Sustainability of grape-ethanol energy chain

Ester Foppa Pedretti,[1] Daniele Duca,[1] Giuseppe Toscano,[1] Giovanni Riva,[1] Andrea Pizzi,[1] Giorgio Rossini,[1] Matteo Saltari,[1] Chiara Mengarelli,[1] Massimo Gardiman,[2] Riccardo Flamini[2]

[1]Dipartimento di Scienze Agrarie, Alimentari e Ambientali, Università Politecnica delle Marche, Ancona; [2]Consiglio per la Ricerca e la Sperimentazione in Agricoltura - Centro di Ricerca per la Viticoltura, Conegliano (TV), Italy

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 Viticulture Research Centre (CRA-VIT) 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. Life cycle assessment (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 Renewable Energy Directive 2009/28/EC implementation; ii) using a dedicated LCA software. Emissions were expressed in CO_2 equivalent (CO_2eq). These two tools gave very similar results. The overall emissions impact of ethanol production from grapes on average is about 33 g CO_2eq MJ^{-1} of ethanol if prunings are used for steam production and 53 g CO_2eq MJ^{-1} of ethanol if methane is used. 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. 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.

Correspondence: Daniele Duca, Dipartimento di Scienze Agrarie, Alimentari e Ambientali, Università Politecnica delle Marche, via Brecce Bianche, 60131 Ancona (AN), Italy.
Tel.: +39.071.2204297 - Fax: +39.071.2204167.
E-mail: d.duca@univpm.it

Key words: life cycle assessment, biofuel, no-food grapes, sustainability, CO_2 emission.

Received for publication: 18 July 2014.
Accepted for publication: 24 September 2014.

Journal of Agricultural Engineering 2014; XLV:425
doi:10.4081/jae.2014.425

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). Some authors evaluated the sustainability of different biofuels taking into account the methodology defined by the recent European policy (Duca *et al*., 2013; Martinez-Hernandez *et al*., 2013; Spugnoli *et al.,* 2012).

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 *Vitis 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 Viticulture Research Centre (CRA-VIT). Breeding programs were carried on with the aim of improving grapevine characteristics in particular against diseases, and a large number of hybrid vine varieties were produced. Most of these varieties belong to the *French-American hybrids* (crosses between *V. 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 production, 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.

Again in the CRA-VIT grapevine germplasm repository are maintained over 150 different genotypes of hybrid varieties including accessions of complex genealogy obtained crossing 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 for 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 hybrid varieties of grapes and evaluates the environmental sustainability with respect of greenhouse gas emissions savings, in accordance with the European law, which establishes the sustainability criteria for biofuels (Renewable Energy Directive 2009/28/EC, known as RED) (European Commission, 2009). A simplified life cycle assessment (LCA) analysis of the chain has been performed to calculate the impact of bioethanol production from hybrid varieties of grapes (indicated as *grape* in the paper) on global warming, in order to obtain an indication of its sustainability. Two different tools have been applied to perform this evaluation and a comparison between the bioethanol production from grapes emission and other productions has been carried out.

Materials and methods

LCA of grape ethanol energy chain was performed following two different tools: 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 (SimaPro 7.3; PRé Consultants bv, Amersfoort, the Netherlands). 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 with the exception of the bioethanol transport taken from the BioGrace Project (BioGrace, 2010). 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:

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

where:
E_B, total emissions from the use of fuel;
e_{ec}, emissions from the extraction and cultivation of raw materials;
e_l, annualised 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.

Values are expressed as g CO_2eq MJ^{-1}.

