# Life Cycle assessment of bio-methane obtained by valorization of food waste

**Vignali G. (a), Vitale G. (a)**

*(a)Department of Engineering and Architecture, University of Parma, Viale delle Scienze, 43124 - Parma – Italy.*

*(giuseppe.viganli@unipr.it, g.vtl@libero.it)*

**Abstract**: The aim of this study is to carry out a comparative analysis of the environmental impact of different upgrading processes for the production of bio-methane obtained by organic fraction of municipal solid waste. The analysis, carried out exploiting the Life Cycle Assessment approach, takes into account the transport phases of organic fraction of municipal solid waste, biomass pretreatment processes, anaerobic digestion, purification and upgrading of the biogas, disposal of off-gases and $CO_2$ and the evaluation of a combine heat and power system utilization. The study is mainly focusing on different bio-methane production methods considering three upgrading technologies, such as, Water Scrubbing, Membrane separation and Chemical adsorption. The production processes of bio-methane (powered by network) are also compared with self-sufficient cogeneration system scenario and other green energy input such as Hydroelectric system and Photovoltaic system scenario. The main characteristics of each component of the scenarios were derived by case of study and data available in literature. The evaluation of the impact is performed considering the Italian scenario, exploiting, in particular the data of the region Emilia Romagna when available. Other data for the inventory analysis phase were extrapolated from the SimaPro databases (e.g., Ecoinvent). ReCiPe Midpoint method has been adopted as the impact assessment method. The results obtained show that the Membrane separation technology is the most environmental friendly solution for most of the considered impact category comparing to the other upgrading technologies and that the cogenerative scenarios result to be the most environmentally sound if compare to the others.

**Keywords**: LCA; Environmental impact; OFMSW; Bio methane; Food Waste.

## 1. Introduction

Around 88 million tonnes of food are wasted annually in the European Union (EU), with associated costs estimated at 143 billion euros, while in the Italian region of Emilia Romagna are estimated to be around 14 thousand tonnes. Different studies show that around 1/3 of the world food production is not consumed (Gustavsson et al. 2011) (Bio Intelligence study, 2010), leading to negative impacts throughout the food supply chain including households. There is a pressing need to prevent and reduce food waste (FW) to make the transition to a resource efficient Europe. The sectors contributing the most to FW are households and processing, accounting for 72 % of EU FW. Of the remaining 28 percent, (12%) comes from food service, (10%) comes from primary production and (5%) comes from wholesale and retail. As consequence of the Kyoto protocol, the European Community with the “Renewable Energy Directive 2009/28/EC” requires that 20% of the energy consumed in the EU have to be renewable. The strategy of this objective is to reduce the carbon dioxide emissions by 20%, to increase the share of renewable energy to 20% and to achieve energy savings of 20% or more. To fulfil this objective lately the EU encouraged innovative ways of alternative energy production, such as valorisation and transformation of biogas to produce energy and bio fuels. Biogas, which is obtained through the anaerobic digestion (AD), is then purified through the upgrading process to obtain bio methane, which can be used both as a non-pollutant fuel and to be injected into the national natural gas grid.

