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Case Study

Environmental impact assessment as a complement of life cycle assessment. Case study: Upgrading of biogas

Betzabet Morero [a,*], María B. Rodriguez [b], Enrique A. Campanella [a,b]

[a] Instituto de Desarrollo Tecnológico para la Industria Química (INTEC), Universidad Nacional del Litoral-CONICET, Güemes 3450, 3000 Santa Fe, Argentina
[b] Facultad de Ingeniería y Ciencias Hídricas, Universidad Nacional del Litoral, Ruta Nacional N° 168 Km 472.4, 3000 Santa Fe, Argentina

HIGHLIGHTS

- This work presents a comparison between the LCA and EIA in the upgrading of biogas.
- Three upgraded biogases formed using the absorption–desorption process are compared.
- The advantages and disadvantages of each tool are analyzed.
- The EIA and LCA are not opposites but rather are complementary tools.

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ABSTRACT

This work presents a comparison between an environmental impact assessment (EIA) and a life cycle assessment (LCA) using a case study: upgrading of biogas. The upgrading of biogas is studied using three solvents: water, physical solvent and amine. The EIA follows the requirements of the legislation of Santa Fe Province (Argentina), and the LCA follows ISO 14040. The LCA results showed that water produces a minor impact in most of the considered categories whereas the high impact in the process with amines is the result of its high energy consumptions. The positive results obtained in the EIA (mainly associated with the cultural and socioeconomic components) make the project feasible and all the negative impacts can be mitigated by preventive and remedial measures. From the strengths and weaknesses of each tool, it is inferred that the EIA is a procedure that can complement the LCA.

1. Introduction

The impact of industrial activity on the environment has led to both the study of the feasibility of industrial processes, using tools such as the life cycle analysis (LCA) and international, national, provincial and municipal legislation requiring environmental impact assessment (EIA) for project approval and implementation.

In the literature, there are works that discuss the relationship between LCA and EIA (Tukker, 2000; Manuilova et al., 2009). Other papers discuss other tools (Finnveden et al., 2003; Finnveden and Moberg, 2005) and even other approaches to tackle the problem of the environmental management of industrial projects (Buytaert et al., 2011; Marvuglia et al., 2013; Tufvesson et al., 2013; Huttunen et al., 2014). In general, the studies show that the different management tools do not exclude each other and can even become complementary. A necessary requirement is to adapt tools to the requirements of environmental legislation and to the impacts generated by a specific project.

The biogas from organic wastes and its subsequent purification is presented as a renewable alternative for power generation (Demirbas et al., 2011). Particularly in Argentina, there are a number of projects being pursued by the production sectors of the country, mainly agricultural (Menéndez and Hilbert, 2013), based on the potential to generate biogas from their waste (EPA, 2009). One biogas use is as a substitute for methane. To convert the biogas into biomethane, purification is necessary. One purification stage is the upgrading of biogas through the elimination of CO_2 (Morero, 2014; Morero et al., 2015; Abatzoglou, 2009; Patterson et al., 2011; Ryckebosch et al., 2011).

This work analyzes and compares existing tools (LCA and EIA) useful for environmental assessment of upgrading biogas, to use as biomethane. To upgrade the biogas, three solvents are used (water, polyethylene glycol dimethyl ether (DEPG) and amines) in the absorption–desorption process (Morero, 2014). To evaluate

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* Corresponding author. Tel.: +54 0342 4559174x2165; fax: +54 0342 4559174x2006.

E-mail addresses: bmorero@intec.unl.edu.ar (B. Morero), mbelenrodriguez89@gmail.com (M.B. Rodriguez), tquique@santafe-conicet.gov.ar (E.A. Campanella).

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the tools, the advantages and disadvantages of each one are analyzed in this study case.

2. Methods

A wide range of environmental assessment methods have been development in the last years. Two well-known are LCA and EIA. In this chapter was analyzed the upgrading biogas process using these methods. The methodology of both, LCA and EIA, are presented in the subchapters 2.1 and 2.2, respectively.

