Sustainability of grape-ethanol energy chain

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Abstract

The aim of this work is to evaluate the sustainability, in terms of greenhouse gases emission saving, of a new potential bio-ethanol production chain in comparison with the most common ones. The innovation consists of producing bio-ethanol from different types of no-food grapes, while usually bio-ethanol is obtained from matrices taken away from crop for food destination: sugar cane, corn, wheat, sugar beet. In the past, breeding programs were conducted with the aim of improving grapevine characteristics, a large number of hybrid vine varieties were produced and are nowadays present in the CRA-VIT (Viticulture Research Centre) Germplasm Collection. Some of them are potentially interesting for bio-energy production because of their high production of sugar, good resistance to diseases, and ability to grow in marginal lands. LCA (Life Cycle Assessment) of grape ethanol energy chain was performed following two different methods: (i) using the spreadsheet "BioGrace, developed within the "Intelligent Energy Europe" program to support and to ease the RED (Directive 2009/28/EC) implementation; (ii) using a dedicated LCA software. Emissions were expressed in CO2 equivalent (CO2eq). The results showed that the sustainability limits provided by the normative are respected to this day. On the contrary, from 2017 this production will be sustainable only if the transformation processes will be performed using renewable sources of energy. The comparison with other bio-energy chains points out that the production of ethanol using grapes represents an intermediate situation in terms of general emissions among the different production chains..

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Introduction

Bioethanol is currently produced from raw material obtained from dedicated crops diversified in nature and origin such as, for example, sugarcane, corn, wheat, sugarbeet, grape. Since this production strategy is in direct competition with food production, with a consequent increase in basic foods prices, the trend is to use residual materials (Sarkar et al., 2012) or matrices to be used in bio-refineries (Cherubini, 2010).

In the specific case of bioethanol produced from grape, biofuel fits generally in a larger project for the production of complex molecules such as polyphenols (Kavargiris et al., 2009; Scram et al., 1993). In addition, the cultivation in marginal areas of no-food vine, native throughout Italy (Arroyo and Revilla, 2013), would solve, in this case, most of the issues related to land use competition with the food sector.

Among grapevine beside the V. vinifera varieties used for grapes production for the food industry (as wine, table grapes, raisins or juice), there are many hybrid varieties produced from the innumerable experiments conducted in the past by CRA-VIT. Breeding programs were carried on with the aim of improving grapevine characteristics in partic ular against diseases, and a large number of hybrid vine varieties was produced. Most of these varieties belong to the "French-American hybrids" (crosses between Vitis vinifera varieties and North American Vitis species) created in Europe to overcome grape phylloxera, powdery mildew and other diseases attack. Some of them potentially are interesting for bio-energy production because have high sugars pro duction, good resistance to diseases, and ability to grow in marginal lands (Esmenjaud and Bouquet, 2009). Moreover, also the production of grape seed oil and biomasses from branches and vine shoots can be significant for bioenergy uses.

In the CRA-VIT grapevine germplasm repository are maintained over 150 different genotypes of hybrid varieties including accessions of complex genealogy obtained crossin g several species from the Vitis genus. Data in the literature indicate that there is a large genetic variability among the genotypes about their pest resistance, soil adaptability, length of the cycle, and productivity (from 1-2 to 15-20 kg grape per plant with average sugar content of 13-22 Brix).

Due to technological and legal reasons, the grapes from hybrid vine varieties cannot be used in Italy f or winemaking, and nowadays are not significantly used as table grapes. Therefore, these grapes can be included among "no food" products, and their use for energy production overcomes the ethical discussions on the use of food crops for biofuel production.

Given these assumptions, the present work investigates about the chain of bioethanol production from grapes and evaluates the environmental sustai nability with respect of greenhouse gas emissions savings, in accordance with the European law which establishes the sustainability criteria for biofuels (Directive 2009/28/EC). A simplified LCA analysis of the chain has been performed to calculate the impact of bioethanol production from grapes on global warming, in order to obtain an indication of its sustainability.

Material and methods

LCA of grape ethanol energy chain was performed following two different methods: (i) using the spreadsheet "BioGrace", developed within the "Intelligent Energy Europe" program to support and to ease the RED implementation (BioGrace, 2010); (ii) using a dedicated LCA software. The analysis entailed the development of different LCA phases, i.e. the choice of the functional unit, the definition of system boundaries, the inventory of inputs and outputs.

