

ASSESSING THE GHG EMISSIONS OF RAPESEED AND SOYBEAN BIODIESEL IN COMPLIANCE TO THE EU RENEWABLE ENERGY DIRECTIVE METHODOLOGY FOR BIOFUELS

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ABSTRACT: The Renewable Energy Directive (RED) of the European Union proposes default GHG emission savings values for different types of biofuels. In this paper rapeseed and soybean biodiesel chains were evaluated, comparing RED values to typical values obtained for Italian case. In compliance to the EU RED methodology, each chain was divided in four steps: biomass cultivation, transport and processing and fuel transport. Each input and output was compared to data of typical Italian chains of producing rapeseed and soybean biodiesel. For the cultivation phase, typical farming techniques in the Veneto region were assumed, employing the IPCC methodology for the calculation of N₂O direct and indirect emissions. Processing step was divided in three processes: oil extraction, refining of vegetable oil and esterification of refined oil; data were obtained from the most important Italian biodiesel production plants. Results for rapeseed biodiesel showed that GHG saving for Italian chain was 49%, against 38% reported as default value in the EU RED, while for soybean biodiesel this difference was more marked (67% for Italian chain against 31%), mainly due to the fact that Brazilian cultivation was considered in the EU RED. **Keywords:** biodiesel, oil crops, greenhouse gases (GHG)

1 INTRODUCTION

The Renewable Energy Directive of the European Union (RED) [1] promotes the use of biofuels in order to help Europe to meet its greenhouse gas (GHG) emission reduction commitments, to improve its security on energy supply and to increase the use of renewable energy sources and to reduce its dependence on oil imports. The Directive encourages the production and use of biofuels by establishing a binding minimum target for renewable energy sources of 10% of final energy use in the transport sector by 2020.

In order to maximize its associated environmental benefits and to avoid as far as possible any potential negative effect, the biofuel Directive recognizes that the increase in the use of biofuels should be accompanied by a detailed analysis of their environmental impacts with a view to determining their benefits in comparison to the traditional fuels.

Biofuels must comply with the sustainability criteria that are provided in the RED in order to be eligible for financial supports; these criteria have to be met by all biofuels whether produced within the Union or imported from a third country. Specific requirements are laid out for GHG emissions-saving criteria and a 35% threshold is set once the RED is implemented through national legislation. From 2017, the GHG emission saving has to be 50%. For biofuels produced in installations for which production starts from 2017 and onwards, the GHG savings must be 60%.

RED contains also default and typical carbon intensities and GHG emission savings for a list of common biofuel production pathways (Fig. 1). Typical value is an estimate of the representative GHG emission for a particular biofuel production pathway, while default value, more conservative, is calculated by multiplying typical value for processing emissions by 1.4. Economic operators can use default values or own actual data, applying the GHG saving calculation methodology (Tab. I), to demonstrate that their products satisfy GHG thresholds.

In this paper the GHG emission balances, applying RED methodology, of biodiesel from rapeseed and

soybean were carried out. Italian chains were analyzed comparing relative actual values to default values and assuming no net carbon emissions from land - use change. In compliance to the RED methodology, each chain was divided in three stages: cultivation, processing and transport, including biomass and fuel transports.

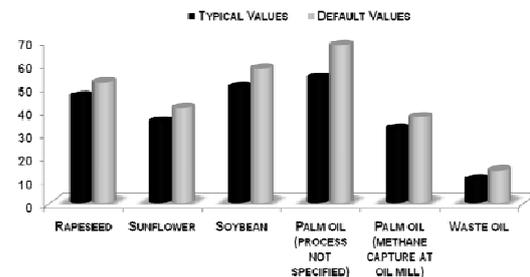


Figure 1: Typical and default GHG emissions (gCO₂eq/MJ) for different biodiesel pathways as calculated by the RED

2 CULTIVATION STEP

2.1 Rapeseed

The rapeseed plant (*Brassica napus*) is an annual crop; it can grow on sandy as well as clay soils. Typical farming technique in the Veneto region was assumed (Tab. II) [2].

Data regarding diesel consumption were drawn from [3]. The yield, assumed in the present work, was equal to 3256 kg ha⁻¹ of moist seeds (moisture content: 10%, Lower Heating Value: 23.76 MJ kg⁻¹); it was chosen to take into account the Veneto statistical data for rapeseed cultivation in 2009 [4].

