LIFE CYCLE ASSESSMENT OF RAPESEED OIL AS SELF-SUFFICIENT AGRICULTURAL BIOFUEL – RESULTS OF CASE STUDIES FROM BAVARIA

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ABSTRACT: Cold-pressed rapeseed oil (cRSO) is produced in decentralized oil mills and can be used as self-sufficient biofuel in agriculture machinery. In context of European policy for climate and energy it could offer some environmental advantages. For this study input data for rapeseed cultivation (year of harvest 2013) from 15 farms and for rapeseed processing from three decentralized oil mills in Bavaria have been collected. Using life cycle assessment (LCA) methodology with different allocation procedures for co-products, regional and specific GHG balances of cRSO have been calculated. The results were compared with the default value for pure vegetable oil (PVO) from rapeseed defined in the Renewable Energy Directive (RED). The results for rapeseed cultivation show a wide range among analyzed case studies highly depending on site and management conditions (28.0 to 46.3 g CO_2eq MJ^{-1} cRSO). The GHG emissions of rapeseed processing in the three decentralized oil mills including the related transport processes average 1.4 g CO_2eq MJ^{-1} cRSO, which marks a considerable reduction of GHG emissions compared to the RED default value for PVO from rapeseed (6 g CO_2eq MJ^{-1} PVO). Furthermore there is a strong influence of allocation procedures on the values for GHG emission savings, ranging from 58 to 80 %.
Keywords: rapeseed oil, biofuel, life cycle assessment (LCA), greenhouse gases (GHG), 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 [1]. In the transport sector GHG emission saving can be achieved using fuels based on renewable sources like biomass. The Renewable Energy Directive (RED) defines legal thresholds for GHG emissions of biofuels and GHG emission savings compared to fossil fuels [2]. Currently predominantly biofuels of the so-called first generation contribute towards achieving this goal. The RED default value for GHG emissions of pure vegetable oil (PVO) from rapeseed amounts to 36 g CO_2eq MJ^{-1} which is equivalent to GHG emission saving of 57 % compared to fossil fuel. From the year 2018 GHG emission saving shall be at least 60 % for biofuels produced in plants in which production started in or after January 2017.

PVO from rapeseed is commonly produced in industrial-scale plants using chemicals (hexane) and high amounts of energy for several extracting and refining steps [3]. Moreover, there are often long transport distances for feedstock and products. In contrast, processing of rapeseed in small-scale decentralized oil mills is based on solely mechanical cold-pressing and succeeding filtration. The products of this simplified technology are cold-pressed rapeseed oil (cRSO) and rapeseed cake which can substitute imported soybean meal as local protein feed. This self-sufficient production system of agricultural biofuel could offer even more environmental advantages which result from a reduction of chemicals and energy used in processing as well as the avoidance of long transport distances [4] [5].

The quality of rapeseed oil as fuel is ensured by the German standard DIN 51605 [6]. The use of cold-pressed rapeseed oil in compatible diesel engines as well as in combined heat and power plants is already a proven state-of-the-art technology [7] [8] [9] [10].

The RED default value of GHG emissions for rapeseed oil (PVO from rapeseed) solely represents the processing of rapeseed in industrial-scale plants and does furthermore not include detailed region-specific differences regarding rapeseed cultivation (that go beyond NUTS2 values). In view of this situation the goal of this study is to obtain specific data for GHG emissions of rapeseed oil production in Bavaria. For this purpose differences regarding methods of rapeseed cultivation and technologies of rapeseed processing have been analyzed. Moreover, different allocation procedures are used as a contribution to biofuels policy and legislation analysis.

2 MATERIALS AND METHODS

2.1 Production system and areas

In this study GHG emissions of rapeseed oil as self-sufficient agricultural biofuel have been balanced. This rapeseed oil is produced in decentralized oil mills where rapeseed processing is based on mechanical cold-pressing and succeeding filtration [11]. At the beginning the rapeseed needs to be cleaned and dried to moisture of 7 %. The next step is the storage of the rapeseed, where different ventilators can be installed. In case of the three oil mills analyzed there is a pre-conditioning 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 pre-heats the seed before the extraction. This procedure optimizes the amount of oil extracted. The rapeseed oil is separated from the rapeseed and stored in a stainless steel tank. Depending on the required product properties some adsorbents can be added to the uncleaned oil and filtered off in order to reduce the content of elements such as P, Ca, Mg. Rapeseed cake is an important high-protein feed especially for dairy or cattle. For this purpose, the oil content of the cake needs to be adjusted at a low level through upstream process optimization (e.g. quality of seed, pre-heating, pre-conditioning, pressing parameters). Residual oil content of 10 to 12 % is normally achieved. The extracted cold-pressed rapeseed oil (cRSO) has to be filtered whereby different methods are used. Cold-pressed rapeseed oil can be used in diesel engines as well as in combined heat and power plants or as a feedstock for biodiesel production. As a second co-product of minor content, the filter cake is mixed to the rapeseed and pressed a second time, where its oil content of about 50 % can partly be exploited. Alternatively, filter cake is mixed with the rapeseed cake.