To make a comparison of data obtained with those derived from other bioethanol production chains the functional unit chosen for the study was "1 MJ of bioethanol." In a second step, the overall emissions of the supply chain were correlated also to the cultivated hectare.

The inventory phase has been extended both to operations of raw material production (field operations for grape production) and processing for biofuel production (fermentation, distillation) and to its use. The data constituting the inventory were obtained through direct surveys at CRA-VIT or taken from literature. The input and output flows of materials and energy considered as part of the production chain are represented in Figure 1 in order to assess its impact in terms of greenhouse gases (system boundaries).

In compliance with the RED directive, the greenhouse gas emissions of fuels, biofuels and bioliquids were calculated by the following equation:

$$E_B = e_{ec} + e_l + e_p + e_{td} + e_u + e_{sca} + e_{ccs} + e_{ccr} + e_{ee} \qquad \text{(Eq.1)}$$

where:

E_B = total emissions from the use of fuel ;

e_{ec} = emissions from the extraction and cultivation of raw materials;

e^l = annualized emissions from carbon stocks changes caused by land use change;

e_p = emissions from processing;

e_{td} = emissions from transportation and distribution;

e_u = emissions from the fuel in use;

e_{sca} = emission saving from soil carbon accumulation via improved agricultural management;

e_{ccs} = emission saving from carbon capture and geological storage;

e_{ccr} = emission saving from carbon capture and replacement;

e_{ee} = emission saving from excess electricity from cogeneration.

When analyzing the grape-to-ethanol chain, the following assumptions were assumed:

- Changes in land use were not considered (e_l);
- Improvements in agricultural practices were not considered (e_{sca});

