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Using Life Cycle Assessment methodology to minimize the environmental impact of dryers

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Abstract

Drying is known as a high energy consuming unit operation, representing between 12 to 25% of the global industrial energy consumption in developed countries. Consequently, drying contributes to several environmental impacts mainly associated to its heat or electricity requirements. One can cite global warming, emission of particles, acidification, photochemical ozone formation, …

Based on a literature review and some dedicated case studies, this work will illustrate how Life Cycle Assessment (LCA) can be used to evaluate the environmental impacts associated to a drying operation. The results will be presended in a way to indicate some eco-design strategies for dryers.

Keywords: *drying; eco-design; Life cycle assessment; environmental impact.*

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1. Introduction

Drying is known as a high energy consuming unit operation, representing between 12 to 25% of the global industrial energy consumption in developed countries. Consequently, drying contributes several environmental impacts associated to heat or electricity production. One can think, among others, to global warming via greenhouse gas emissions, acidification or photochemical ozone formation via nitrogen oxides emissions, human toxicity via particule matter emissions, … Besides these impacts directly linked to energy consumption, industrial drying operations may also induce other environmental impacts, depending on the choice and the quantity of the materials it is made of, for example.

Life Cycle Assessment (LCA) is now considered as the most complete methodology to evaluate the potential environmental impacts associated with a process, product or service, following a cradle to grave approach. In addition to International Standards ISO 14040 [1] and 14044 [2], the European Joint Research Center developed guidance rules published in the International Reference Life Cycle Data System (ILCD) Handbook [3]. As mentioned in one guest editorial of A. Mumudar [4], LCA of competeting systems has to carried out before selecting the optimal one.

Based on a literature review and some dedicated case studies, this work will illustrate how this methodology can be used to assess the environmental impacts associated to a drying operation. The results will focus on the main process parameters influencing the environmental impacts in a way to indicate some eco-design strategies for dryers.

2. Materials and Methods

This section will summarize the principles of the LCA methodology allowing to understand the results that will be extracted from the literature and from our case studies.

Following ISO standards, LCA studies include 4 phases. The first step consists in defining the “goal and scope”, namely determining the functional unit, to which all the results will be associated, the system boundaries, cut-off rules, time period, impact categories, etc. A typical functional unit could be ‘the drying of one ton of product’ with some specifications on final quality of the product (dryness, …). The system boundaries specifies the different so-called ‘unit processes’ included in the scope, for example, the supply chain, the feed preparation, the packaging, the maintenance, treatment of exhaust gases, …

The second step is called the Life Cycle Inventory (LCI). This phase involves data collection and modeling of the product system, as well as description and verification of data. The data must be related to the functional unit previously defined. Besides specific data, several databases can be used, as well as the scientific literature. The LCI provides information about inputs and outputs in form of elementary flows from and to environment for all the unit processes included in the system boundaries. In the context of drying, a part of the data can be obtained via process control sofwares or energy audit systems allowing the report of any consumption or emissions.

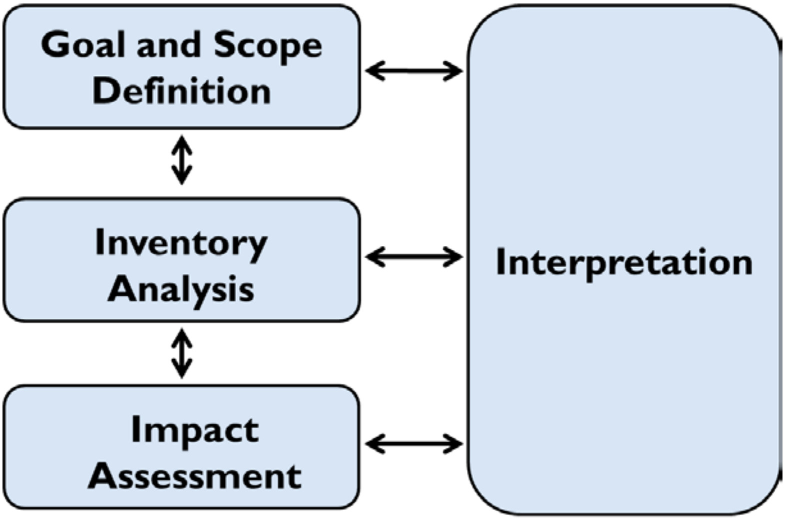

Fig. 1 The four steps of a Life Cycle Analysis.