The methodology of Life Cycle Assessment (LCA) gives the opportunity to analyses the environmental impact through an entire life-cycle treatment to understand the valorization of FW or dedicated crops into bio-methane, focusing on the environmental evaluation of the entire process transformation (Cammardella et al. 2014; Adelt et al. 2011). Other works focus their attention on the environmental analysis of the upgrading processes giving an overview of the impact of some of the technologies available now on the market (Starr et al 2012; Xu et al. 2015; Morero et al. 2015). As answer to the increasing problem of the FW, in the last years several studies and solution were carried out. Some examples are: The European Horizon 2020 project “Resource Efficient food and drink for the entire supply chain”; private projects such as the French project Bionerval; the MIUR financed Italian project SORT and minor projects like Slow Food and Food Waste Stand Up. In particular, the SORT project aims to valorize the expiring products collected from stores and along the distribution phase, in order to produce pet food or less noble product such as biogas, and to valorize its packaging. This project has still demonstrated an environmental efficiency in the recovery and reuse of floor food for animal feed (Mosna et al. 2016). Other researches in this specific project, both from an environmental and an economic point of view, are still on going. An evolution of the project will be the collecting of household wastes. As previously mentioned above, the amount of FW collected from retails result to be minimum; for this reason the SORT project and in particular, the present work will focus their attention on the wastes from households that result to be the major contribution to the entire amount of wastes. The work will then consider the organic fraction of municipal solid waste (OFMSW) as a case of study to evaluate the environmental impact of the FW. As part of the total OFMSW amount, an average of 30% of mowing and lignocellulosic materials has been also considered in order to facilitate the AD and in particular to give a better structure and to ensure the best characteristics for a possible digestate reuse. Other way of improvement to reduce the FW suggested by the European commission are the use of preventive actions. To this end it is important to remind that a possible way of solution would be to minimize all the potential wastes by means of an extension of the shelf life of food products (Manfredi et al. 2015).

On these premises, the aim of the study is to carry out an analysis of the environmental impact of the production of biogas obtained by the valorisation of OFMSW, and secondly, to carry out a comparative analysis of the environmental impact of three different upgrading processes to purify biogas into bio-methane. Finally, it aims to carry out a comparative analysis between valorisation of OFMSW and dedicated crop by means of a Combined Heat and Power (CHP) systems, of the environmental impact of bio-methane's production.

The present paper is thus organize as follows. The next section (section 2) provides the systems description giving some information about the case of study under examination presenting a brief review of the literature about the problem. Section 3 describes the LCA methodology focusing on the system boundaries and life cycle inventory. Section 4 shows the results and discussion to the analysis. Section 5 concludes by analysing the sensitivity analysis highlighting the main limitations and improvements focusing on different approach. Section 6 focus on the main conclusions of the paper work.

## 2. Systems description

The production plant is considered located for this study in Emilia Romagna Region, and is characterized by a Dry AD system and feed with the OFMSW of the nearly province. The system is composed by various stages such as pre-treatment of the OFMSW, dry process of AD, and three different upgrading processes such as Chemical scrubbing, using Monoethanolamines (MEA), Membrane separation and Water scrubbing (WS). The pre-treatment phase consists of all the treatments of the OFMSW to ensure the best characteristics of the organic matter for the next step of AD. In this phase, are included all the processes of handling, shredding, separation of the non-compostable compounds and all the energy requirements inputs needed to fulfil the processes. The AD phase consists of all the processes of handling, heating of the organic matter, pumping the processing water and pumping for the digestate extraction. The upgrading consists of the process of purification of the raw biogas into bio-methane trough the separation of the $CO_2$ and other off-gasses composts. Several types of bio-methane upgrading are nowadays available on the market, especially in the Europe area. There are many papers evaluating the process of transformation of biogas into bio-methane through its upgrading (Sun. et al 2014; Ryckeboash et al. 2008). The most adopted technologies are Chemical scrubbing (MEA) (Leozio. 2015; Huertas et al. 2015), Membrane separation (Scholz et al. 2012) and WS (Rotunno et al. 2016). For the upgrading of biogas were considered three types of process, in particular: (i) Water scrubbing, (ii) Chemical scrubbing (MEA) and (iii) Membrane separation.

*Water scrubbing:* Water is used as a solvent in WS. The solubility of $CH_4$ in water is much lower than that of $CO_2$. In principle, $H_2S$ can be removed together with $CO_2$, since the solubility of $H_2S$ in water is higher than that of $CO_2$. However, because gaseous $H_2S$ is poisonous and dissolved $H_2S$ can cause corrosion problems, pre-separation of $H_2S$ is normally necessary. WS can achieve a $CH_4$ purity of 80–99%, depending on the volume of non-condensable gases such as $N_2$ and $O_2$ that cannot be separated from $CH_4$. The $CO_2$ released from water regeneration is usually not collected. Except with air stripping, it is possible to achieve high purity of $CO_2$, up to 80–90%. The $CH_4$ losses, mainly due to dissolution in water, are usually between 3% and 5% according to theoretical calculations, although equipment suppliers sometimes claim that the losses can be controlled to below 2% (Nilsson & MaritaLinné 2001). The energy consumption is mainly use for compressing raw gas and processing water by circulation pumps.

