Application of life cycle assessment methodology to methane production from solid waste

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Abstract The increasing depletion of non-renewable resources has led to search for cleaner fuels and also develop advanced technologies. Among them, hydrogen fuel appears as an alternative, although its production from natural gas is far of being sustainable. In this work, raw materials derived from solid wastes (municipal solid wastes and sewage sludges) were studied as an alternative carbon resource to obtain methane from biogas. The comparison between the production of methane (1 Nm^3) using both materials was carried out applying the LCA methodology. Energy, CO_2 balances and environmental impacts of each alternative were calculated using GaBi 4.3. Obtained results show that the use of municipal solid wastes reduces the energy requirements, although the greenhouse gases emissions are higher. The overall comparison of the raw materials reveals global potential warming as the main impact of the process.

1 Introduction

The growing concerns about climate changes along with the increasing depletion of non-renewable resources have led to develop advanced technologies with low levels of pollutant emissions and high efficiency. The reduction of environmental harms (especially greenhouse gas emissions) involves minimizing the dependency on fossil fuels and the use of renewable energy. Hydrogen fuel provides clean energy conversion when compared to conventional fossil fuels in internal combustion engines, fuel cells and other applications. However, production of hydrogen from fossil fuels is far of being sustainable due to their high greenhouse gas (GHG) emissions [1], and therefore, CO_2 capture and storage (CCS) techniques are commonly used to reduce these emissions.

Currently, 96% of world hydrogen production comes from fossil fuels, being natural gas commonly used as raw material (>75% of production) [2]. In order to avoid the use of fossil fuels to obtain hydrogen, other raw materials are under investigation, especially those derived from solid wastes. Thus, sewage sludge, municipal solid waste, agricultural and industrial wastes are considered as potential substitutes of natural gas. These materials present an organic fraction which can be converted, usually via anaerobic digestion, into biogas (rich in methane) after upgrading. This refined biogas can be used to obtain highly pure hydrogen using different technologies.

The aim of this work is to compare the production of refined biogas using municipal solid waste (MSW) and sewage sludge (SS) as carbon source. This comparison was carried out applying the Life Cycle Assesment (LCA) methodology to produce 1 Nm^3 of CH_4. The subsystems considered were: transport of the raw materials, digestion and upgrading plant facilities and the further application of the digested matter as fertilizer. The average composition of the raw materials was taken from the literature and the inventories were adapted for each system, taking those from Ecoinvent Database [3] as reference. Thereafter, energy and CO_2 balances were calculated using GaBi 4.3 software. Obtained results show that the process using MSW is less energy demanding, althogh its contribution to the global warming is higher. Finally, the environmental impacts of the overall process calculated using Gabi 4.3. show that global warming is the most important impact regardless of the raw material used.

2 System definition and life cycle assessment assumptions

Table 1 shows the composition of municipal solid waste (MSW) and sewage sludge (SS) in terms of carbon content taken from different sources [3, 4].

Tab.1: Composition of raw materials in terms of carbon content.

	MSW [3]	**SS** [3, 4]
Dry matter (wt. %)	40	5
Organic content in dry matter (wt. %)	77	65
Carbon content of organic matter	53	32.7
Sulphur (wt. %)	0.15	1.45
Nitrogen (wt. %)	0.4	3.91

The reference system selected was the same for both raw materials and consists of: transport of the raw materials, anaerobic digestion (including composting), biogas upgrading and application of the digested matter as fertilizer as can be seen in Fig. 1. The anaerobic digestion of the raw material was performed at 30-40ºC (mesophilic conditions) . It was assumed a total organic decomposition of 55%, considering a carbon share decomposition of 76% during anarobic digestion and 24% during post-composting for MSW [3]. Carbon decomposition of 85% during anaerobic digestion and 15% during post-composting was assumed for SS [5].

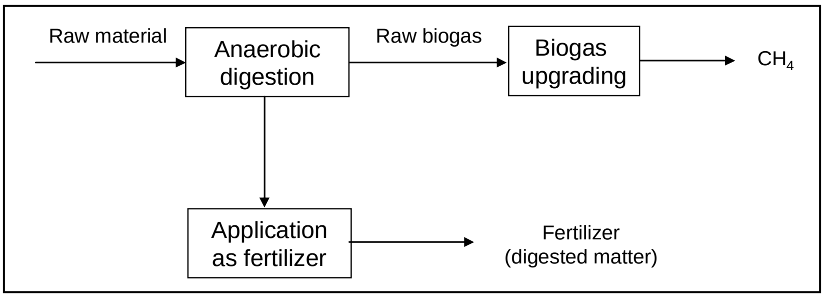

Fig.1: Assumed process to obtain methane from biogas.

The composition of the raw biogas obtained using MSW and SS was taken from Ecoinvent database [3] and it is summarized in Table 2.

Tab.2: Composition of raw biogas.