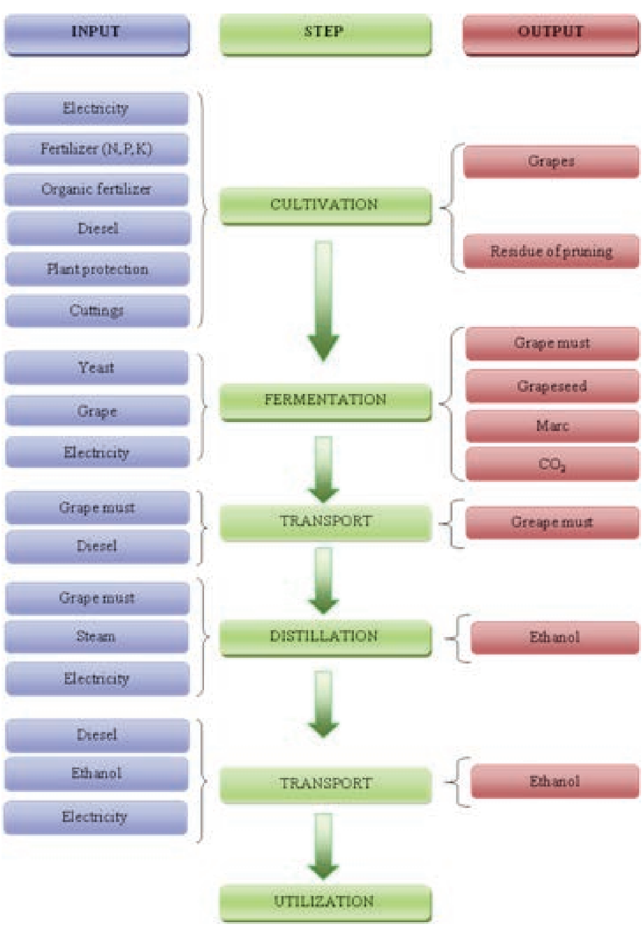

Figure 1. Representation of system boundaries of the analysis

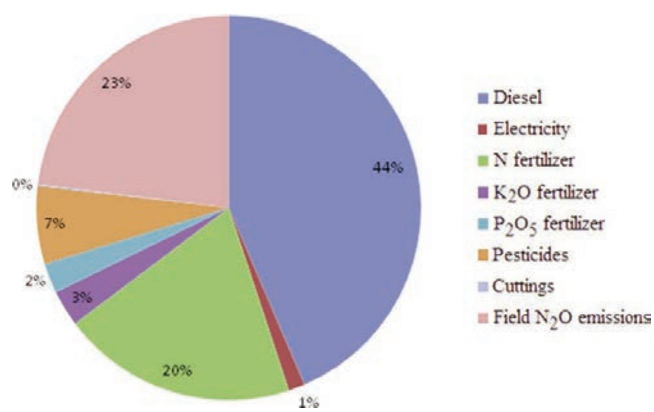

Figure 2. Effect of different inputs used during cultivation stage.

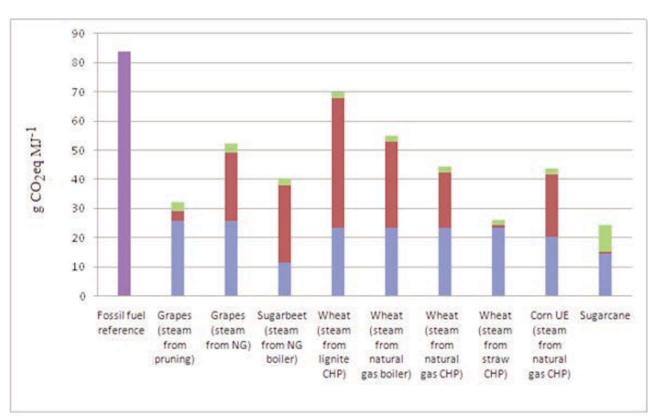

Figure 3. Comparison among overall emissions (g CO2eq MJ-1) of different ethanol production chains and the reference fossil fuel chain.

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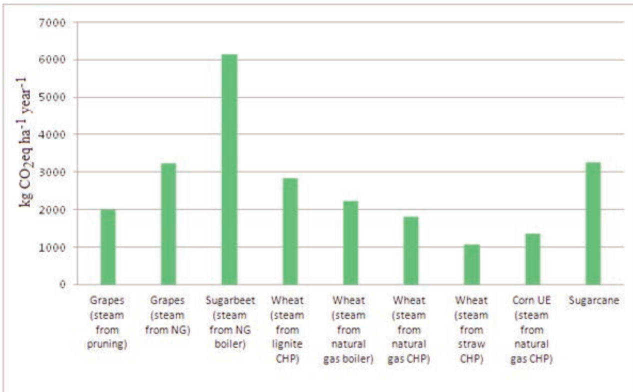

Figure 4. Comparison among overall emissions (kg CO_2eq ha^{-1} year^{-1}) of different ethanol production chains.

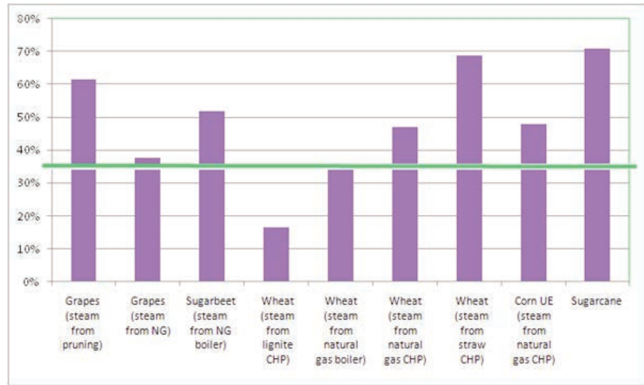

Figure 5. Percentage emission saving compared to the reference fuel. The minimum saving value identified by European Community as threshold is shown in green.