The third step aims to convert the LCI results into environmental impacts, using several recommended methodologies (following the ISO Standards and the ILCD handbook). Depending on the methodology (ReCiPe, ILCD, Impact World, etc.), the contribution of the functional unit to impact categories such as global warming, eutrophication, acidification, inorganic respiratory effects, tropospheric ozone formation, etc. can be assessed. Fig. 2 illustrate 15 midpoint (problem oriented) impact categories and 3 areas of protection at endpoint. Characterization factors are used to calculate the contribution of each elementary flow of substances to the impacts they are known to be related.

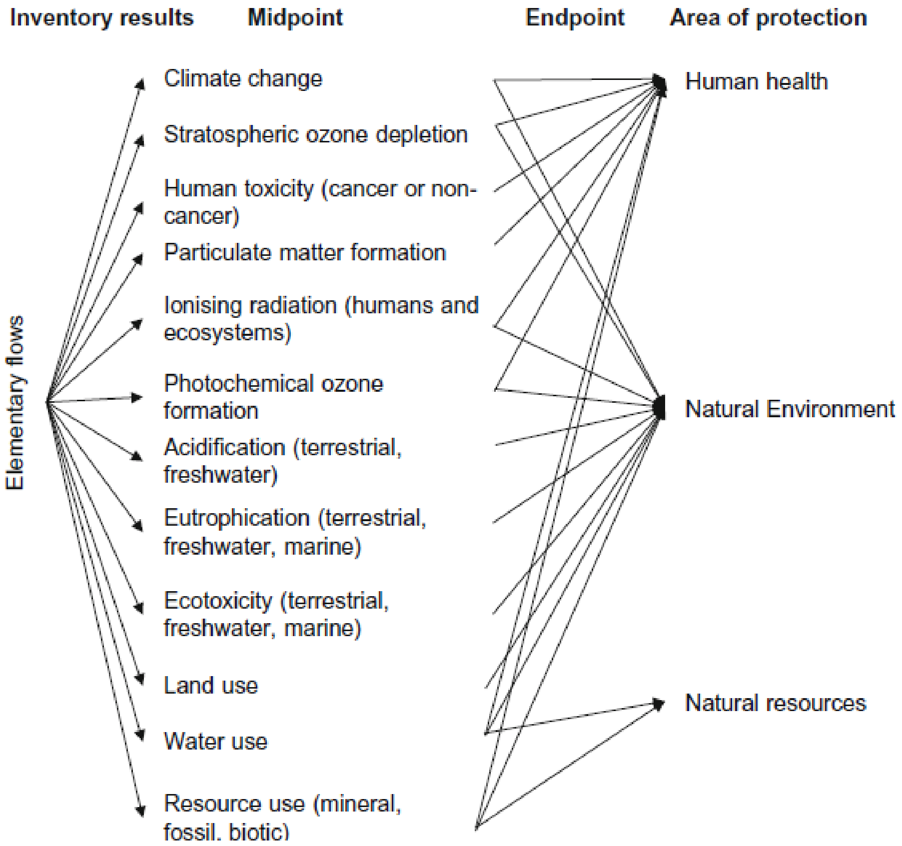

Fig. 2 Impact assessment according to the ILCD handbook.

The last step of a LCA is the interpretation of the results, with three significant steps: the identification of the significant issues, the evaluation of the quality of the study and the drawing of the conclusions, recommendations and reporting.

3. Literature review

Even through an increasing number of papers mention the importance of using an holistic approach to design drying in a sustanaible way, the number of studies really using LCA as an eco-design tool is still low.

Ciesielski and Zbicinski [5] compared two spray dryers, one at laboratory scale and one at industrial scale using LCA. They found that both units generated the greatest environmental load at the usage stage of the life cycle and have an effect mainly in the damage category of resources depletion.

De Marco et al. [6] studied the industrial production of apple powders. Both the drum drying and the storage are the steps that have high impacts (more than 35% each one) on global warming potential and aquatic eutrophication; for the other midpoint categories, the main contribution (> 67 %) is due to drum drying.

Romdhana et al. [7] developed a general eco-design model of biomass drying. Their idea was to develop an assessment computer-aided process engineering tool that compares environmental impacts of different operating conditions and fuel types to support decision-makers for an improved compliance to environmental criterion. However their optimization only includes carbon footprint, which is not representative of the overall process performance.