When analysing the grape-to-ethanol chain, the following assumptions were assumed: i) changes in land use were not considered (e_l); ii) improvements in agricultural practices were not considered (e_{sca}); iii) operations of carbon capture and geological storage were not considered (e_{ccs}); iv) operations of capture and carbon substitution were not considered (e_{ccr}); v) 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:

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

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

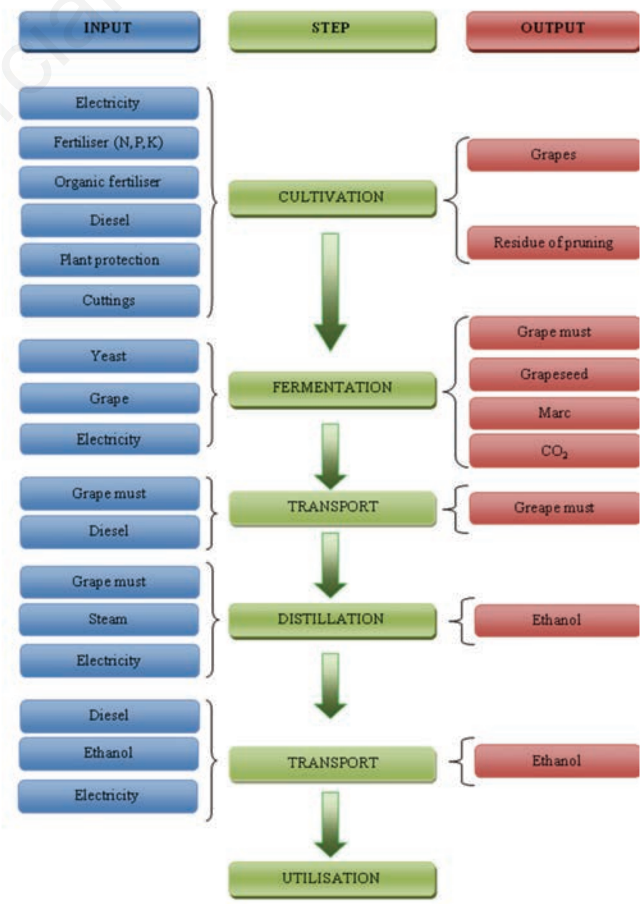

Figure 1. Representation of system boundaries. N, nitrogen; P, phosphorus; K, potassium.

CO_2eq) according to the 2006 and 2007 guidelines of the Intergovernmental Panel on Climate Change. Emissions relating to the construction of machineries, equipment and structures used were not considered, in accordance with the RED requirements (Directive 2009/28/EC - Annex V, point C.1) (European Commission, 2009). Using the dedicated LCA software, inputs have been processed using the Ecoinvent database that allows obtaining 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, equipment 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 (Directive 2009/28/EC - Annex V, Point C.13) (European Commission, 2009) and considering other works (Stichnothe and Azapagic, 2009; González-García *et al*., 2012), 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 was calculated through the ratio shown in Equation 3.

$$ES = (E_F - E_B) / E_F \times 100 \quad (3)$$

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 discussion

Through the two software an evaluation of emission level of the studied production chain compared to that of a reference fuel, in accordance to European normatives, was obtained. Results show that the emission level is about 40% lower than the reference fossil values with both BioGrace method and SimaPro (fossil references: 83.8 g CO_2eq MJ^{-1} and 90.8 g CO_2eq MJ^{-1} respectively). 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%.

In the following pharagraphs the results obtained by the two tools and the comparison between the studied production chain with the principal ethanol production chains present in BioGrace are reported.

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 kWh y^{-1} Inorganic fertiliser: 92 kg N y^{-1} 68 kg P_2O_5 y^{-1} 144 kg K_2O y^{-1} Organic fertiliser (manure): 40,000 kg Plant protection products: 16.2 kg y^{-1} of active ingredients (of which approximately 2 kg of copper hydroxide and about 6 kg of Fosetyl-Al) Cuttings: 3500 units	Electricity 56 kWh y^{-1} Yeasts: 5 kg y^{-1}	Electricity 330 kWh y^{-1} Steam**: 15,120 MJ y^{-1}	Fuel: 33.3 l y^{-1}	Fuel: value taken from Biograce
Output	Grapes: 40,000 kg y^{-1} Pruning residues: 70,000 kg y^{-1} with 50% moisture content	Fermented: 5906 kg y^{-1} Grape seeds: 1040 kg y^{-1} Marc: 10,960 kg y^{-1} CO_2: 2094 kg y^{-1}	Ethanol: 58,700 MJ y^{-1}		