2.1. Life cycle assessment

The goal of the LCA is to analyze the environmental impact of different solvents used in the process of upgrading biogas to determine which the most environmentally friendly. The processes were simulated using the commercial simulator ProMax (ProMax, 2013), and the emissions were calculated. A flow diagram of the water process is shown in Fig. 1, and similar flow diagrams correspond to the use of amine (diglycolamine, DGA) and DEPG as solvents. The LCA was carried out according to ISO 14040-44 (ISO 14040: 2006; ISO 14044: 2006) using specific software (OpenLCA, 2013).

2.1.1. Functional unit

The functional unit is the removal of 1 kg of CO_2 from the biogas. The biogas input stream to the different upgrading plants has a theoretical composition of 58.4% CH_4, 37.3% CO_2, 1% N_2, 0.1% H_2S, and 3.2% H_2O at atmospheric pressure and room temperature (25 °C) and a flow rate of 250 m^3/h. The final biogas quality is an adequate substitute for natural gas.

2.1.2. System boundaries

The LCA of the biogas upgrading processes considers the reactants and the energy used in each process. This work does not include the transport of the reactants and the materials used for manufacturing the necessary valves, pipes and plant. Only the supplies in each process were analyzed. Fig. 1 shows, by way of example, the boundaries of the absorption–desorption process using water as a solvent.

2.1.3. Inventory analysis

The data used in each process were obtained from simulations carried out in the ProMax commercial simulator. From these simulations, was determined the amounts of supplies needed for each process and the energy consumption. The operating variables were previously optimized (Morero, 2014). The flow rate of each solvent (water, amines and DEPG) is the solvent lost during the process. The data used in the processes of DEPG and DGA production were obtained from the literature (Frischknecht, 1999; Sutter, 2007) and were loaded into the program. The flow of power was adapted to the energy matrix of Argentina. This information was obtained from the local Department of Energy (SEN, 2011) and loaded into the program. In addition, the water treatment process was provided by the local supplier company (Aguas Santafesinas, 2013). The input and output of these processes were obtained from the NREL database (U.S. Life Cycle Inventory Database, 2012).

2.2. Environmental impact assessment

The environmental impact assessment is the identification, forecasting, interpretation and measurement of the environmental consequences of projects. The assessment of the environmental impact is a set of procedures that identify the actions and the medium to be impacted, establish the possible alterations and evaluate them. The minimum content of the EIA is in accordance with Decree 101/03 of Santa Fe Province, Argentina (Decree 101/03), where the project is located.

The effect of human activities on the environment can be characterized by the importance of their respective impacts. For this purpose, the methodology of a cause and effect matrix, which evaluates the interactions between the project and each environmental factor (Item 7 of Appendix A), is used. Therefore, for this case, the model proposed by Vicente Conesa Fernández-Vítora (1997) was chosen. The significance of the impact is measured in terms of both the degree of incidence or the intensity of the alteration produced and the characterization of the effect, which responds to a series of qualitative attributes. Each attribute is assigned a score according to its characteristics, which are unified in Eq. (1):

$$\text{Importance} = \pm(3I + 2EX + MO + PE + RV + SI + AC + EF + PR + MC) \tag{1}$$

where:

± (Character of impact or Nature): The impacts can be beneficial or harmful. The former are characterized with a positive sign, while the latter are expressed as negative.

I (Intensity): Represents the incidence of the causal action over the impacted factor in the area where the effect occurs. The intensity is measured with the following scores: low, 1; medium–low, 2; medium–high, 3; high, 4; very high, 8.

EX (Extension): Refers to the influence zone of the effects. In some cases, it may manifest beyond the project area and the location zone. The impact can be localized (punctual) or spread throughout the environment of the project or activity

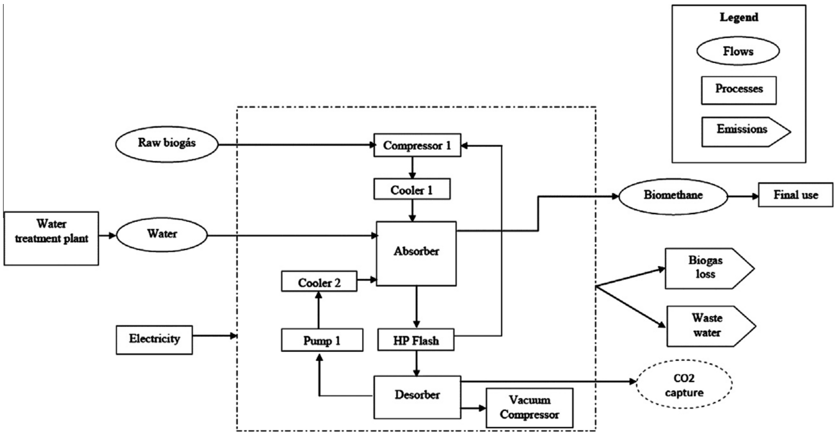

Fig. 1. Flow diagram and system boundaries (dot-dashed line) of the upgrading process using water as solvent.