*Chemical scrubbing:* Chemical scrubbing differs from physical absorption in the chemical reaction between absorbed substances and solvent. Chemical solvents tend to favour over physical solvents when the concentration of $CO_2$ is low. Amines are widely used as chemical solvent to absorb $CO_2$, as there are no $CH_4$ losses since the chemical solvent reacts selectively with $CO_2$. For example, an equipment suppliers has report $CH_4$ losses of only 0,1-0,2 % in plant with a capacity of 300 [$Nm^3/h$] (Persson 2003) (raw gas). However others simulation show quite different results, namely that more than 4% of $CH_4$ can be lost due to the dissolution of $CH_4$ in water (Kapoor & Yang 1988). Another downside of this study technology relates to energy consumption, as large amount of high-temperature heat is needed to regenerate chemical solvents.

*Membrane separation:* Membrane separation is a separation at molecular scale, and it has number of merits, including low cost, energy efficiency and easy process (Öhman 2009). For biogas upgrading, $CO_2$ and $H_2S$ pass through the membrane to permeate side, while $CH_4$ is retained on the inlet side. Since some $CH_4$ molecules may also pass through the membrane, achieving a high purity of $CH_4$ involves large losses of $CH_4$. (Basu et al. 2010) and (Scholz et al. 2013) reviewed membrane-based technologies, which have benne commercially applicable to biogas. Polymide and cellulose acetate-based membranes were found to be the most suitable commercial membranes for biogas separation and enrichment for biogas separation and enrichment. (Deng & Hägg 2010) tested an efficient $CO_2$-selective polyvinyl amine/polyvinyl alcohol blend membrane and report that the optimal process can deliver a $CH_4$ purity of 98% with recovery of 99%. For state-of-the-art generally membrane technologies, the electrical energy consumption for biogas upgrading is around 0,3 [$kWh/m^3$](Makaruk et al. 2010). The CHP system consists of a cogenerative system with the aim to cover all the production process energy inputs;

the selection of the specific CHP systems was done taking into account the total amount of energy and heat needed by the processes.

## 3. Life cycle assessment

The present study is based on the international standards ISO 14040:2006 and ISO 14044:2006. Life Cycle Assessment is a methodology useful to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment. The aim is to assess the impact of the energy and materials used and the releases to the environment and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product process or activity, encompassing, extracting and processing raw materials; manufacturing; transportation and distribution; use and final disposal. A LCA consists of four different steps, defined by ISO 14040 (International Organization for Standardisation 2006a) and ISO 14044.

### 3.1. Goal and scope definition

The goal of this study is to evaluate the environmental impact of the OFMSW's valorisation into biogas and to compare the environmental impacts of three different upgrading processes to produce bio-methane and to evaluate the critical aspects of their life cycles. The study also presents a comparison between the valorisation of OFMSW and the use of dedicated crops integrating also a case of CHP.

#### 3.1.1. Functional Unit

The purpose of the Functional Unit (FU) is to provide a reference unit, for which the inventory data are normalized (ISO 14040, 2006). The functional unit is essential since it facilitates the comparison of alternative products and services (ISO 14044, 2006). The functional unit adopted in this analysis is the annual capacity amount of OFMSW estimated at 18,000 tons. From the FU it was estimated to obtain, from the AD process, the amount of 1.9 millions of [$Nm^3$] of biogas. The lifespan of the production plant has been assumed of 30 years, according with other similar published studies (Vignali, 2017).