	MSW	**SS**
CH_4 (%vol.)	67.00	63.00
CO_2 (%vol.)	32.05	33.60
N (%vol.)	0.7	3.40
H_2S (%vol.)	0.024	Trace

Obtained biogas from anaerobic digestion is upgraded in the second subsytem. In this case, it was assumed a pressure-swimming-adsorption (PSA) process to obtain a refined biogas containing mainly CH_4 and CO_2 (96% and 2% vol., respectively) [3]. Finally, the application of the digested matter as fertilizer was considered as the third subsystem.

Lyfe Cycle Assessment (LCA) approach was used to calculate the energy, CO_2 balances and the environmental impacts related to the production of methane from the selected raw materials. In all cases, the selected functional unit was 1 Nm^3 of methane (96%vol.). Fig. 2 shows the system boundaries considered for LCA which is focused on the raw material, energy requirements and the facilities needed to carry out anaerobic digestion and biogas upgrading.

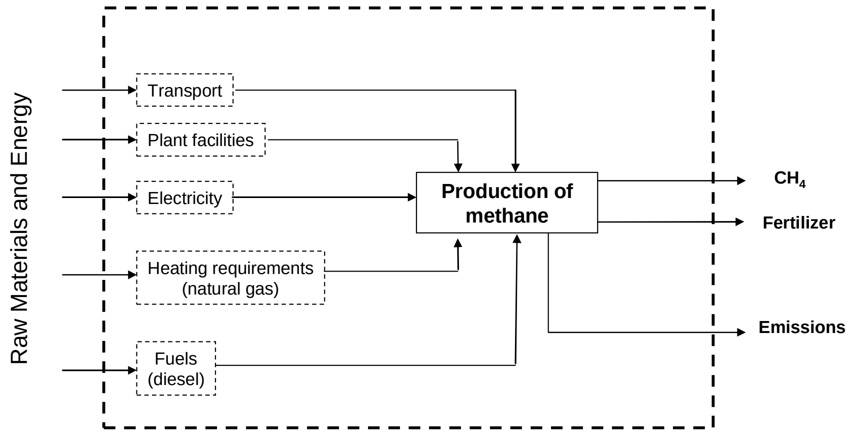

Fig.2: Scheme of the basic process to obtain methane from solid wastes.

3 Results and discussion

In this work, the energy, the CO_2 balances and the environmental impacts were the criteria selected to compare the use of MSW and SS as raw materials to obtain methane.

3.1 Energy balance

Fig. 3 shows the results obtained from the energy balance of the different steps to obtain methane from MSW and SS. As can be seen, the upgrading process, performed using pressure swing adsorption (PSA), is the most energy consumption step when MSW is used as raw material. This result is directly related to the electricity consumption of this precocess (1.8 MJ) clearly higher than the energy requirements of the rest or processes. Concerning the use of SS, the anaerobic digestion is the most energy demanding step due to the high water content of this material, which make the heating requirements increase to achive temperatures within the mesophilic range (30-40°C)

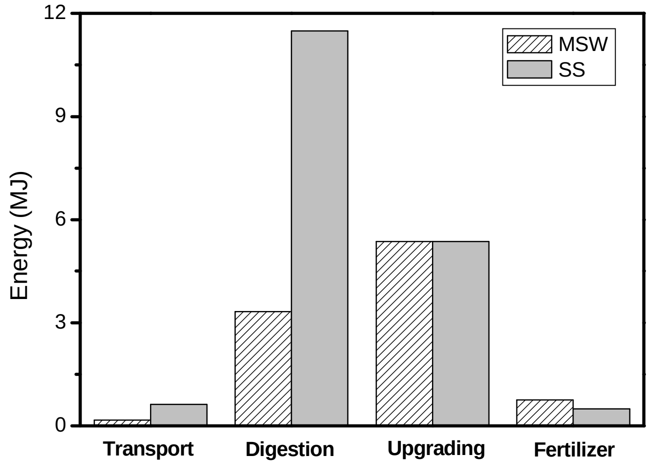

Fig. 3: Energy requirements to obtain methane from solid wastes.

The comparison of the total energy consumption for both alternatives show that the use of MSW allows the energy requirements to decrease about 50%. The calculated values of NER (product heating value/energy input) were 4.4 for MSW and 2.2 for SS, respectively.

3.2 CO_2 balance

One of the main aspects concerning environmental analyses is the quantification of CO_2 balance, as it is directly related to greenhouse effect and, therefore it allows the global potential warming effect to be estimated. In this work, it was calculated using CLM 2001 (Southern Europe) method for the diffferent steps involved in methane production, obtaining the results shown in Fig. 4. In this case, the highest values of kg CO_2 -equivalent were obtained for the anaerobic digestion for both materials. This result can be explained due to the emissions of methane in this step. As it is well-known, methane greatly contributes to the global warming due to its high greenhouse effect and emissions of this gas are mainly produced during the aerobic post-treatment of digested matter, as reported in the literature [6].

