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Environmental Impact Assessment of a Solar Drying Unit for the Transformation of Food Waste into Animal Feed

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Abstract: Food waste valorization via its transformation into animal feed is a viable alternative for improving food security and the diversion of organic waste from landfills. The manuscript presents the environmental impact assessment of the construction and operation of a novel solar food waste drying unit on the island of Crete in Greece, which is treating food waste from hotels. Life cycle assessment is utilized for the impact assessment. The results indicate a total carbon footprint of approximately 217.5 kg CO_2 eq. per ton of treated food waste. In conclusion, the operation phase is the major contributor to the environmental impacts, due to the utilization of electricity.

Keywords: food for feed; food waste; solar drying; valorization; life cycle assessment

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Citation: Abeliotis, K.; Chroni, C.; Lasaridi, K.; Terzis, E.; Galliou, F.; Manios, T. Environmental Impact Assessment of a Solar Drying Unit for the Transformation of Food Waste into Animal Feed. *Resources* **2022**, *11*, 117. https://doi.org/10.3390/resources11120117

Academic Editors: Eva Pongrácz and Eleni Iacovidou

Received: 13 September 2022
Accepted: 7 December 2022
Published: 9 December 2022

1. Introduction

Animal feed plays an important role in the food chain and has implications for the composition and quality of the livestock products (milk, meat, and eggs) consumed by people [1]. The potential use of food waste as animal feed, via livestock sector innovations, is explicitly included both in the EU Waste Framework Directive [2] and in the updated EU Bioeconomy strategy, provided that the applicable rules and legal requirements for the protection of human health are observed [3]. Feeding food scraps to animals, a food waste re-use action based on the practical application of the EU waste hierarchy for food [4], has been in practice worldwide for many years [1], with the downside being the risk of diseases, such as foot-and-mouth disease and swine fever [5], to animals. Existing European and national legislation permits the utilization of food waste as feed for fur-bearing animals and pets after undergoing an extremely demanding management procedure, which involves essentially sterilizing food waste [6–8]. Sterilization, due to its high energy requirements, dramatically increases the cost and environmental footprint of the process. Shurson recently reviewed all the implications associated with the transformation of food waste into animal feed [9]. Feed is defined as 'any substance or product, including additives, whether processed, partially processed, or unprocessed, intended to be used for oral feeding to animals' [10]. The recognition by the animal feed industry that food not suitable for human consumption is a feasible resource and not a waste product, is reducing the amount of waste sent to landfill every year, saving costs, and lessening environmental damage [11]. Finally, due to the energy and material inputs required for the exploitation of food waste as animal feed, the environmental footprint of the feed production process is affected [12]. Note, however, that there is, in principle, a big difference in utilizing food waste as feed for animals in the food system as opposed to animals outside of it (cats, dogs, and fur-bearing animals). The scope of the present study focuses on the utilization of food waste for feed for pets and fur-bearing animals.

Former foodstuffs should be regarded as a resource, not a waste product. Diversion of food waste from disposal is becoming an increasing priority for governments, which are promoting recycling and the development of markets for valuable products [7]. Many of these former foodstuffs—of non-animal origin and, therefore, not restricted for their utilization in feed for farmed animals, including bread, biscuits, breakfast cereal, crisps, and confectionery—have a high nutritional value, being a source of high-quality fats, sugar, and carbohydrates. Truong et al. [1] reviewed the use of food waste in monogastric animals in the United States while Paßlack et al. [8] examined the use of food waste in cats and dogs in Germany. The authors concluded that food waste use, especially as chicken feed, can provide nutrients to animals and, subsequently, to humans [1].

The present manuscript aims to present the environmental impact assessment results for the installation and operation of a solar drying unit that was built within the framework of a project titled "Food for Feed: An Innovative Process for Transforming Hotels' Food Waste into Animal Feed (F4F)". The F4F process aims to produce animal feed from food wastes via solar drying. A solar drying pilot unit has been installed for the first time in Greece to help transform food waste into animal feed. Solar drying has been identified as a waste treatment method that is energy efficient and meets hygienic criteria [13,14]. It has been recently examined for its use in transforming, specifically, food waste into animal feed in Afghanistan [15]. The scientific importance of the F4F process in the transformation of food waste into animal feed, a process that facilitates the concept of a circular economy, is its utilization of solar energy.

