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Environmental effects of decentralized rapeseed oil production in Bavaria – A life cycle assessment (LCA) case study

Karsten Engelmann, Lorenz Strimitzer and Edgar Remmele, Technologie- und Förderzentrum (TFZ), Schulgasse 18, D-94315 Straubing

Abstract

The reduction of greenhouse gas (GHG) emissions and the increased use of energy from renewable sources is an important topic in the European policy for climate and energy (European Commission, 2011). In the transport sector GHG emission savings can be achieved using fuels based on renewable sources like biomass. The Renewable Energy Directive (RED) set a binding target for reduction of GHG emissions by substituting fossil fuel with biofuels. Pure vegetable oil (PVO) from rapeseed used for biofuels is commonly produced in industrial-scale plants. In contrast, production of cold-pressed rapeseed oil (cRSO) as fuel in decentralized oil mills could offer some environmental advantages because there is a reduction of chemicals and energy used in processing as well as the avoidance of long transport distances.
According to RED the aggregated default value for GHG emissions of rapeseed oil amounts 36 g CO_2eq MJ^{-1} which is equivalent to GHG emission saving of 57 % compared to fossil diesel. The given default value refers solely to pure vegetable oil (PVO) from rapeseed produced in industrial-scale and does furthermore not include region-specific differences regarding rapeseed cultivation. In view of this situation the aim of this study is to obtain specific data for GHG emissions for decentralized rapeseed oil production in Bavaria, where rapeseed is the most important oil crop. For this purpose differences regarding methods of rapeseed cultivation and technologies of rapeseed processing have been analyzed. The GHG emissions were modelled according to the ISO standards 14040 and 14044 for life cycle assessment (LCA) and calculated following the framework and methodology provided by the RED, respectively.
The results show a wide range among analyzed case study highly depending on site and management conditions of rapeseed cultivation. For harvest of 2013, GHG emissions of rapeseed cultivation in the three Bavarian regions range from 31.0 to 37.0 g CO_2eq MJ^{-1} cRSO using LCA modelling and from 37.5 to 41.3 g CO_2eq MJ^{-1} cRSO following the RED. The GHG emissions of rapeseed processing in three decentralized oil mills as well as the related transport processes amount to 1.3 to 1.6 g CO_2eq MJ^{-1} cRSO using LCA modelling and around 1 g CO_2eq MJ^{-1} cRSO following the RED. Furthermore there is a strong methodological influence on GHG emission savings by method for evaluation of co-products. GHG emission saving amounts to 57 % if allocation method based on lower heating value (LHV) is applied while GHG emission savings using carbon crediting method amounts to 71 % and 80 % in comparison to fossil diesel in the RED, respectively.

Keywords: Renewable Energy Directive, life cycle assessment, rapeseed oil, biofuels, greenhouse gas emissions

