Greenhouse gas emissions of regionally produced alternative feedstuffs rich in protein for Austrian dairy production

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Abstract: *The aim of this study was to analyse the potential greenhouse gas emissions (GHGE) of locally and regionally produced, alternative protein-rich feedstuffs (APRFs) which can be utilised in dairy cattle feeding as compared to extracted soybean meal (SBME) in a complete life-cycle chain for Austria. In addition to GHGE from soil (N_2O), from the production of mineral fertilizers and pesticides, industrial processes (oil milling, distillery, drying plant) and use of fuels, the effects of land use change (LUC) were included in the calculation of GHGE. Currently, SBME, which is mainly imported from South-America, is the most important protein feedstuff for livestock in Austria, but recently it was started to replace it by APRFs in diets for dairy cows for various reasons. In this study, the GHGE of SBME were compared to those of regionally cultivated and locally processed APRFs. Furthermore, mixtures of APRFs were evaluated which provided energy and available protein equivalent to one kg of SBME. In conclusion, utilisation of more locally produced APRFs shows clear advantages in terms of GHGE. Balanced mixtures of APRFs may offer specific benefits in this regard. On average of all four balanced mixtures of APRFs presented in this study, they result in a reduction of GHGE of about 55% as compared to SBME.*

Keywords: *soybean meal, protein-rich concentrates, carbon footprint, greenhouse gas emissions, land use change*

Introduction

Agriculture, especially animal husbandry, causes considerable greenhouse gas emissions (GHGE). Within livestock husbandry, dairy production systems are the largest source of GHGE (Weiske et al., 2006). Within these, feed supply and feeding were found to have a high impact on GHGE (Hörtenhuber et al., 2010).

For several decades extracted soybean meal (SBME) has been an important ingredient of livestock diets in Western Europe. As a consequence of the increased performance of livestock, the required dietary contents of protein and essential amino acids also increased substantially in the last decades. Even ruminants, which are able to utilize forage have to be fed high proportions of concentrate if their performance shall be high (Knaus, 2009). Because of its high protein and amino acid contents and the availability of standard technologies for the inactivation of anti-nutritive components, SBME possesses a wide utilizability and is the major protein-rich concentrate in livestock feeding (Wurm, 2007). In the disputed field of ecological and ethical consequences of the production and import of SBME, two topics are of special interest besides the consumers' general scepticism towards the use of genetically modified feedstuffs in livestock nutrition (Wurm, 2007): (1) Land use change (LUC) from grasslands, savannahs and tropic forests to agricultural land for the production of soybeans (and other crops), especially in South-America. This land use change is connected with a great loss of carbon in the soils emitted as GHGE (CO2) and with a reduced biodiversity (Fehrenbach et al., 2008; IPCC, 2006). (2) Transports over long distances consume high amounts of energy, contribute to GHGE from fossil fuels and render possible nutrient flows over great distances which counteract attempts to maintain fairly closed nutrient cycles.

Alternative protein-rich feedstuffs such as grain legumes and by-products from certain oilseeds (cakes, extracted meals and by-products from distilling) are regionally produced and are used for livestock feeding in Austria, as in other European countries. In the context of ecological sustainability, the question arises whether specific benefits exist for home- or regionally produced, alternative protein-rich feedstuffs in terms of GHGE. This study will therefore cover the potential benefits of selected alternative feedstuffs rich in protein in terms of GHGE related to their production and dietary use in dairy cows. Emissions caused by LUC will be specifically emphasized, because other carbon footprints and life cycle assessments for feedstuffs did not take this factor into account (Garnett, 2009).

Materials and methods

Alternative protein-rich feedstuffs (APRFs) and mixtures thereof (APRMs)

Carbon footprints were calculated for SBME and alternative protein-rich feedstuffs (APRFs) as well as for mixtures of these (APRMs) to be used in dairy cattle feeding. Three APRFs which are frequently used in the nutrition of dairy cattle were estimated according to the GHGE associated with their supply chain: rapeseed cake (RSC), distiller's dried grains with solubles (DDGS, produced from wheat), and faba beans (FB).

