Life Cycle Assessment for biodiesel production under Latvian climate conditions

Francesco Romagnoli[1, *], **Jelena Pubule**[1], **Dagnija Blumberga**[1]

[1]Riga Technical University, Institute of Energy systems and Environment, LV-1010 Riga, Latvia

[*] Francesco.Romagnoli@rtu.lv

Abstract. In Latvia, biodiesel from rapeseed is generally supposed to be one of the more valuable possibilities. As the investments are growing, it is important to evaluate the environmental impacts of these productions and to stress the main sources of these impacts. The aim of this paper is to understand and to model the environmental performance of biodiesel produced by rapeseeds under local Latvian conditions. A comparison with the impacts of the related fossil based diesel has been conducted. This study shows that the environmental benefits from biodiesel have better results compared to the conventional diesel. The valorization of by-products leads to a considerable environmental improvements. The results lead to the conclusion that is feasible to successfully increase the environmental and sustainable efficiency of the analyzed Latvian biodiesel production model.

1 Introduction

Nowadays, the only economically viable feedstock for liquid biofuels is biomass [1]. Biodiesel in Europe is mainly made of rapeseed, other oilseeds and, to a minor extent, of palm oil [1]. In Latvia the share of biofuels in the transport sector is attested on a value of 0.3% (around 75% biodiesel and 25% bioethanol). The biofuel production in Latvia doubled in the last two year: the total biodiesel production is now around equal to 64 ktonne/year (year 2009).

Bioliquid biofuels can be seen as the only viable alternatives for road transportation and one feasible alternative to fossil fuels in the short to medium-term because they can avoid problem related to the distribution (e.g. they can be used by the current fuel infrastructure) and used by vehicles on the roads today [2-6]. In order to provide a sustainable substitution to fossil base fuels, biofuels need to present a net energy gain and deliver in the same time a reduction of the greenhouse gas (GHG) emissions compared with fossil fuel alternatives.

Sustainability of biofuels has been increasingly investigated, receiving large-spread attention from science, politic and by media [2-6].
In this study will be presented the environmental aspects mainly addressed to the GHG and energy balances for the biodiesel production chain for Latvian conditions including the final combustion end use in a car engine. The production of biodiesel will be also compared with the environmental impact from the use of the fossil based diesel including always the final combustion end use in a car engine thorough LCA methodology.

2 Life cycle definition

Biofuel sustainability has been widely debated. Nevertheless, political decisions are being made, economic investment is on course and environmental and social impacts are taking place [7, 8].
Sustainability of a human activity involves a comparison between the environmental status resulting from it and the natural or desired status [8]. A favorable comparison, in case of a biofuel production, would ideally agree with the following aspects: i) the fuel should supply an amount of energy superior to that required to produce it; ii) long term feedstock supply should be guaranteed in order to assure long term biofuel; iii) supply to the market, which depends on the sustainability of the underlying activities; iv) the emission of unwanted substances to the environment should be less than those that would result from the use of a fossil fuel to obtain the same amount of energy; v) land use should not compromise food production nor the respect for the ecosystem balance.
Due to their comparable physical properties, biodiesel and fossil-based diesel can be used for conventional diesel engines [9-11]. Thus, the primary concern of this study is the question as to whether or not the production of biodiesel is comparable to the production of fossil diesel from an environmental point of view, taking into account all stages of the life cycle of these two products.
In this LCA study has been investigated the biodiesel production from rapeseed in Latvia on three types of different scenarios: a model based on a Latvian existing biodiesel production not including the avoided products coming from the use of the co-products and/or waste from production, a model considering the avoided products, the comparable LCA model for the diesel production and final use in Latvia. The potential environmental benefits and/or damages identifying the environmentally optimum of the biodiesel production in the Latvian condition will be identified. This study was based on the ISO 14044 [12].

2.1 Goal and scope definition

The development of the biofuels industry in Europe has lead to a lot of environmental studies [1, 13-16].

Therefore the aim of this study is to perform a full comparative Life Cycle Assessment of the production and use of biodiesel providing a comparison with the corresponding fossil fuel for Latvian conditions in order to investigate its environmental benefit.