1 Introduction

The reduction of greenhouse gas (GHG) emissions and the increased use of energy from renewable sources is an important topic in the European policy for climate and energy (European Commission, 2011). In the transport sector GHG emission savings can be achieved using fuels based on renewable sources like biomass. The Renewable Energy Directive (RED) set a binding goal for the reduction of GHG emission by substituting fossil fuel with biofuels (European Parliament and Council of the European Union, 2009). Currently predominantly biofuels of the so-called first generation contribute towards achieving this goal. Pure vegetable oil (PVO) from rapeseed used for biofuels is commonly produced in industrial-scale plants using chemicals (hexane) and high amounts of energy for several extracting and refining steps (Kaltschmitt, Hartmann, & Hofbauer, 2009). Moreover, there are often long transport distances for feedstock and products. In contrast, production of cold-pressed rapeseed oil (cRSO) as fuel in decentralized oil mills is based on a mechanical pressing and a succeeding filtration step. This simplified technology of biofuel production could offer ever more environmental advantages (Widmann, 2005). This results from a reduction of chemicals and energy used in processing as well as the avoidance of long transport distances (Grau, Bernat, Rita, Jordi-Roger, & Antoni, 2013). Additional, GHG emissions can be reduced significantly using the local co-produced rapeseed cake as protein feed in comparison to feeding systems relying on soybean meal.
The quality of rapeseed oil as fuel is ensured by a German standard (DIN 51605). The use of rapeseed oil in diesel engines as well as in combined heat and power plants is already a proven state-of-the-art technology (Emberger, Thuneke, & Remmele, 2012; Emberger, Thuneke, & Remmele, 2013; Hassel et al., 2006; Rathbauer, Krammer, Kriechbaum, Prankl, & Breinesberger, 2008). According to RED the aggregated default value for GHG emissions of rapeseed oil amounts 36 g CO_2eq MJ^{-1} which is equivalent to GHG emission saving of 57 % compared to fossil diesel. From 2018 GHG emission saving shall be at least 60 % for biofuels produced in plants in which production started on or after January 2017. The given default value refers solely to PVO from rapeseed produced in industrial-scale and does furthermore not include region-specific differences regarding rapeseed cultivation. In view of this situation the aim of this study is to obtain specific data for GHG emissions for decentralized rapeseed oil production in Bavaria, where rapeseed is the most important oil crop. For this purpose differences regarding methods of rapeseed cultivation and technologies of rapeseed processing have been analyzed. The GHG emissions were modelled according to the ISO standards 14040 and 14044 for life cycle assessment (LCA) and calculated following the framework and methodology provided by the RED, respectively.

2 Materials and methods

2.1 Production systems and areas

For this study data for rapeseed processing as well as for transport processes of three decentralized oil mills are collected by face-to-face interviews. The three oil mills differ in size (processing capacity) and region (soil-climate-areas) (Roßberg, Michel, Graf, & Neukampf, 2007). Nearby the three decentralized oil mills data for rapeseed cultivation (year of harvest 2013) of five to six farms are also collected by face-to-face interviews. Thereby, it was possible to include local site conditions and farm structure in the analysis. Regarding site conditions there are relevant differences in annual precipitation and soil productivity between the three soil-climate-areas (see Table 1). The analyzed farms represent typical farming types in their agriculture region. While arable farming is typical in region A, mixed farming is widely-used in region B and C.

2.2 Decentralized rapeseed oil production

Decentralized processing of rapeseed produces cold-pressed, only mechanically extracted rapeseed oil (Remmele, 2009; Widmann, 2005). At the beginning the rapeseed needs to be cleaned and dried to a moisture content of 7 % before further processing. The next step is the storage of the rapeseed, where different ventilators can be installed. In case of the three oil mills analyzed there was a preconditioning and additional cleaning before the rapeseed is extracted in oil presses with a capacity of 500 to 1800 kg h^{-1}. The heat is partially recovered and preheats the seed before the extraction. This procedure optimizes the amount of oil that can be extracted. The rapeseed oil is separated from the rapeseed cake and stored in a stainless steel tank. Depending on the required product, some adsorbents can be added and filtered off in order to reduce the content of elements such as P, Ca, Mg. Rapeseed cake is an important high-protein feedstuff for dairy cattle. For this purpose, the oil content needs to be adjusted at a low level through upstream process optimization (e.g. quality of seed, pre-heating, pre-conditioning). Residual oil content of 10 to 12 % is normally achieved. The extracted rapeseed oil has to be filtered, whereby different methods are used. After filtering, possible applications are the use in diesel engines as well as in combined heat and power plants or as a feedstock for biodiesel production. As a second co-product, the filter cake is either mixed to the rapeseed and pressed a second time, where its oil content of about 50 % can partly be exploited. Alternative applications are the distribution as pig feed or the mixing with the rapeseed cake (see above).

The main assumption is that the energy demand depends linearly on the mass of seed processed. The whole processing requires about 0.013 to 0.014 MJ of electric energy per MJ of cold-pressed rapeseed oil.

Table 1: Data for site conditions, structure and rapeseed cultivation of Bavarian farms as well as decentralized oil mills analyzed.