(considered total). The extension is evaluated with the following scores: punctual impact, 1; partial impact, 2;, extended impact, 4; total impact, 8.

MO (Moment): Refers to the period between the action and the appearance of the impact. The prediction of the moment of occurrence of the impact is better the smaller the period of the appearance of the effect. Furthermore, the prediction is important because of corrective measures to the impacts that should be made. The moment is measured with the following scores: immediate, 8; short-term (less than one year), 4; medium-term (1–5 years), 2; long-term (over 5 years), 1.

PE (Persistence): Refers to the time that the effect is manifested until the return to its initial situation naturally or through corrective measures. An effect considered permanent may be reversible or irreversible when the causal action is finished. In other cases the effects may be temporary. The impacts are evaluated using the following scores: fleeting, 1; temporary (1–10 years), 2; permanent (longer than 10 years), 4.

RV (Reversibility): The persistence and reversibility are independent. This attribute refers to the possibility of the recuperation of the medium component or the affected factor by a certain natural action. To the reversibility is assigned the following scores: short-term (less than one year), 1; medium-term (1–5 years), 2; irreversible (over 10 years), 4.

SI (Synergy): Refers to the overall effect of two or more simple effects being greater than their sum when they act independently. The following scores are given: not synergistic, 1; moderately synergistic, 2; highly synergistic, 4.

AC (Accumulation): Refers to the increase of the effect when the cause persists. The allocation of the score is as follows: no cumulative effects, 1; cumulative effects, 4.

EF (Effect): The impact of an action on the environment can be direct or indirect (that is, a secondary result that is a result of a primary effect). For the effect, the following scores are applied: secondary effect, 1; direct effect, 4.

PR (Periodicity): This attribute refers to the rate of the appearance of the impact. The following scores are assigned: if the effects are continuous, 4; if the effects are periodic, 2; if the effects are discontinuous, 1.

MC (Recoverability): Measures the ability to recover (fully or partially) the conditions of initial environmental quality as a result of the implementation of corrective measures. The recoverability is assigned the following scores: if the recovery can be total and immediate, 1; if the recovery can be total in the medium term, 2; if the recovery can be partial (mitigation), 4; if it is unrecoverable, 8.

The number that results from applying Eq. (1) varies between 13 and 100. According to the score and sign, the impacts are classified as shown in Table 1.

Table 1
Color and numerical scale of impact assessment.

Negative	Score	Positive
Compatible or irrelevant	13–25	Compatible or irrelevant
Moderate	26–50	Moderate
Severe	51–75	High
Critical	76–100	Very high

3. Results and discussion

3.1. Life cycle assessment of the biogas upgrading process

The CML 2001 impact assessment method (Guinee, 2001) was used because it includes many categories for analyzing ecological and human health effects and resource depletion. The 11 selected impact categories included the acidification potential (AP) [kg SO_2-Equiv.]; climate change, 100 years (GWP) [kg CO_2-Eq]; eutrophication potential (EP) [kg PO_4-Eq]; freshwater aquatic ecotoxicity potential, 100 years (FAETP) [kg 1,4-DCB-Eq]; freshwater sediment ecotoxicity potential, 100 years (FSETP) [kg 1,4-DCB-Eq]; human toxicity potential, 100 years (HTP) [kg 1,4-DCB-Eq]; malodorous air (MO) [m^3 air]; photochemical oxidation (summer smog) (EBIR) [kg ozone FORMED]; abiotic resource depletion (ARD) [kg antimony-Eq]; stratospheric ozone depletion, 40 years (ODP) [kg CFC-11-Eq]; and terrestrial ecotoxicity, 100 years (TAETP) [kg 1,4-DCB-Eq].