The last step will be the identification of the main sources of the environmental impacts and the proposition of improvements of the environmental performances.

In the following are described the main aims to be reached during the analysis:

i) Demonstrate that the biodiesel has a positive energy balance and it is a renewable source (study of the energy ratio among the renewable energy output produced and the amount of non renewable energy spend for the production); ii) Savings of green house gas (GHG) emissions; iii) Use of LCA to evaluate the life cycle environmental burdens of a biodiesel (BD) system use (B100) from rapeseed oil; iv) Identify the hot spots of the system and suggest improvement opportunity.

2.2 Functional unit

The functional unit to which all emissions and consumptions in this assessment have been reported is 100 km covered with a pick-up recent car in off-road type. Even if biofuels are generally used as additives, results will be presented for cars working with pure biofuels (B100) as the mixing with fossil fuels could have an influence on the conclusions of the comparison and the aim is to determine which biofuel offers the highest environmental benefit. The Impact 2002+ [17] has been used in this study.

The relevant environmental mid-point impact categories studied are: non-carcinogens effects, respiratory effects, terrestrial ecotoxicity, land occupation, global warming, non-renewable energy.

2.3 Life Cycle Inventory (LCI) and system boundaries

Data gathering on rapeseed cultivation and biodiesel production has been based on international conditions and loca Latvian sources (see Table 1 and 2). Other types of data has been collected from the ecoinvent 2.1 database (included in the Simapro 7.2 software [18]) and from GEMIS [19].

Different scenarios were evaluated in order to assess methods to decrease potential negative environmental impacts. For the simplification of the simulation the following four stages have been considered per energy crop: (i) soil preparation and cultivation (including nursery of the seeds); (ii) rapeseed oil production (including refinery); (iii) biodiesel production (including refinery), (iv) final end use (see Figure 1).

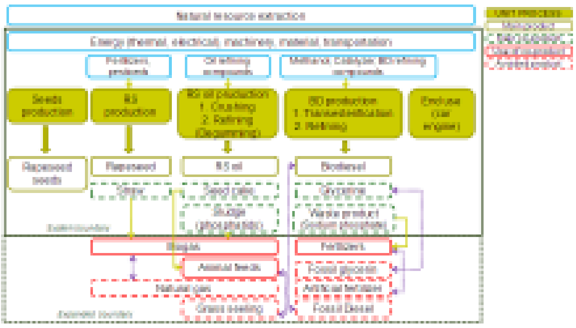


Fig.1: LCA model and boundary: scheme used to be implemented in the Simapro software considering also the expanded boundaries. In the figure are reported the main inflows and outflows in the model in terms of material/product also the avoided products are also reported.

How one can see in the model has been assumed that the straw is used for production of biogas, the seed cake for production of animal feeds, and waste products (e.g. sodium phosphates) as fertilizers. The model foresees the co-production of glycerine in the process. The use of these wastes and co-products is fundamental to increase the environmental benefits of the whole process since is displacing the production of other products (natural gas, grass siling artificial fertilizer, fossil glycerine).

The production (or nursery) of the seeds needs to produce the future repaseed culture is the preliminary step, the data implement in the model are directly extracted from the ecoinvent 2.1 database.

The culture of rapeseed is the first real step in the production of biofuel. The production of the fertilizers (N, P, K) and the pesticides, soil/water/ground emissions, the consumptions and emissions of the tractors (fertilizing, tillage, sowing, harvesting, transport) and the valorization of by-products, like rapeseed straw, substituting fertilizers (also in terms of N, P, K) or producing biogas have been taken into account.