Soil-climate-area	**A Tertiär-Hügelland Donau-Süd**	**B Albflächen und Ostbayerisches Hügelland**	**C Verwitterungs-böden in den Übergangslagen**
Oil mill	**X**	**Y**	**Z**
Max. capacity (kg seed h^{-1})	500	800	1.800
Farms	n = 5	n = 6	n = 5
Site conditions			
- Altitude (m)	530	490	395
- Annual precipitation (mm)	925	760	740
- Annual temperature (°C)	7.2	7.2	7.4
- Soil texture	Loamy sand to sandy loam	Loam to heavy loam	Sand to clay
- Arable land productivity[1] (0 – 100 soil score)	30 – 50	40 – 50	30 – 60
Farm structure			
- Farming type	Arable farming	Mixed farming	Mixed farming
- Farm size (ha)	30 – 382	83 – 330	81 – 208
- Rapeseed (% AL[2])	10 – 23	17 – 24	14 – 28
Rapeseed cultivation			
- Yield[3] (kg ha^{-1})	4266	4065	3728
- Seeds (kg ha^{-1})	2.3	2.6	2.3
- Plant protection[4] (kg ha^{-1})	2.1	2.0	2.0
- Diesel (kg ha^{-1})	77	79	80
- N-fertilizer (kg N ha^{-1})	201	196	188
- P-fertilizer(kg P_2O_5 ha^{-1})	26	34	6
- K-fertilizer(kg K_2O ha^{-1})	30	19	6
- Ca-fertilizer (kg CaO ha^{-1})	0	7	15
- Manure (kg N ha^{-1})	40	37	89
- Field N_2O emissions[5] (kg N_2O ha^{-1})	6.9	6.7	6.8

[1]BodSchätzG, 2007; [2]AL = Arable land; [3]water content of 9 %; [4]active substances; [5]calculated with IPCC (2006)

2.3 Methods for calculation of GHG emissions

LCA methodology consists on analyzing the complete life cycle of a product evaluating different impact categories. The general framework for conducting an LCA is found in the ISO standards 14040 and 14044. This study models the rapeseed oil production of three decentralized oil mills in Bavaria. The functional unit used is g CO_2eq MJ^{-1} cold-pressed rapeseed oil (cRSO). The models have been developed using GaBi 6.0 (PE, 2013). As databases were used GaBi 6.0 professional and ecoinvent v2.2 (Swiss centre for life cycle inventories, 2013). The impact assessment is done according to the International Reference Life Cycle Data System (ILCD) (European Commission Joint Research Centre, 2010; European Commission Joint Research Centre, 2011). In the present study only climate change is considered as impact category. Field N_2O-emissions of rapeseed cultivation were calculated according to the IPCC 2006 method (IPPC, 2006).
As a reference GHG emissions were calculated with BioGrace version 4b which is following the framework and methodology provided by the RED. BioGrace project were funded to align biofuel GHG emission calculations in Europe (European Commission Joint Research Centre, 2012). By now, the BioGrace project provides a compilation of standard values and conversion factors and a calculation tool to reconstruct the RED default values and perform actual calculations. Figure 1 gives an overview over the system boundaries of LCA and the RED (BioGrace). For reasons of comparability results of both methods are presented in the phases cultivation, transport and processing given in the RED.