Fig. 2 summarizes the results obtained when comparing the biogas upgrading processes using water, amine and DEPG as solvents. The x-axis shows the impact categories and the impact within each category. This figure shows that the amine process generates the greatest impact in nearly all categories, except for the human toxicity potential, photochemical oxidation and climate change categories. The process with amine has the least impact on the EBIR category due to the low methane losses, which is the biggest contribution in the water process. The highest impact to the EBIR category is from the DEPG process due to two major contributions: the ethylene glycol monoethyl ether and the methane losses. The ethylene glycol monoethyl ether is generated during DEPG production. The impacts on human toxicity are related to the production of ethylene oxide, which is required for manufacturing DEPG and DGA solvents. Thus, the water process was the least harmful to human health. The water process generated minor impacts in all of the studied categories, except for climate change, because of the methane losses that were generated during the biogas upgrading process. The significant environmental impact of the process with amines resulted from the high energy consumptions of the chemical amine production process and the solvent regeneration process with vapor in the upgrading process.

3.2. Environmental impact assessment of the biogas upgrading process

Using the methodology described in Section 2.2, the importance matrix of impact for biogas upgrading was obtained (see Table 2). The matrix was performed for a generic solvent because the differences between water, DEPG and DGA are small. The process is presented in Fig. 1. In the columns of the matrix are the project actions, considering the stages of construction and operation, and in the rows are the environmental factors that may plausibly be impacted.

From the 32 possible interactions registered, 21 were negative (1 severe, 5 moderate and 15 irrelevant) and 11 were positive (2 high, 3 moderate and 6 irrelevant). Table 3 summarizes the results of the interactions.

Among the negative impacts, no potentially critical effects were detected; rather, most of them are moderate or irrelevant, and all can be mitigated by preventive and remedial measures. Most negative impacts are bound to the construction stage and are therefore temporary. The major negative impact is gaseous emissions into the atmosphere, which should be reduced or mitigated.

On the other hand, the moderate positive impacts are mainly associated with the cultural and socioeconomic components, especially the improvement of labor demand and the development of the zone in which the project is promoted. There is also a positive contribution to education because operation techniques friendly to the environment are used.

Finally, most important components in the matrix are the two high positive impacts. They are focused on the generation of resources due to the biomethane production and its use in the same plant as an alternative to conventional energy. In general, the assessment presents the positive results in environmental

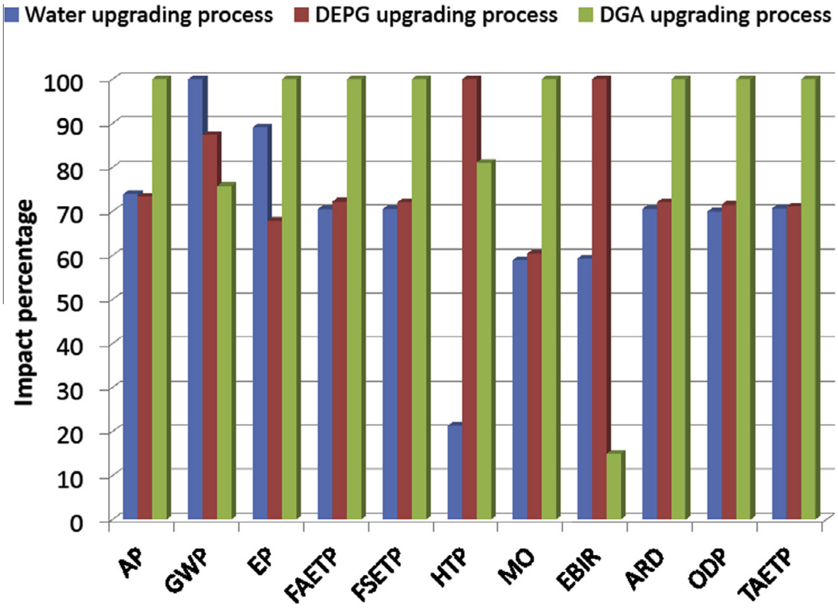

Fig. 2. Environmental impacts associated with the biogas upgrading process. Comparison of the different upgrading technologies. Abbreviations: AP: acidification potential; GWP: global warming potential; EP: eutrophication potential; FAETP: freshwater aquatic ecotoxicity potential; FSETP: freshwater sediment ecotoxicity potential; HTP: human toxicity potential; MO: malodorous air; EBIR: photochemical oxidation; ARD: abiotic resource depletion; ODP: stratospheric ozone depletion; TAETP: terrestrial ecotoxicity.