The next step is the conversion of the feedstock to biofuel. After drying the rapeseed grains, oil is extracted in two steps, involving a mechanical extraction followed by an extraction with an organic solvent. Two products are generated: the oil, and the rapeseed meal (or seed-cake), rich in proteins and easily integrated in rations of animal feed. The extracted oil is then refined, and finally reacts with

fossil methanol to produce rapeseed methyl ester and glycerine, which is purified and then generally used in the chemical industry.
In the final use the exhaust emissions and fuel consumptions of the vehicle use for the study have been calculated on the basis of those of the fossil fuel vehicles. The energetic contents of the biofuels are different from those of the corresponding fossil fuels and the consumptions, expressed in kg/km, are also different. In the study amounts of 16.5 kg/km in regard to the car fuelled by biodiesel and 18.0 kg/km for a car totally fuelled by diesel have been taken into account.
As it belongs to the natural cycle of carbon, carbon based emission (CO2 and CO) emitted by the combustion of the biofuels doesn't contribute to global warming and is not taken into account in the model. Using biodiesel leads to an increase of the emissions of nitrogen oxides, a decreased of the emissions particulates (PM), and hydrocarbon. This has been considered according to the pictures below according to Environmental Protection Agency (EPA) [20].

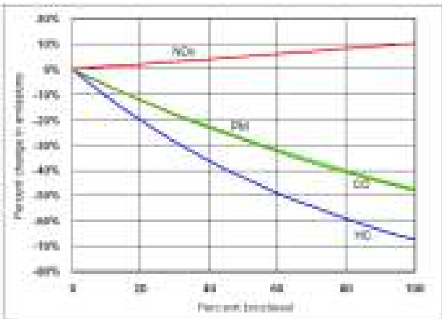


Fig.2: percent change in emission of a biodiesel engine respect to fossil based diesel engine [20].

In our study in reference to a diesel engine of an off-road car type [8] has been considered the following coefficients:
- NOX=0,312 g/km – increase of 10% respect diesel engine;
- PM=0,039g/km – decrease of 45%.

The complete Life Cycle Inventory has been established using Simapro 7.2 databases. By-products have been taken into account with energetic or mass allocation. Environmental credits (avoided impacts of the production of equivalent products) for the substitution to other products, like animal feed or chemical products, have been calculated. As no data was available for some of the by-products, assumptions has been done to calculate equivalencies with some products described in the Simapro databases.
The glycerin at the end of the production process was assumed to substitute for the chemical glycerine, produced by hydrolysis of epichlorohydrin (from Ecoinvent 2.1 database).

Tab. 1: Inflows and outflow in the model.

FLOWS	Cultivation	RS oil production	BD production	Source
Land [ha]	-0,97			[21]
Seeds [kg]	-3,39			[21]
N fertilizer [kg]	-49,44			[21]
P fertilizer [kg]	-12,80			[21]
K fertilizer [kg]	-60,35			[21]
S fertilizer [kg]	-84,34			[21]
Pesticides [kg]	-1,95			[21]
Leaf fertilizers and Surfactants [kg]	-7,46			[21]
Straw [t]	5,82			[22]
Rapeseeds [t]	3,10	-3,10		[21]
Rapeseed cake [t]		2,01		[23]
H3PO4 (deg.) [t]		0,00		[23]
NaOH (deg.) [t]		-0,02		[23]
Citric acid (deg.) [t]		-0,0003		[23]
Rapeseeds oil [t]		1,05	-1,05	[23]
Methanol [t]			-0,11	[23]
KOH (for trans.) [t]			-0,01	[23]
H2SO4 (for trans.) [t]			-0,01	[23]
NaOH (for glycerine prod.) [t]			-0,02	[23]
H3PO4 (refin.) [t]			-0,0011	[23]
Gliceryn [t]			0,11	[23]
Biodiesel (RME) [t]			1,00	

The system boundaries include the biodiesel production (rapeseed cultivation and processing for biofuel, extraction and refining for fossil fuels), but also the final use of the fuel and the valorization of the different by-products. In the tables 1, 2, and 3 are shown the best results concerning the LCI.

In the model has been considered that the plant has not enough capacity to produce the rapessed oil needed for the required diesel production, consequently has been considered that 2/3 of the oil are coming not from the plant production but from an oil mix imported.

Tab. 2: Energy and non renewable fuels requirements.

ENERGY and NON RENWABLE FUELS	Cultivation	RS oil oil production	BD production	Source
Electricity [kWh/biodiesel tonne]			203.35*	[23]

Thermal energy [MJ/ biodiesel tonne]			2737*	[23]
Diesel [tonne/biodiesel tonne]			0.07*	[23, 24]
Machinery [tractor/ha]	0.0009			[24]
Boiler efficiency [15 MW boiler house]		90%	90%	[25-27]
Biodiesel (RME) [t]			1,00	

*considering rapeseed production and biodiesel production.