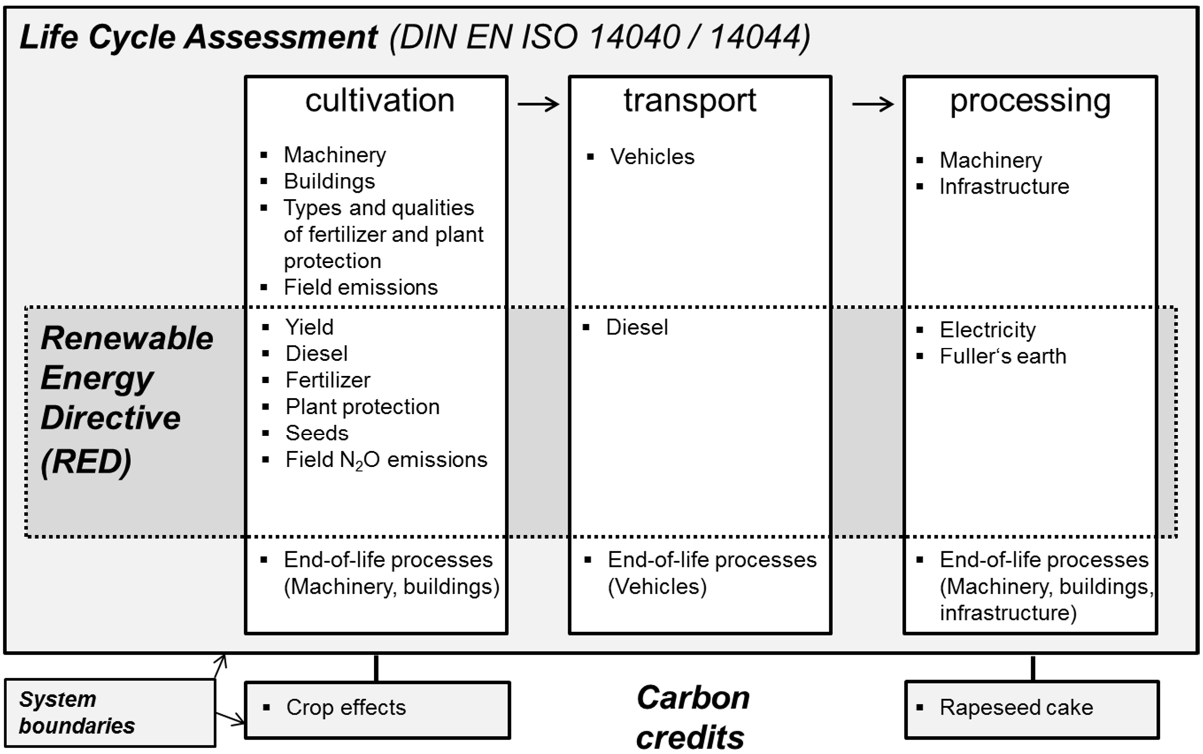

Figure 1: System boundaries of LCA and RED for decentralized rapeseed oil production.

BioGrace has features to defined default values of biofuels. But there is no calculation for decentralized rapeseed oil production. Therefore, within the conducted calculation the values in the processing and refining steps regarding natural gas boilers and hexane were set to zero. All the other process steps including the cultivation phase, drying, transport, extraction and filling were calculated with the data collected from the three oil mills. Furthermore, the allocation factors assumed in the BioGrace were changed in accordance to the lower heating value (LHV) of the rapeseed oil and rapeseed cake of decentralized processing. Out of 1.0 kg of rapeseed with an assumed oil-content of 42 %, about 0.37 kg rapeseed oil can be extracted. The LHV of cold-pressed rapeseed oil and rapeseed cake used for the calculation amounts to 37.5 MJ kg^{-1} and 20.7 MJ kg^{-1}, respectively (Remmele, 2009). Therefore the allocation rate of cold-pressed rapeseed oil to rapeseed cake accounts 52:48, whereas the ratio PVO from rapeseed (RED) accounts 61:39.

Due to the regional approach a local Bavarian electric energy mix has been modelled using Gabi professional database (107 g CO_2eq MJ^{-1}). The electric energy use in the upstream processes remains unchanged. According to the depreciation periods the life cycle inventory of the processing stage refers to an operational lifetime of 14 years. End-of-life processes are taken into account.

Because rapeseed oil production is a multi-output process an allocation of GHG emissions has to be conducted after extraction process. In this study the allocation of GHG emissions is conducted based on the lower heating value. According to the ISO standards 14040 and 14044 the allocation of GHG emissions should be avoided as far as possible. Therefore it was also applied the carbon crediting method to evaluate rapeseed cake as substitution for soybean meal and crop effects of rapeseed cultivation as substitution of N-fertilizer. The carbon credits for the rapeseed cake are calculated with the ecoinvent v2.2. Those for the crop effects are taken from Kage (2013). In accordance to its nutritional value given in digestible crude protein (DCP) 1.0 kg of soybean meal is equivalent to 1.53 kg of rapeseed cake (rapeseed cake = 208 g DCP kg^{-1} dry matter (DM) and soybean meal = 319 g DCP kg^{-1} DM (Preißinger, Obermaier, Hitzlsperger, & Maierhofer, 2004).

