Sustainability assessment applied to an air treatment biotechnology: methodology and results of Life Cycle Assessment.

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Abstract: - Life Cycle Assessment methodology has been applied to the sustainability evaluation of an environmental biotechnology in an eco-design perspective. This to avoid possible shifting of burdens among different environmental matrices possibly occurring when a remediation activity is performed. GHG Protocol and IMPACT 2002+ calculation methods have been applied. Results show that about 80% of the impact generated is to be attributed to energy consumption during the use phase, thus promoting an integration of the technology under study with renewable energy sources. In order to try and consider environmental benefit deriving from air treatment activity, an evaluation of the technology as carbon sink has been performed, comparing results obtained from impact assessment with specific reference. Results obtained suggest that a single bioreactor unit could act as carbon sink equivalent to a number of trees ranging from 43 (high growth rate species), to 268 (low growth rate species).

Key-Words: - Sustainability, LCA, carbon sink, air treatment, biotechnology, bioreactor.

1 Introduction

The eco-efficiency concept was defined by World Business Council for Development (WBCSD, 2000) and it “is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the earth’s estimated carrying capacity”.

In this sense, environmental impact indicators, such as Carbon Footprint (CF) and Life Cycle Assessment (LCA) represent powerful decision supporting tools.

LCA, in particular, results a comprehensive assessment of environmental performances. Society of Environmental Toxicology and Chemistry provided with a definition of LCA in 1993: “Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product or process by identifying and quantifying energy and materials used and wastes released to the environment”. Developed in compliance with UNI EN ISO 14040:2006 [1] and UNI EN ISO 14044:2006 [2], it is generally applied for the assessment of eco-efficiency and environmental impact of product and processes, allowing the quantification of environmental impacts generated throughout the whole life cycle, already during the design phase.

In the eco-design perspective, the implementation of LCA tool enables to tackle the 80% of the overall environmental impact of a product/process. LCA has been only recently used to evaluate innovative remediation solutions for contaminated groundwater and contaminated sites [3, 4], due to difficulties, on one hand, in adaptation of software tools developed to evaluate product, rather than process (such as SimaPro and Gabi), and, on the other hand, in quantification of environmental benefit granted by the clean-up intervention. Timing to meet the remediation goals and lifespan of the technique applied are also critical elements, strongly affecting the tuning of the model.

Within this framework, a screening LCA has been developed to evaluate the biotechnology under study. SimaPro software, version 7.3.3., by Pré Sustainability (2006), has been applied, as compliant with ISO 14040 [1]-14044 [2] standard and assessment procedure proposed by JRC (2007) in International Reference Life Cycle Data System (ILCD) Handbook e General Guide for Life Cycle Assessment and Detailed Guidance [5].

The goal of the present study is to outline an assessment of environmental performance of a biotechnology, in the form of free-standing bioreactors for air treatment as presented by Bonoli and Zanni [6]. The technology is based on immobilized cell bioreactors, working in open air through a combination of convection and biological digestion of materials captured, as leading mechanism.

For the scope of the study, a single bioreactor for households or healthcare sector application, i.e. small size, was defined as functional unit, over supposed 5 years of activity. Due to the lack of specific information and pilot stage of applications followed, end-of-life phase was not taken into account and it will be subject of further iterations and refinements of the assessment. Considering the longer expected life-span of the technology, the choice of recyclable materials from the supply chain (plastic and metals) and the modular design, this assumption appeared reasonable, at a screening phase. Moreover, no benefit, i.e. positive impact, has been accounted for environmental remediation, except for final evaluation as carbon sink (par. 3.3.).

Where no primary data were available from the manufacturer, literature data has been implemented. In order to improve consistency of data, only one database has been used, among different provided by SimaPro software, i.e. Ecoinvent.

Two different calculation methods have been applied, in order to obtain, on one hand, an overall impact assessment, considering different impact categories and, therefore, effects on the environment, provided by IMPACT 2002+, and on the other hand, a single-issue evaluation, focusing on carbon dioxide, both directly and indirectly, and global warming, with Green House Gases Protocol method.

As screening LCA, significant issues have been identified, in terms of impact categories affected by the technology production and use and key processes, triggering the most relevant contributions to environmental impact. In the eco-design perspective, results have been shared with the manufacturing company, in order to implement conclusions from the present study into production activity.

2 Problem Formulation

The technology evaluated for the present study has been developed in the industrial biotechnology field and it is based on immobilized cell bioreactors. The bioreactors tested and currently applied on air treatment are classified as "Immobilized cell bioreactors" and work with a combination of convection and biological digestion of materials captured, as leading mechanism.