#### 3.1.2. System boundary

In order to quantify the impact of the analysed product, the system boundaries shall be determined. The adopted boundary systems in this case, focuses on three main scenarios as reported in Figure 1; in particular, we define: 1) National Energy mix scenario, 2) CHP scenario, 3) Dedicated crops scenario.

The first scenario is characterized by OFMSW such as input material and by the Energy input of the National Energy Mix, analysing then three type of upgrading processes (all the processes are identified by blue colour). The second scenario is characterized as the first for the exception of the Energy input, that is obtain by a suitable CHP system (identified by orange colour) in order to fulfil all the energy needs. The first two scenarios take into account a comparison of three upgrading processes as shown in (Figure 1) where the entire amount of biogas yield is purify by each upgrading processes. The third scenario is characterized by the input of dedicated crops and a suitable CHP system as energy input, analysing only the membrane separation as upgrading process. In particular, it is considered the additional process of cultivation of dedicated crops (identified by green colour).

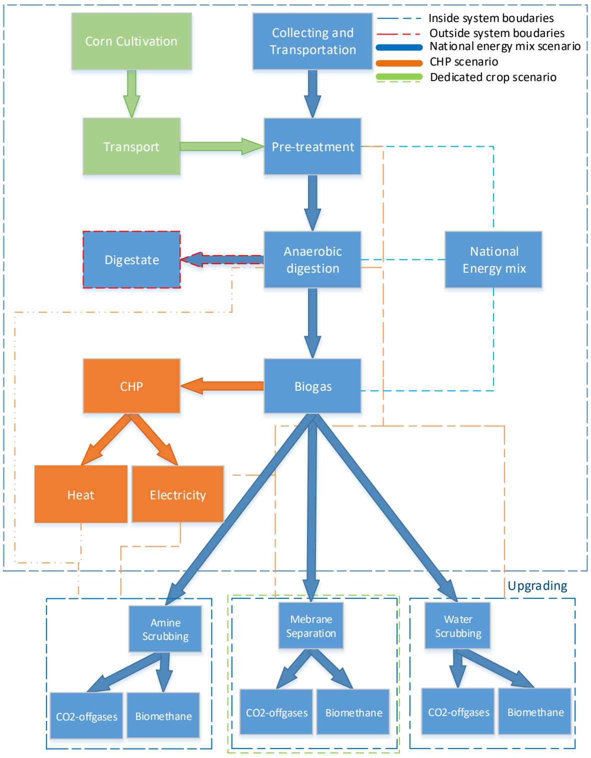

**Figure 1 System boundaries of the considered scenarios.**

### 3.2. Life cycle inventory analysis

The life cycle inventory analysis quantifies the resources use, the energy use, and the environmental releases associated with the system being evaluated by means of a mass and energy balance of each FU (ISO 14040, 2006). All primary data were gathered from works available in literature related to real case of study. In particular the primary data for the production plant and the main data of the OFMSW are gathered from (S.R.T 2011). The pre-treatment process data and the AD process data are also gathered form (S.R.T 2011). All the secondary data such as the energy consumption of the upgrading processes are calculated considering data gathered from (Hinge 2012) and all the other data are calculated considering different cases of study. Ecoinvent database v 3.2 (Swiss Centre for Life Cycle Inventories, 2010) has been used as source of secondary data, by considering data referring to the Italian context when available, otherwise, to the European situation.

#### 3.2.1. Collecting and transportation

The collecting and transportation result to be the same for the first two scenarios, considering the same transportation for OFMSW and the lignocellulosic materials. As collecting and transportation, it was estimated a total distance of 40 km for the collecting and an average of 80 km for the transportation from the collection point to the main production plant. The total amount of OFMSW is estimated to be around 18,000 [tonnes/year], divided as follow: 12,000 [tonnes/year] of organic FW (composed of 23% of dry matter and organic content on the dry product equal to 83%) and 6,000 tonnes/year of mowing and lignocellulosic material (composed of 50% dry substance with organic content on the dry product equal to 72%). For the third scenario is assumed a distance of 40 km from the cultivation area to the production plant and an average amount of 2,160 tonnes of dedicated crops.

