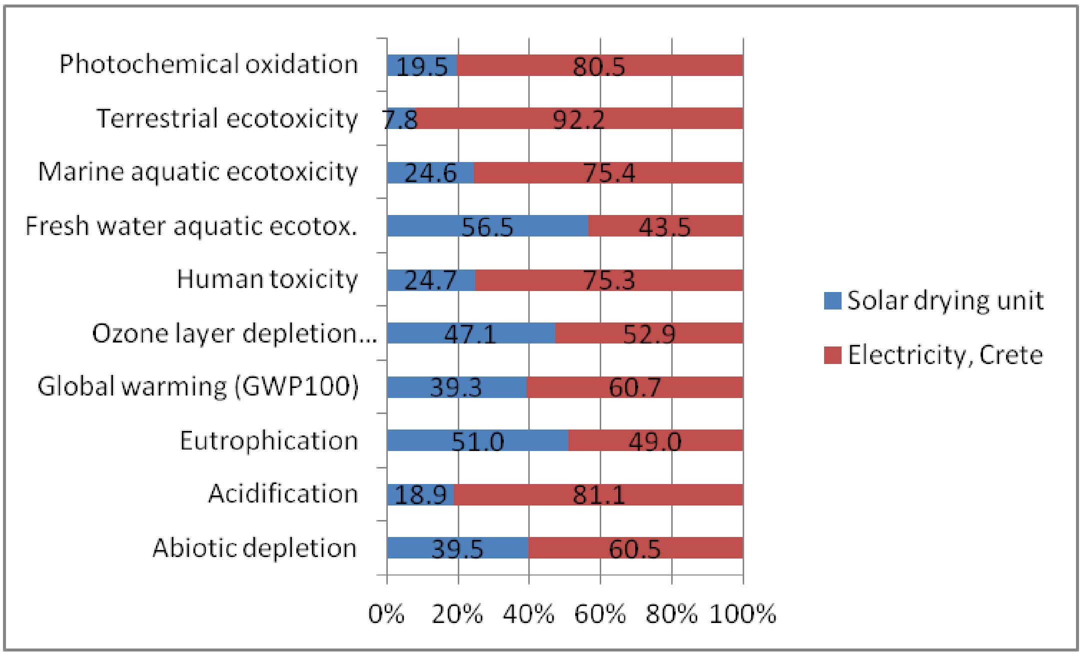


Figure 5. Contribution I%) to the impact categories of the infrastructure and operation of the solar drying unit.

Table 5. Total characterisation impact assessment results from the infrastructure and operation of the solar drying unit.

Impact category	Unit	Total	Solar drying unit	Electricity, medium voltage, GR Crete
Abiotic depletion	kg Sb eq	191.9803	75.92774	116.0525
Acidification	kg SO_2 eq	225.6311	42.63512	182.996
Eutrophication	kg PO_4--- eq	15.86657	8.08568	7.780891
Global warming (GWP100)	kg CO_2 eq	31312.65	12302.43	19010.22
Ozone layer depletion (ODP)	kg CFC-11 eq	0.004223	0.00199	0.002233
Human toxicity	kg 1,4-DB eq	17674.46	4365.376	13309.08
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	4083.613	2306.256	1777.357
Marine aquatic ecotoxicity	kg 1,4-DB eq	12243821	3012148	9231673
Terrestrial ecotoxicity	kg 1,4-DB eq	439.1926	34.35792	404.8347
Photochemical oxidation	kg C_2H_4 eq	9.969963	1.94676	8.023202

Table 6. % contribution to the total impact assessment categories of the infrastructure and operation of the solar drying unit.

Impact category	Unit	Total	Solar drying unit	Electricity, Crete
Abiotic depletion	%	100	39.54976	60.45024
Acidification	%	100	18.89594	81.10406
Eutrophication	%	100	50.96047	49.03953
Global warming (GWP100)	%	100	39.289	60.711
Ozone layer depletion (ODP)	%	100	47.1183	52.8817
Human toxicity	%	100	24.69879	75.30121
Fresh water aquatic ecotoxicity	%	100	56.47587	43.52413
Marine aquatic ecotoxicity	%	100	24.60137	75.39863
Terrestrial ecotoxicity	%	100	7.822973	92.17703
Photochemical oxidation	%	100	19.52625	80.47375

Normalisation

Figure 6 presents the normalisation results for the infrastructure and equipment of the pilot solar drying unit. The results indicate that the most important impact categories are the marine aquatic ecotoxicity, the abiotic depletion, the freshwater aquatic ecotoxicity the global warning and the acidification. In each one of the above-mentioned impact categories the main contribution results from the floor construction.