3 Results and discussion

The GHG emissions of rapeseed cultivation in the three Bavarian regions range from 31.0 to 37.0 g CO_2eq MJ^{-1} cRSO with LCA modelling and from 37.5 to 41.3 g CO_2eq MJ^{-1} cRSO following the RED (Figure 2). For methods the regional means of GHG emissions are higher than the default value for GHG emissions of cultivation step in the RED (red line in figure 2). However, there are high differences of GHG emissions within the regions analyzed. Regarding to GHG emissions with LCA modelling the standard deviations amounts 3.6 (region A), 7.2 (region B) and 4.2 g CO_2eq MJ^{-1} cRSO (region C).

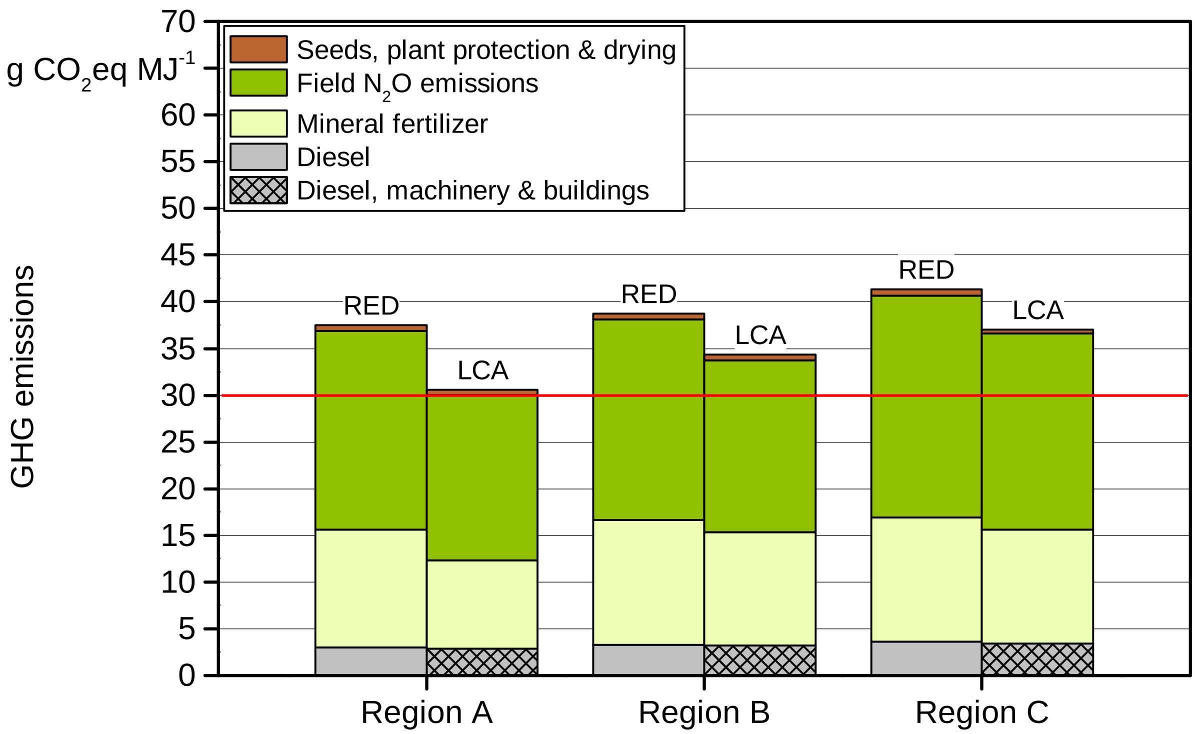

Figure 2: GHG emissions of rapeseed cultivation in the three Bavarian regions using RED and LCA method. Red line shows the disaggregated default value for cultivation according to the RED.