The bioreactors, in analogy to bioscrubber technology [7], consist of three phases in close contact (Fig. 1.):

1. a solid phase, which is the bioreactor itself,
2. a liquid phase, i.e. water,
3. a gas phase, that is air (in case of air treatment application, it corresponds with the polluted medium to be treated).

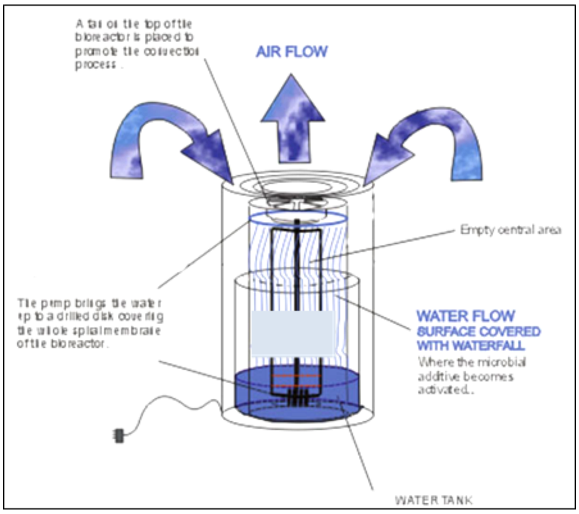

Fig. 1.: Simplified outline of a bioreactor under study (courtesy of U-Earth Biotechnologies s.r.l.)

As in common biofilters, the physical support for biomass growing is offered by a solid medium, but, in this case, a plastic patented bioreactor is provided with optimized configuration [8].

In this case, the air treatment system is based on stand-alone bio-oxidizers providing internal air-mixing within the facility where it is placed and capture particulates and gases by attracting them.

A Life Cycle Assessment is needed, in order to evaluate and quantify the actual environmental impact generated by the production and application of this technology, avoiding possible shifting of burdens among different environmental matrices (e.g. performing remediation over indoor air only to create remarkable impact on water bodies) or locations (e.g. improving air quality at local scale while generating high emissions at global scale).

Compiling Life Cycle Inventory (LCI) represents a major effort, in terms of data collection, processes evaluation, material and energy flows identification and quantification, details definition and simplification decision. Inventory compilation and analysis, in fact, require an extensive data collection and accurate calculations to quantify relevant inputs and outputs of a product system, related to specific functional unit and system boundaries.

As reported by former studies [3], properly accounting the environmental benefits deriving from clean-up activity may be regarded as one of the most challenging aspects of a LCA. In this case, in particular, the technology is applied for a general improvement of indoor air quality and the positive impact should be tuned accordingly to the purpose and standard performance recorded.

3 Problem Solution

Life Cycle Assessment methodology has been applied on the biotechnology under study, following ISO 14040:2006 [1] and 14044:2006 [2].

Within the framework of this study, both primary data (i.e. collected in the production site or provided by the manufacturing company) and secondary data (i.e. collected from manuals, databases and technical specs of similar product currently on the market) have been used.

In order to work on data from literature as coherent and significant as possible, Ecoinvent has been used as only source of database information. As declared by Swiss Centre for Life Cycle Inventory [9, 10], Ecoinvent is aimed to provide a set of generic and unified data, all relevant, reliable and transparent. This to allow easier Life Cycle Assessment, providing public with credible and widely acceptable results.

Life Cycle Inventory was compiled, for the present study and within the framework of a screening LCA, as reported in the following. Several assumption and cut-off decision were necessary in this phase and they will be subject to revision in future iterations of the analysis.

In particular, the process representing the functional unit, i.e. one bioreactor for healthcare application, has been built up on three different phases, as reported in Fig. 1:

1. Production phase
2. Use phase
3. End of Life phase.

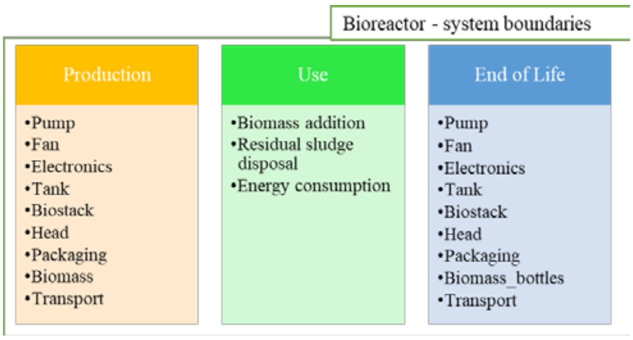

Fig. 2.: Bioreactor, system boundaries for LCA

1. In particular, for the production phase, 8 sub-processes have been modeled on the different bioreactor's components (Fig. 3.):

1.1. Tank: plastic vessel hosting the system, made of granular HDPE, thermoformed in a cylindrical shape, open at the top. The tank is, then, varnished with a PVC layer as decalcomania. Since no specific primary data was available, a rough estimation was performed.