Due to the high content of protein and net energy (NE_L) in SBME, APRFs needed to be mixed and used in greater quantities in order to be nutritionally equivalent to one kg of SBME. The mixtures formulated represent two different substitution levels for SBME, 50% and 100%, respectively (Table 1): four mixtures were formulated which contain the same amounts of NE_L and available protein and a similar amount of rumen undegradable protein (UDP) as SBME; these equivalent amounts also account for the forage-replacing effect of concentrates (Gruber et al., 2005; Table 1).

Table 1. Mixtures of protein-rich alternative concentrates (APRMs) supplying energy and protein equivalent to 1 kg of SBME (on dry-matter basis).

Feed type	Composition of mixtures (%)[a]	Equivalent amount (kg DM)	UDP content (%)
SBME	100.0% SBME	1.000	35
APRM 1	50.0% SBME, 42.2% DDGS, 14.9% RSC	1.105	36
APRM 2	50.0% SBME, 48.0% DDGS, 8.6% FB	1.100	36
APRM 3	84.1% DDGS, 30.0% RSC	1.208	37
APRM 4	95.7% DDGS, 17.6% FB	1.198	36

[a] all mixtures equivalent to 1 kg SBME (8.63 MJ NE_L kg^{-1} DM, 288 g available CP kg^{-1} DM)

System boundaries, conversion factors and sources of GHGE

System boundaries were defined to include the most important processes leading to GHGE, from the supply of input factors relevant for the production of protein-rich concentrates to the provision of the feed to livestock (see paragraphs below).

Total emissions were calculated by adding up the emissions of CH_4, N_2O and CO_2 as CO_2-equivalents (CO_2-eq). Conversion factors used to calculate the global warming potential were 25 kg CO_2-eq per kg methane and 298 kg CO_2-eq per kg nitrous oxide (100-year-horizon; IPCC, 2007).

In the following paragraphs, the sources of GHGE are described which were considered herein.

Agricultural production and land use change (LUC)

Crop yields per ha of conventionally managed land were derived from Austrian statistical databases (BMLFUW, 2006; BMLFUW, 2008a), energy and nutrient contents of crops and feedstuffs, including UDP-content were taken from feed tables (DLG, 1997), except for DDGS from wheat (Wiedner, 2008).

When calculating the GHGE mitigating effect of forage replacement by the amounts of APRMs (Table 1) values for lucerne-grass mixture were used to represent forage.

GHGE from the use of fuels for agricultural production were calculated according to the ACAERD (2005) and Fehrenbach et al. (2008).

GHGE of LUC, as estimated based on Fehrenbach et al. (2008) and data from European Environment Agency (EEA, 2008), were combined with data on imports of SBME, DDGS (from processing of wheat) and RSC. FB were assumed not to be related to LUC as they are integrated in the crop rotation on regional farms and no increase in their production – which could potentially lead to LUC – was observed.

Transports

According to AGES (2005), the vast majority of soy-products imported to Austria originate from Brazil (78%), followed by Argentina (20%) and the USA (2%). The soybeans were assumed to be transported by lorries (1,000 km of transport) to oil mills near the harbour, where they were processed to oil and SBME and shipped to Europe (10,000 km of waterway).

55% of rapeseed processed into oil and RSC in Austrian oil mills were cultivated in the region, whereas the other 45% were imported, mainly from Eastern and Central Europe (28% Hungary, 15% Slovakia, 2% Croatia; Statistics Austria, 2006). The latter results in a 275 km-transport by lorry. However, the transport distances between oil mill and farm were relatively short (50 km by lorry plus 10 km by tractor).

DDGS is produced at only one location in Austria, which leads to higher transport distances between processing plant and farm (150 km by lorry and 10 km by tractor). Shares of raw material imported, import regions and transport distances were assumed to be similar to RSC as given above (325 km by lorry).

GHGE from the use of fuels for transports were estimated according to Wilting et al. (2004) and Fehrenbach et al. (2008).

Mineral fertilizer, pesticides and emissions from soil

Information on mineral fertilizers and pesticides for South-American soybean production was taken from Dalgaard et al. (2008). Amounts of pesticides and fertilizers (N/P/K/Ca) applied per ha of arable land were derived from Austrian statistical databases (BMLFUW, 2008b). GHGE of production of mineral fertilizers and pesticides were estimated from numbers given by Patyk and Reinhardt (1997) and Biskupek et al. (1997), respectively.