For LCA modelling the mineral fertilizer were distinguished in according to the type of nutrient. As an example the emission factor for N-fertilizers is set to 5.9 kg CO_2eq kg^{-1} N in BioGrace whereas the emission factors spread from 2.7 to 8.7 kg CO_2eq kg^{-1} N in LCA modelling. The mineral fertilization and its related N_2O field emissions are the highest share of the GHG emissions of rapeseed cultivation.

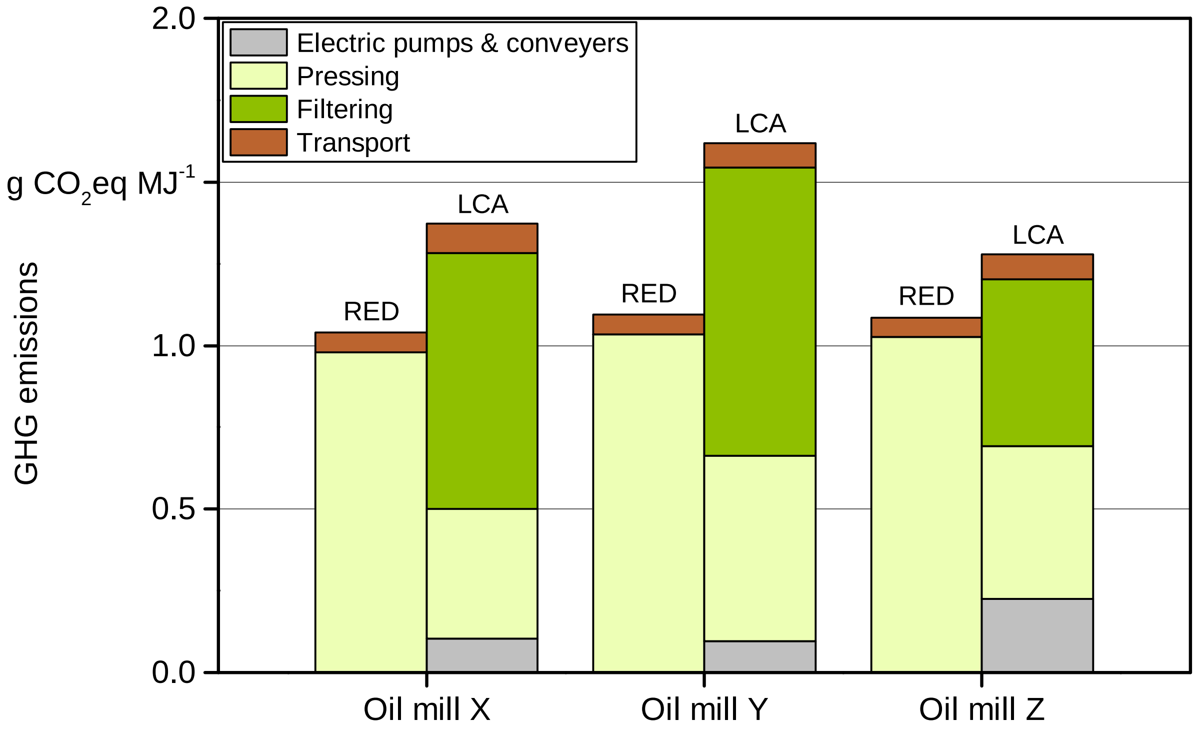

Figure 3: GHG emissions of rapeseed processing and transport in three decentralized oil mills using RED and LCA method.