1.2. Head: metal topping, hosting the fan and electronics. It has been modeled as a top cover, of cylindrical shape, of steel, manufactured by deep-drawing and finished with powder coating. Materials and processes are taken from Ecoinvent database and data are calculated on the basis of manufacturer primary data.

1.3. Biostack: inner plastic structure, with two primary functions, with different parts and materials involved: support for biomass growth, by two cylinders of HDPE with different diameter and holes; water circulation, by top plate of polyurethane, with different holes to allow water trickling down on vertical surfaces, and pump outlet.

1.4. Fan: ventilation system, providing oxygen to the system, which has been modeled by assimilation with processes already implemented into Ecoinvent, referring to average products available on the market. Focusing on the time-span of the study, i.e.5 years, maintenance occurrences are expectable and, therefore, n.2 fans have been included into the inventory.

1.5. Pump: recirculation pump, responsible for water flow inside the system, which has been modeled by assimilation with processes already implemented into Ecoinvent, referring to average products available on the market. Focusing on the time-span of the study, i.e.5 years, maintenance occurrences are expectable and, therefore, n.5 pumps have been included into the inventory.

1.6. Electronics: electronic control system, responsible for water supply electrovalve, overflow valve and system's control. several assumptions were necessary:

1.6.1. Touchscreen was simulated as a LCD screen of equivalent size, since no specific process is present on Ecoinvent version 2.2;

1.6.2. Wiring board was modeled on the basis of size and average weight data and, considering possible maintenance, n.2 have been included in the inventory;

1.6.3. The power adapter implemented is a laptop power adapter, since it is a multifunctional device and, considering possible maintenance, n.2 have been included in the inventory;

1.6.4. Supplementary electronics are simulated as electric cable and clamp connector;

1.6.5. The stick water level sensor has no direct equivalent into Ecoinvent database, therefore a model was built up over a potentiometer connected to electric steel sticks.

1.7. Packaging: corrugated cardboard box, shockproof material and plastic film. Due to the lack of primary data, several estimations were necessary; moreover, since quantities derived were negligible and it is currently a hand-made operation, a cut-off was applied on packaging process.

1.8. Biomass monodose: bacteria consortium of proprietary recipe, added to the system every 30 days. Only partial information was available to be included into the present study:

1.8.1. the biomass is strictly of natural origins;

1.8.2. no GMO (i.e. Genetically-Modified Organism) is included within the bacterial consortium;

1.8.3. no chemical is added;

1.8.4. water is the main constituent of the suspension;

1.8.5. production site is located in New Mexico, US. This allowing to estimate air transport in about 9,000 km.

In addition to this, it must be considered that the amount of U-ox added to the system is typically 1.2 l per year, except for the first year, when two additional mono-dose are necessary for the start-up. Considering the time-span proposed for the study, it corresponds to 6.2 l. In this perspective, with small volume involved and, in comparison with the expected impact deriving from air transport, a cut-off of the elaboration process is considered acceptable.

Since no specific data on each single part supply chain was available, and being the manufacturing company still in a start-up phase, with consequent work-in-progress approach to production, a generic transport process has been outlined, considering the overall weight of the bioreactor, as declared on shipping documents, as transported for average distance normally considered for European Union (i.e. 200 km).

Fig. 3.: Exploded graphic of a commercial bioreactor (courtesy of U-Earth Biotechnologies s.r.l.)

2. For the use phase, four main aspects have been considered: energy consumption, water consumption, biomass addition with consequent disposal of mono-dose bottles and residual sludge disposal. Since no specific information is available regarding CO_2 release by bacterial respiration, but it is reasonably regarded as negligible, this aspect has not been taken into consideration.

2.1. The expected electricity consumption during the use phase was considered as if the technology were applied in Italy. Therefore, the energy production mix implemented is considered as Italian Country Mix process included in Ecoinvent. This proved to be a conservative assumption, compared with the average European mix. Further iteration could focus to specific application and geographical framework. The energy consumption of the bioreactor has been taken into account, starting from a yearly consumption of 259.15 kWh, for the entire use phase expected, i.e. 5 years (as defined, conservatively, as time-span of the project).