2. Materials and Methods

The F4F pilot unit consists of (i) a prefabricated building (14 m × 6 m) where food waste pre-treatment takes place and (ii) a solar drying unit (30 m × 12.8 m). A series of air-conditioning and air extraction and recirculation units (for health and safety issues) have been installed in the prefabricated building. The F4F pilot unit is installed in the city of Heraklion on the island of Crete and is schematically depicted in Figure 1.

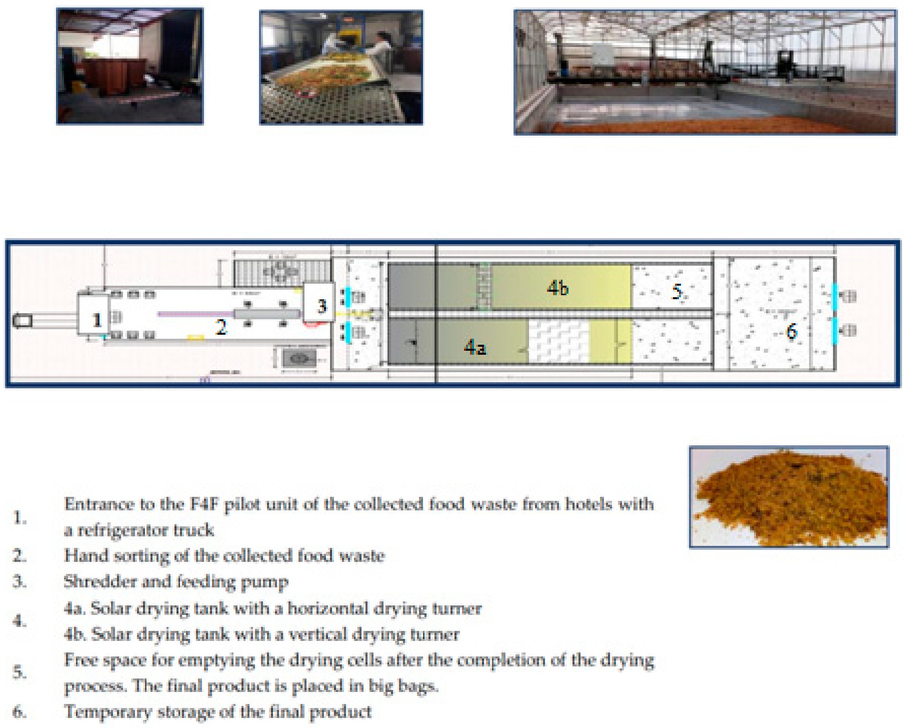

Figure 1. Schematic representation of the scope of the assessment.

The solar drying unit is essentially a metallic-framed polycarbonate greenhouse. Windows are protected with insect nets, and there is a concrete floor for pest control. Roof-based fans are used to extract moisture from the sun drying hall, connected to the operation of the turners. It consists of two drying halls, covered by stainless steel. Each drying hall (20 m long and 5 m wide, with 0.80 m high reinforced concrete side walls), is covered with an extensive network of pipelines connected to solar thermal collectors and a heat pump for hot water to accelerate the drying rate. On the top of the pipelines, high-quality stainless steel covers the drying hall surface, which is in contact with the food waste. 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 motions: (a) moving in the drying hall corridor using wheels rolling on the sidewalls, at various speeds and in both directions, (b) increasing and decreasing the height of the turner's drum, (c) turning the drum both directions and in various control speeds, (d) estimating its position from the ends of the corridor at all times, and (e) including a series of safety operation mechanisms (e.g., emergency stop).