Table 1. Basic assumptions, referring to one hectare, for the calculation of the ethanol-to-energy chain sustainability divided by the steps of production

STEP	Cultivation*	Processing		Transport	
		Fermentation**	Distillation***	Fermented**	Ethanol***
Input	Fuel: 380 l y^{1} Electricity: 80 kWhy^{1} Inorganic fertilizer: • 92 kg N y^{1} • 68 kg P_2O5 y^{1} • 144 kg K_2O y^{1} Organic fertilizer (manure): 40.000 kg Plant protection products: 16,2 kg y1 of active ingredients (of which approximately 2 kg of copper hydroxide and about 6 kg of Fosetyl-Al) Cuttings: 3500	Electricity 56 kWh y^{1} Yeasts: 5 kg y^{1}	Electricity 330 kWh y^{1} Steam#: 15.120 MJ y^{1}	Fuel: 33,3 ly^{1}	Fuel : value from Biograce
Output	Grapes: 40.000 kg y-1 Pruning residues: 70.000 kg y^{1} with 50% moisture content	Fermented: 5.906 kg y^{1} Grape seeds: 1.040 kg y^{-1} Marc: 10.960 kg y^{1} CO2: 2094 kg y^{1}	Ethanol: 58700 MJ y^{1}		

Table 2. Allocation percentage (%) of emissions at different steps of the production chain

STEP	Cultivation*	Fermentation**	Distillation***	Transport	
Product				Grape must	Ethanol
Ethanol	55	55	100	100	100
Marc	34	34			
Grapeseed	11	11			

- Operations of carbon capture and geological storage were not considered (e_{ccs});
- Operations of capture and carbon substitution were not considered (e_{ccr});
- Since the cogeneration is not present in the studied chain, the emissions saved as a result of the production of excess electricity were not considered (e_{ee} is however present in some control chain).

The equation used in the specific case can therefore be simplified as follows:

$$E_B = e_{ec} + e_p + e_{td} + e_u \ (+ e_{ee}) \qquad \text{(Eq.2)}$$

The application of Equation 2 made it necessary to start with some assumptions, which focused on inputs and outputs of the different production steps (Table 1).

In the calculation of emissions using the BioGrace method, inputs have been processed using the JEC E3-database, obtaining the three main greenhouse gases (carbon dioxide, methane and nitrous oxide) emitted from the chain, expressed in terms of g CO_2 equivalents (g CO2eq) according to the 2006 and 2007 IPCC guidelines. Emissions relating to the construction of machineries, equipments and structures used were not considered, in accordance with the RED requirements (Annex V, point C).

Using the dedicated LCA software, inputs have been processed using the Ecoinvent database that allows to obtain the emissions evaluation of over fifty greenhouse gases expressed, as in the previous case, in CO_{2eq}.

The emission factors from the Ecoinvent database take into account also emissions related to the construction of machineries, equipments and structures used in their supply chain. In order to evaluate the impacts of biofuels also co-products were considered, using the energy allocation, in agreement with the method used in the BioGrace project and as specifically required by the RED, energy allocation among co-products was adopted in the present work. In particular, the emissions associated with each step in the chain were then distributed in function of the masses and their energy content (Table 2).

Concerning the utilisation step, in accordance with the RED, it was assumed that the combustion of biofuels and biomass generally produces the same amount of CO_2 employed by the plant to grow. Therefore, this contribution should not be recorded in the emission balance.

The percentage in greenhouse gas emission savings were calculated through the ratio shown in Equation 3.

$$ES = (E_F - E_B) / E_F \qquad \text{(Eq.3)}$$

where:
ES (Emission Savings) is the percentage of emissions avoided;
E_B is the total emission from the biofuel (bioethanol, in this case);
E_F is the total emission from the reference fossil fuel.

Results and considerations

Through the two softwares (the values coupled in brackets in the text refer to results obtained with BioGrace system and with LCA software respectively. If values are not coupled and no other clarification is given, then it must be considered that the reported value is representative for both the methods) an evaluation of emission level of the studied production chain compared to that of a reference fuel, in accordance to Eupean normatives, was obtained. Results show that the emission level (83,8 g CO_{2eq} MJ^{-1} and 90,8 g CO_{2eq} MJ-1 with BioGrace method and with LCA software respectively) is about 40% lower than the reference value. Thus the studied chain results to be sustainable for the RED parameters. These results became even better if the fossil fuel (methane) used during the distillation step for the production of steam is substituted with a renewable fuel (prunings from cultivation): in this case the emission saving is more than 60%.

