GHG EMISSIONS OF RAPESEED OIL FUEL – IMPACT OF SPECIFIC DATA AND BALANCE METHODS

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ABSTRACT: Achieving the international goals for climate and resource protection is a more and more important task in the 21st century. To assess GHG reduction potential of bio-based products and bioenergy specific data and a profound knowledge about how to calculate are necessary. The evaluation of rapeseed production in Bavaria pointed out that GHG emissions and nitrogen balances show significant farm-specific and site-specific differences. For example, farm-specific GHG emissions range from 0.541 to 1.039 kg kg^{-1} rapeseed. Influencing key factors are the site-specific biomass yield and the nutrient management. In this context a needs-based using of organic fertilizers is one important factor to reduce GHG emissions in cultivation rapeseed. Default values e.g. specified by RED are not practicable for deriving recommendations for action. Related to the chosen method for evaluating N_2O-field emissions and co-products default values by RED describe the GHG emissions for rapeseed oil fuel from Germany insufficiently, too.
Keywords: CO_2 balance, fertilization, life cycle assessment (LCA), rapeseed, rapeseed oil, regional

1 INTRODUCTION

Climate and resource protection are among the most important social tasks in the 21st century, especially since the international climate protection agreement of Paris in 2015 (COP21). In this context the member states of the UN climate summit in 2017 (COP23) have committed to present their proposals for climate protection in the agricultural sector by 03/31/2018. With the German government's Climate Action Plan 2050, it is determined, that in 2030 31 up to 34 % greenhouse gas (GHG) emissions of the German agriculture have to be reduced compared to 1990 [1]. The production and use of decentralized rapeseed oil fuel offers a great potential to achieve this goal. Another important measure to reduce GHG emissions in the agricultural sector is to significantly reduce the nitrogen surplus and the associated N_2O-field emissions (nitrous oxide). To assess the GHG reduction potential of these measures a profound knowledge about how to calculate the GHG emissions is necessary. Furthermore, site- and farm-specific data is needed. Several previous investigations pointed out farm- and site-specific production conditions along the supply chain of bio-based products and bio-energy as determining factors of the GHG balance [2][3][4]. Default values, e.g. specified by the Renewable Energy Directive (Directive 2009/28/EC (RED) [5]) do not consider specific data. Furthermore the approach for calculating N_2O-field emissions by IPCC [6] is a global approach without considering regional aspects. Consequently default values are not suitable to identify site-specific optimization potentials and to derive recommendations for action to reduce GHG emissions in the agricultural sector.

The purpose of this work is to identify site-specific optimization potentials for reducing greenhouse gas emissions of rapeseed production and subsequent processing to rapeseed oil fuel. Based on the optimization potential recommendations for action for farmers and foresters are derived. Additionally, a special attention would be given to the method of calculating and assessing N_2O-field emissions and co-products, respectively. Finally the specific GHG emissions are compared to and discussed with the default values specified by Directive 2009/28/EC (RED I) [5] and the draft of its amendment (RED II) [7].

2 MATERIALS AND METHODS

2.1 Farm- and site-specific data

Within the research projects "Expert Group Resource Management Bioenergy in Bavaria" (ExpRessBio) and "Region-specific GHG emissions of rapeseed production in Bavaria" (RegioTHGRaps) regional and farm-specific data for rapeseed cultivation and decentralized rapeseed oil fuel production were collected. The collected data based on face-to-face interviews (ExpRessBio) and surveys (RegioTHGRaps) over four crop years. A total of 36 farms and three decentralized oil mills in six soil-climate-areas of Bavaria, Germany could be assessed. **Figure 1** shows the location of the investigated farms and decentralized oil mills within various soil-climate-areas. The area classification "soil-climate-area" is chosen because of its consideration of site conditions for soil and climate (Roßberg (2007) [8]).