The food waste is collected on-site at hotels, in specific INOX containers and transported with a refrigerated truck that keeps the waste residues separate from the surrounding environment, accordingly keeping odors to a minimum, minimizing the attraction of insects, rodents, and other vectors, and also reducing the contamination of the food residues during transport.

The first stage of food waste management takes place in the prefabricated building and concerns hand-sorting of the food waste to remove unwanted materials (paper napkins, plastic, metal, etc.) that may be mixed with the food waste. At the end of the hand-sorting belt, the food waste is forwarded into a shredder. With a screw and then with a high-power pump, the shredded food waste is introduced into the elongated drying halls of the solar drying unit. Each drying hall is fed with the shredded waste to a specific level inside the hall (approximately 15 cm in height) and then operates in a closed loop until the moisture content is reduced from 75% of the original material to 12% or lower.

2.1. Goal and Scope Definition

The goal of the present study is the environmental impact assessment via means of life cycle assessment (LCA) of the installation and operation of the pilot scale solar drying unit designed, constructed, and operating in the framework of the F4F project. LCA is an established decision support tool for the comparison of different food waste management systems [16]. Recently, researchers requested comprehensive LCAs to assess the environmental benefits of replacing feed grains with by-products or food waste [17] and to valorize meat waste for pet food production [18]. Our study aims to answer the following research questions: (i) what is the most important environmental burden during the installation of the drying unit's infrastructure, (ii) how does installation infrastructure compare with the operation of the drying unit in terms of environmental impacts, and (iii) what is the avoided energy burden of the food waste drying process attributed to the utilization of solar power.

The system boundary is presented in Figure 2. The scope of the present study includes all infrastructure and equipment of the pilot solar drying unit, as described in the previous section. 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 with concrete, and 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 transportation of the collected food waste to the solar drying unit is not included in the scope of the study.

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, and the hydraulic and electrical infrastructure of the solar drying unit.

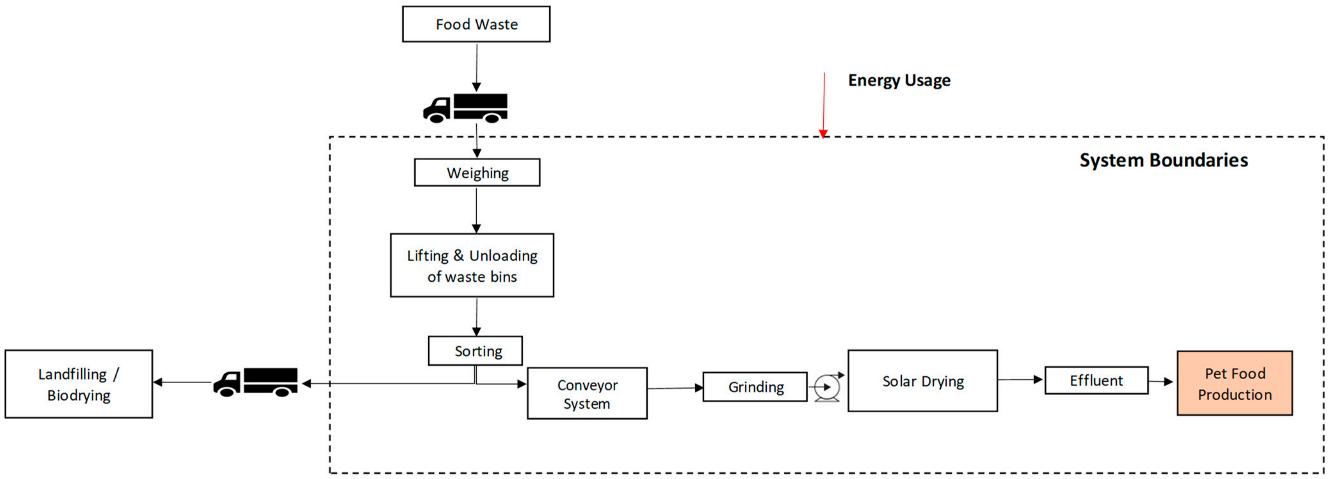

Figure 2. System boundary.

