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## METHODOLOGY FOR THE ECOCONCEPTION OF AN INNOVATIVE PROCESS: A BIOELECTROSYNTHESIS FROM ORGANIC WASTE

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### Abstract

Bulk chemicals and liquid fuels are currently produced almost exclusively from petrochemical feedstock. In the light of emission reduction targets and the dependence on non renewable resources, the production of the same or functionally equivalent chemicals from renewable resources may play an important role [1, 2]. The project BIORARE (Bioelectrosynthesis for the refinery of residual waste) was set up to contribute to this objective. Its purpose is to use microbial electrosynthesis for the direct production of fuels and chemicals from organic waste and CO<sub>2</sub> (see figure 1).

Ecoconception is used to help to make choices. This is this work which is study.

In a first step, we had to determine which parameters of the Bioelectrosynthesis (BES) could be the most impacting ones to define the priorities to be considered to minimize the potential impacts of the entire process. Some flows could be sensitive: the nature and the quantity of outputs, the nature and the quantity of materials, and the amount of energy used.

The inventory of these flows had to be the first step. Thanks to databases and literature four have been identified as sensitive: electrodes, membrane, energy and chemicals produced.

After determining this, we have to design the model for coupling anaerobic digestion to the BES. This was realized using Life Cycle Assessment approach. The goal of this assessment is to determine the relative influence of various target parameters on the impacts of the process. For example, results will allow assessing if the choice of a material for the electrode could have a significant influence on total impacts.

Our methodology illustrates to what extent Life Cycle Assessment could help for the conception of a process, through the evaluation of the contribution of various parameters to the impacts. After, it is possible to integrate them into a model to determine what impacts they could have on the whole production chemicals or fuels from organic waste system.

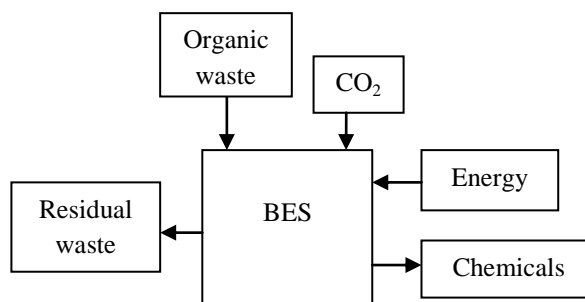


Figure 1

## 1- INTRODUCTION

Bulk chemicals and liquid fuels are currently produced almost exclusively from petrochemical feedstock. In the light of emission reduction targets, production of the same or functionally equivalent chemicals from renewable resources ("bio-based chemicals") may play an important role in decreasing our environmental impact and reducing our dependence on non-renewable fossil resources [1, 2]. The sustainability of these bio-products is however substantially determined by the choice of the feedstock and their production process, which may have strong implications for food production as well as for the eventual reduction of greenhouse gas emissions. In this context, using organic waste for bio-based chemicals production represents an attractive option because of high potential for fossil fuel displacement and low feedstock costs.

The BIORARE (Bioelectrosynthesis for the refinery of residual waste) project relies on a new and potentially disruptive technology: microbial electrosynthesis. It has indeed been shown that it is possible to directly power microbial activity with electricity in order to catalyse microbial reductions leading to the synthesis of organic molecules. This opens the door to one of the most exciting technological application: the direct production of bio-based chemicals from electricity organic waste.

However, bioelectrosynthesis processes are not technologically mature and this situation therefore also constitutes an opportunity for an early integration of environmental constraints for the design of the process. This is an eco-design approach. To achieve the eco-design of this process, some skills are needed: microbiology and electrochemistry of course but also environmental sciences. A transversal work package of BIORARE project focuses on the eco-design approach. The aim is to help the consortium to eco-design the bioelectrosynthesis process. In this work package, different tasks take place but this paper focuses on one of them: the sensitivity analysis of some bioelectrosynthesis process parameters through a Life Cycle Assessment (LCA) approach.

In this paper, the methodology of the sensitivity analysis through a LCA approach is first presented and implementation rules for the analysis of bioelectrosynthesis are described. Then the results of the sensitivity analysis for some targeted parameters are explained. For each parameter, some conclusions are given in an eco-design perspective.