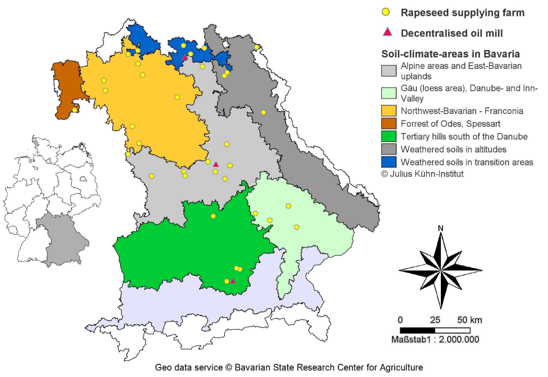

Figure 1: Location of farms and decentralized oil mills within various soil-climate-areas of Bavaria, Germany

Regarding site conditions there are relevant differences in annual precipitation, temperature and productivity between the six soil-climate-areas listed in **Table 1.** The results of the interviews show also huge differences in farm structure, yield and nutrient management. The farms with livestock farming in the soil-climate-areas C and D, achieved the lowest yields on average. However, the detailed evaluation of nutrient management pointed out, that the amount of applied mineral and organic nitrogen was highest in these soil-climate-areas.

Table I: Overview of data for site conditions, farm structure and rapeseed cultivation of analyzed farms in various soil-climate-areas in Bavaria

Soil-climate-area	**A**[1]	**B**[2]	**C**[3]	**D**[4]	**E**[5]	**F**[6]
Farms	n = 5	n = 9	n = 5	n = 4	n = 4	n = 9
Site conditions						
Altitude (m)	542	458	303	449	447	358
Annual precipitation (mm)	916	675	657	716	690	658
Annual temperature (° C)	8.9	9.3	9.6	8.6	9.3	9.7
Productivity of arable land (Soil score 0 -100)[7]	30 – 50	40 – 50	30 – 60	22 – 33	43 – 64	30 – 55
Farm structure						
Farming type	arable farming	mixed farming	livestock farming	livestock farming	arable farming	mixed farming
Stock density (LU)[8]	0 – 1.7	0 – 2.1	0.2 – 2.3	0.9 – 1.4	0	0.5 – 3.1
Farm size (ha)	156	124	107	140	71	244[9]
Rapeseed (% arable land)	13	19	15	23	14	17
Yield (kg ha^{-1})	4,390	4,380	4,060	3,900	4,120	4,310
N-fertilizer total (kg N ha^{-1})	240	232	257	255	235	225
N-fertilizer mineral (kg N ha^{-1})	191	170	172	186	174	180
N-fertilizer organic (kg N ha^{-1})	49	63	85	69	61	45

[1] Tertiary hills south of the Danube
[2] Alpine areas and East-Bavarian uplands
[3] Weathered soils in transition areas
[4] Weathered soils in altitudes
[5] Gäu (loess area), Danube- and Inn-Valley
[6] Northwest-Bavarian – Franconia
[7] based on [9]
[8] Livestock unit
[9] including a farm with a size of 800 ha, without this farm the cultivated arable land amounts 175 ha

2.2 Method for calculating GHG emissions
The calculation of GHG emissions is based on the “ExpRessBio methods” [10]. The “ExpRessBio methods” are harmonized methods to analyze and assess selected environmental and economic impacts of product systems derived from agricultural and forestry resources. These methods are according to the ISO standards 14040 [11] and 14044 [12] and were developed by the “Expert group on resource management Bioenergy – ExpRessBio” in Bavaria in the period from 2012 to 2016. **Figure 2** shows the elements harmonized within the “ExpRessBio methods”, which resulted in the “system description” as the center outcome of the method.

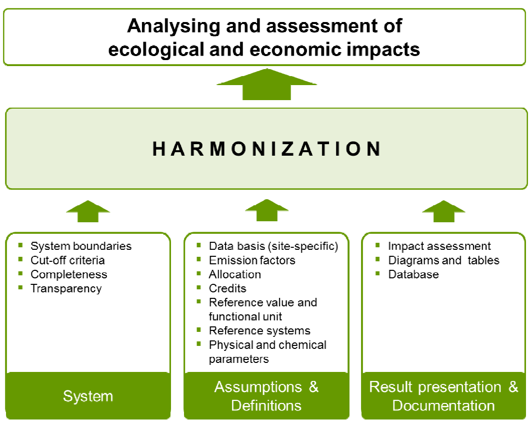

Figure 2: Elements of harmonization of “ExpRessBio-methods”

For evaluating rapeseed cultivation and decentralized production of rapeseed oil fuel the most important elements listed in **Figure 2** are defined below.