Concerning energy demand it is assumed that there is linearly dependency on the mass of rapeseed processed. The whole processing requires 0.014 MJ of electric energy per MJ of cRSO.

The data for rapeseed processing and 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 location (soil-climate-areas [12]).

Nearby of each decentralized oil mill data for rapeseed cultivation (year of harvest 2013) from five 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 listed in **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.

Table I: Overview of data for site conditions, farm structure and rapeseed cultivation of analyzed farms and decentralized oil mills

Soil-climate-area [12]	A[1]	B[2]	C[3]
Oil mill	n = 1	n = 1	n = 1
Max. processing capacity (kg rapeseed h^{-1})	500	800	1800
Farms	n = 5	n = 5	n = 5
Site conditions			
Altitude (m)	530	490	395
Annual precipitation Ø (mm)	925	760	740
Annual temperature Ø (°C)	7.2	7.2	7.4
Productivity of arable land[4] (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 (% arable land)	10 – 23	17 – 24	14 – 28
Rapeseed cultivation			
Yield with 9 % moisture (kg ha^{-1})	4266	4065	3728
Seeds (kg ha^{-1})	2.3	2.6	2.3
Plant protection (active substances) (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]Tertiär-Hügelland Donau-Süd
[2]Albflächen und Ostbayerisches Hügelland
[3]Verwitterungsböden in den Übergangslagen
[4]based on [13]
[5]calculated by [14]

2.2 Life cycle assessment

According to the ISO standards 14040 and 14044 life cycle assessment (LCA) methodology is based on analyzing the complete life cycle of a product evaluating different impact categories [15] [16]. In this study LCA methodology is used for evaluation of cold-pressed rapeseed oil as self-sufficient agricultural biofuel. **Figure 1** shows the system boundary which includes rapeseed cultivation, transport processes and rapeseed processing.

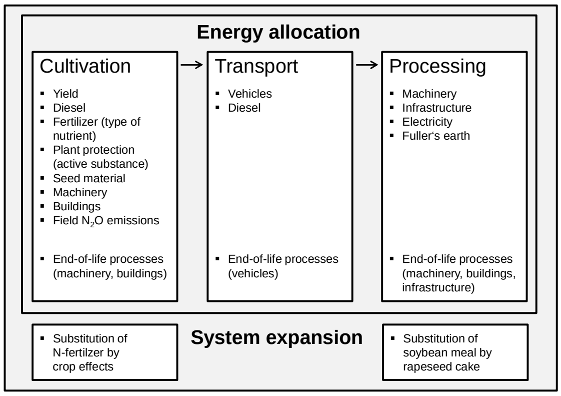

Figure 1: System boundaries for LCA of cold-pressed rapeseed oil (cRSO) as self-sufficient agricultural biofuel

The functional unit used is g CO_2eq MJ^{-1} cold-pressed rapeseed oil (cRSO). The models have been developed using GaBi 6.0 with GaBi professional database and ecoinvent database v2.2 [17] [18]. The impact assessment is done according to the International Reference Life Cycle Data System (ILCD) [19] [20]. In the present study only global warming potential (GWP) is considered as impact category. Field N_2O-emissions of rapeseed cultivation were calculated according to the IPCC [14].

Because rapeseed oil production is a multi-output process an allocation of GHG emissions has to be conducted. The RED requires the energy allocation based on the lower heating value (LHV). In this study the energy allocation based on LHV is also used but the ratio of cold-pressed rapeseed oil to rapeseed cake accounts 52:48 which is differing to the RED (61:39) [21]. The reasons are the lower extraction rate of rapeseed oil by mechanical cold-pressing (0.37 kg cRSO and 0.63 kg rapeseed cake out of 1.0 kg rapeseed with an assumed oil-content of 42 %) and the higher residual oil content in the co-product rapeseed cake (12 %) compared to industrial-scale plants using hexane. 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 [11]. Furthermore, system expansion by carbon crediting was also used to evaluate rapeseed cake as substitution for soybean meal and crop effects of rapeseed cultivation as substitution of N-fertilizer. The carbon credit for the rapeseed cake is calculated with the ecoinvent v2.2. 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 [22]. The carbon credit for the crop effects of rapeseed cultivation is taken from literature [23].

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 also taken into account.

3 RESULTS AND DISCUSSION

According to the RED the results are presented for the process steps rapeseed cultivation, transport and rapeseed processing. **Figure 2** and **Figure 3** only present results calculated by energy allocation based on LHV.

Figure 2 shows the calculated GHG emissions of rapeseed cultivation for cRSO on farm level, which vary greatly from 28.0 to 46.3 g CO_2eq MJ^{-1} cRSO. For orientation the RED default value for PVO from rapeseed is marked as red line. However calculation methods differ in detail between applied LCA and default values of the RED. Considering this, five farms are below the RED default value for cultivation (30 g CO_2eq MJ^{-1} PVO from rapeseed). The production of fertilizer and fertilization related N_2O field emissions make up the biggest share of GHG emissions from rapeseed cultivation for cRSO. Modelling the rapeseed cultivation fertilizers were distinguished in accordance to the type of nutrient. As an example the emission factors for N-fertilizers spread from 2.7 to 8.7 kg CO_2eq kg^{-1} N.