## 2- MATERIALS AND METHODS

### 2.1 Description of the sensitivity analysis methodology

In order to help BIORARE project consortium to eco-design the bioelectrosynthesis process, it appears necessary to identify, first at the process scale, the sensitive parameters. These parameters combine uncertainty for their absolute value and high environmental impacts. For that, it has been chosen to lead a sensitivity analysis through a Life Cycle Assessment approach. Life Cycle Assessment (LCA) is the « compilation and evaluation of

the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle » [4]. ISO standards [3, 4] and ILCD Handbook [5, 6] provide a frame and guidelines on how to do a LCA study. It is possible to assess around ten main environmental impact categories for a system [5]: toxicity; climate change; photochemical ozone formation; marine, fresh water, and terrestrial ecotoxicity; depletion of the ozone layer; depletion of abiotic resources, acidification and eutrophication.

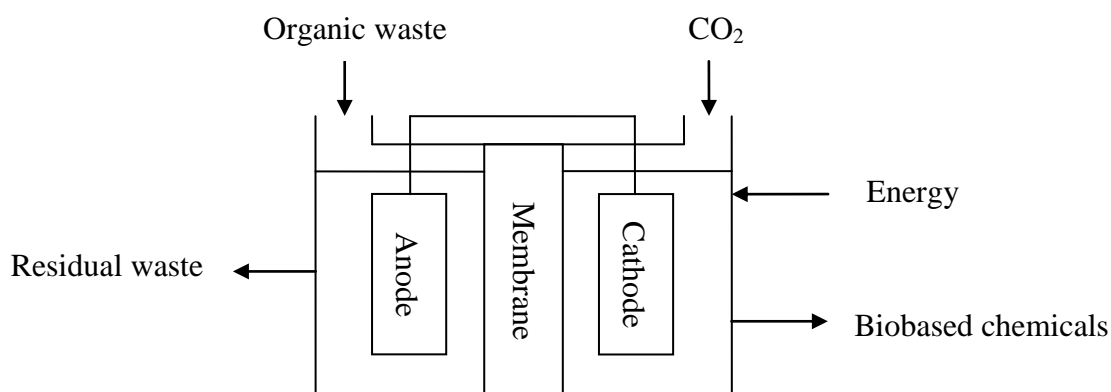
LCA results are highly dependent of data collection and modelling assumptions for the studied system. So performing, during the LCA realization, a sensitivity analysis on data values (e.g. quantity of matter or energy) or assumptions (e.g. energy yield) is usual. Classically in LCA, it is possible to carry out a sensitivity analysis thanks to two methods:

- A simple variation of each assumed sensitive parameter according to its different target values or its different target materials and by “holding all else constant” (*Ceteris paribus* clause);
- A Monte Carlo analysis of a set of independent parameters according to a range of values for each parameter.

The main difference between both sensitivity analysis methods is the independent nature of the tested parameters. Besides Monte Carlo analysis is interesting when a lot of parameters have been tested.

## 2.2 Implementing rules for the sensitivity analysis of bioelectrosynthesis

The first step to implement rules for the sensitivity analysis of BES is the understanding of the BES process. The principle of BIORARE project is to insert a bioelectrosynthesis step in a classical waste treatment scenario including pre-fermentation and anaerobic digestion steps. The pre-fermentation provides the substrate for BES (volatile fatty acids (VFA)) and anaerobic digestion provides the energy (from biogas recovery) and the CO<sub>2</sub> (from digestion process) for BES. The goal of the BES is to use microorganisms to transform a part of the organic waste into bio-based chemicals of interest (Figure 1).



**Figure 1:** Description of the studying process

There are two compartments in the BES part: the anode and the cathode. There is one electrode in both compartments where reactions take place. A membrane separates these two parts of the BES system. In the BES, microorganisms transform these VFA into electrons,

which are transported to the cathode. In this cathodic compartment, carbon dioxide and electricity are added to produce the target bio-based chemical. Finally, BES system allows a cathodic biochemical production and an anodic organic waste treatment.