Rapeseed irrigation in Veneto is not a common practice, and the irrigated area is not significant.

Direct and indirect N₂O emissions were calculated applying the IPCC methodology [5]. Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification.

Table I: Summary of key aspects of the RED GHG emission calculation methodology for biofuels

Methodological aspects	Selected approach	Additional information
<i>System boundaries</i>	Well-to-Wheel	direct emissions from the construction of infrastructure, plants and transportation machinery are not included
<i>GHGs included</i>	CO ₂ , CH ₄ , N ₂ O	conversion factors to CO ₂ eq: CO ₂ (1), CH ₄ (23) and N ₂ O (296)
<i>Functional unit</i>	g CO ₂ eq per MJ of fuel	-
<i>Emission savings calculation</i>	GHG Saving = (E _F - E _B)/E _F	E _F : total emissions of the reference fossil fuel; E _B : total emissions of the biofuel
<i>Fossil fuel reference</i>	latest available average from the fossil part of petrol and diesel consumed in the Community	if not available, the value to be used is 83.8 g MJ ⁻¹ of CO ₂ eq, for any type of biofuels
<i>Allocation method</i>	allocation based on energy content (defined as LHV of co-products) for most co-products	wastes (produced by the biofuel chain) and biogenic CO ₂ eq from fermentation are treated by system expansion. Export electricity is treated by an adapted system expansion procedure
<i>Direct Land Use Change (LUC)</i>	a calculation method for carbon stocks of different land use types is still missed	discounting of future emissions by annualized emissions over 20 years; bonus of 29 g MJ ⁻¹ of CO ₂ eq if biomass is produced on degraded land
<i>Baseline for LUC</i>	the reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later	-

The emissions of N₂O from N mineralization occur through both a direct pathway (directly from the soils to which the N is added) and through two indirect pathways: (i) following volatilization of NH₃ and NO_x from managed soils and the subsequent redeposition of these gases and their products NH₄⁺ and NO₃⁻ to soils and

waters; (ii) after leaching and runoff of N, mainly as NO₃⁻, from managed soils.

Table II: Agricultural operations for rapeseed cultivation (Veneto Region, Italy).

Agricultural operations	Diesel (kg ha ⁻¹)	Materials
Ploughing	26.1	-
Spring harrowing	4.4	-
Pre-sowing herbicides	1.8	trifluralin: 2.5 kg ha ⁻¹
Pre-sowing fertilization	5.3	N: 50 kg ha ⁻¹ P ₂ O ₅ : 70 kg ha ⁻¹ K ₂ O: 65 kg ha ⁻¹
Sowing	3.8	seeds: 7 kg ha ⁻¹
Pre-emergency herbicides	1.8	metazachlor: 2 kg ha ⁻¹
Top-dressing fertilization	5.3	N: 60 kg ha ⁻¹
Harvesting	33.3	seeds: 3256 kg ha ⁻¹

Direct N₂O emissions were calculated in compliance to eq. (1) [5], taking into account only the contribution of synthetic fertilizer N applied to soil and N in crop residues (above-ground and below-ground):

$$N_{2O_D} = [(F_{SN} + F_{CR}) * EF_1] * 44/28 \quad (1)$$

where:

- N₂O_D: direct N₂O emissions produced from managed soils, kg N₂O ha⁻¹;
- F_{SN}: amount of synthetic fertiliser N applied to soil, kg N ha⁻¹;
- F_{CR}: amount of N in crop residues (above-ground and below-ground) returned to soil, kg N ha⁻¹;
- EF₁: emission factor for N₂O emissions from N inputs, kg N₂O-N (kg N input)⁻¹ (assumed equal to 0,01 [5]).

F_{CR} was determined according to eq. (2) [5]:

$$F_{CR} = YF * D * [R_{AG} * N_{AG} * (1 - F_{REM}) + R_{BG} * N_{BG}] \quad (2)$$

where:

- YF: harvested fresh yield, kg fresh weight ha⁻¹;
- D: dry matter (d.m.) fraction of harvested crop, kg d.m. (kg fresh weight)⁻¹ (0.9);
- R_{AG}: ratio of above-ground residues dry matter to harvested yield, kg d.m. (kg d.m.)⁻¹ (2 [6]);
- N_{AG}: N content of above-ground residues, kg N (kg d.m.)⁻¹ (0.004505 [7]);
- F_{REM}: fraction of above-ground residues removed annually, kg N (kg crop-N)⁻¹ (0, it was assumed no removal);
- R_{BG}: ratio of below-ground residues dry matter to harvested yield, kg d.m. (kg d.m.)⁻¹ (0.35 [8]);
- N_{BG}: N content of below-ground residues, kg N (kg d.m.)⁻¹ (0.00405 [7]).