2.2. Functional Unit

The functional unit is defined as the "processing of 1 ton of collected food waste". The lifespan of the infrastructure of the pilot unit is estimated to be 20 years, while the lifespan for the equipment (i.e., pumps, heat pumps, and solar collectors) is assumed to be 10 years (see Figure 3). This methodological approach was chosen to highlight the environmental impact of the infrastructure on the total F4F process. All quantitative input and output data that will be collected during the study shall be calculated to this reference flow. Data were sourced from primary qualitative and quantitative data derived from the F4F pilot plant. The average energy consumption of the plant is based on actual primary data.

2.3. Life Cycle Inventory

As the product is produced on the island of Crete in Greece, impacts from electricity production were sourced from Ecoinvent databases using Greek data [19]. Furthermore, electricity losses during low-voltage transmission and transformation from medium-voltage are also considered in the analysis. In general, the overall quality of the data is considered to be adequate for the scope and the requirements of this study.

The key components of the inventory of the pilot plant infrastructure are presented in Table 1. The weights and volumes for each component were extracted from the analytical master plan description of the pilot plant provided by the construction company.

Table 1. Life cycle inventory of the solar drying unit.

Infrastructure Material/Process	Measure	Unit
Landscaping		
Excavation, hydraulic digger	129.3	m^3
Floor construction		
Aerated concrete block, reinforced	271,780	kg
Lightweight concrete block	31,200	kg
Epoxy resin insulator (Al_2O_3)	18,648	kg
Gravel, crushed	800	kg
Bitumen sealing Alu80	14,853	kg
Excavation, hydraulic digger	0.8	m^3
Electrical cabling		
PVC pipe	62.2	kg
Copper wire	29.8	kg
Water supply		

Table 1. *Cont.*

Infrastructure Material/Process	Measure	Unit
Cast iron	10	kg
HDPE pipes	21.7	kg
Drainage		
Cast iron	20	kg
HDPE pipes	55	kg
PVC pipe	17	kg
Excavation, hydraulic digger	5	m^3
Metallic structures		
Stainless steel	580	kg
Polyurethane rigid foam	12.8	kg
Polycarbonate	1112	kg
Electricity consumption (operation for 126 d)	28,882	KWh
Heat pump		
Stainless steel	74.3	kg
Copper tube	17.44	kg
Lubricant oil	0.4	L
PVC pipe	0.2	kg
HDPE pipes	4	kg
Acrylonitrile–butadiene–styrene copolymer	0.5	kg
Refrigerant R134a	1.35	kg
Cast iron	1.5	kg
Brass	0.23	kg
Solar collectors		
Solar glass, low-iron	84	kg
Copper tube	37.1	kg
Aluminum sheet	77	kg

The key components of the pilot plant infrastructure are (see Figure 3):

- 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),
- electrical infrastructure (e.g., cables).