### 3.2.2. Pre-treatment

The pre-treatment phase consists of all the treatment processes of the OFMSW/lignocellulosic material with an average energy demand of 314,700 [kWh/year]. All the data are gathered from (SRT 2011).

### 3.2.3. Anaerobic digestion

The AD phase is characterized by an average energy demand of 675,000 [kWh/year] and average heating demand of 1,235,000 [kWh/year]. In this phase is also considered the AD losses assume as 2 % of the total biogas yield. All the data are gathered from (SRT 2011).

### 3.2.4. Upgrading biogas

For this analysis the specific energy consumption and the methane losses data are gathered from (Hinge 2012) reported in Table 1.

**Table 1: specific energy consumption and the methane losses data (Hinge 2012).**

| | Membrane | Water Scrubbing | Chemical Scrubbing |
|---|---|---|---|
| Energy consumption [kWh/m3] | 0,26 | 0,43 | 0,19 |
| Methane losses % | 5 | 2 | 0,2 |

For the MEA the specific heat consumption needed for the regeneration of the solvent assumed is 0.5 [kWh/m$^3$]. All the data concerning the upgrading specifics, such as water consumption, amount of chemical solvent, are the result of calculation staring from data gathered from (Hinge 2012) and cases of study.

### 3.2.5. Avoided impact

In this analysis, we considered as avoided impact, for the first two scenarios, the transportation to landfill and the disposal of in landfill of the OFMSW/lignocellulosic materials. As transportation, it was considered an average distance of 70 km considering the collecting and transport to landfill. In the second and third scenario characterized by CHP systems, the avoid impact consider also the amount of electricity and heat produced by the CHP system in substitution of the National ones.

### 3.3. Impact assessment method

The life cycle impact assessment (LCIA) results are calculated at midpoint level by using the ReCiPe (Goedkoop et al. 2009) method. This method is the most recent indicator approach available in LCA analysis which is based on the result of Eco-indicator 99 (Goedkoop & Spriensma 2000) and Centrum voor Milieukunde Leiden on LCA (Guinée et al. 2001). The ReCiPe method uses impact mechanisms that have a global scope and considers 18 midpoint categories as reported in Table 2. To compare midpoint impacts and to analyse the respective share of each midpoint impact to the overall impact, normalization, which is determined by the ratio of the impact per unit of emission divided by the per capita world impact, could be applied in this study. The detailed methodology and complete characterization factors for ReCiPe are available on the website of the Institute of Environmental Science of Leiden University of the Netherlands (Anon n.d.). This methodology gives as a result 18 impact categories allowing a complete view of the processes analysed, however some categories result difficult to interpret and still characterized by uncertainty.

## 4. Result and discussion

The results of impact assessment for the first scenario comparing the three processes are reported in Table 2 and Figure 2.

**Table 2 Absolute environmental impacts of National Energy mix scenario.**

| Impact category | MEA | Membrane | WS |
|---|---|---|---|
| Climate change | 3,22E+06 | 5,42E+06 | 3,98E+06 |
| Ozone depletion | -1,08E-01 | -1,09E-01 | -9,17E-02 |
| Terrestrial acidification | -1,31E+04 | -1,42E+04 | -1,37E+04 |
| Freshwater eutrophication | 3,55E+01 | 2,46E+01 | 2,83E+01 |
| Marine eutrophication | -8,11E+02 | -9,42E+02 | -9,29E+02 |
| Human toxicity | -1,31E+05 | -1,39E+05 | -1,38E+05 |
| Photochemical oxidant formation | -9,45E+03 | -1,03E+04 | -1,03E+04 |
| Particulate matter formation | -3,75E+03 | -4,09E+03 | -3,95E+03 |
| Terrestrial ecotoxicity | -1,05E+03 | -1,06E+03 | -1,05E+03 |
| Freshwater ecotoxicity | -1,20E+04 | -1,21E+04 | -1,20E+04 |
| Marine ecotoxicity | -3,98E+03 | -4,04E+03 | -3,98E+03 |
| Ionising radiation | 1,77E+03 | 1,71E+03 | 2,68E+03 |
| Agricultural land occupation | -2,09E+05 | -2,25E+05 | -2,20E+05 |
| Urban land occupation | -1,61E+04 | -1,84E+04 | -1,79E+04 |
| Natural land transformation | -2,95E+02 | -3,14E+02 | -2,95E+02 |
| Water depletion | 5,92E+03 | 4,46E+03 | 5,44E+03 |
| Metal depletion | -7,03E+04 | -7,18E+04 | -6,69E+04 |
| Fossil depletion | -1,06E+06 | -1,12E+06 | -1,08E+06 |