Indirect N₂O emissions were obtained taking into account volatilization and leaching processes, according to eq. (3) [5]:

$$N_2O_1 = [(F_{SN} * F_G * EF_2) + (F_{SN} + F_{CR}) * F_L * EF_3] * 44/28 \quad (3)$$

where:

- F_G : fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x , kg N volatilized (kg of N applied)⁻¹ (0.1 [5]);
- EF_2 : emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N– N_2O (kg NH_3 –N + NO_x –N volatilised)⁻¹ (0.01 [5]);
- F_L : fraction of all N added to soil that is lost through leaching and runoff, kg N (kg of N additions)⁻¹ (0.3 [5]);
- EF_3 : emission factor for N_2O emissions from N leaching and runoff, kg N_2O –N (kg N leached and runoff)⁻¹ (0.0075 [5]).

Overall N_2O emissions were equal to 2887 g ha⁻¹, constituted by 2216 g ha⁻¹ of direct emissions and 671 g ha⁻¹ of indirect emissions.

In compliance to RED, seeds drying process was included in the cultivation step. In particular a reduction of seeds moisture from 10% to 9% was assumed, assuring their preservation over a prolonged storage period. For this process the following energy consumptions were considered [3]:

- diesel: 5 MJ kg⁻¹ of evaporated water (equal to 0.05 MJ/kg of seeds);
- electricity: 1 kWh kg⁻¹ of evaporated water (equal to 0.01 kWh kg⁻¹ of seeds).

2.2 Soybean

The soybean plant (*Glycine max.*) is an annual leguminous plant. In Italy, soybeans are produced in the northern regions, with Veneto accounting for 48% of the national soybean production [4]. Italian soybeans are planted from the end of April through the end of May and harvest runs from the first of October through the end of November.

In Tab. III typical agricultural operations in the Veneto region are shown [9, 10, 11, 12]. Soybean irrigation in Veneto is not a common practice, and the irrigated area is not significant.

Table III: Agricultural operations for soybean cultivation (Veneto Region, Italy).

Agricultural operations	Diesel (kg ha ⁻¹)	Materials
Ploughing	26.1	-
Rotary harrowing	11.5	-
Pre-sowing fertilization	5.3	P ₂ O ₅ : 70 kg ha ⁻¹ K ₂ O: 75 kg ha ⁻¹
Sowing	3.8	seeds: 80 kg ha ⁻¹
Pre-emergency herbicides	1.8	imazamox: 1 kg ha ⁻¹ thifensulfuron-methyl: 0,005 kg ha ⁻¹ fluazifop-p-butyl: 2 kg ha ⁻¹
Harvesting	33.3	seeds: 3649 kg ha ⁻¹

The yield was equal to 3649 kg ha⁻¹ of moist seeds (moisture content: 15%; Lower Heating Value: 20 MJ kg⁻¹); it was chosen to take into account the Veneto statistical data for soybean cultivation in 2009

[4].

In the following the only parameters, regarding N_2O emissions calculation, different from rapeseed example are reported:

- D : dry matter fraction of harvested crop, kg d.m. (kg fresh weight)⁻¹ (0.85);
- R_{AG} : ratio of above-ground residues dry matter to harvested yield, kg d.m. (kg d.m.)⁻¹ (1.37 [5]);
- N_{AG} : N content of above-ground residues, kg N (kg d.m.)⁻¹ (0.008 [5]);
- R_{BG} : ratio of below-ground residues dry matter to harvested yield, kg d.m. (kg d.m.)⁻¹ (0.19 [5]);
- N_{BG} : N content of below-ground residues, kg N (kg d.m.)⁻¹ (0.008 [5]).

Total N_2O emissions were 866.8 g ha⁻¹: 707.6 g ha⁻¹ as direct emissions and 159.2 g ha⁻¹ as indirect emissions.

As regards seeds drying, a decrease of moisture content from 15% to 14% was considered, corresponding to the following energy consumptions [3]:

- diesel: 0.05 MJ kg⁻¹ of seeds;
- electricity: 0.04 kWh kg⁻¹ of seeds.