2.2. Water consumption has proven to be highly dependent on the different application of the bioreactor, but, for the present study, it has been estimated in 30 l per month, leading to 1800 l of water (modeled as tap water, of drinking quality.

2.3. The biomass addition is performed manually and, therefore, the specific process has been cut-off. The mono-dose plastic bottles have been included as disposal process for PET in municipal incineration, i.e. considering the *worst case scenario*, compared with recycling opportunities. In particular, from Ecoinvent database, the process for municipal incineration of polyethylene terephtalate, 0.2% water has been accounted for 1.24 kg, corresponding to n.62 bottles for 5 years of the life-span of the technology.

2.4. The residual sludge is generated by bioreactor's activity and it is composed mainly by water, sacrificed biomass and minerals derived by airborne pollutants digestions. Consequently, a disposal process has been modeled on the basis of wastewater treatment sludge disposal process included in Ecoinvent database.

3. For the End of Life (EoL) scenario, different processes have been defined, in parallel with production phase modeling:

3.1. A generic transport process has been outlined, considering the overall weight of the bioreactor, as declared on shipping documents, as transported for average distance normally considered for European Union (i.e. 200 km);

3.2. Bioreactor's components have been accounted as dismantling and disposal processes, as reported in Table 2, considering the amount included into the original bioreactor's production and spare parts necessary for expected maintenance. A cut-off has been made on "Head" disposal process: since it is entirely constituted in polished steel, a high recyclability rate is expectable and, therefore, it has been taken into account only for transport.

3.1 Calculation method

The calculation method applied is IMPACT 2002+. The IMPACT 2002+ (IMPact Assessment of Chemical Toxics) calculation method has been developed by Swiss Federal Institute of Technology - Lausanne (EPFL, now Ecointesys-life cycle systems). Its most distinctive feature is the implementation of a combined midpoint/damage approach, relating LCI results (i.e. elementary flows) to 4 main damage categories through 14 midpoints indicators.

As required by ISO 14040:2006 [1] and ISO 14044:2006 [2], comprehensive Life Cycle Impact Assessment shall include several mandatory elements, such as the selection of impact categories and characterization models, the assignment of results obtained with LCI to the specific impact categories (i.e. Classification phase) and consequent quantification of category indicators (i.e. Characterization). For the present study, additional elaborations have been performed, by the application of Normalization and Weighting, in order to obtain results easier to communicate and share with manufacturer, to promote design effort to improve environmental efficiency of the bioreactor system.

Typically, during Characterization phase, LCI results are converted, by the application of specific factors, to a common unit and aggregated for impact categories.

Applying SimaPro software, a modified methodology is used: characterization factors for human toxicity and aquatic and terrestrial ecotoxicity, in fact, are taken from directly IMPACT 2002+, while factors for other categories are adapted from other methods (i.e. Eco-indicator 99, CML 2001, IPCC and Cumulative Energy Demand) and human toxicity is split up in 'Carcinogens' and 'Non-carcinogens'.

Normalization phase is focused on defining the relative magnitude for each indicator result of the product system: each categories' results is, therefore, referred to a reference information, making them dimensionless and, consequently, allowing comparisons.

The Weighting phase involves numerical factors to be attributed to each category on the basis of choice-value.

3.2 Impact assessment results

Impact assessment results obtained with the application of Simapro software are reported in the following, first with regards to the general bioreactor process, comparing the relative impact of the three phases modeled, i.e. Production, Use and End of Lofe, then with details of sub-processes created for each phase.

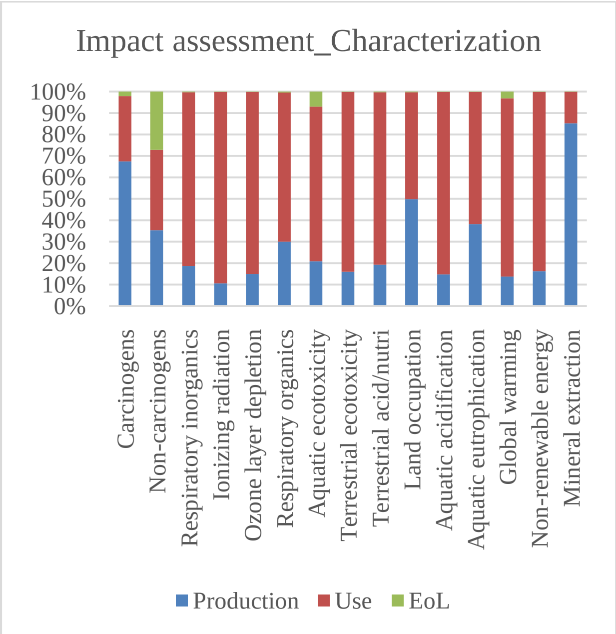

Fig. 4.: Impact assessment results on bioreactor's system (including Production, Use and End of Life), characterization.