The second step to implement rules for the sensitivity analysis of BES is the identification of the assumed sensitive parameters. In this case study, only the nature and the quantity of BES inputs and outputs are considered as parameters. More precisely the nature and the quantity of electrode, of membrane, of energy and of bio-based chemicals are concerned. Each of these parameters is described and its sensitive nature is characterized (Table 1).

**Table 1:** Parameters listed in the BES and assessment of their sensitivity

Targeted parameters	Feature	Sensitive: yes or no
Membrane material	Just one type available in LCA databases	Yes but untestable because of the lack of data on this topic [7,8]
Mass of membrane	Membrane surface is proportional with the electrode surface	Yes (see § 3.3)
Electrode material	Two electrodes used: stainless steel and carbon cloth available in LCA databases	Yes because of the assumed strong difference between the impacts of the production of these two materials
Mass of electrode	Electrode surface is proportional with the surface of membrane	Yes but the test of the mass of membrane is enough
Type of produced bio-based chemicals	Six molecules identified	Yes because the type of expected molecules is assumed to influence highly the process control
Quantity of electricity	From anaerobic digestion	The source of electricity and CO <sub>2</sub> is the treatment of organic waste and so both present zero burden assumption (zero environmental impacts). Both inputs are not considered like sensitive flows and they are considered as two intermediate flows
Quantity of Carbon dioxide		

This table shows why parameters are sensitive or not. Indeed, for the flows electricity and carbon dioxide, anaerobic digestion before the BES gives a renewable origin. They are just intermediate flow, so they have no impacts and cannot be sensitive.

The parameter “quantity of electrode” is sensitive because it is directly proportional with the quantity of membrane which is sensitive. So assess the influence of one of this parameter is enough.

For the nature of the membrane it is different. It is difficult to study its (certain) influence because there is only one available membrane in LCA databases. This restriction and the confidentiality of recent processes force to remove this parameter from tested ones.

So the influence of three parameters is assessed: the choice of chemicals, the material of electrode and the quantity of membrane.

A sensitivity analysis is led on these parameters of the bioelectrosynthesis process in order to identify the order of magnitude of the variation for their environmental impacts. The environmental impact quantification is performed by the use of a characterization method, CMLIA (2010 version). It is a common characterization method used in LCA. It translates inputs and outputs of a process in ten potential environmental impacts.

### 3- RESULTS AND DISCUSSION

The sensitivity analysis method has been chosen. It appears that it is not necessary to make a Monte Carlo analysis to test few parameters. So for each of the three sensitive parameters, a simple variation analysis is performed.

#### 3.1 Targeted bio-based chemicals for electrosynthesis

In order to eco-design the BES process, it is essential to choose the expected bio-based chemical. Indeed, the interest of including BES step in an organic waste treatment scenario is to produce a chemical of which conventional production has strong environmental impacts.

The first work package of BIORARE project aims to identify which bio-based chemicals could be produced from organic waste through a BES step. Six potentially interesting chemicals were selected: butanediol, butanol, acrylic acid, glycerin, acetic acid and ethanol. These targeted chemicals have been environmentally compared to choose which one could be replaced by the one produced by the BES.

The environmental analysis involves comparing the production of 1 kg of these different chemicals produced according to a “classical” way (e.g. from petro-chemical resources). The goal is to determine which one presents the highest environmental impacts. Indeed in that case, chemicals produced by BES could replace one produced by an impacting process.

In the table 2, in each row, the reference (100%) is given to the most impacting process. Percentages of the other chemicals are calculated according to this reference.