3 PROCESSING STEP

The processing step of the oil seeds for both sources is the same and it is divided into three processes: extraction of vegetable oil, refining and transesterification. Data about mass and energy flows of the processing step were supplied by the most important Italian biodiesel plants.

As regards the oil mill stage, solvent extraction technology was considered; it uses hexane as a solvent, in order to achieve an higher oil extraction rate. This process includes raw material reception, storage, screening, pre-heating, rolling and conditioning. After rolling the flakes from the press process are sent to solvent extraction. There are two outputs from the solvent extraction: extraction cake and miscella. The solvent is removed from the cake and after drying the meal is finished. Miscella is a mix of oil approximately 10-30% oil and 70-90% solvent. The solvent is removed and reused and the oil is clarified and centrifuged.

The main parameters for the calculation of the GHG balance of extraction process are reported in Tab. IV, V

Table IV: Assumptions for extraction of rapeseed oil.

Input data	Unit	Value
Electricity	kWh litre ⁻¹ of crude oil	0.149
Natural gas	MJ litre ⁻¹ of crude oil	1.852
Hexane	g litre ⁻¹ of crude oil	1.600
Yield	kg of crude oil (kg of seeds (d.m.) ⁻¹)	0.439
Rapeseed meal	kg (kg of seeds (d.m.) ⁻¹)	0.638

In this paper chemical refining (Tab. VI) was analyzed, including neutralisation, bleaching and deodorisation of the oil. The same process and yield were considered for both chains.

The purpose of neutralisation, which includes degumming and neutralisation, is to remove lecithin and free fatty acids. Firstly, the lecithin is removed by applying phosphoric acid in the degumming process. Then the content of free fatty acids are removed by applying sodium hydroxide; when the sodium hydroxide

reacts with the free fatty acids, the outcome is soap and water. Next, the mix of oil, soap and water is centrifuged in order to separate out the soap. The soap is sent through the soap stock splitting process, where sulphuric acid is applied. The soap and acid react and the outcome are free fatty acids and sodium sulphate which is sent with waste water to the municipal sewage water system. Loss in the neutralisation process includes the separated free fatty acids and loss of oil to the soap fraction. Thus the total loss of the crude oil input to the process was 2.1%.

Table V: Assumptions for extraction of soybean oil.

Input data	Unit	Value
Electricity	kWh litre ⁻¹ of crude oil	0.187
Natural gas	MJ litre ⁻¹ of crude oil	4.668
Hexane	g litre ⁻¹ of crude oil	3.860
Yield	kg of crude oil (kg of seeds (d.m.)) ⁻¹	0.217
Soybean meal	kg (kg of seeds (d.m.)) ⁻¹	0.946

Table VI: Assumptions for chemical refining.

Input data	Unit	Value
Electricity	kWh litre ⁻¹ of refined oil	0.013
Natural gas	MJ litre ⁻¹ of refined oil	0.764
Fuller's earth	g litre ⁻¹ of refined oil	9.0
Phosphoric acid	g litre ⁻¹ of refined oil	1.0
Sodium hydroxide	g litre ⁻¹ of refined oil	6.0
Sulphuric acid	g litre ⁻¹ of refined oil	0.760
Yield	kg of refined oil (kg of crude oil) ⁻¹	0.973

The bleaching process is applied in order to remove undesired coloured particles and substances. In the bleaching process, the oil is brought in contact with surface-active substances which absorb the undesired particles. Fuller's earth is the most common used agent for filtering the oil. Loss of oil to the Fuller's earth was assumed as 2% (as referred by Italian biodiesel producers).

Finally, the oil is sent through the deodorisation process. The purpose of deodorisation is to remove undesired odoriferous or flavouring compounds. In the deodorisation process, minor amounts of different ancillaries are applied, e.g. ascorbyl palmitate and A and D vitamins. Since these ancillaries constitute insignificant amounts (0.19 – 20 g Mg⁻¹ of refined oil) and since there is a lack of life cycle inventory data on these ancillaries, they are omitted from the study. 0.4% of the oil is lost in the deodorisation process.

Transesterification process (Tab. VII) is the reversible reaction of the oil (which is composed of triglycerides) with methanol to form fatty acid alkyl esters and glycerol. Stoichiometrically, the reaction requires a 3:1 molar methanol-to-oil ratio, but excess alcohol is usually added to drive the equilibrium toward the products side. The reaction takes place with the use of NaOH as catalyst and then the oil is sent for downstream purification. Downstream purification consisted of the following steps: methanol recovery by distillation; glycerine separation and purification; catalyst neutralization (with HCl) and methyl-ester purification by distillation.