*Inputs and outputs are referred to an average year, with the exception of manure and cuttings that were given in one solution and reported as such in the inventory; °duration of cultivation: 25 years; #this phase occurs in fermenters with a capacity of 5000-10,000 hL; §this phase occurs in continuous plants; ^the distance between vineyard and winery is about 50 km and the trailer used has a capacity of 28 t and a consumption of 0.3 l km^{-1}. Losses were not considered; $distance, fuel consumption and emissions are taken from the BioGrace project. Losses were not considered; **the steam production is carried out in two ways: using natural gas in boiler with features borrowed from the project BioGrace; using pruning residues (calorific value of 18 MJ kg^{-1}) in boiler with a yield of about 70%.

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

Step	Cultivation	Fermentation	Distillation	Transport	
				Grape must	Ethanol
Product					
Ethanol	55	55	100	100	100
Marc	34	34	-	-	-
Grapeseed	11	11	-	-	-

Results obtained by the two tools

In Table 3 the results obtained using the two tools for evaluating the bioethanol from grape chain are reported.

The two tools gave very similar results. Taking into account different production steps (cultivation, transformation, transport), both the methods show that cultivation produces higher emissions (49-51%), followed by processing (45-44%) and transport (6-5%). [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.] The use of prunings as fuel instead of methane for steam production entails significant modifications about emission impacts: 4/5 of total emissions in this case are due 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 mechanisation, followed by inorganic fertilisers and by nitrous oxide emissions, that are however related to fertilisation. 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 biomass (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%.

Comparison with the most important ethanol production chains

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 hybrid-grapes varieties (indicated as grape) 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 Brazil 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.

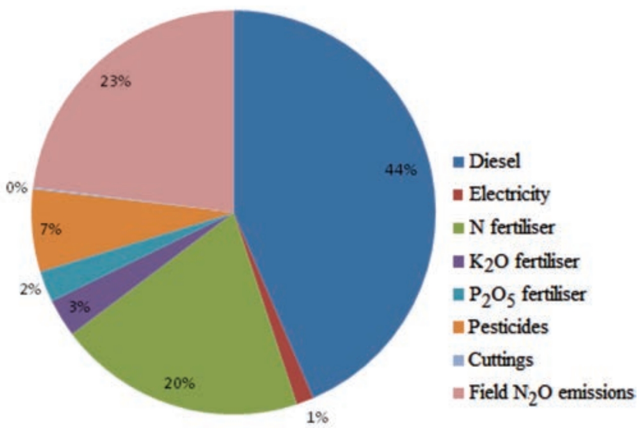

Figure 2. Effect of different inputs used during cultivation stage.

Table 3. Results of the greenhouse gas calculation for the bioethanol from grape chain carried out with the two tools (all values are expressed as g CO_2eq MJ^{-1} ethanol).

Tool	Fuel for distillation	Cultivation	Fermentation	Distillation	Transport		Total	Fossil references
					Grape must	Ethanol		
BioGrace	Natural gas	25.7	0.6	22.7	1.8	1.5	52.4	83.8
BioGrace	Prunings	25.7	0.6	2.6	1.8	1.5	32.3	83.8
SimaPro	Natural gas	27.6	0.3	23.7	1.6	1.0	54.2	90.8
SimaPro	Prunings	27.6	0.3	3.3	1.6	1.0	33.8	90.8