Taking into account different production steps (cultivation, transformation, transport), both the methods show that cultivation produces the higher emissions (49-51%), followed by processing (45-44%) and transport (6-5%). The use of prunings as fuel instead of methane for steam production entails significant modifications about emission impacts: 4/5 of total emissions are, in fact, attributed to cultivation while the remaining 1/5 is equally distributed between processing and transport

The analysis of cultivation (Figure 2), carried out with BioGrace method, underlines the important environmental impact of mechanization, followed by inorganic fertilizers and by nitrous oxide emissions, that are however related to fertilization. On the contrary, the environmental impact of cuttings is less than 1%.

Inputs that produce emissions during processing are methane and electricity used mostly for steam production. In particular, methane produces 4/5 of emissions in that step. The substitution of the fossil fuel with wood bio mass (prunings) only reduces the electricity input.

During the transport (both the transport of grape must to the distillation step and the transport of ethanol to the pump) the higher contribution in terms of emissions is given by the diesel used for road transports (80%). Electricity used for materials handling contributes for the remaining 20%.

The sustainability of the production chain can be evaluated not only referring to the reference fuel fixed by the normative, but also referring to other well established biofuel production chains. The results reported (Figure 3) refer to elaborations carried out with BioGrace software. The dedicated LCA software produced values in accordance with the previous ones.

The overall emissions impact of ethanol production from grapes is placed in an intermediate position compared to the other production chains considered. The sugarcane-to-ethanol production chain has the lower emission value (24,3 g CO_{2eq} MJ^{-1} of ethanol) while the wheat-to-ethanol production chain that considers the co-generation of lignite appears to be the worst (69,9 g CO_{2eq} MJ^{-1}). If considering the production steps, the grape-to-ethanol production chain has slightly higher emissions during cultivation compared to the other production chains (mean value 20 g CO_{2eq} MJ^{-1}) and in particular compared to those production chains with higher yield for hectare of crops. (beetroot and sugarcane). With the exception of sugar cane-to-ethanol chain (9 g CO_{2eq} MJ^{-1}), where the shipment of ethanol from Brasil has great influence on emissions, the other production chains – including the grape-to-ethanol chain – show low emission deriving from transport (mean value 3 g CO_{2eq} MJ^{-1}). The processing step shows more oscillating emission values. This is evident particularly in the wheat-to-ethanol chain, with values ranging between 0,8 g CO_{2eq} MJ^{-1} and 44,5 g CO_{2eq} MJ^{-1} that refer to wheat-to-ethanol chain through co-generation of straw and lignite respectively.

Figure 4 shows a comparison between the studied production chain with the principal ethanol production chains present in BioGrace (steam production methods are indicated in brackets) in terms of emissions of kg CO_{2eq} ha^{-1} $year^{-1}$.

As it can be seen the overall emission per hectare per year (e.g. in the case of beetroot) does not have the same trend of the overall emission per energy unit, because it takes into account just the territorial unit yield, not the production yield. It is however a useful parameter to identify the magnitude of impacts at local level. In the case of greenhouse gas emission, affecting at global level, this parameter seems to be not significant. For these reasons the RED requires the calculation of emissions per energy unit, not per territorial unit. Finally (Figure 5), it is shown the emission savings after production and use of 1 MJ ethanol with respect to the reference value (the minimum threshold of 35% indicated in normative is shown in green).

The studied grape-to-bioethanol chains allow to exceed the threshold of 35% greenhouse gas emission saving in all scenarios considered. Using methane as fuel the emission saving is just above the threshold while in the case of using prunings the saving exceeds the 60% (in line with the best bioethanol production chains). This would permit also to stay within the future, and more restricted, sustainability threshold.

Conclusions

Results about the grape-to-ethanol production chain study, with the binding hypothesis of using marginal lands, permit to give a clear indication of its sustainability in terms of greenhouse gas savings compared to the reference fossil chain. The information that emerges with both methods used is that the sustainability is currently respected, considering the threshold limit indicated in the normative. On the other hand, another consideration must be formulated for the future: with a raising of the minimum threshold of emission saving, the grape-to-ethanol chain could be sustainable only if prunings will be used for steam production instead of methane

It must be stressed that all factors used during the cultivation step contribute, directly or indirectly, to increase the production bu t, at the same time, are also responsible of a certain quantity of emissions. Among them, relevant factors are nitrogen fertilization, diesel (attributable to cultivation) and the type of fuel (prunings or methane) used during the distillation step.

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