Impact Category (CML 2001)	Unit	1,4-butanediol	1-butanol	Acrylic acid	Glycerin	Acetic acid	Ethanol
Climate Change (CC)	kg CO <sub>2</sub> -Equiv.	100	51	44	-19	30	1
Abiotic Depletion (AD)	kg Sb-Equiv.	31	64	63	9	100	62
Acidification (A)	kg SO <sub>2</sub> -Equiv.	85	56	40	10	53	100
Eutrophication (E)	kg Phosphate-Equiv.	5	27	9	5	25	100
Human Toxicity (HT)	kg DiChloroBenzene-Equiv.	9	57	50	11	100	55
Ozone Layer Depletion (OD)	kg R11-Equiv.	2	87	7	24	100	65
Photochem. Ozone Creation (POC)	kg Ethene-Equiv.	36	100	38	6	64	23
Freshwater Aquatic Ecotoxicity (FAET)	kg DCB-Equiv.	2	33	33	11	89	100
Marine Aquatic Ecotoxicity (MAET)	kg DCB-Equiv.	11	40	37	10	100	39
Terrestrial Ecotoxicity (TET)	kg DCB-Equiv.	15	28	24	6	49	100

Table 2: Percentage of impact for each impact category and each process

Less than 50%	Between 50 and 75%	Between 75 and 100%	100%
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This table is just a resume of the total study on the choice of chemicals. It shows main results:

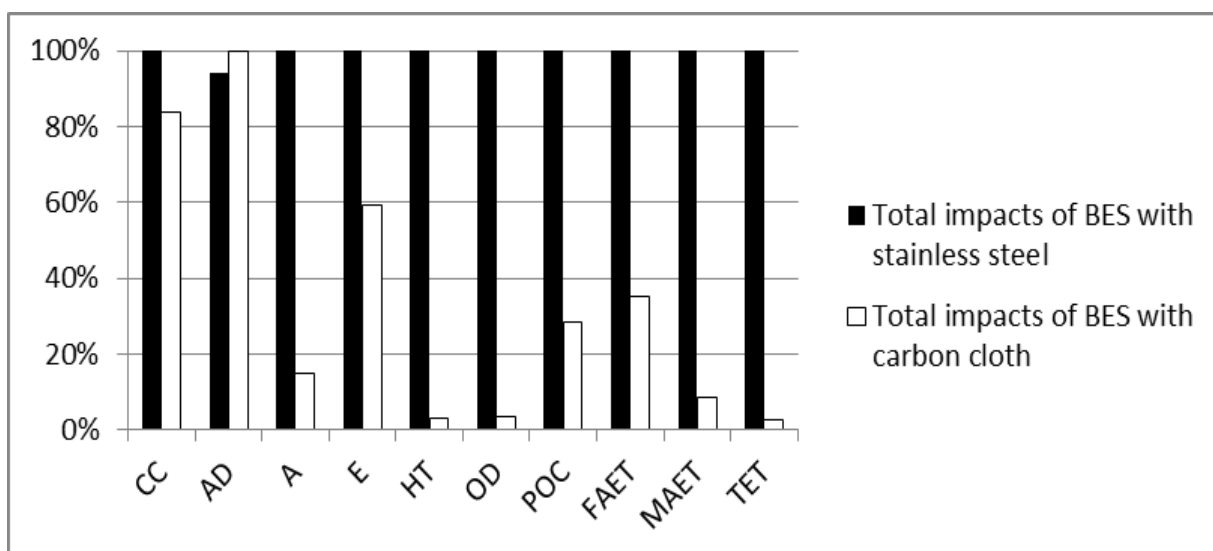
- Two chemicals do not present high environmental impacts: Acrylic acid and Glycerin;
- Two chemicals present high environmental impacts in more than four impact categories: Acetic acid for five impact categories and Ethanol for four impact categories;
- Two chemicals present high environmental impacts only for two impact categories: 1,4-butanediol and 1-butanol.

A basic interpretation could orient the choice on Acetic acid or Ethanol. However it is not so easy to conclude because the different chemicals tested do not present high or low results for the same impact categories. A weighting method for the impact categories could allow the consortium to arbitrate between the different impacting chemicals. For the moment, no use of weighting method is provided. The consortium could select to use a weighting method or to focus on political environmental priority (e.g. like climate change or resources depletion).

### 3.2 Material of electrode

Two kinds of common electrode have been chosen: stainless steel and carbon cloth according to technical constraints. To study the influence of the material of the electrode, others parameters must be fixed (*Ceteris paribus* clause). So, ethanol has been chosen as chemical and the ratio between membrane surface area and electrode surface area ( $r$  in  $\text{m}^2/\text{m}^2$ ) has been fixed at  $2 \text{ m}^2/\text{m}^2$ .