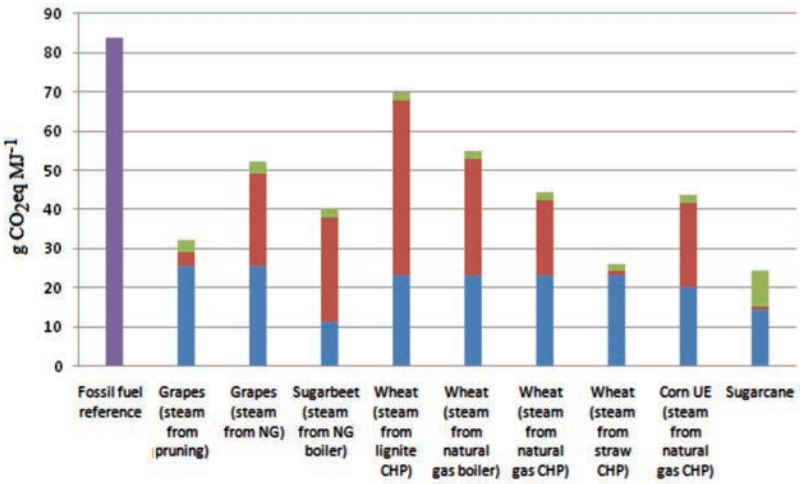

Figure 3. Comparison among overall emissions (g CO_2eq MJ^{-1}) of different ethanol production chains and the reference fossil fuel chain.

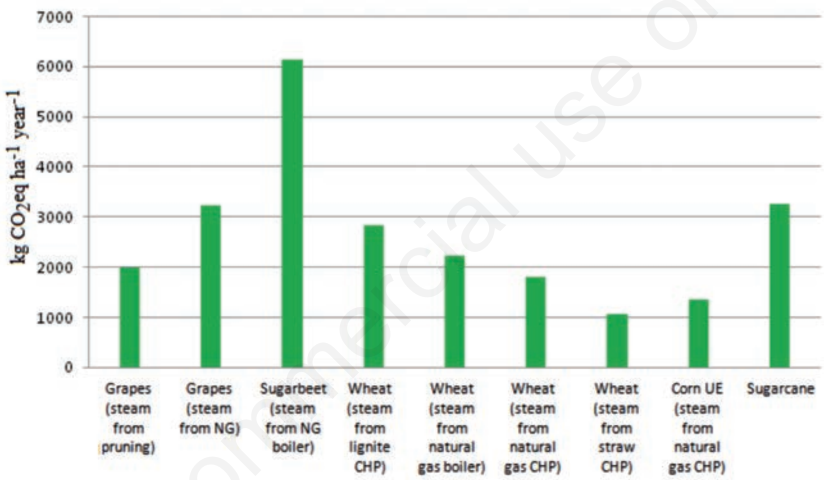

Figure 4. Comparison among overall emissions (kg CO_2eq ha^{-1} $year^{-1}$) of different ethanol production chains.

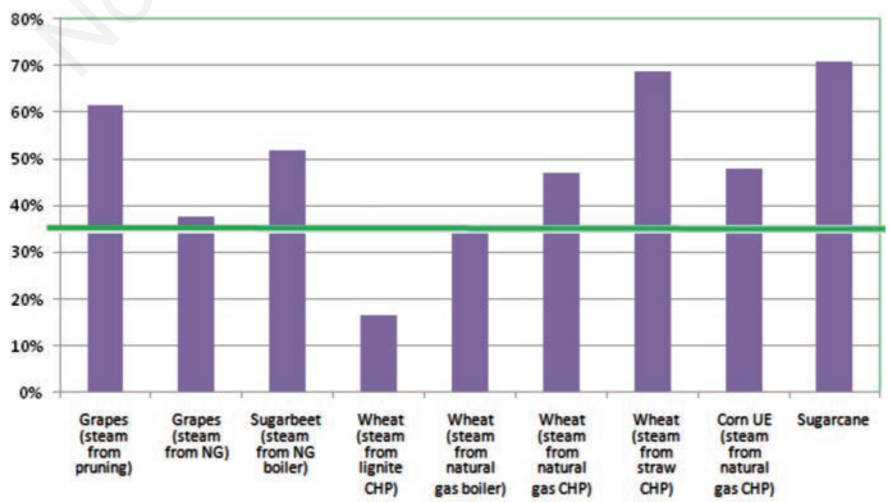

Figure 5. Percentage of emission saving compared to the reference fuel. The minimum saving value identified by European Community as threshold is shown in green.