In addition to direct N_2O emissions from soils – which corresponded to the amount of fertilizers applied – N from atmospheric deposition and from crop residues was considered for N_2O emissions according to IPCC guidelines (IPCC, 2006). Additional indirect emissions of N_2O from leaching were calculated following IPCC guidelines (IPCC, 2006), using a default value for leached N of 30% of total soil N.

Industrial processing of feedstuffs and allocation of GHGE to products

One kg of soybeans was assumed to be transformed into 0.18 kg of oil and 0.80 kg SBME, with 0.02 kg of loss (Dalgaard et al., 2008). One kg of rapeseed is transformed into 0.30 kg oil and 0.70 RSC (Eder and Eder, 2004). According to Vetter et al. (2005), bio-ethanol and DDGS are produced at a ratio of 50:50 in a distillery, with an efficiency of about 0.34 kg each per kg of wheat. Based on these numbers and on the energy content of the products (Fehrenbach et al., 2008 and DLG, 1997), caloric values were calculated for allocation of GHGE to the individual product.

GHGE from industrial processing of feedstuffs were taken from Fehrenbach et al. (2008) for the bio-ethanol distillery and from Lehuger et al. (2009) for oil mills.

Results and Discussion

GHGE of protein-rich feedstuffs (APRFs)

The supply of different concentrates rich in protein is linked to the emission of different amounts of greenhouse gases: one kg of SBME (DM) was found to result in GHGE of 6.023 kg CO_2-eq if LUC was taken into consideration; if soybeans were produced without LUC, GHGE would be reduced to 0.613 kg CO_2-eq. However, the vast majority of SBME imported to Austria is assumed to be connected to LUC in the countries of origin (Fehrenbach et al., 2008). Values for GHGE connected to the production of DDGS were 1.450 kg CO_2-eq if LUC occurred and 1.191 without LUC (per kg DM). Emissions for RSC were found to be at 1.013 kg CO_2-eq and 0.616 if LUC was and was not considered, respectively. The provision of FB resulted in the lowest GHGE (0.445 kg CO_2-eq per kg DM). Figure 1 shows the results for GHGE of protein-rich feedstuffs and the contributions from different sources.