Figure 4 reports impact assessment results for Characterization, while Figure 5 reports Weighting results.

Focusing on the CO_2 equivalent impact, results identified bioreactor contribution in about 1 ton of CO_2 equivalent over the 5-year time-span accounted to the technology.

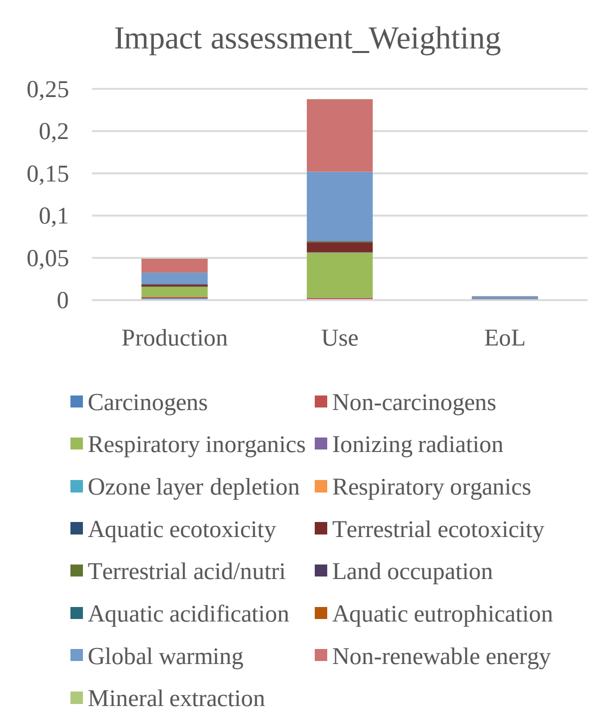

Fig. 5.: Impact assessment results on bioreactor's system (including Production, Use and End of Life), weighting.

As evidently displayed by graphics, Use phase generates the major environmental burden. Global Warming and Non-renewable energy utilization, together with Respiratory Inorganics category account for more than 90% of the overall impact and the Use phase process is directly responsible for the most part of them (about 80%).

In the following Table 2, relative impacts are attributed to the three life-phase for each impact categories. The average relative impact attributed to Production phase is 30.1% as average, while the Use phase carries the 67.1% of the total impact for each category and the End of Life generates less than 3% of the overall impact, as envisaged from Fig. 5. In particular, as evident from Fig. 4 and Table 2, the Use phase produces more than ¾ of impact for Respiratory Inorganics, Ionizing Radiation, Terrestrial Ecotoxicity, Terrestrial and Aquatic Acidification, Global Warming and Non-renewable Energy.

Tab. 2.: relative impacts attributed to the different impact categories

Impact categories	**Production**	**Use**	**EoL**
Carcinogens	67,5%	30,4%	2,1%
Non-carcinogens	35,4%	37,4%	27,1%
Respiratory inorganics	18,6%	81,1%	0,3%
Ionizing radiation	10,6%	89,2%	0,2%
Ozone layer depletion	15,0%	84,9%	0,1%
Respiratory organics	29,9%	69,7%	0,4%
Aquatic ecotoxicity	20,9%	72,1%	7,0%
Terrestrial ecotoxicity	16,0%	83,9%	0,1%
Terrestrial acid/nutri	19,3%	80,3%	0,4%
Land occupation	49,8%	49,9%	0,3%
Aquatic acidification	14,8%	85,0%	0,2%
Aquatic eutrophication	38,2%	61,7%	0,1%
Global warming	13,8%	83,1%	3,1%
Non-renewable energy	16,3%	83,6%	0,1%
Mineral extraction	85,3%	14,7%	0,1%

Over 1/3 of the overall impact is represented by tank, pump and electronics production. Electronics, in particular, account for more than 50% of the impact category of aquatic ecotoxicity.

The biomass production and transport accounts for about 45% of the total impact generated by the production phase. Focusing on this aspect, freight transport on aircrafts proved to be the primary impact source (Fig.7). Given the limit represented by the lack of information on biomass preparation, this suggests that, in the eco-design perspective, the opportunity of a de-centralized production of the biomass would be crucial to enhance the environmental performance of the technology.