Prosapio et al.[8] used LCA to optimize the production of strawberries by freeze-drying. They found that that agricultural steps, packaging and end of life only marginally influenced emissions, whereas processing steps are the main contributors. Their analysis revealed that the process was sensitive to vacuum drying time and rather insensitive to freezing time; They proposed an improved solution using osmotic pre-treatment allowing reduced process times and a decrease of 25% of emissions.

Van Oirschot et al.[9] used LCA to evaluate the system design of seaweed cultivation and drying. They found that the drying step (using light fuel oil in a industrial furnace) had the highest contribution on the environment.

4. Case study

In order to illustrate some information that can be used as decision support tool when designing dryers, a simplified LCA of a sludge dryer has been carried out, varying some parameters. The aim of the study is to compare the environmental impact associated to the evaporation of 1 ton of water, i.e. the functional unit, following the scenarios indicated in Table 1. Scenario 1 defines the base case.

Table 1. Modeling scenarios

Scenario	Thermal energy consumption kWh	Thermal energy production	Electricity consumption kWh	Electricity production
1	700	Gas boiler (EU-28)	80	EU-28 grid mix
2	700	Gas boiler (DE)	80	DE grid mix
3	700	Light Fuel Oil boiler (EU-28)	80	EU-28 grid mix
4	700	Biomass boiler (EU-28)	80	EU-28 grid mix
5	770	Gas boiler (EU-28)	80	EU-28 grid mix
6	700	Gas boiler (EU-28)	80	Wind power (EU-28)

The value of thermal and electrical energy consumptions correspond to the claimed performances of Innodry® 2E (Suez-Degrémont). Depending on the scenario, the thermal energy is produced via gas, light fuel oil or biomass boiler, which technical characteristics corresponding to Germany (DE) or to the average situation found in EU-28. The electricity is taken from the grid, i.e. the German or average European one. All these scenario also include the transportation of the wet sludge (20% DS) on 100 km using a EURO 6 truck-trailer, up to 28 t gross weight. The dryer infrastructure in itsef has been neglected. GaBi 7 software and associated datasets have been used to carry out the LCA, with ReCiPe 2016 v1.1 Midpoint (H) as impact assessment method.

Fig. 3 shows the results at the characterization stage: for each of the selected impact category, the highest score is put at a value of 100% and other scores are represented using a relative scale. The absolute values are given in Table 2. In order to facilitate the interpretation of the results, only the most relevant impacts are given.

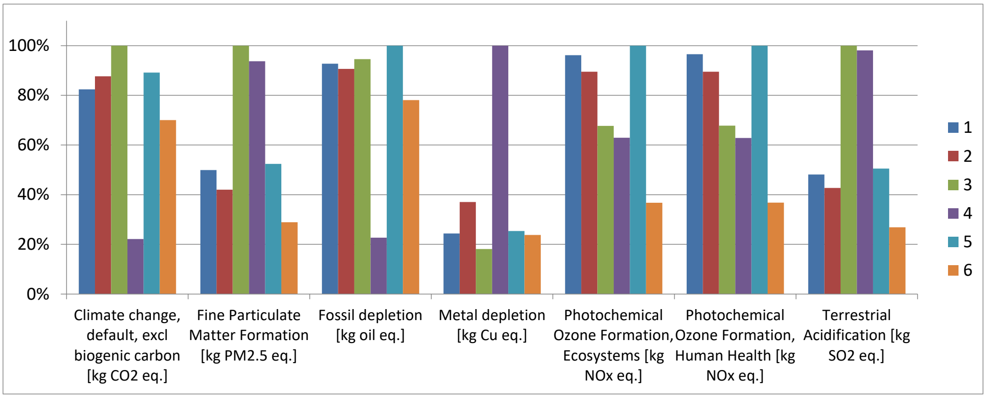

Fig. 3 Impact of the evaporation of 1 ton of water: characterization results.

