Life Cycle Assessment of maize cultivation for biogas production

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Introduction

The renewable sources for energy production is considered to be a potential solution for reducing the environmental problems derived from the fossil fuels use (Gonzalez-Garcia et al. 2012a). Besides the reduction of their consumption, during the past few decades more and more interest has been focused on the production of renewable energy.

In Europe, the interest for Renewable Energy Sources (RES) has strongly increased due to the need to reduce also the greenhouse gas (GHG) emissions, as RED (European Parliament, 2009) indicates.

Energy crops and the derived bioenergy production are expected to bring environmental, social and economic benefits. Several studies have reported benefits in terms of the reduction of GHG, air pollution, acidification or eutrophication (Buratti and Fantozzi 2010; Bacenetti and Fiala 2011; Bacenetti et al. 2012a; González-García et al. 2012b).

However, the environmental impacts concerning bioenergy strongly depend on crops cultivation (Fazio and Monti 2011; Uchida and Hayashi 2012). Among the several possible solutions, the Anaerobic Digestion (AD)represents one of the most promising ways to use RES (Angelidaki and Ellegaard 2003; Jury et al. 2010; Patterson et al. 2011; Capponi et al. 2012).

The agricultural byproducts, such as animal slurry and manure, are commonly used for biogas production; nevertheless, the main biomass for digesters feeding are often represented by cereal silages (maize, wheat and triticale, in particular).

In Italy, about 1000 agricultural biogas plants are currently in function (380 located in Lombardy), for a global electrical power of 156 MW. Although no detailed information concerning the amount of silages used to feed the AD plants is available, the areas in which biogas production is more widespread along with an increase in biomass prices and the value of lands has taken place (Povellato, 2011).

The environmental effects due to energy crop cultivation come not only from field operations but also from the inputs (fuels, fertilizers and pesticides) extraction, production and transportation. Therefore, in order to perform a complete evaluation of the system, all of these aspects must be taken into account.

The aim of this study is to analyze the environmental performances of maize silage for biogas production

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Key words: biogas production, bioenergy, maize cultivation.

Acknowledgments: the present work is funded by RegioneLombardia - Fondo per la Promozione di AccordiIstituzionali, project BIOGESTECA 15083/RCC". The Authors thank also the RegioneLombardia which financed a Postdoctoral Research Fellowship ("Progetto Dote Ricerca" financed by FSE - RegioneLombardia).

Journal of Agricultural Engineering 2013;XLIV(s2):e114
doi:10.4081/jae.2013.s2.e114

Introduction

Goal and scope definition

The environmental performances of maize FAO class 700 (maize 700) cultivation were assessed in terms of methane potential production. Maize is commonly used as animal feed, but nowadays -in Northern Italy- it plays an important role for biogas production, too.

This analysis was performed using the Life Cycle Assessment (LCA) methodology able to analyze products, processes or services from an environmental perspective (Guinée et al. 2002; ISO 2006).

Description of the crop cultivation

The cultivation under assessment is carried out in the Po Valley area, district of Milan, Lombardy Region (Italy). The local climate is characterized by an average annual temperature of 12.7°C and the rainfall is mainly concentred in Autumn and Spring (average annual precipitation is equal to 745 mm).

Field and ensilage operations are reported in Table 1 and shown in Figure 1. Field operations can be divided into: (1) soil tillage, (2) crop management (cover fertilization, weed and pest control), (3) biomass harvesting and transport and (4) biomass ensilage.

The crop cultivation starts on May with organic fertilization and ends on September when maize is harvested and immediately ensiled. The biomass yield is 75 twb·ha-1(dry matter content of 34.9%).

Functional unit and system boundaries

Considering that the analysis was performed on the crops that were specifically cultivated for energy generation by means of AD plants, the selected functional unit was 1 tonne of fresh silage (1tWB).

The system boundaries (Figure 1) included crop cultivation and harvesting, biomass transport and ensilage to the close biogas plant.

Life cycle inventory

Data (year 2011) concerning the field operations, ensilage and transport were directly obtained by means of questionnaires (administered to farmers) as well surveys and tests on the field.

Information regarding seeds, fertilizers, pesticides and water use were provided by the farmer as well as the diesel fuel consumption. Emissions due to the fertilizers includenitrogen emissions (nitrate, ammonia, and nitrous oxide) computed in according to Brentrup et al. (2000). Phosphate emissions were calculated following Smil (2000). Climatic data for year 2011, which were necessary for calculating the fertilizer emissions, were obtained from the meteorological station closest to the farm. Pesticide emissions were also estimated using PestLCI (Birkved and Hauschild 2006).