Tab. 31: Emissions in the model.

EMISSIONS	Field prep.	Cultiv.	RS oil production	BD production	End use	Source
Emission to water (NO3) [kg/ha]	22.4					[8]
Emission to air (NH3) [kg/ha]	7.47					[8]
Emissions to water (NO3) [kg/ha]		326				[8]
Emissions to water (PO4) [kg/ha]		0.6				[8]
Emissions to air (NH3) [kg/ha]		12.2				[8]
Emission to air (CO2)					0*	[8, 20]
Emission to air (Hydrocarbon)					0*	[8, 20]
Emission to air (NOx) [g/km]					0.312	[8, 20]
Emission to air (PM) [g/km]					0.039	[8, 20]

* Considering carbon-neutral perception of the biomass lifecycle.

C-derived emissions were left out of biodiesel system assuming the neutrality of the carbon cycle. The system foresees the use of two boiler house system (around 15 MW total capacity) supply by fossil diesel. The emissions related to the use of fossil diesel for the needs of thermal energy required from the plant processes have been directly taken from the database of the ecoinvent 2.1. The total amount of the thermal energy in the whole production processes was equal to 2737 MJ/tonne biodiesel produced.

2.3.1 Assumptions

In the following tables are described the main assumptions for the model taking also into account: i) a 25 year biodiesel plant technical lifetime; use of straw for biogas production; use of average EU electricity mix (EU25); transportation distances estimation based in the following table 4.

Table 42: transportation assumption.

Material	Unit process	From	Distance [km]	Way of transport
Seeds	Cultivation	UK (50%), FR (50%)	1270, 1750	40 t truck
Fertilizers	Cultivation	GER	1400	40 t truck
Pesticides	Cultivation	GER	1400	40 t truck
Tractor	Cultivation	SWE	400	Medium size cargo, 89000 t
Rapeseed	RS oil production	LV (35%), LT (35%), BY (15%), KZ (15%)	150, 300, 600, 1000	40 t truck
Oil mix	BD production	RU (60%), BY (40%)	500, 600	40 t truck
Methanol	BD production	RU	500	40 t truck

The production of biogas from 1 of straw has been taken into account with the relation of: 0,38 m3 biogas =1 kg straw [28].
The amount of artificial fertilizers displaced has been calculated taken into account that: 1 kg of slurry = 0,15kg NKP fertilizers [8].
The relative amount of natural gas displaced has been calculated respect the ratios of the values of the two low heating values (LHV) using the following data:

Biogas LHV = 23.3 MJ/m3 [19],

Natural gas LHV = 23.3 MJ/m3 [19].

This corresponds to an overall avoided amount of natural gas equal to 1514 m3.

3 LCA results

The life cycle's environmental impact assessment was carried out by IMPACT2002+ [17] included in the SimaPro database.
Six mid-point categories was analyzed with four end point categories. The characterization and weighted results are presented in terms of mPt where one point is the impact on one person per year. The results for biodiesel are concerning the implementations and the not implementation of the avoided products in the model, then the final comparison with the fossil diesel LCA.
In the figure 3 is possible to understand the main impact category that presents the strongest environmental load. Regarding the biodiesel LCA model that takes into account the avoided products is important to highlight how, in regards to non-renewable energy source used within the model, there is a negative value that means an environmental benefit. If this is compared with the model with no avoided products is evident how strong the effect of reusing waste and/or co-products is (around fivefold increase). One can also see how, for the model

considering fossil based diesel, almost 80% of the total impact is related to the non-renewable energy source used.

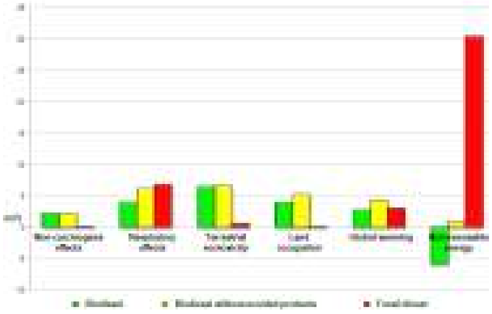


Fig.3: midpoint impact categories [mPt/functional unit].