Figure 2 shows results of this study. The CML-IA method has been used with ten impact categories (previously explained). The reference in each category is the total impact of the BES for the most impacting choice.



**Figure 2:** Influence of the material choice of the electrode on impacts of the BES

CC: Climate Change; AD: Abiotic depletion; A: Acidification; E: Eutrophication; HT: Human toxicity; OD: Ozone layer depletion; POC: Photochemical ozone creation; FAET: Fresh water aquatic ecotoxicity; MAET: Marine aquatic ecotoxicity; TET: Terrestrial ecotoxicity

It has been considered that a 20% gap between these two scenarios is significant. So, in one hand, stainless steel appears as the most impacting choice for the electrode in eight categories. In other hand, there is almost no difference between these two scenarios for abiotic depletion and climate change. But clearly stainless steel is more impacting than carbon cloth. This is an expected result and confirms that when stainless steel is used, total impacts of the whole process are bigger.

### 3.3 Mass of membrane

It is impossible for us to model different membrane materials because of a lack of data on the impact of various membrane materials. Therefore, we used a classical material for the membrane: an anionic resin based on divinylbenzene and we chose to vary its quantity. Its quantity is a function of the electrode surface.

The mass of membrane is calculated thanks to the equation (1):



$$m_m = s_e \cdot r \cdot \rho_m \cdot e \quad (1) \quad \text{with :}$$

$m_m$  : membrane mass (kg)

$s_e$  : electrode surface area (m<sup>2</sup>)

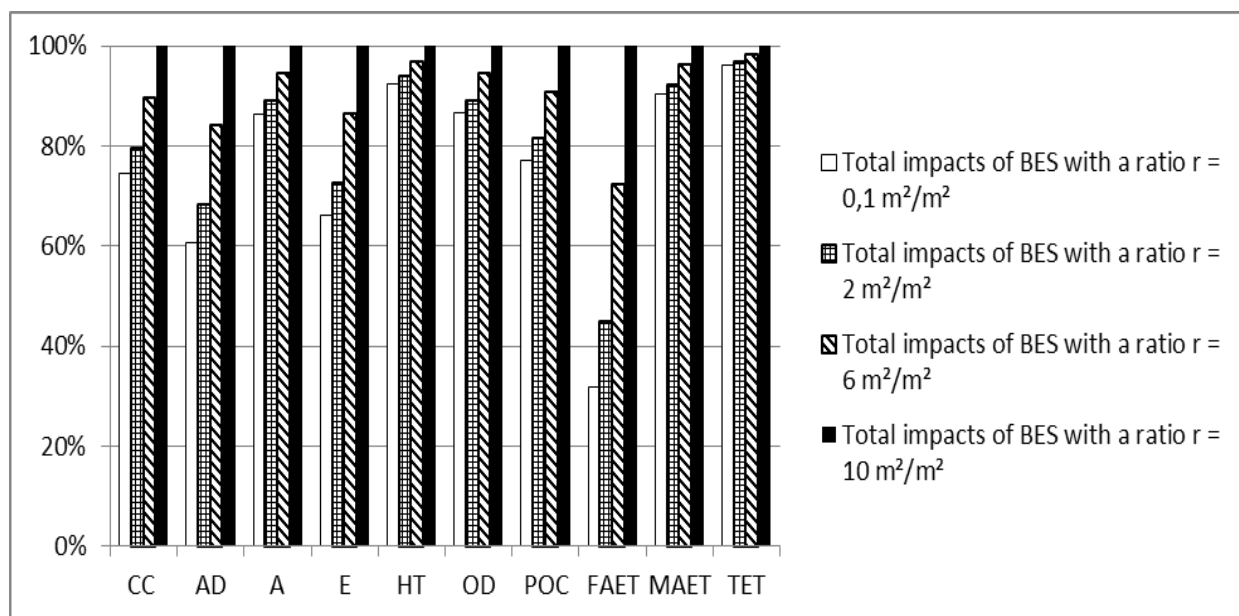
$r$  : ratio between membrane surface area and electrode surface area (m<sup>2</sup>/m<sup>2</sup>)

$\rho_m$  : membrane density (kg/m<sup>3</sup>)

$e$  : membrane thickness (m)

This is the ratio  $r$ , which will be changed to assess the influence of the membrane mass on environmental impacts. Four values have been chosen according to experts in BIORARE consortium: 0,1; 2; 6 and 10 m<sup>2</sup>/m<sup>2</sup>. To respect the *Ceteris paribus* clause, ethanol is chosen for chemical and stainless steel for the electrode material.