The emissions due to diesel fuel use were estimated using the Swiss Federal Office for the Environment Database (Federal Department of the Environment, Transport, Energy and Communications, or DETEC); secondary data for seed production, diesel fuel, fertilizers and pesticides were obtained from the Ecoinvent database and the LCA Food DK database (Nielsen et al. 2003).

Considering that the soil was previously dedicated to maize cultivation,zero change in the overall soil carbon content has been assumed.

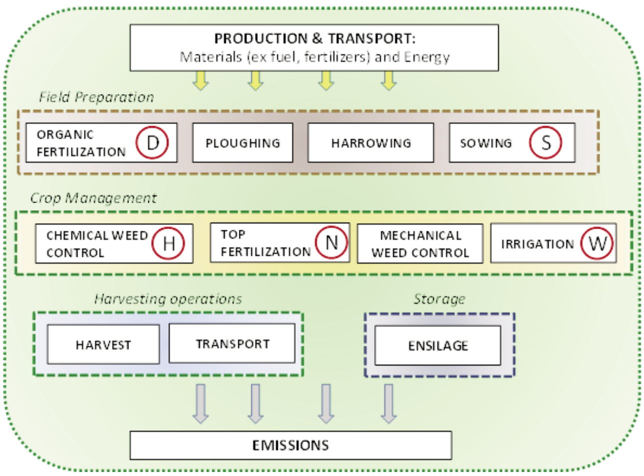

Figure 1. System boundaries

Note: D = digestate, S = seeds, H = herbicide, N = nitrogen fertilizer, W = water

Methods

A life cycle impact assessment (LCIA) was performed using SimaPro software (PRé Consultants - http://www.pre-sustainability.com/simapro -lca-software) and CML 2000 (Guinée et al. 2002) was chosen as a method with which to assess the environmental impact.

Table 2. Scores for all impact categories for the FU

IMPACT CATEGORIES	UNITS	TOTAL
Abioticdepletion	kg Sb eq	0,104624
Acidification	kg SO_2eq	1,378419
Eutrophication	kg PO4eq	0,412833
Global warming (GWP100)	kg CO_2eq	29,75866
Ozonelayerdepletion (ODP)	kg CFC-11 eq	2,11E-06
Human toxicity	kg 1,4-DB eq	3,445905
Fresh water aquaticecotoxicity	kg 1,4-DB eq	0,830076
Marine aquaticecotoxicity	kg 1,4-DB eq	2305,503
Terrestrialecotoxicity	kg 1,4-DB eq	0,023476
Photochemicaloxidation	kg C_2H_4eq	0,003256