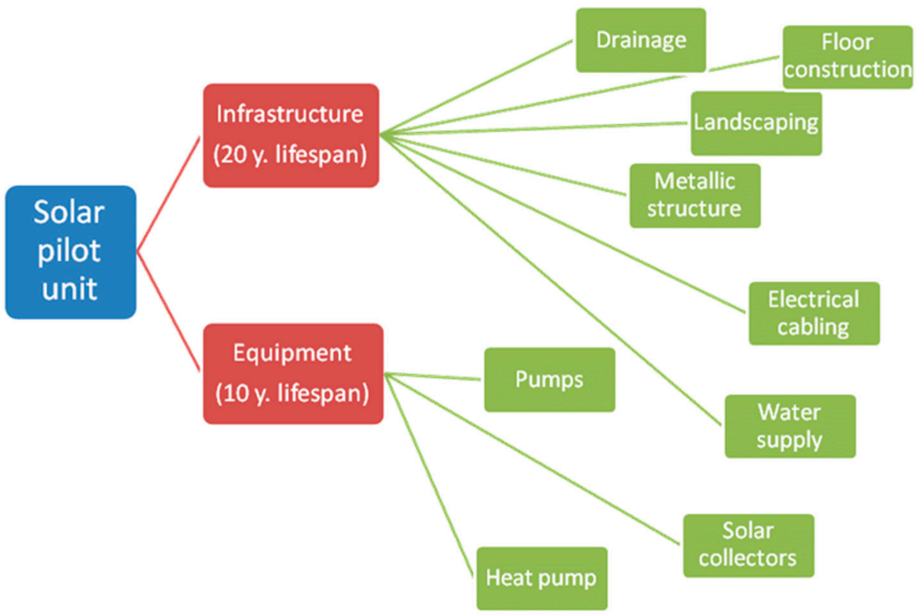

Figure 3. Infrastructure and equipment included in the assessment.

2.4. Life Cycle Impact Assessment

The CML2 baseline 2000 impact assessment method was utilized [20]. The ten impact categories and their respective units of measurement are presented in Table 2. Abiotic resource depletion potential includes depletion of fossil fuels, metals, and minerals, expressed in kg of antimony (Sb) used, which is taken as the reference substance for this impact category. Acidification potential is based on the contribution of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) to the potential acid deposition. The reference substance for acidification is sulfur dioxide. Eutrophication is defined as the potential of nutrients to cause over-fertilization of water and soil, which can result in increased growth of biomass. The reference substance for eutrophication is phosphorus ions. Climate change is calculated as global warming potential (GWP), which equals the sum of emissions of greenhouse gases multiplied by their respective GWP factors. The reference substance is carbon dioxide. Stratospheric ozone depletion potential (ODP) indicates the potential of emissions of chlorofluorohydrocarbons (CFCs) and other halogenated hydrocarbons to deplete the ozone layer, with the reference substance being CFC-11. Human toxicity potential is calculated by taking into account releases that are toxic to humans with respect to three different media, i.e., air, water, and soil. The reference substance for this impact category is 1,4-dichlorobenzene. The same substance, i.e., 1,4-dichlorobenzene, is the reference for freshwater and marine sediment toxicity and terrestrial ecotoxicity. Photochemical oxidation is related to the potential of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) to generate photochemical or summer smog. The reference substance for this impact category is ethylene (C_2H_4) [20].

Table 2. Total characterization impact assessment results for the infrastructure of the pilot solar drying unit (per FU, i.e., per t of incoming 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	0.53	0.00	0.50	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Acidification	kg SO_2 eq	0.30	0.00	0.28	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Eutrophication	kg PO_4^- eq	0.06	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Global warming (GWP100)	kg CO_2 eq	85.43	0.03	81.02	0.08	0.08	3.66	0.00	0.26	0.03	0.29
Ozone layer depletion (ODP)	kg CFC-11 eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Human toxicity	kg 1,4-DB eq	30.32	0.02	29.50	0.14	0.06	0.40	0.00	0.10	0.01	0.09
Freshwater aquatic ecotoxicity	kg 1,4-DB eq	16.02	0.00	15.90	0.02	0.02	0.05	0.00	0.01	0.01	0.01
Marine aquatic ecotoxicity	kg 1,4-DB eq	20,917.69	4.18	20,773.36	0.00	12.55	71.12	0.00	23.01	6.28	27.19
Terrestrial ecotoxicity	kg 1,4-DB eq	0.24	0.00	0.23	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Photochemical oxidation	kg C_2H_4 eq	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3. Results

The scope of the study includes the construction and operation of the solar drying unit. The solar drying unit replaces the need for utilizing fossil fuels (e.g., low sulfur diesel) for drying food waste. The first full-scale operational period started on the 3 June 2019, and concluded on 31 October. Within 126 days, 144 t of food waste was collected from hotels and a catering service and treated in the pilot drying unit. From this input quantity of food waste, ultimately, 30 t of dried feed was produced, thus giving an average weight reduction of 80% by weight. Note, however, that this is not the maximum operational capacity of the unit, due to the limited availability of food waste. The initial moisture of the food waste was approximately 75% (average value of different batches) and the final moisture content of the product was 12%.