The system boundary includes rapeseed cultivation, transport of rapeseed to oil mill and processing which are the same process groups as in the requirements of RED. The functional units used are kg CO_2-eq kg^{-1} rapeseed and kg CO_2-eq MJ^{-1} rapeseed oil. The balancing models have been developed using GaBi ts software [11] with GaBi professional database and ecoinvent database v3.3 [14] (both state Oct. 2017). The impact assessment is done according to the International Reference Life Cycle Data System (ILCD) [15][16] considering only global warming potential (GWP) as impact category.

Field-N_2O-emissions of rapeseed cultivation are calculated in base analysis according to the IPCC approach [6]. In scenario analysis the specific emission factor for rapeseed cultivation in Germany for calculating direct N_2O-field emissions is used. This emission factor was developed by RUSER, FUß et al. (2017) [17] on the basis of measurement data from field trials on rapeseed cultivation in Germany.

Rapeseed oil production is a multi-output process with rapeseed oil as main-product and rapeseed press cake as co-product. The RED requires the energy allocation based on the calorific value to assess the co-product. In the base analysis energy allocation based on the calorific values of decentralized produced rapeseed oil (37.5 MJ kg^{-1}) and rapeseed cake (20.7 MJ kg^{-1}), respectively [18]. In a scenario analysis the substitution method with credits for the avoided reference product is used to evaluate the rapeseed press cake as protein feed for cattle feeding, according to the actual utilization. Thereby, the credit for the rapeseed is based on the German import mix of soy and soybean meal and was calculated with the ecoinvent v3.3 database. Furthermore the credit is distinguished between credits with and without considering land use change in cultivation of soy in South America. In case of land use change in South America 8.4 % of soy originates from converted areas e.g. through the clearing of rain forest and ploughing up of scrublands [19]. The amount of the credit is in accordance to the rapeseed cake`s nutritional value given in digestible crude protein (DCP). Based on the crude protein content 1.0 kg of soybean meal is equivalent to 1.53 kg of rapeseed cake [20].

3 RESULTS

The specific GHG emissions of rapeseed cultivation in the various soil climate areas in Bavaria are illustrated as mean values for the crop years 2013 to 2016 in **Figure 3.** They show a considerable variation, both annual effects and farm-specific differences. Some of the annual effects (extremes) are very high and are mainly due to crop failures caused by drought stress or hail damage (e.g. farm B1). The farm-specific range which is between 1.04 kg CO_2-eq kg^{-1} rapeseed in farm C3 and 0.541 kg kg^{-1} in farm B8 is due to farm- and region-specific differences in nutrient management and yield. The farm specific yield in soil-climate-area C "weathering soils in transition areas" and in soil-climate-area D "weathering soils in altitudes" is lowest at 39.4 and 41.3 dt ha^{-1}, respectively (see **Table 1**). At the same time, the amount of nitrogen fertilizer is the highest (257 or 255 kg N_{ges} ha^{-1}), because of the largest amount of organic fertilizer applied there, additionally. Organic fertilizers such as pork or cattle manure as well as fermentation residues have a lower N-efficiency as mineral fertilizers. Depending on the type of organic fertilizer the amount of ammonium nitrogen is only 50 to 70 %. In addition, organic fertilizers are significantly more affected by losses (e.g. ammonia emissions) than nitrogen mineral fertilizers. This inevitably leads to higher nitrogen surpluses in the application of organic fertilizers than in mineral nitrogen fertilizers. In the case of an inappropriate use of organic fertilizers, this effect is significantly increased.

The highest farm-specific nitrogen surpluses are achieved in C3 and F9 and result in the highest farm-specific GHG emissions too (1.04 kg CO_2-eq kg^{-1} at farm C3 and 0.85 kg CO_2-eq kg^{-1} at farm F9, see **Figure 3**). An excessive supply with organic nitrogen from fermentation residues could be identified in both farms in autumn. In general the nutrient management, autumn fertilization in particular, is a significant key factor for reducing GHG emissions in rapeseed cultivation.