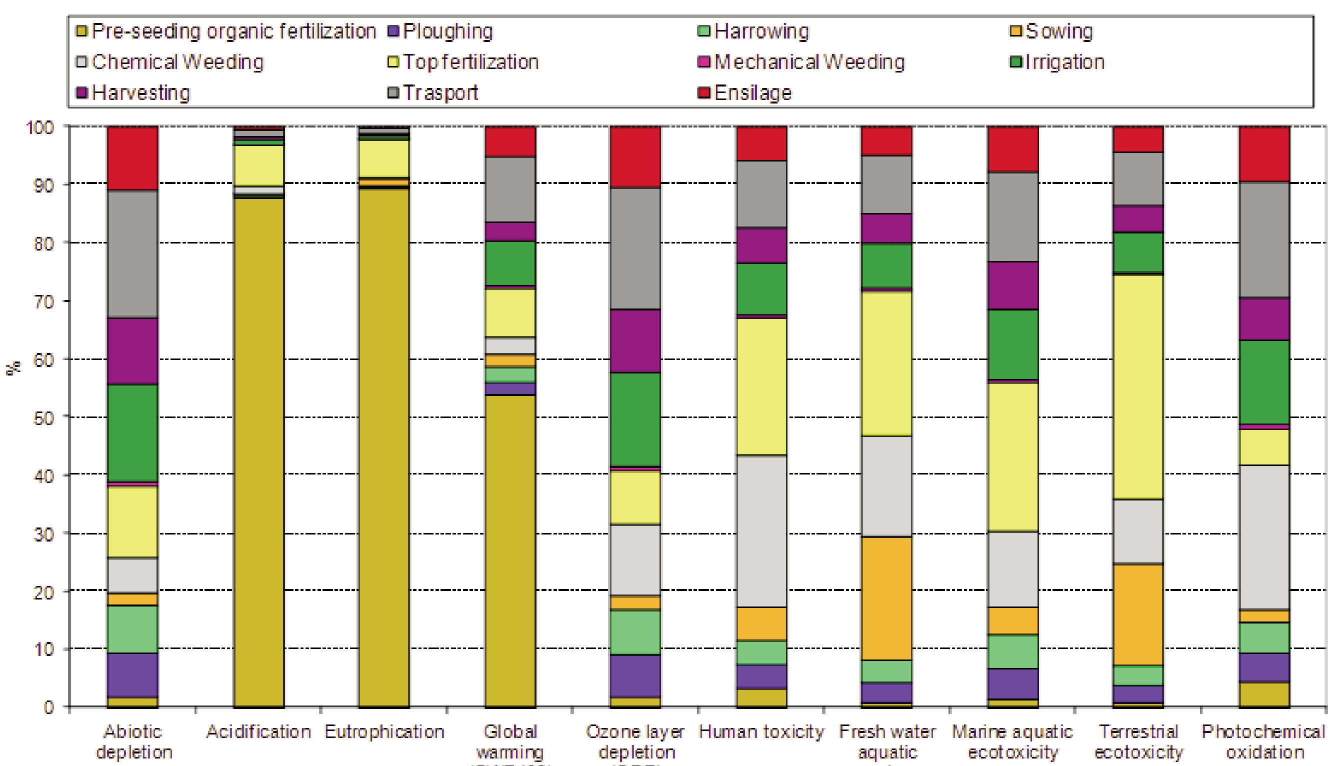

Figure 2. Impact of operations on the different impact categories

Results and discussion

The environmental impact is widely influenced, as expected, by the field operations; on the contrary, less than 5% of the overall environmental impact is due to the ensilage activity. Consequently, the operations carried out on the field are the main responsible (more than 95%) of the environmental burdens for all the 10 impact categories.

Among the different inputs and output s, the key aspects are: (i) fertilizer emissions (mainly for acidification and eutrophication impact categories), (ii) diesel fuel emissions (mainly for global warming potential impact category), (iii) diesel fuel production (mainly for abiotic depletion and ozone layer depletionimpact categories) and(iv) pesticides production (important for human toxicityimpact category).

Regarding the different f ield operations, the influence over the 10 impact categories is quite variable (Figure 2);for example, the fertilization is responsible for about 95% of acidification and eutrophication but less than 35% for the others impact categories.

Conclusions

The study assesses the environmental performances of maize FAO class 700; this cereal is the most widespread in Italy and it islargely utilized for biogas production.

The study points out that the environmental burdens of maize 700 cultivation are mainly due to: (i) crop fertilization (in particular nitrogen application, primarily via organic fertilizers) and (ii) mechanization of field operations.

The analysis highlighted that the nitrogen cycle and the linked emissions are relevant for the environmental burden of crop cultivation, especially foracidification and eutrophication. Organic fertilization, carried out with a high-rate of digestate, involves high emissions in atmosphere of ammonia and nitrogen dioxide, especially when the spreading is performed distributing the digestate directly on the soil surface and without a fast burial.The digestateinjection into the soil largely reducesthe ammonia emissions.

Mechanization requiresa high diesel fuel consumption and, consequently, a significant impact on GWP and abiotic depletion as well. Reduction of the diesel fuel consumption, thatcould significantly improve the environmental performances, can be achievedthrough:

1. the introduction of proper technical solutions connected with lower mechanical power requirements (i.e. minimum tillage, sod seeding, slattedmouldboards).

The obtained results represent the environmental evaluation onlyof the first step of the whole biogas process. Future analysis will take into consideration the biogas production (microbiological digestion) and its final conversion into energy by a cogenerated i.c. engine (CHP).

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Table 1. Field and ensilage operations for single crop (maize 700)

OPERATION	NN.	MONTH	TRACTOR	OPERATIVE MACHINE			NOTE
			Mass (kg) Power (kW)	Type Size	Mass (kg)	Time (h/ha)	
Organic fertilization	1	May	5050 (90)	Manure spreader 20 m^3	2000	3.33	85 $t \cdot ha^{-1}$ Digestate[a]
Ploughing	1	May	10500 (190)	Plough	2000	1.11	-
Harrowing	1	May	7300 (130)	Rotary Harrow 4,0 m	1800	1.20	-
Sowing	1	May	5050 (90)	Pneumatic seeder 4 rows	900	1.00	20 $kg \cdot ha^{-1}$
Chemical Weeding	3	May Jun Jun	4450 (80)	Sprayer 15 m	600	0.33	4 kg·ha-1lumax
							1 $kg \cdot ha^{-1}$dual
							1 $kg \cdot ha^{-1}$ dual
Irrigation	5	Jun Jul Aug	4450 (80)	Pump 950 m^3/h	550	1.20	4400 m3·ha^{-1}
Mechanical Weeding	1	Jun	5050 (90)	Weeder 2,8 m	550	0.33	-
Top fertilization	1	Jun	6850 (120)	Fertilizer spreader 2500 dm^3	500	0.13	60 $kg \cdot ha^{-1}$Urea
Harvesting	1	Sep	-	Forage harvester	335 kW	13000	1.00

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