During the characterization, the analysis, quantification, and aggregation of environmental burdens and impacts belonging to the various individual categories were carried out. The impact assessment characterization results are presented in Table 2. The % contribution of each one of the materials utilized in the infrastructure is presented in Table 3. The results of Table 3 indicate that floor construction is dominant in all impact categories. Almost 300 t of concrete are utilized for the floor construction, in addition to 15 t of bitumen for sealing the floor.

Table 3. Percentage contribution of the various infrastructure materials to the total impact assessment results of the pilot solar drying unit.

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

Then, in Table 4 the environmental impact results of the total drying process are presented per functional unit, namely per ton of food waste processed. Figure 4 presents the percentage contribution of construction and operation per impact category. The operation, due to the utilization of electricity, is the dominant factor in eight out of ten impact categories (except eutrophication and freshwater aquatic ecotoxicity).

Table 4. Contribution of the infrastructure materials and the operation to the total impact assessment results of the pilot solar drying unit.

Impact Category	Unit	Infrastructure	Operation (Electricity)	Total	Total per Ton
Abiotic depletion	kg Sb eq	75.93	116.05	191.98	1.33
Acidification	kg SO_2 eq	42.63	183.00	225.63	1.57
Eutrophication	kg PO_4^- eq	8.09	7.78	15.87	0.11
Global warming (GWP100)	kg CO_2 eq	12,302.43	19,010.22	31,312.65	217.45
Ozone layer depletion (ODP)	kg CFC-11 eq	0.002	0.00	0.00	0.00
Human toxicity	kg 1,4-DB eq	4365.38	13,309.08	17,674.46	122.74
Freshwater aquatic ecotoxicity	kg 1,4-DB eq	2306.26	1777.36	4083.61	28.36
Marine aquatic ecotoxicity	kg 1,4-DB eq	3,012,147.54	9,231,673.00	12,243,820.54	85,026.53
Terrestrial ecotoxicity	kg 1,4-DB eq	34.36	404.83	439.19	3.05
Photochemical oxidation	kg C_2H_4 eq	1.95	8.02	9.97	0.07

Following the characterization results, normalization is an optional process to compare several impact category indicators. Normalization is a process to calculate the magnitude of the results of impact category indicators, with some reference information [20]. 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. Regarding construction, the normalized results indicate that the most important impact categories are marine aquatic ecotoxicity, abiotic depletion, 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 normalized results indicate that the most important impact category, in order of magnitude, is marine aquatic ecotoxicity, and the categories of freshwater aquatic ecotoxicity and human toxicity seem to be relatively significant.

However, please note that the solar drying process should be taken into account as an avoided heat product. Table 5 presents the water balance of the pilot drying unit. Almost 6000 tons of low-sulfur diesel, and corresponding environmental impacts, were avoided because of solar drying.