Figure 3 shows results of this study. The CML-IA method has been used with ten impact categories (previously explained) and for each category, the reference used is the total impact of the ratio 10 m<sup>2</sup>/m<sup>2</sup>.



**Figure 3:** Influence of the mass of the membrane on impacts of the BES

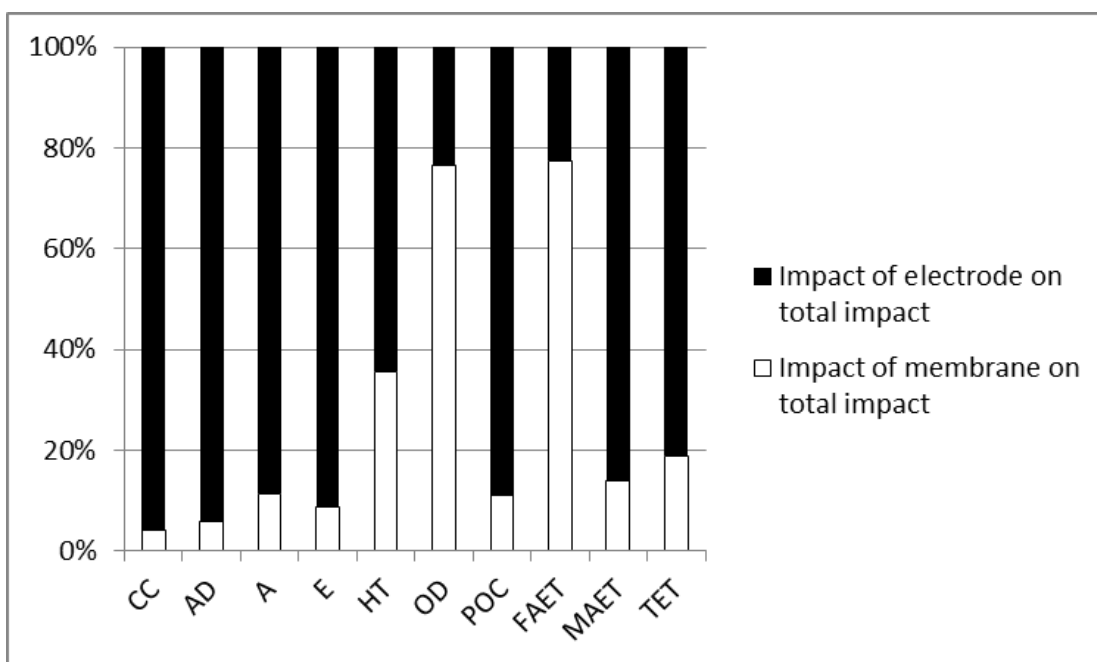
CC: Climate Change; AD: Abiotic depletion; A: Acidification; E: Eutrophication; HT: Human toxicity; OD: Ozone layer depletion; POC: Photochemical ozone creation; FAET: Fresh water aquatic ecotoxicity; MAET: Marine aquatic ecotoxicity; TET: Terrestrial ecotoxicity

A difference exceeding 20% is again considered as being significant. In five impact categories the gap between extremes values are lower than 20%. That implies that in these categories, there is no influence of the mass of membrane on impacts of the BES. For the climate change and photochemical ozone creation, the gap is almost 20%. So the quantity of the membrane could have an influence on these impact categories. In eutrophication, fresh water aquatic ecotoxicity and abiotic depletion the gap is bigger than 20%. In these impact categories, there is a really influence of this parameter on impacts.