Table VII: Assumptions for transesterification of refined oil.

Input data	Unit	Value
Electricity	kWh litre ⁻¹ of biodiesel	0.0088
Natural gas	MJ litre ⁻¹ of biodiesel	0.664
HCl	g litre ⁻¹ of biodiesel	3.17
Methanol	g litre ⁻¹ of biodiesel	95.74
NaOH	g litre ⁻¹ of biodiesel	3.50
Citric acid	g litre ⁻¹ of biodiesel	0.60
Yield	kg of biodiesel (kg of refined oil) ⁻¹	1.005
Glycerine	g litre ⁻¹ of biodiesel	91.71

4 TRANSPORT STEP

Transport step involves both seeds transport from field to oil mill plant and biodiesel transport from processing plant to filling station (Tab. VIII). The same transports were considered for both the chains.

Transport of seeds over a distance of 50 km was assumed in 40 t trucks with a payload of 27 t. Fuel consumption takes into account an empty return trip.

Biodiesel transport was divided in two phases: transport via 40 t truck over a distance of 150 km from transesterification plant to biodiesel depot and the same transport from diesel depot to filling station. Fuel consumption takes into account an empty return trip. In both cases electricity required to store, handle and load biodiesel was considered.

Table VIII: Assumptions for transport step [13].

Input data	Unit	Value
Diesel consumption of 40 t truck	km litre ⁻¹	1.410
Electricity – biodiesel depot	kWh litre ⁻¹ of biodiesel	0.007
Electricity – filling station	kWh litre ⁻¹ of biodiesel	0.029

5 RESULTS AND DISCUSSION

GHG emissions were obtained applying to each input used in the two chains the relative emission factors (Tab. IX). The emission factors of natural gas and diesel take into account both production and use.

The last step for the GHG emissions calculation was the allocation method definition. Allocation refers to the distribution of environmental burdens between co-products in the LCA of a multifunctional system. In the analyzed chains, meal and glycerine were the co-products. According to the RED, GHG emissions were splitted between biodiesel and its coproducts, based on their energy content (in terms of Lower Heating Value). Energy contents were assumed to be:

- rapeseed and soybean meal: 15.5 MJ kg⁻¹ [13];
- glycerine: 16.0 MJ kg⁻¹ [13];
- biodiesel: 37.2 MJ kg⁻¹ [13].

Allocation was carried out assuming GHG emissions that take place up to and include the process step at which a co-product is produced. Therefore two splits were defined:

- between biodiesel (35% for rapeseed, 60% for

soybean) and meal + glycerine (65% for rapeseed, 40% for soybean) for cultivation, seeds transport and oil extraction steps;

- between biodiesel (96% for rapeseed, 96% for soybean) and glycerine (4% for rapeseed, 4% for soybean) for oil refining, oil transesterification (without glycerine separation and purification) steps.

Table IX: GHG emission factors.

Input	Unit	Value	Reference
Electricity	gCO ₂ eq kWh ⁻¹	462.0	[14]
Diesel	gCO ₂ eq MJ ⁻¹	87.5	[13]
Natural gas	gCO ₂ eq MJ ⁻¹	67.7	[13]
N fertilizer	gCO ₂ eq kg ⁻¹	6065.3	[13]
K ₂ O fertilizer	gCO ₂ eq kg ⁻¹	583.2	[13]
P ₂ O ₅ fertilizer	gCO ₂ eq kg ⁻¹	1017.8	[13]
Herbicides	gCO ₂ eq kg ⁻¹	17257.6	[13]
Seeds	gCO ₂ eq kg ⁻¹	200.0	[13]
Hexane	gCO ₂ eq kg ⁻¹	3933.4	[13]
Fuller's earth	gCO ₂ eq kg ⁻¹	436.0	[15]
HCl	gCO ₂ eq kg ⁻¹	1199.0	[16]
Methanol	gCO ₂ eq kg ⁻¹	1981.4	[13]
NaOH	gCO ₂ eq kg ⁻¹	929.0	[17]
Citric acid	gCO ₂ eq kg ⁻¹	963.1	[17]

GHG emissions, divided in the three stages of the chains, are reported in Tab. X and XI with the default values defined in the RED.