Table 2. Characterization results

	1	2	3	4	5	6
Climate change, default, excl biogenic carbon [kg CO_2 eq.]	220	234	267	59	238	187
Fine Particulate Matter Formation [kg $PM_{2.5}$ eq.]	0,050	0,042	0,100	0,094	0,052	0,029
Fossil depletion [kg oil eq.]	86,6	84,6	88,3	21,2	93,4	72,9
Metal depletion [kg Cu eq.]	0,089	0,135	0,066	0,364	0,092	0,087
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	162	151	114	106	168	62
Photochemical Ozone Formation, Human Health [kg NOx eq.]	101	94	71	66	105	39
Terrestrial Acidification [kg SO_2 eq.]	0,153	0,136	0,318	0,312	0,161	0,085

The results show clearly the influence of the choice of the energy source, either thermal or electrical, on the environmental impact. The use of a biomass boiler (4) allows to reduce the climate change by 80% in comparison with light fuel oil (3). This biomass scenario also gives the lowest impact regarding fossil depletion but the highest one for metal depletion. With respect to the base case, an increase of 10% of the thermal energy consumption (7) induces a similar relative increase in all categories. Bigger changes are obtained when replacing the electricity of the grid by wind power (6), especially for photochemical ozone formation and fine particle matter formation. The comparison between scenarios 1 and 2 also shows the impact of the localization of the drying plant on its environmental footprint.

As a sensitivity study, the transportation distance, initially fixed at 100 km, was set to 50 and 150 km, using energy consumptions of scenario 1. Fig. 4 shows that an increase of the transport distance influences almost all impact categories, except the ones related with photochemical ozone formation. Nevertheless, Table 3 indicates, for example, that an increase of 100 km leads to an increase of 15 kg CO_2 eq. This illustrates that the transportation step is not prevailing in this case study (less than 10%), in regards with a total climate change indicator of 220 for the base case. A more detailed analysis shows, in this case, that the most impacting step is the production of thermal energy, contributing to 78% of the climate change score.

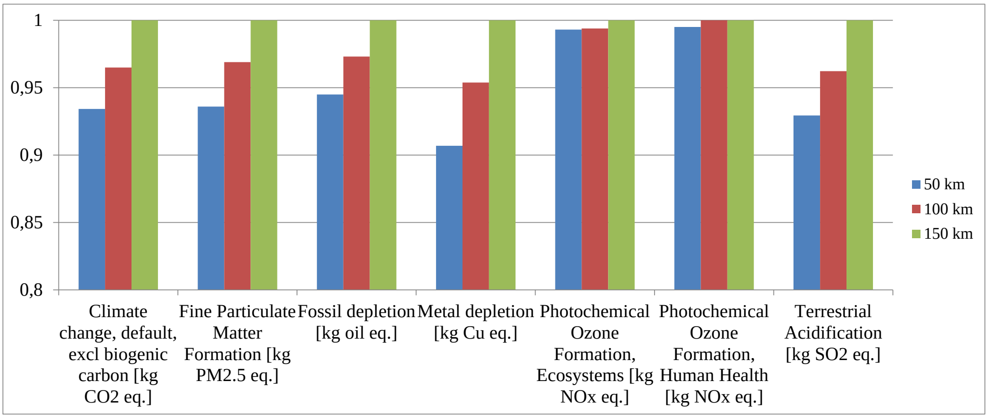

Fig. 4 Influence of the transportation distance on the impact associated to the evaporation of 1 ton of water: characterization results.

Table 3. Influence of transport distance - Characterization results

	50 km	100 km	150 km
Climate change, default, excl biogenic carbon [kg CO_2 eq.]	213	220	228
Fine Particulate Matter Formation [kg $PM_{2.5}$ eq.]	0,0482	0,0499	0,0515
Fossil depletion [kg oil eq.]	84,1	86,6	89
Metal depletion [kg Cu eq.]	0,084	0,089	0,093
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	162	162	163
Photochemical Ozone Formation, Human Health [kg NOx eq.]	100,4	101	101
Terrestrial Acidification [kg SO_2 eq.]	0,147	0,153	0,159

5. Conclusions

As already mentioned in 2011 by Haque [10] in his guest editorial, hopefully LCA will soon become one of the key tools that drying practitioners and R&D personnel will utilize on a regular basis. This very simple case study illustrates that LCA can be used to evaluate the influence on energy production source on the environmental impact. Besides logistical aspects, LCA could also includes the infrastructure (building material options, …), namely in the case where several configurations or technologies could be used. This tool could allow to predict whether energy intensification strategies are really worth and do not lead to impact shifting.

6. References

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