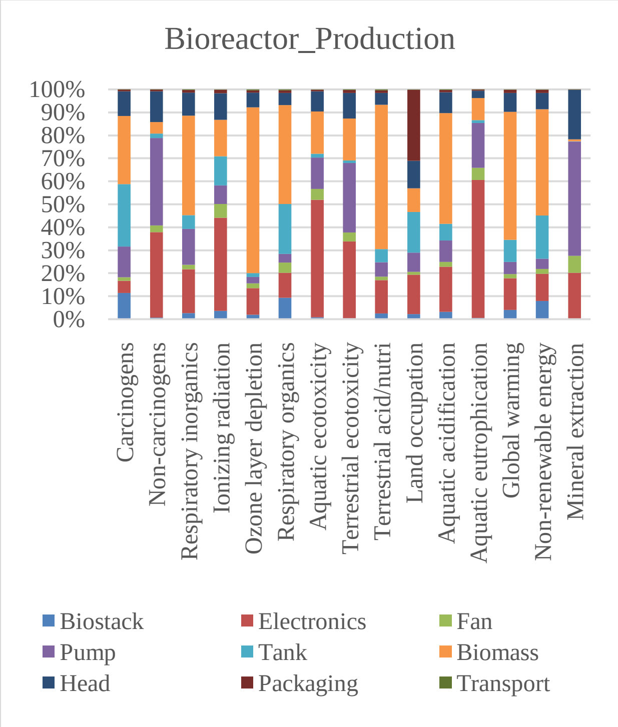

Fig. 6.: Impact assessment results, production phase, characterization.

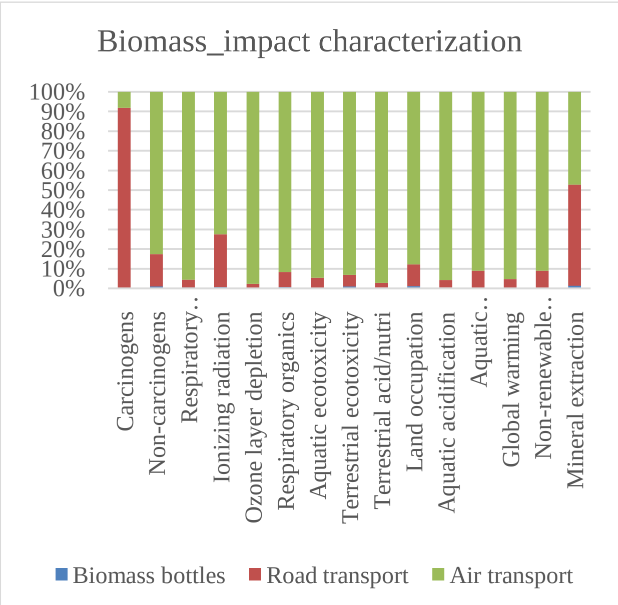

Fig. 7.: Impact assessment results, biomass production and transport, characterization.

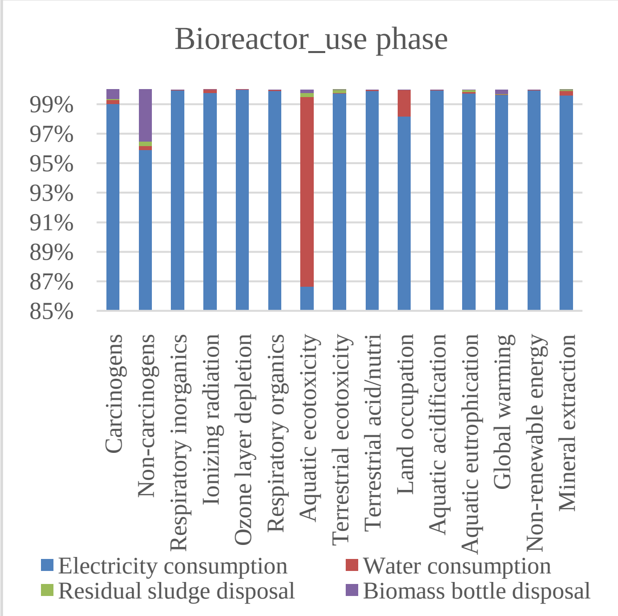

Fig. 8.: Impact assessment results, use phase, characterization.

As evident in Figure 8, Energy consumption accounts for over 95% of the overall environmental burden for each impact category, except aquatic ecotoxity, where the water consumption displays a 10% of the impact.