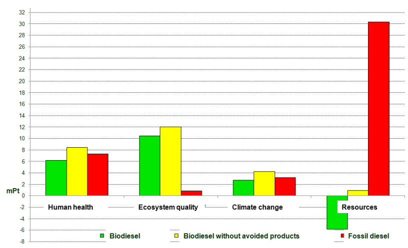
Mainly due to the use of fertilizers, pesticides and arable land the LCAs for the biodiesel present higher impacts in relation to the land use and ecotoxicity impact category. If the attention is driven to the global warming impact category can be seen how is fundamental the role play by the avoided products to have an overall reduction of the CO2 equivalent in the biodiesel production. From our model this reduction is around the value of 15%.

In the pictures 4 is presented the same results but in terms of end point categories: human health, ecotoxicity quality, climate change and use of resources. The results confirm what was already highlighted in the analysis at the mid-point category:

- for the climate change and human health impact categories the role of the use of waste and co-products is fundamental in order to have and environmental load lower that one foreseen in the fossil based LCA model;
- the impact on the ecosystem quality for the fossil diesel is almost negligible if referenced to the those of the biodiesel models. This is related to the effects of the use of fertilizers, pesticides and impact on the arable land.

The last picture 5 clearly shows the reduction in terms of total environmental impact driven by the use of biodiesel. Already taken into account the model without including any use of the waste or co-products the decrease is around 38%, including the avoided products and theirs benefits the total decrease is on the level of 67%.

Together with the implementation of the LCA can be carried out the energy balance that can be considered as the first start for a benchmarking analysis. In the light of that is presented in the following table is presented the indicator Ei defined as the ratio of the total energy used for fuel production (in terms of non renewable sources)and the biodiesel fuel energy (in terms of calorific value).



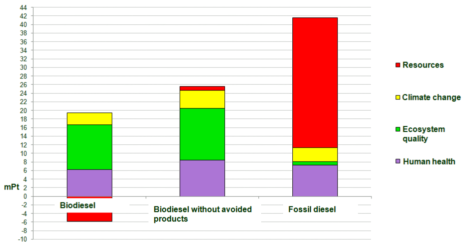


Fig.4: **endpoint impact categories [mPt/functional unit].**

Fig.5: **single score analysis [mPt/functional unit].**

In the same time with this process will be possible to evaluate the strength and the level of the theoretical renewable processes since as much more the ratio is lower than one as much the processes has more efficient renewable peculiarities.

Table 53: energy indicator.

LCA	Ei
Biodiesel	- 0,18
Biodiesel (without allocation)	0,14
Other sources	- 1,34 < Ei < 0,64

Where:
Ei = MJin/ MJout = energy indicator;
MJin = global non renewable sources spent within the model [MJ];
MJout = biodiesel energy (specific heating value – 37,7 MJ/kg).
In our analysis the value are in line with those findable in literature.

4 Conclusions

The results lead to the conclusion that is feasible to successfully increase the environmental and sustainable efficiency of the analyzed Latvian biodiesel production model.
In specific after the work can be conclude that for Latvian conidtions:

1) Biodiesel is a renewable energy source using the energy indicator Ei presented as benchmarking (lower then 1);
2) It has been shown that using biodiesel reduces the consumption of non-renewable energy;
3) Biodiesel effects on the environment are less than that ones for fossil diesel, around 38% not considering the avoided product and around 67% considering the avoided products;

4) for the climate change and human health impact categories the role of the use of waste and co-products is fundamental in order to have and environmental load lower that one foreseen in the fossil based LCA model;
5) the impact on the ecosystem quality for the fossil diesel is almost negligible if referenced to the those of the biodiesel models. This is related to the effects of the use of fertilizers, pesticides and impact on the arable land;
6) If the attention is driven to the global warming impact category can be seen how is fundamental the role play by the avoided products to have an overall reduction of the CO2 equivalent in the biodiesel production. From our model this reduction is around the value of 15%.

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