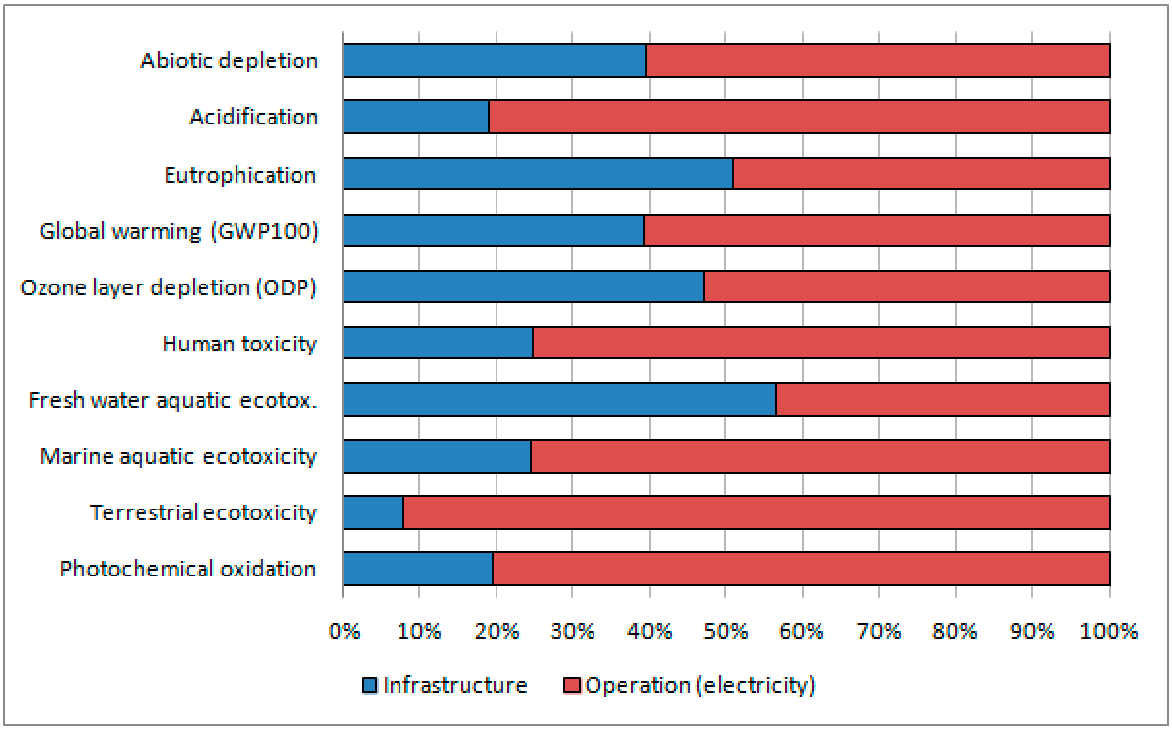

Figure 4. Relative % contribution of infrastructure and operation on the overall pilot drying process.

Table 5. Water balance and energy requirements of the overall drying process.

Description	Units	Result
Water in: 144 t ∗ 75% humidity	t of water	108
Water out: 30 t ∗ 12%	t of water	3.6
Water evaporated	t of water	104.4 (i.e., 108–3.6)
Total energy required for evaporation *	MJ	254,913.48
Low sulfur diesel avoided by solar heating **	t of low-sulfur diesel	5984

* Water heat of vaporisation (at 25 °C): 2.4417 MJ/Kg; ** Net heating value of low sulfur diesel: 42.6 MJ/kg.

4. Discussion

Animal feed is included among the goods that can be substituted by food waste treatment [21]. Therefore, the F4F process adheres to the principles of circular economy because it represents a complete cycle, where food is devalued in food wastes through human consumption, and then it is upgraded through a very simple low-cost, low-energy demand process into animal feed. Overall, the thermal treatment achieved by solar drying converts food waste not suitable for animal feed, to animal feed. Our vision is that once the circular system is in full operation, food waste will be diverted from landfills, thus saving greenhouse gases emissions; valuable food ingredients (e.g., proteins) will be in circular use, agricultural activities will be avoided, and natural systems will be protected due to reduced need for conventional raw materials (e.g., soy bean and corn) required for animal feed. The utilization of non-fossil energy, such as solar, is also a key component of a circular economy.

Feed sample analysis generated by the F4F process, and feed quality parameters are beyond the scope of the present manuscript. Regarding these issues, the readers may find more technical detailed information in references [7,8]. The published results of the techno-economic analysis indicate that the products of the F4F process are quite valuable and can be used as raw material in animal feeding (in line with the EU directives) due to their relatively high energy and protein content [7,8,22]. This is supported by the experimental results with broilers and fattening pigs (growth rate and carcass quality parameters) and from the relatively high potential market price (at least quite comparable with that of soy bean meal) they can get [23].

Valorization of food waste from the residential and commercial sectors is valuable from the viewpoints of both environmental sustainability and circular bioeconomy [24,25]. Using food waste as an animal feed resource, respecting all the legislative restrictions, would complement food and processing residues already used as animal feed [26]. For countries such as Greece, it is clear that without successful long-term food waste prevention and re-use activities, in order to achieve a notable behavior change in the way people buy and use food, the treatment capacity required to handle food waste will need to increase by more than a factor of two as waste volumes continue to grow. In simple terms, more money will be required and fewer results will be achieved.