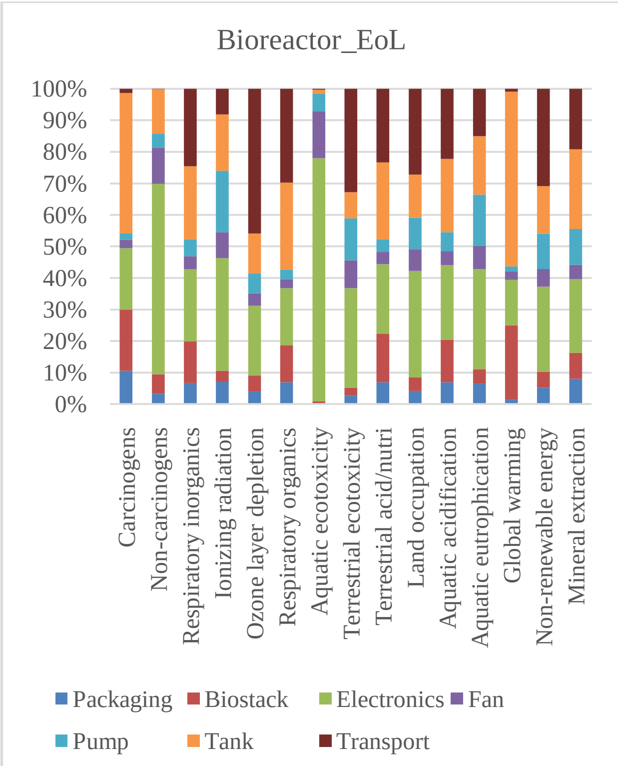

Fig. 9.: Impact assessment results, production phase, weighting.

Electronic components disposal account for the major impact on non-carcinogens pollutants and for more than 70% for aquatic ecotoxicity, due to potentially harmful substances included. Ozone layer depletion is affected for about 45% by road transport, related to fossil fuel combustion.

3.3 Carbon sink evaluation

In order to try and assess the environmental burden actually posed by the biotechnology implementation, at present (i.e. with energy consumption affecting the overall performance by 80%), the benefit deriving from air treatment performed should be considered. In particular, greenhouse gases sequestration, in terms of CO_2 equivalent, is considered. Even thought the bioreactor is not able to sequestrate CO_2 and it release a small amount of it, due to bacterial respiration, it works on treatment and mineralization of other gases, with a greenhouse potential of their own. Based on information provided by the manufacturer, each bioreactor can capture up to 3.5 kg of airborne contaminants per day. Considering a theoretical scenario, with air pollution represented only by VOC, it could be assessed that a single bioreactor unit should be able to treat up to 3.5 kg of VOCs per day. With a rough estimation, i.e. attributing to the VOCs an average Global Warming Potential related to CO_2 equal to 1 (which is a rather conservative assumption, as reported by IPCC [13]), the bioreactor should be able to sequestrate up to 1277.5 kg CO_2 equivalent per year.

This result, compared with the impact calculated, i.e. 193.6 kg CO_2 equivalent per year, returns a net CO_2 equivalent uptake of about 1083.9 kg per year, which can be regarded as quite a remarkable result, even considering limitations of the present study.

An additional comparative evaluation may support the definition of the overall environmental performance, i.e. comparison of the estimated CO_2 equivalent uptake of a bioreactor unit with trees, as typical carbon sinks. In fact, as clearly defined by several studies, they are able to absorb carbon dioxide from the atmosphere, releasing it only partially through night respiration and storing the rest in various organic compounds. Based on most recent results presented by Proietti et al. [12], trees may store from 4.048 (e.g. oak) to 25.391 (e.g. walnut, poplar) kg CO_2 per year per plant, over the a 14-year time-span, considering both standing and accumulated biomass.

These data, compared with results obtained for the bioreactor allow to compare the biotechnological system performance with a number of trees ranging from 43 (42.68), in case of high growth rate species (e.g. walnut, poplar), to 268 (267.76) in case of low growth rate trees (e.g. oaks).

Considering an average tree density spanning from 230 to 455, as proposed by Khan and Chaudhry [14] (Table 2), it could be assessed that the CO_2 net uptake of 1 hectare of properly spaced (i.e. about 300 trees/ha) trees is equivalent to:

- n. 1 bioreactors, in case of low growth rate species,
- n. 7 bioreactors, if high growth rate species are involved.

Table 2: Bioreactor unit/trees equivalence.