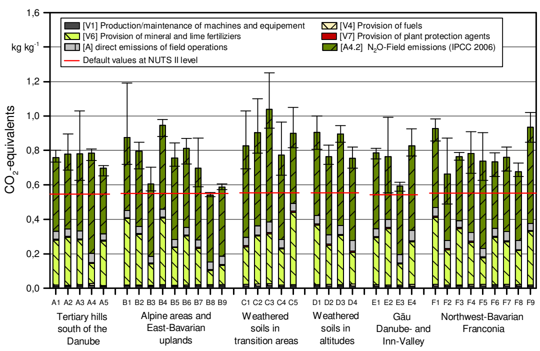

Figure 3: Farm-specific GHG emissions from rapeseed cultivation in Bavaria, Germany (N_2O-field emissions by IPCC (2006) [6])

The influencing key factors for GHG emissions are the N_2O-field emissions on the one hand and the GHG emissions from the provision of mineral fertilizers on the other. Hence, the biggest shares of GHG emissions from rapeseed cultivation are making up by these two parameters. For modelling the rapeseed cultivation the fertilizers were distinguished in accordance to the type of nutrient. The emission factors for N-fertilizers spread from 1.8 for ammonium to 8.8 for Calcium ammonium nitrate [14]. For the provision of the organic fertilizer no GHG emissions are considered. Consequently the choice of mineral nitrogen fertilizer has an important impact on the GHG emissions of cultivating rapeseed.

In base analysis (see **Figure 3**) direct and indirect N_2O-field emissions were calculated by IPCC (2006) [6], which is also used within the evaluation method by RED [5][7]. This approach is a global assessment of nitrous oxide emissions without taking into account specific regional aspects such as the type of soil, climate conditions or crop. The shortcomings of these global assumptions in the IPCC approach have already been pointed out in different investigations. In particular, studies of RUSER, FUß et al. (2017) [17] discussed the global emission factor of the IPCC approach for the calculation of direct N_2O-field emissions critically. On the basis of measurement data from field trials on rapeseed cultivation in Germany a specific emission factor for rapeseed cultivation was developed. Referring to a fertilizer level of 200 kg N ha^{-1} the determined specific emission factor for calculating direct N_2O-field emissions is 0.6 % and thus clearly below the IPCC default value of 1 %.

The influence of the emission factor for calculating the direct N_2O-field emissions on the GHG emissions of rapeseed production in Bavaria is shown in **Figure 4**. The results presented differ only in the calculation of direct N_2O-field emissions. Indirect emissions in both cases are assessed according to the IPCC approach. Using the specific emission factor of rapeseed cultivation, GHG emissions in rapeseed production are reduced by up to 20 % in soil-climate-area A. This demonstrates the importance of a specific assessment of N_2O-field emissions. In context of political and social debate about sustainability and greenhouse gas reduction potential of biofuels, the cultivation of rapeseed, as one of the most important raw material crops for the production of biofuels, should be assessed on the basis of current scientific knowledge.

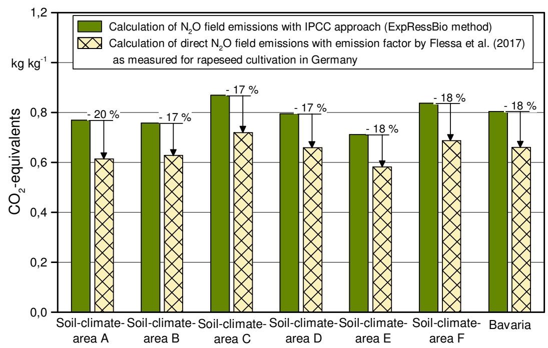

Figure 4: GHG emissions of rapeseed production in Bavaria: Influence of the emission factor for calculating the direct N_2O-field emissions

Figure 5 shows the GHG emissions for the complete product system of decentralized rapeseed oil fuel in Bavaria compared to the default values of the Directive 2009/28/EC (RED I) [5] and the draft of its amendment (RED II). Thereby, the default values are calculated with allocation by calorific value and are related to industrial scale oil production (36 or 40 g CO_2-eq MJ^{-1} rapeseed oil [5][7]). The GHG emissions calculated with specific data and for decentralized rapeseed oil production in Bavaria, are slightly lower (approx. 33.3 g MJ^{-1} by calorific value allocation). The lower GHG emissions of decentralized rapeseed oil fuel are due to the shorter transport distance on the one hand and due to the lower energy demand for decentralized oil production compared to industrial processing, on the other hand.