Regarding regional differences it can be noted that farms in soil-climate area A in average produce the least GHG emissions (31.0 g CO_2eq MJ^{-1} cRSO) followed by farms in soil-climate area B (34.4 g CO_2eq MJ^{-1} cRSO) and farms in soil-climate area C (37.0 g CO_2eq MJ^{-1} cRSO). However, differences between farms and thus farm specific production management are larger than between analysed soil-climate areas.

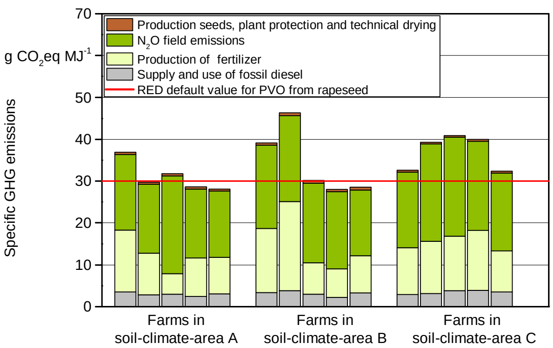

Figure 2: Calculated GHG emissions of rapeseed cultivation for cRSO and RED default value for PVO from rapeseed

Figure 3 shows the calculated GHG emissions of rapeseed processing in three decentralized oil mills as well as the related transport processes which vary slightly from 1.3 to 1.6 g CO_2eq MJ^{-1} cRSO and the RED default values for PVO from rapeseed. Regarding to the RED default values for processing (5 g CO_2eq MJ^{-1} PVO from rapeseed) and transport (1 g CO_2eq MJ^{-1} PVO from rapeseed) there is a significant GHG emission saving by decentralized production of rapeseed oil.

The consumption of electricity for pressing rapeseed and filtering the crude rapeseed oil has the highest share of the GHG emissions of rapeseed processing for cRSO.

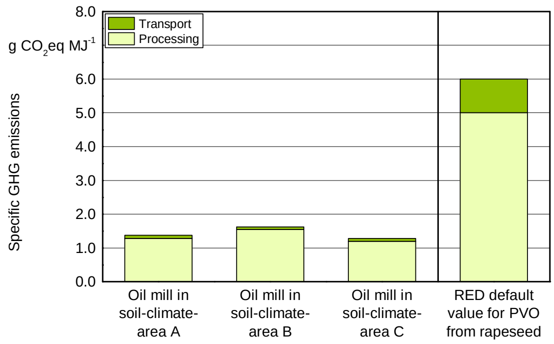

Figure 3: Calculated GHG emissions of processing and transport for cRSO in the three analyzed decentralized oil mills and RED default values for PVO from rapeseed

Figure 4 shows GHG emission savings for cold-pressed rapeseed oil (cRSO) using different allocation procedures. The RED default value for PVO from rapeseed is marked as red line, and for the fossil diesel reference as grey bar. Using energy allocation based on LHV GHG emission saving of cRSO amounts to 58 % which is in the range of the RED default value for PVO from rapeseed. Using carbon crediting to evaluate rapeseed cake as substitution for soybean meal and crop effects of rapeseed cultivation as substitution of N-fertilizer the values for GHG emission savings of cRSO are considerable higher (I) only rapeseed cake (71 %) and (II) rapeseed cake and crop effects (80 %), respectively.

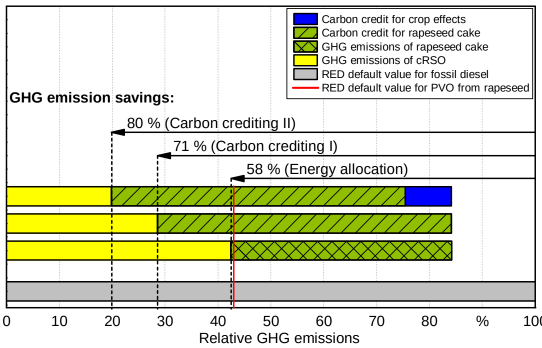

Figure 4: Calculated GHG emission savings of cRSO using different allocation procedures compared to RED default values for PVO from rapeseed and for fossil diesel

4 CONCLUSIONS

The study shows that cold-pressed rapeseed oil used as self-sufficient biofuel in agriculture, has a high potential in saving GHG emissions. By decentralized processing of rapeseed GHG emissions can be reduced considerably compared to industrial-scale plants. GHG balance results of rapeseed oil strongly depend on rapeseed cultivation (fertilization management and its related field N_2O emissions). For optimisation of GHG emissions farm specific GHG balances are required.

Energy allocation based on lower heating value (LHV) characterizes the benefit of rapeseed cake insufficiently. System expansion by carbon crediting strongly influences the results. In this context the use of rapeseed cake instead of soybean meal is of particular relevance.

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