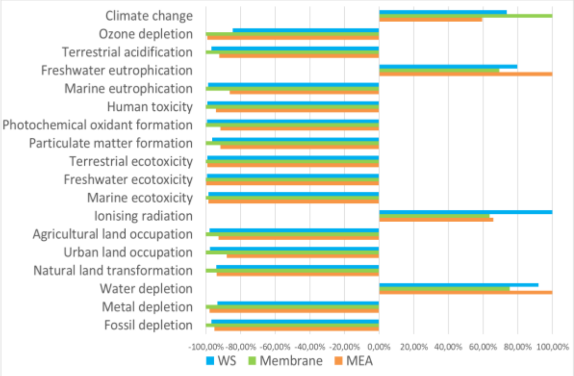

**Figure 2: Relative environmental impacts of upgrading processes of National Energy mix scenario.**

As can be seen by Table 2 and Figure 2 the environmental analysis shows significant environmental benefits for most of the categories analysed, showing generally negative impacts, for the exception of Climate change, Fresh water depletion, Ionising radiation and Water depletion. In particular the impact of the production process of bio-methane through membrane separation turns out to be the most environmental friendly; in fact it has for seventeen out of eighteen categories the highest value if is considered the avoided impact and the lowest if considered the generated impact. The process shows the highest value only in the Climate change category, indicating a greater impact of about 30% if compared to the second most impactful technology; this is due mainly to the fact that this technology appears to be characterized by high methane losses. Separation through membrane technology results to be, in most of the categories, the one with lowest impact and highest avoided impact. Its low power consumption and non-use of solvents such as water or amines makes this process the lesser affecting process. Taking into account the other upgrading processes, the MEA shows a lower value of avoided impact in a range from 5 to 10 % if compared to the others. In particular shows a major impact of 20 % in the Freshwater eutrophication category, and a 10% major impact into the Water depletion, this is mainly due to the use of chemical products such as monoethanolamine. Furthermore, for the MEA the amount of heat needed for the regeneration of the solvent contributes to a greater impact. If we take into account WS the result shows in general an average less avoided impact of 5% if compared to membrane and in particular a greater generated impact of 40% if considered Ionising radiation and respectively 10% and 15% if considered Freshwater eutrophication and Water depletion. In Figure 3 is shown, as a reference case, the relative environmental impacts of valorization through membrane separation, focusing on each phases.

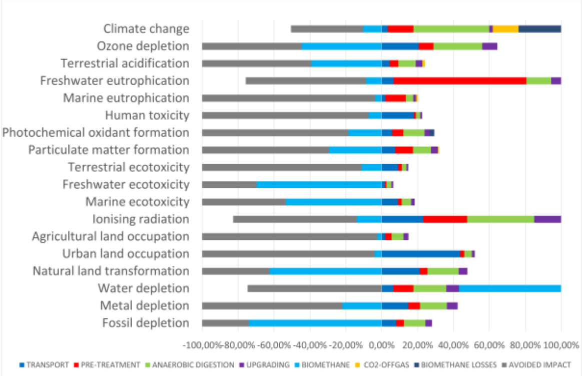

**Figure 3: Relative environmental impacts of the upgrading process through membrane separation considering first scenario.**