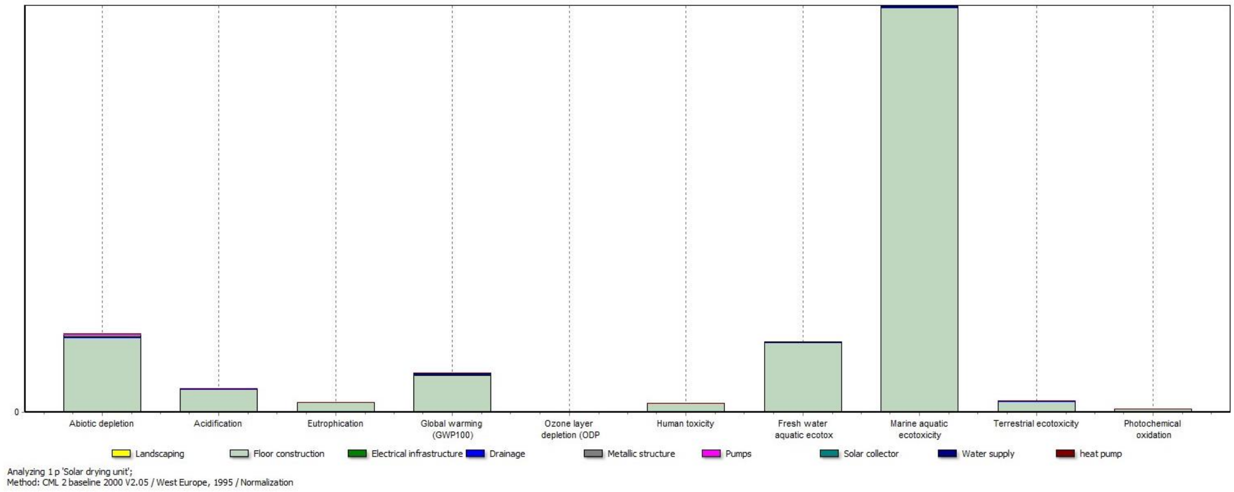


Figure 6. Normalisation results

Figure 7 presents the normalisation results for the overall pilot plant solar drying process. The results indicate that the most important impact categories, in order of magnitude, are: (i) the marine aquatic ecotoxicity, (ii) the abiotic depletion of resources, (iii) the terrestrial ecotoxicity, (iv) the freshwater aquatic ecotoxicity, (v) the acidification and (vi) the global warming.

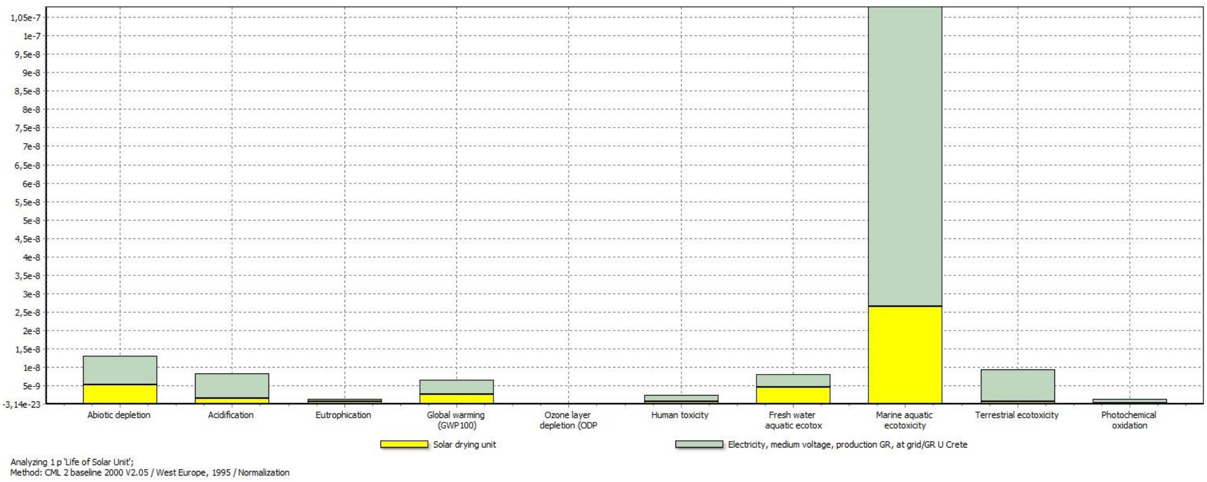


Figure 7. Normalisation results for the pilot plant solar drying process.

Interpretation

The results presented so far indicate that the major environmental impacts of the solar drying unit are generated by the operation of the solar drying unit, due to the usage of electricity.