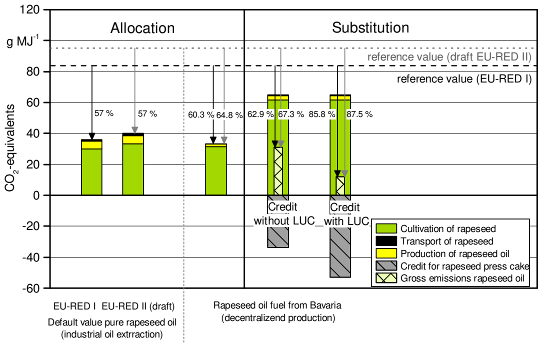

Figure 5: GHG emissions of rapeseed oil from decentralized oil production in Bavaria: Comparison of different methods for assessing co-products with default values specified by RED

Figure 5 also shows results of different methods for assessing co-products: allocation by calorific value and substitution with credits for substituted soybean meal, respectively. By applying the substitution method without considering land use change due to the cultivation of soy in South America gross GHG emissions of rapeseed oil amount 33.1 g MJ^{-1}. Taking land use change into account gross GHG emissions of rapeseed oil decrease to 11.9 g MJ^{-1}.The comparison of GHG emissions of rapeseed oil fuel with the reference value for fossil diesel of RED II shows that the GHG reduction potential reaches up to 87.5 %. However, the substitution method including credits for co-products has not been accepted to be applied for quota counting according to RED I as well as the draft of RED II. For political analysis the substitution method is recommended.

4 CONCLUSIONS

Due to the farm- and region-specific analyzation of rapeseed production in Bavaria recommendations for action to reduce nitrogen balances and GHG emissions could be derived. Most influencing key factor in this context is the appropriate handling of organic fertilizers with a balanced use of mineral fertilizers. With needs-based nitrogen fertilization adapted to plant growth nitrogen surpluses as well as GHG emissions can be significantly reduced. When using mineral fertilizers, products with low GHG emission factors should be selected, because the different nitrogen variants show significant differences in the level of their emission factor.

Using the specific emission factor for rapeseed cultivation according to RUSER, FUß et al. (2017) [17] the calculated direct N_2O-field emissions are lower than using the IPCC approach. This is because the IPCC approach is associated with higher climate-damaging N_2O-field emissions than they were measured in field trials in Germany. Consequently the IPCC approach for calculating N_2O-field emissions should be adapted to the scientific standard.

Allocation by calorific value, which is used in the balancing approach of RED, characterizes the benefit of the co-product (rapeseed press cake) insufficiently. Using the substitution method, the co-product is assessed in accordance with its actual use as protein feed for livestock farming. Consequently the substitution method is recommended for the purpose of policy analysis (e.g. within the amendment of the Directive 2009/28/EC (RED II)).

Finally, producing decentralized rapeseed oil fuel and using it in agricultural machines generates a high valued protein feed and leads to a reduction of GHG emissions up to 87.5 %.

5 REFERENCES

[1] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016a): Klimaschutzplan 2050. Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung, Kabinettsbeschluss vom 14. November 2016. Berlin: 91 Seiten

[2] Engelmann, K., Dressler, D., Strimitzer, L., Thuneke, K., Remmele, E. Life cycle assessment of rapeseed oil as self-sufficient agricultural biofuel –results of case studies from Bavaria. 22nd European Biomass Conference and Exhibition, 23-25 June 2014, Hamburg, Germany.

[3] Dressler, D.; Engelmann, K.; Serdjuk, M.; Remmele, E.: Rapsölkraftstoffproduktion in Bayern. Analyse und Bewertung ökologischer und ökonomischer Wirkungen nach der ExpRessBio-Methode. Berichte aus dem TFZ, Nr. 50. Straubing: Technologie- und Förderzentrum, 2016. ISSN 1614-1008

[4] Dressler, D.; Loewen, A.; Nelles, M.: Life cycle assessment of the supply and use of bioenergy: impact of regional factors on biogas production. Int. JLCA 17 (9), S. 1104–1115, 2012. DOI 10.1007/s11367-012-0424-9.