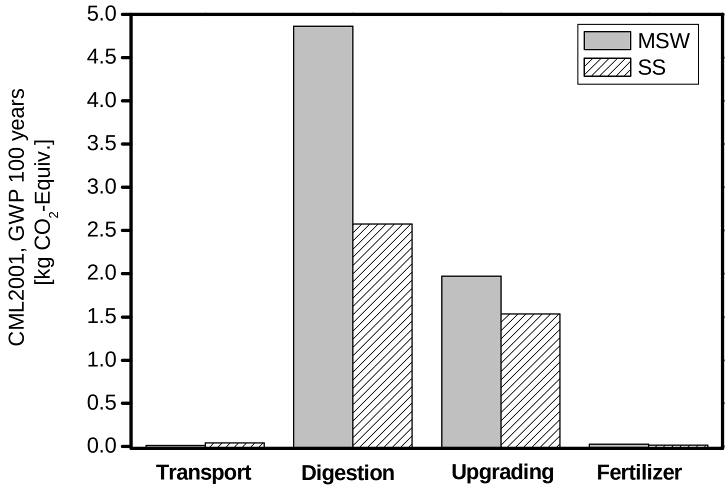

Fig. 4: CO_2 balance calculated for the studied process

The remarkable difference between the emissions of CO_2 during anaerobic digestion regarding the raw material used are due to the different extent of carbon decomposition. Thus, in the case of MSW, the carbon decomposition during the anaerobic digestion was assumed to be 76%, whereas higher degradation can be achieved when using sewage sludge (85% in this work). This difference affects to the share of carbon during post-composting, being higher when using MSW, and therefore increasing the emissions of CO_2 and CH_4.

Concerning biogas upgrading, the emissons of gases related to global potential warming are slightly higher in the case of using MSW as the content of CH_4 in the raw biogas is higher than in the case of that obtained from SS. Therefore, as the refined biogas was assumed to present the same composition in both cases, the content of CH_4 in the sewage effluent from MSW biogas upgrading has to be higher.

3.3 Evaluation of environmental impacts

The environmental evaluation of the overall process using MSW or SS was carried out using CML 2001 method. Obtained results were obtained from Gabi 4.3 software and the main impacts are shown in Fig. 5. In both cases, using MSW and

SS, the global warming is the most important impact, being clearly superior for MSW, as expected according the CO_2 balance shown in Fig. 4.

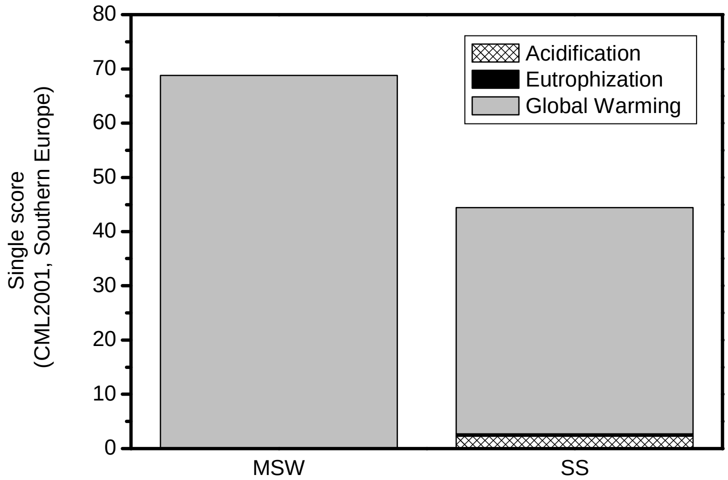

Fig. 5: Evaluation of environmental impacts for the studied process.

It is noticeable the presence of acidification as an important impact in the case of SS, motivated by the content of nitrogen and sulphur in this raw material, clearly higher than in the case of MSW.

4 Conclusions

Lyfe Cycle Assessment allows the comparison of the processes studied in this work concerning energy consumption, CO_2 balance and overall impacts. The production of methane from municipal solid wastes is less energy consuming than that using SS as livestock. However, the CO_2 balance show negative effects when using MSW regarding global potential warming, due to limitations of the carbon decomposition of this material. According to the obtained results, global potential warming appears as the main impact regardless of the raw material used. Comparing overall impacts, the process using SS is less harmful from an environmental point of view.

5 References

[1] N. Z. Muradov, T. N. Veziroglu, From hydrocarbon to hydrogen-carbon to hydrogen economy, *International Journal of Hydrogen Energy,* Vol. 32, 2007, pp 1225-1234.

[2] J. Dufour, D. P. Serrano, J. L. Gálvez, J. Moreno, C. García, Life cycle assessment of processes for hydrogen production. Environmental feasibility and reduction of greenhouse gases emissions, *International Journal of Hydrogen Energy*, Vol. 34, 2009, pp 1370-1376.

[3] Ecoinvent database, 2007.

[4] D. Fytili, A. Zabaniotou, Utilization of sewage sludge in EU application of old and new methods—A review, *Renewable Sustainable Energy Reviews*, Vol. 12 2008, pp 116–140.

[5] G. Tchobanoglous, F. L. Burton, *Waste Water Engineering*, 3rd Ed., McGraw-Hill, 1994.

[6] W. Edelmann, K. Scheleiss, Ecologic, energetic and economy comparison of treating biogenic wastes by digesting, composting or incinerating. http://www.arbi.ch/ecobalan.htm, (Accessed 05, 03, 2010).