It is important to remember that this membrane is the only one that it was possible to find in databases. Because of this and because trends are not really uniform, it is difficult to conclude on influence of the parameter quantity of membrane. This must be a focus of attention in a larger study.

### 3.4 Environmental impacts of the whole BES process

To compare impacts from electrode and impact from membrane the total of impacts for the BES process is calculated with fixed parameters. Carbon cloth is chosen for the electrode because the goal of the study is to minimize impacts. For the membrane, the value of 1 m<sup>2</sup>/m<sup>2</sup> for the ratio is chosen because this choice has no consequences on impacts and because this is the classical value used in laboratories. Figure 4 shows how impacts of the whole process between electrode and membrane are divided.



**Figure 4:** Part of electrode and membrane in total impacts of the process

These results confirm trends of previous parts: for nine impact categories it is the electrode that has the highest impacts. So, even if the electrode with the less impact is chosen, its impacts remains predominant compared to the membrane.

That allows to confirm previous trends: the choice of the electrode is a key point for determining the environmental impact of the BES. Selecting carbon cloth rather than stainless steel for the electrode would be environmentally beneficial.

## 4- CONCLUSIONS

The goal of this paper is to show the possibility to lead an eco-design methodology for an innovative process. This innovative process is the bioeletrosynthesis (BES) process which

is implemented in an organic waste treatment scenario (with pre-fermentation and anaerobic digestion steps) in order to produce bio-based chemicals. Eco-designing BES through a Life Cycle Assessment approach is necessary. It is performed thanks to the realization of a sensitivity analysis for the chosen parameters of the process. Sensitive parameters of the process have been identified to achieve this objective: a first qualitative sorting was made, a first set of influence parameters were studied: the type of bio-based chemicals, the type of electrode material, and the mass of membrane. Indeed, impacts of these parameters have been calculated to determine their respective contribution. It has been shown that the choice of molecules as well as the choice of the material of electrode could have an influence. Because there is no choice in LCA databases, it is more difficult to conclude for the membrane. It probably has an influence on environmental impacts but it cannot be show in this study. A special attention must be paid to it. Finally, total impacts of the BES have been calculated. The nature of electrode is the parameter which has the largest impact.

This work is in progress because this process is just the innovative part of a bigger one. The next step will be to assess how the impacts generated by the BES process compare with those generated by whole organic waste treatment scenario.

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## REFERENCES

- [1] Domburg, V., B. G. Hermann, and M. K. Patel: Scenario projections for future market potentials of bio-based bulk chemicals. *Environmental Science & Technology* 42:2261-2267 (2008)
- [2] Hermann, B. G., K. Block, and M. K. Patel: Producing bio-based bulk chemicals using industrial biotechnology saves energy and combats climate change. *Environmental Science & Technology* 41:7615-7921 (2007)
- [3] ISO, 2006a. Environmental management - Life cycle assessment - Principles and framework. EN ISO 14040:2006. International Organization for Standardization.
- [4] ISO, 2006b. Environmental management - Life cycle assessment - Requirements and guidelines. EN ISO 14044:2006. International Organization for Standardization.
- [5] EC JRC IES, 2010a. International Reference Life Cycle Data System (ILCD) Handbook – Framework and requirements for Life Cycle Impact Assessment models and indicators. Luxembourg, Publications Office of the European Union. EUR 24586 EN.
- [6] EC JRC IES, 2010b. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. Luxembourg, Publications Office of the European Union. EUR24708 EN.
- [7] Hancock, N.T., Black, N.D., Cath, T.Y., 2012. A comparative life cycle assessment of hybrid osmotic dilution desalination and established seawater desalination and wastewater reclamation processes. *Water Res.* 46, 1145-1154
- [8] Troy, S.V., Wagner, H.J., 2011. Screening Life Cycle Analysis of Post Combustion CO<sub>2</sub>-Capture Technologies - A Comparison of Construction Phase Results, in: Gale, J., Hendriks, C., Turkenberg, W. (Eds.), 10th International Conference on Greenhouse Gas Control Technologies. Elsevier Science Bv, Amsterdam, pp. 480-487.