The results of the present manuscript, at first, can serve as a baseline for future solar drying units aimed at valorizing food waste. Table 1 presents the analytical numerical life cycle inventory data of the examined solar drying unit. Then, Table 2 presents the life cycle impact assessment results of the infrastructure per FU, i.e., per t of incoming waste, based on the CML2 baseline 2000 impact assessment ready-made method. Normally, in the literature, the results of the infrastructure are neglected. However, in our case, the results for the infrastructure are presented explicitly. Furthermore, regarding the infrastructure, Table 3 presents the analytical breakdown of the infrastructure components. The results of Table 3 indicate that the contribution of floor construction is the major contributor to the total impacts of the infrastructure. The specifics of floor construction can be found in the inventory Table 1.

With regard to the comparison between infrastructure and operation, Table 4 and Figure 4 reveal the fact that operation is the key contributor to eight of the impact categories examined, including global warming. The main operational burden is placed on the use of electricity. On the basis of our data, the use of electricity is estimated to be 200.5 KWh per ton of incoming food waste. This value is 4–12 times higher compared with that which was reported for composting of food waste by a review paper [21]. This is due to the solar drying pilot unit not operating at its maximum capacity and the differences in system-boundary settings and assumptions that were used [21]. Note that the penetration of renewable energy sources into the Greek electricity grid is increasing significantly each year, and, thus, the current relative characterized impacts are expected to decrease.

The results (see Table 4) of our analysis of the total carbon footprint for the solar drying process (217.45 kg CO_2 eq. per ton of food waste) are very close to those reported by Kim and Kim [27] (200 kg CO_2 eq. per ton of food waste with dry based treatment). Focusing explicitly on the global warming potential, compared with 25 other LCA studies on food waste treatment options, such as anaerobic digestion, composting, incineration, and landfill, reviewed by Bernstad and la Cour Jansen [21], our results are comparable to those of composting and anaerobic digestion. However, our results are substantially less than that of landfills. Moreover, zu Ermgassen et al. [28] reported that the LCA results from various studies of transforming food waste into animal feed vary considerably and are sensitive to local conditions and study assumptions [28]. Finally, the results presented in Table 5 indicate that a total of 5984 tons of low-sulfur diesel (or approx. 41.5 tons of low-sulfur diesel per ton of incoming food waste) was avoided by solar heating. This is a major contribution of solar heating, engaged in food waste treatment, toward the mitigation of global warming.

Regarding the limitations of the study, as mentioned in the system description, the transportation of collected food waste to the solar drying unit was not included in the study. Moreover, it is important to mention that the potential environmental benefits due to the diversion of food waste from other treatment alternatives (e.g., landfill or composting) were not included in the scope of the study. In the case of alternatives with high environmental impacts (e.g., landfill), the total offset environmental benefits could be increased. Future research directions should focus on assessing the total environmental impact of transforming food waste into commercialized feed for animals.

5. Conclusions

The present paper aimed to assess the environmental impacts of the infrastructure and the operation of the pilot solar drying unit via means of LCA. The results presented 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. The use of electricity resulting from renewable energy sources will alleviate the carbon footprint of the entire process.

Author Contributions: Conceptualization, K.A. and K.L.; methodology, K.A.; software, K.A.; validation, K.L., C.C. and E.T.; formal analysis, C.C.; investigation, E.T.; data curation, C.C., F.G. and E.T.; writing—original draft preparation, K.A. and C.C.; writing—review and editing, K.L.; visualization, C.C.; supervision, F.G. and E.T.; project administration, K.L. and T.M.; funding acquisition, T.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by EU LIFE15 ENV/GR/0002057: "Food for Feed: An Innovative Process for Transforming Hotels' Food Wastes into Animal Feed".

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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