Table 2
Importance matrix of impacts of biogas upgrading. See color and numerical scale in Table 1.

Environmental components				Actions project						
				Construction stage					Operation stage	
				Soil movement	Floor construction and building	Equipment installation	Waste generation	Obtaining biomethane	Gaseous emissions	Loss of liquid effluent
Physical – biological environment	Inert Environment	Air	Quality/ Noise	−27 −24	−23 −24	−23 −24	−25	70	−65	
		Soil	Quality/ Structure	−24	−26		−28			−19
		Water	Quantity					−28		
	Biotic Environment	Flora		−24			−22			
		Fauna	Poultry	−24				−36		
	Perceptual Environment	Landscape	Quality				−23			
Socioeconomic cultural environment	Public utility							61		
	Education							36		
	Health						−25		−24	−19
	Jobs (temporary or permanent)			22	22	22		32		
	Urban development			23	23	23		38		

terms that make the project feasible. The identified negative effects require that the company implement an environmental management plan to maintain an adequate standard of environmental quality.

3.3. Comparison of tools

Table 4 summarizes the strengths and weaknesses of LCA and EIA. The difference between the two tools has led to their differing uses. LCA can be used to improve processes, products or services from the cradle to the grave and as a planning tool. By contrast, the EIA is primarily an application requirement by law to identify environmental weaknesses of a project and implement mitigation plans. In summary, EIA and LCA are not opposites but, rather, complementary tools.

While the EIA is specific to a project, LCA comprehensively compares similar alternatives (such as a comparison of different solvents to upgrade biogas) and takes into account all important aspects not present when studying only one project.

3.4. Comparison with other studies

Considering the study case of upgrading biogas, was demonstrated that use the results of the LCA methodology as a basis for the EIA allows a more complete evaluation of environment impacts. This is consistent with previous studies available in the literature. Tukker (2000) shows some case studies (for waste management plan, electricity plan, oil desulphurization plant and flue gas treatment) that demonstrated the feasibility of use elements of LCA in EIA. The author concluded that EIA is a procedure rather

Table 3
Nature of the impact of biogas upgrading.

Environmental components	Severe		Moderate		Irrelevant	
	–	+	–	+	–	+
Air	1	1	1		6	
Soil			2		2	
Water			1			
Flora					2	
Fauna			1		1	
Landscape			1			
Public utility		1				
Education				1		
Health					3	
Jobs				1		3
Urban development				1		3
Total	1	2	6	3	14	6

Table 4
Comparison of LCA and EIA.

	EIA	LCA
Strengths	Assess positive and negative effects. Analyzes the impacts at different stages of a project (construction, operation and closure). Analyzes socio-economic variables.	Comprehensive analysis of impact. Cradle to grave approach.
Weaknesses	Is limited to the object of study. Does not incorporate global impacts. Does not exist within a specific period. Is not possible to compare similar alternatives.	Does not take into account social and economic variables. The data to assess the impact are scarce.

than a tool, in which LCA certainly may be useful. In the same sense, Manuilova et al., 2009 compared EIA versus LCA for CO2 capture and storage projects. They concluded that the EIA regulations for these projects should be developed with a life cycle perspective in mind. And they believe that the EIA procedure can never be complete without using elements of the LCA methodology. Finally, Buytaert et al. (2011) evaluated different tools in bioenergy systems. They ensure that different assessment focus may lead to a different choice of assessment tool. And they concluded that the various existing assessment tools are not necessarily complementary, but might be combined in practice in the form of a toolbox.

4. Conclusions

The results of the application of LCA to the biogas upgrade demonstrate that the water upgrading process produces the least impact in most of the analyzed categories and permits select this solvent as the best option. The EIA shows positive results in environmental terms that make the project feasible, whereas negative impact can be mitigated by preventive and remedial measures. Complementing the EIA with an LCA allows an assessment of the environmental impact as required by law when using the results of the LCA methodology as a basis for the EIA.

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