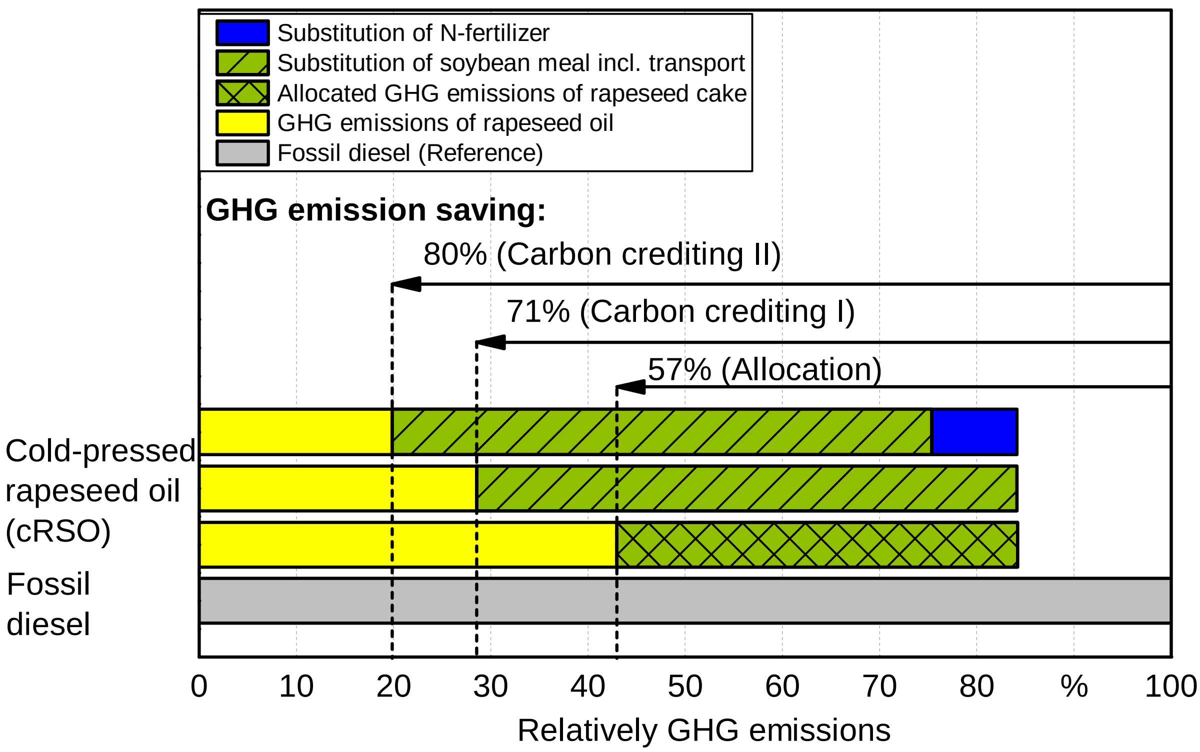

Figure 4: GHG emission savings of cold-pressed rapeseed oil in comparison to fossil diesel (RED reference) in accordance to different methods for evaluation of co-products (allocation, carbon crediting).

The GHG emissions of rapeseed processing in three decentralized oil mills as well as the related transport processes are slightly higher with LCA modelling (1.3 to 1.6 g CO_2eq MJ^{-1} cRSO) than following the RED (around 1 g CO_2eq MJ^{-1} cRSO) (Figure 3). LCA modelling is

taken into account the machinery, infrastructure and building. The consumption of electricity for pressing rapeseed and the filtering the crude rapeseed oil have the highest share of the GHG emissions within the rapeseed processing. Regarding to the default value of GHG emissions for PVO from rapeseed (5 g CO_2eq MJ^{-1} PVO for processing and 1 g CO_2eq MJ^{-1} PVO for transport) there is significant potential of GHG emission saving by decentralized processing of rapeseed.
Figure 4 shows GHG emission savings for cold-pressed rapeseed oil in comparison the default value of fossil diesel in the RED. Applying the allocation method based on LHV for evaluation of the co-product rapeseed cake GHG emission saving amounts to 57 % while carbon crediting method for evaluation of rapeseed cake (I) and rapeseed cake and crop effects (II) is applied GHG emission savings amount to 71 % and 80 %, respectively.

4 Conclusions

The present study shows that the GHG emissions of rapeseed oil can be reduced if decentralized processing of rapeseed is applied. GHG emissions of rapeseed oil production are strongly depending on rapeseed cultivation. The GHG emissions of rapeseed cultivation are highly depending on fertilization (fertilizer production and field N_2O emissions). Differing qualities of fertilizers can be distinguished in LCA which leads to more accurate results.
Using carbon crediting method for evaluation of co-products GHG emissions savings increase to 80 % compared to fossil diesel. In this context the use of rapeseed cake instead of soybean meal is of particular relevance.

5 Acknowledgements

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