The analysis shows the percentage of the different processes starting from the collection of the OFMSW. Taking into account the generated impact, relevant, result to be the processes of AD and pre-treatment. This is due to the impact generated from the energy consumption used for all the handling processes and heating process of digestion and in particular due to the digestion losses and impact of the non-compostable compounds. Moreover, the transportation has a relevant impact, in particular for the category of Urban land occupation and Human toxicity. It should be noted that the contributions of $CO_2$, methane losses and the contribution of upgrading appear to be separated in Figure 3; to have an overall result of the environmental impact of upgrading process, they should be considered as one. As it can be seen from Figure 3, the avoided impacts result to be relevant, this is due to high contribution of the avoided impacts of landfilling and the outputs of bio-methane obtain by the valorisation. The results of impact assessment for the second scenario of the three processes are reported in Figure 4. In this analysis, it has been considered to fill the energy intake by specific CHP systems. In particular, it has been estimated the use of 19% of the total biogas yield for the Chemical scrubbing and 24% for the other two, in order to make the systems self-sufficient. The three processes are also compared with a scenario of total conversion of the biogas into electricity and heat through a CHP system.

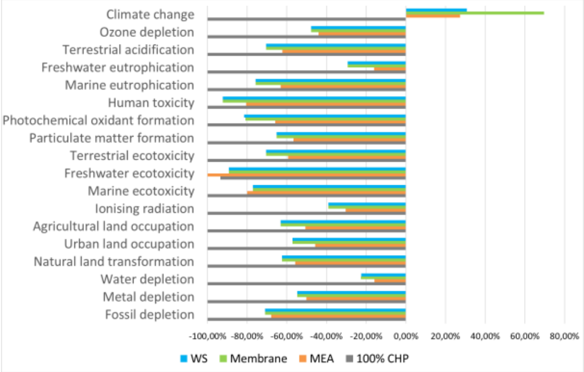

**Figure 4 Relative environmental impacts of CHP scenarios.**

According to Figure 4, the analysis shows the high benefits due to the impact avoided. This result is due to the high contribution of heat and electricity outputs obtain by CHP and the produced bio-methane. The analysis shows a great advantage in terms of avoided impacts for the case of total cogeneration; this is due to the great contribution of heat and electricity outputs, which are greater influence compared to the created impacts. In particular, 17 out of 18 categories result to be negative highlighting the benefits of the avoided impacts; the only exception results in Climate change that, as in the previous case, shows in the membrane separation the most impactful method. The analysis for WS and membrane separation shows almost the same result, this is due to the fact that the CHP systems used are the same for both methods. The results of impact assessment for the third scenario are reported in Figure 5. The analysis shows a comparison between the second and third scenarios characterized by different inputs, considering as upgrading process the membrane separation. The inputs result to be the amount of 18,000 [tonnes/year] of OFMSW and its equivalent in terms of biogas yield of corn corresponding to 2,160 [tonnes/year].

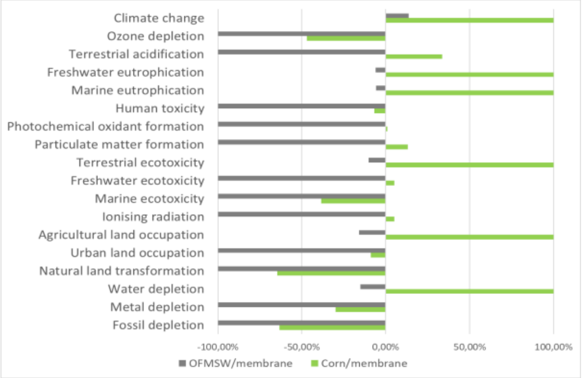

**Figure 5 Relative environmental impacts of the comparison of second and third scenarios.**

According to Figure 5, the analysis shows significant impacts and a less avoided impacts for the scenario characterized by dedicated crops. This result is due to the great impact of the cultivation of corn, which in the other scenario is not considered, giving a greater advantage due to the valorisation of the OFMSW. The analysis shows that the highest impact is refer to impact category connected with the cultivation, such as Agricultural land transformation, Water depletion, Terrestrial ecotoxicity, etc, as a demonstration of the made consideration. In particular, the advantage of the CHP system showed in the previous analysis, resulting in high values of avoided impacts, in this case is less relevant compared to the great impacts generated from the cultivation process.