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. From a methodological point of view it is interesting to note that the two tools give very similar results, not only in terms of total emissions but also in terms of single steps.

It must be stressed that all factors used during the cultivation step contribute, directly or indirectly, to increase the production but, at the same time, are also responsible of a certain quantity of emissions. Among them, relevant factors are nitrogen fertilisation, diesel (attributable to cultivation) and the type of fuel (prunings or natural gas) used during the distillation step. To improve sustainability in terms of greenhouse gas savings, it is of most importance that nitrogen fertilisation is balanced with the yield and to keep the tillage at the minimum when possible.

References

Arroyo Garcia R.A., Revilla E. 2013. The current status of wild grapevine population (Vitis vinifera spp sylvestris) in the Mediterranean basin. In: D. Poljuha and B. Sladonja (eds), The Mediterranean genetic code - grapevine and olive. InTech, Rijeka, Croatia, pp 51-72.

BioGrace. 2010. Harmonised calculations of biofuel greenhouse gas emissions in Europe, BioGrace_GHG_calculations_-_version_4b_-_Public.xls. BioGrace, Utrecht, The Netherlands. Available from: http://www.biograce. net

Cherubini F. 2010. The biorefinery concept: using biomass instead of oil for producing energy and chemicals. Energy Convers. Manage. 51:1412-21.

Duca D., Toscano G., Foppa Pedretti E., Riva G. 2013. Sustainability of sunflower cultivation for biodiesel production in central Italy according to the Renewable Energy Directive methodology. J. Agric. Engine. 44:175-80.

Esmenjaud D., Bouquet A. 2009. Selection and application of resistant germoplasm for grapevine nematodes management. In: A. Ciancio and K.G. Mukerji (eds), Integrated management of fruit crops and forest nematodes. Springer, Berlin, Germany, pp 195-214.

European Commission. 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. In: Official Journal L 140, 5/6/2009, pp 16-61.

González-García S., Iribarren D., Susmozas A., Dufour J., Murphy R.J. 2012. Life cycle assessment of two alternative bioenergy systems involving Salix spp. biomass: Bioethanol production and power generation. Appl. Energy 95:111-22.

Kavagiris S.E., Mamolos A.P., Tsatsarelis C.A., Nikolaidou A.E., Kalburtji K.L. 2009. Energy resources' utilization in organic and conventional vineyards: Energy flow, greenhouse gas emissions and biofuel production. Biomass Bioenerg. 33:1239-50.

Martinez-Hernandez E., Ibrahim M.H., Leach M., Sinclair P., Campbell G.M., Sadhukhan J. 2013. Environmental sustainability analysis of UK whole-wheat bioethanol and CHP systems. Biomass Bioenerg. 50:52-64.

Sarkar N., Ghosh S.K., Bannerjee S., Aikat K. 2012. Bioethanol production from agricultural wastes. An overview. Renew. Energ. 37:19-27.

Scram J.I., Hall D.O., Stuckey D.C. 1993. Bioethanol from grapes in the European community. Biomass Bioenerg. 5:347-58.

Spugnoli P., Dainelli R., D'Avino L., Mazzoncini M., Lazzeri L. 2012. Sustainability of sunflower cultivation for bodiesel production in Tuscany within the EU Renewable Energy Directive. Biosyst. Engine. 112:49-55.

Stichnothe H., Azapagic A. 2009. Bioethanol from waste: Life cycle estimation of the greenhouse gas saving potential. Resour. Conserv. Recycl. 53:624-30.