Table X: GHG emissions and GHG saving for rapeseed biodiesel.

	This study	RED	Difference (%)
<i>Cultivation</i> (gCO ₂ eq MJ ⁻¹)	26	29	- 10.3
<i>Processing</i> (gCO ₂ eq MJ ⁻¹)	16	22	- 27.3
<i>Transport</i> (gCO ₂ eq MJ ⁻¹)	1	1	0
<i>Total</i> (gCO ₂ eq MJ ⁻¹)	43	52	- 17.3
<i>GHG saving</i> (%)	48	38	+ 10.0

Table XI: GHG emissions and GHG saving for soybean biodiesel.

	This study	RED	Difference (%)
<i>Cultivation</i> (gCO ₂ eq MJ ⁻¹)	11	19	- 42.1
<i>Processing</i> (gCO ₂ eq MJ ⁻¹)	16	26	- 38.5
<i>Transport</i> (gCO ₂ eq MJ ⁻¹)	1	13	- 92.3
<i>Total</i> (gCO ₂ eq MJ ⁻¹)	28	58	- 51.7
<i>GHG saving</i> (%)	66	31	+ 35.0

For rapeseed biodiesel, the main difference compared to RED is in the cultivation step because, as previously

said, default value of processing step is increased respect to typical value by 1.4 factor. In particular a farming technique typical of Germany was considered in the RED, characterized by different inputs and yield [13]. The main differences are:

- diesel consumption: 82.6 litre ha⁻¹ instead of 98.3 litre ha⁻¹;
- N fertilizers: 137.4 kg ha⁻¹ instead of 110.0 kg ha⁻¹;
- yield: 3113 kg ha⁻¹ (moisture 10%) instead of 3256 kg ha⁻¹.

Moreover N₂O emissions were calculated applying a well-validated soils chemistry model, DNDC [8], and combining GIS information on soil, daily climate and crop distribution with data on fertilizer use and farm calendar. In the RED 3113 kg N₂O ha⁻¹ [13] was assumed against 3426 kg N₂O ha⁻¹ achievable if IPCC method is applied.

In the soybean biodiesel chain, the main differences are referred to cultivation and soybean transport steps. In the first case the RED assumes that soybean is cultivated in Brazil, with a yield of 2798 kg ha⁻¹ and employs IPCC methodology for the N₂O calculation but, for N_{BG} parameter, it consider a value of 0.074 kg N (kg d.m.)⁻¹ instead the IPCC default value (0.008 kg N (kg d.m.)⁻¹) [13]. Therefore N₂O emissions were 2226 g ha⁻¹ instead of 856 g ha⁻¹ with IPCC default value. For soybean transport, it was assumed soybean trucking to a river-port (700 km) and then trans-shipping to a transatlantic vessel (10186 km) [13].

6 CONCLUSIONS

The RED was published in the Official Journal of EU on June 5, 2009. The Directive will have to be implemented 18 months after it is published, which means November 2010. In particular RED establishes that biofuels have to meet certain sustainability criteria among which reduction of GHG emissions by at least 35% compared to fossil fuels beginning autumn 2010. From 2017, the reduction will have to be 50% and at least 60% for new installations.

In this paper two biodiesel chains, from rapeseed and soybean, were analyzed; GHG emissions were calculated assuming typical Italian data relative to Veneto region for cultivation step. Values were compared to the default values reported in the RED. In both cases results showed that GHG savings were higher than those reported in the RED; in particular soybean biodiesel chain would be sustainable also considering the target from 2017.

For the rapeseed biodiesel chain, the step characterized by the most impact was cultivation; the relative GHG emissions were mostly caused by diesel consumption (15%), nitrogen fertilizers production (33%) and N₂O emissions (42%).

In the soybean biodiesel chain, cultivation step was less important in terms of GHG emissions because of soybean is a leguminous crop that performs nitrogen fixation; therefore it doesn't need nitrogen fertilizers. In this case the processing step was characterized by the highest GHG emissions, mostly due to the transesterification process (60%); its GHG emissions were above all caused by methanol production (59%) and natural gas consumption in the glycerine purification step (26%).

In the next studies it would be interesting to verify if

the GHG saving of 35% could be reached in other Italian Regions, characterized by different farming techniques and seeds yields.

8 LOGO SPACE



7 REFERENCES

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