Trees density/ha	**High growth rate species (walnut, poplar)**	**Low growth rate species (oak)**
230 (3.7X12.2 M)	5.4 bioreactor unit	0.9 bioreactor unit
455 (3.7X6.1 M)	10.7 bioreactor unit	1.8 bioreactor unit

4 Conclusion

A screening LCA was accomplished considering production and use phase of a single bioreactor unit. The assessment performed implied several assumptions, simplifications and cut-off, mostly related to:

1. use of standard Ecoinvent database processes to simulate where a lack of primary data was recorded
2. cut-off of biomass elaboration processes, due to proprietary recipe involved

It returned, nevertheless, interesting results, both in terms of impact categories affected and processes triggering the major environmental impacts.

In particular, energy consumption of the device during the use phase proved to develop the major environmental burden (around 80% of the total), confirmed by GHG Protocol and IMPACT 2002+ method. Therefore, the energy production mix used in the specific context of application, is crucial to define the overall impact and measures could be taken accordingly, as to obtain a remarkable reduction.

At the same time, biomass freight transport from the production site, located in New Mexico, US, heavily affects the global warming effect, as well as respiratory contaminants release, suggesting that a modified logistic would ensure a better environmental performance at the production stage. In particular, in an eco-design and scale-up perspective, a de-localized production network would ensure an improved sustainability as well as contained logistic costs. More detailed information are required about biomass preparation, since, at this stage of development, the study remains incomplete.

A proper interpretation of results required to take into consideration that a remediation technology is involved, and, therefore, that and environmental benefit should be generated by its application. For this reason, a rough comparison has been performed between net impact, i.e. combining negative and positive impacts, in terms of CO_2 equivalent, provided by bioreactor unit and typical carbon sinks, i.e. trees with different growth rate. The main limit of this approach is represented by the necessity to convert the typical pollutants treated by the bioreactor and CO_2, as greenhouse gas. Further iteration of the study would require more detailed information about the actual treatment potentiality of the bioreactor, in order to obtain a finer and more realistic comparison. Results obtained suggest that a single bioreactor unit could act as carbon sink equivalent to a number of trees ranging from 43, in case of high growth rate species (e.g. walnut, poplar), to 268, in case of low growth rate trees (e.g. oaks).

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Tab. 1: End of Life process modelled for bioreactor's parts, in parallel with production phase

Bioreactor's components	Process	Amount	Unit	Notes
U-ox bottles	Disposal, polyethylene terephtalate, 0.2% water, to municipal incineration	1,24	kg	Assumption of 20 gr per bottles, n.62 bottles
Electronics	Disposal, power adapter, external, to WEEE treatment	2	p	Assumption: n.2 power adapter in order to consider possible maintenance
	Disposal, treatment of printed wiring boards	74	g	Assumption: n.2 wiring boards in order to consider possible maintenance
	Dismantling, LCD screen, manually	65	g	Modeling from standard Ecoinvent process
	Disposal, LCD flat screen, to WEEE treatment	0,294118	p	Modeling from standard Ecoinvent process
	Dismantling, IT accessoires, mechanically	300	g	Connectors and cables
	Disposal, treatment of cables	200	g	
Fan	Dismantling, IT accessoires, mechanically	436	g	Assumption: n.2 fans in order to consider possible maintenance
	Disposal, industrial devices	436	g	Assumption: n.2 fans in order to consider possible maintenance
Tank	Disposal, polyethylene, 0.4% water, to municipal incineration	5,076766	kg	
	Disposal, polyvinylchloride, 0.2% water, to municipal incineration	0,1	kg	Printed decalcomania disposal
Biostack	Disposal, polyethylene, 0.4% water, to municipal incineration	2	kg	
	Disposal, polyurethane, 0.2% water, to municipal incineration	0,25	kg	
Packaging	Disposal, packaging cardboard, 19.6% water, to municipal incineration	1,1025	kg	Undefined
	Disposal, PVC sealing sheet, 1.64% water, to municipal incineration	0,05	kg	Undefined
	Disposal, plastics, mixture, 15.3% water, to municipal incineration	0,1	kg	Undefined

Bioreactor's components	Process	Amount	Unit	Notes
Pump	Dismantling, industrial devices, mechanically	1	kg	Assumption: n.5 pumps in order to consider possible maintenance
	Disposal, industrial devices	1	kg	Assumption: n.5 pumps in order to consider possible maintenance
	Disposal, polyvinylchloride, 0.2% water, to municipal incineration	0,070281	kg	Modeling from standard Ecoinvent process of plastic tubes