## 5. Sensitivity analysis

As previously demonstrate the contribution of the transformation processes and the relevant contribution of electricity demand are to be the main impacts in the entire considered categories. For this reason, we carried out a sensitivity analysis concerning the electricity inputs: in particular, as a first case of analysis, we assumed that the electricity production is obtained by renewable energy systems, in particular, Photovoltaic and Hydroelectric. In this case, OFMSW is considered as input of the process.

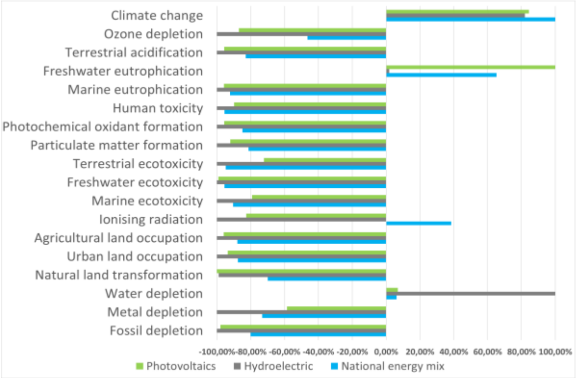

**Figure 6 Sensitivity analysis considering Photovoltaic or Hydroelectric as renewable energy input.**

As can be seen from the Figure 6, excluding the category of Water depletion, which is closely connected to the use of water, the total impact of the Hydroelectric energy input results to be minor. The avoided impact results to be, in this case, the highest in most of the categories with an average 20 % better values if compared to the National energy mix case.

As second case, we assumed that the energy production is realize using CHP systems, as was previously consider for the second scenario, analyzing how different percent of biogas allocated cogeneration would influence the analysis. In this case, OFMSW is consider as input of the process. This second sensitivity analysis shows that the increase of the CHP percentage is connect to an improvement in terms of avoided impact, showing greatly benefits in case of cogeneration to 80%. This result is due to the great contribution of electrical and thermal energy obtain from cogeneration as output of the system.

## 6. Conclusions

Three different scenarios for production of bio-methane were compared using Life Cycle Assessment methodology. The first scenario considers all the production line from valorization of OFMSW to the transformation into bio-methane using a National Energy mix. The impact of the overall processes using membrane technology as upgrading process, result to be the more environmental friendly if compared to the MEA and WS; in particular MEA results to be the most impactful process due to the use of chemical products and energy/heat demand for regeneration of the solvent, as already previously shown in accord with (Morero et al. 2015; Xu et al 2015). All the three cases of the first scenario show the high impact connected to the energy demand of the processes and in particular, the high need for AD and for the upgrading process. The greatest impact is also due to high losses in AD process and the waste materials of non-compostable components. The three upgrading processes are characterized by different impacts, showing in particular disadvantages in terms of energy demand and methane losses. The overall impact in the second scenario, characterized by CHP in order to obtain a self-sufficient process, result to be greatly lower than the first scenario, highlighting the great advantages of the CHP system in terms of avoided impact, as already previously shown in accord with (Cammardella et al. 2014). The third scenario shows the great contribution to the generated impacts of the cultivation, in particular as can be seen from the proposed analysis this scenario shows, if compared to the second one, the great advantage in terms of avoided cultivation, highlighting the valorisation process of OFMSW as the most environmental friendly. As regarding the sensitivity analysis, it was demonstrated that the total impact is reduced by using renewable energy inputs and greatly reduce by using higher percentage values of biogas allocated to CHP systems.

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