[5] 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.

[6] IPCC 2006 IPCC Guidelines for National Greenhouse Gas Inventories, prepared by the National Greenhouse Gas Inventories Programme. Eggleston H.S., Buendia L., Miwa K., Ngara T., & Tanabe K. (eds). Published: IGES, Japan.

[7] European Commission): ANNEXES to the Proposal for a Directive of the European Parliament and the Council on the promotion of the use of energy from renewable sources (recast). Brussels: European Commission, 2016

[8] Roßberg, D., Michel, V., Graf, R., Neukampf, R. Definition von Boden-Klima-Räumen für die Bundesrepublik Deutschland. Nachrichtenblatt des Deutschen Pflanzenschutzdienstes 2007; 59(7):155–161.

[9] BodSchätz G. 2007. Bodenschätzungsgesetz vom 20. Dezember 2007 (BGBI. I S. 3150, 3176), das durch den Artikel 232 der Verordnung vom 31. August 2015 (BGBI. I S. 1474) geändert worden ist [Law on the estimation of soil fertility]
[10] Wolf, C.; Dressler, D.; Engelmann, K.; Klein, D.; Weber-Blaschke, G.; Böswirth, T.; Bryzinski, T.; Effenberger, M.; Hijazi, O.; Hülsbergen, K.-J.; Maze, M.; Remmele, E.; Röder, H.; Schulz, C.; Serdjuk, M.; Thuneke, K.; Tiemann, A.; Zerle, P.: ExpRessBio – Methoden (ExpRessBio methods). Methoden zur Analyse und Bewertung ausgewählter ökologischer und ökonomischer Wirkungen von Produktsystemen aus land- und forstwirtschaftlichen Rohstoffen. Berichte aus dem TFZ, Nr. 45. Straubing: Technologie- und Förderzentrum, 2016. ISSN 1614-1008
[11] DIN EN ISO 14040:2009. Environmental management – Life cycle assessment – Principles and framework.
[12] DIN EN ISO 14044:2006. Environmental management – Life cycle assessment – Requirements and guidelines.
[13] Thinkstep AG. GaBi software and database contends for life cycle assessment (October 2017)
[14] Swiss centre for life cycle inventories. Ecoinvent database v3.3. (October 2017) http://www.ecoinvent.org/
[15] European Commission Joint Research Centre. (2010). International Reference Life Cycle Data System (ILCD) Handbook: General guide for Life Cycle Assessment - Detailed guidance (EUR – Scientific and Technical Research series No. LB-N -24708 -EN-C). Ispra, Italy.
[16] European Commission Joint Research Centre. (2011). International Reference Life Cycle Data System (ILCD) Handbook: Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors (EUR – Scientific and Technical Research series No. LB- NA-24571 -EN-C). Ispra, Italy.
[17] Ruser, R.; Fuß, R.; Andres, M.; Hegewald, H.; Kesenheimer, K.; Köbke, S. et al. Nitrous oxide emissions from winter oilseed rape cultivation. In: Agriculture, Ecosystems & Environment 249, S. 57–69. 2017. DOI: 10.1016/j.agee.2017.07.039.
[18] Remmele, E. Handbuch - Herstellung von Rapsölkraftstoff in dezentralen Ölgewinnungsanlagen. Fachagentur Nachwachsende Rohstoffe e. V. (FNR) (ed.), Gülzow, 2009.
[19] Sutter, J. Soybean. In: Jungbluth, N. (ed.) Life Cycle Inventories of Bioenergy. Ecoinvent Report No. 17. Swiss Centre für Life Cycle Inventories, p. 125 – 140. Dübendorf, 2007.
[20] Preißinger, W., Obermaier, A., Hitzelsperger, L., Maierhofer, R. Zum Einsatz von Rapskuchen in der intensiven Bullenmast. http://www.lfl.bayern.de/mam/cms07/ite/dateien/rapskuchen_bullenmast.pdf (May 2018)

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