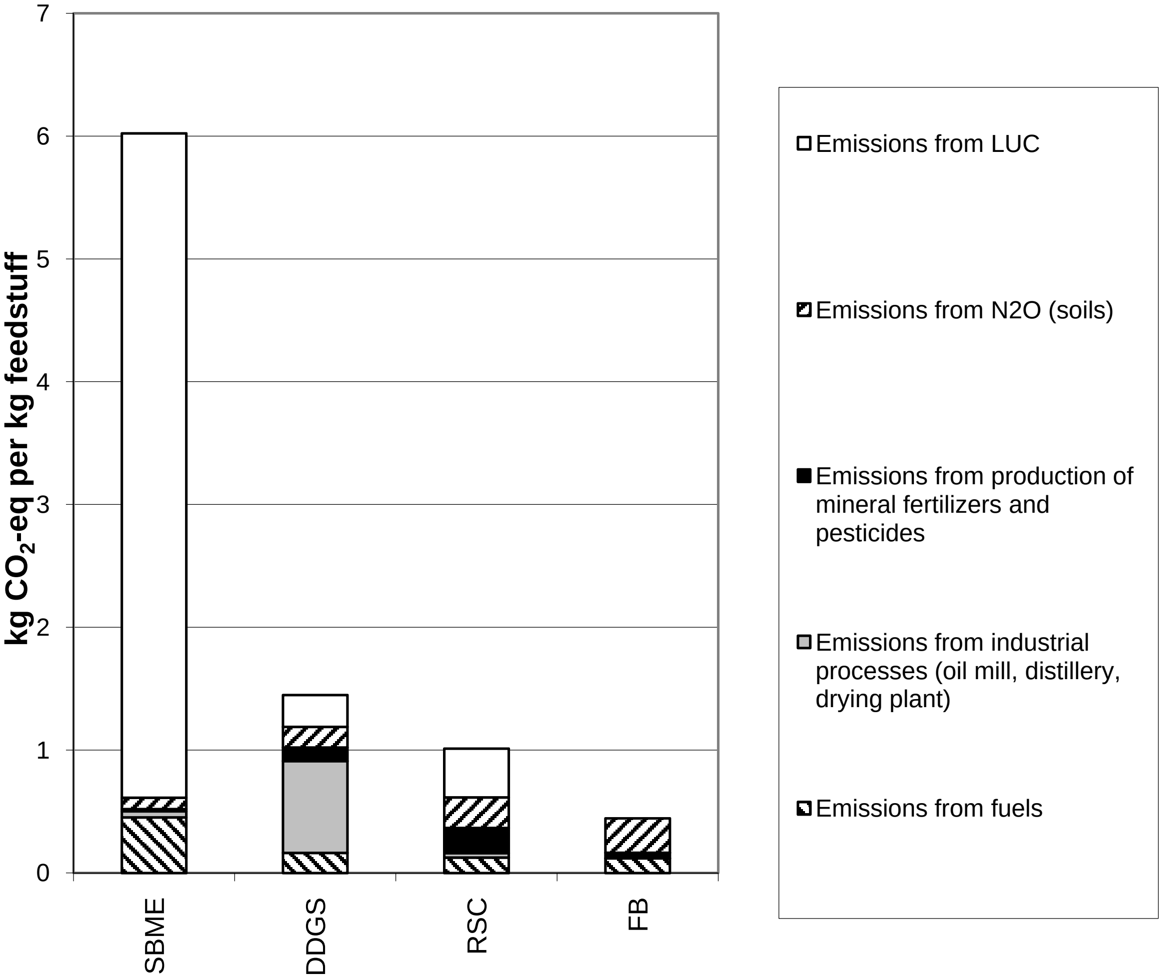

Figure 1. GHGE per kg of protein-rich feedstuffs (kg CO_2-eq per kg DM feedstuff).

Land use change (LUC)

LUC plays a central role for the GHGE which are related to the use of the feedstuffs anaysed in this study: LUC contributed 18% to total GHGE for DDGS (the co-product ethanol is loaded with a greater share due to its higher caloric value), while LUC plays a much greater role (up to 90%) in the case of SBME. For SBME and RSC, LUC was responsible for the highest proportion of GHGE, in the case of DDGS only the emissions from industrial processes were higher (Fig. 1). Specifically high GHGE from LUC arise for SBME which was produced in South-America, where rainforest clearance and the ploughing of savannahs (the latter with a lesser effect) result in high CO_2-emissions from burning of huge amounts of organic material and from reduced organic carbon stocks and mineralization in agricultural soils (Fehrenbach et al., 2008; IPCC, 2006).

If no LUC occurred, GHGE would be highest for DDGS due to the industrial processes involved in their production. GHGE would be much more favorable for SBME and similar to those for RSC, if it was produced without converting grassland or even forests into arable land (LUC). If transport could be reduced by growing soybeans locally or importing them from nearby countries of Southern and Eastern Europe, SBME would come off even better, mainly due to its biological N-fixation (i.e. no mineral N-fertilizer needed).

However, LUC was not considered in former carbon footprints, but is assumed to contribute up to one-fourth to anthropogenic GHGE (IPCC, 2001). Especially where forest clearing occurs in the tropics, LUC will be the major source of emissions and should therefore be introduced into estimations of GHGE from food supply chains.

Mineral fertilizer, pesticides and emissions from soil

The production of mineral fertilizers consumes high amounts of energy and emits N_2O during production, but also the N applied to soils results in N_2O emissions. Therefore total GHGE from crop production are closely connected to the amount of fertilizers applied. Rapeseed usually needs high amounts of mineral fertilizer and pesticides. Subsequently, RSC showed highest GHGE from mineral fertilizer and pesticide production, as well as soil N_2O emissions.

The relative contribution of mineral fertilizer and pesticide production to overall GHGE varied from 0.3% for South-American SBME to about 20% for RSC. On average, direct and indirect N_2O emissions from soil accounted for 25% with a range from 2% for SBME to 63% for FB. N_2O emissions per kg RSC (dry matter) were found to be 25%. GHGE from soil N_2O were relatively high for FB, although no N-fertilizers were used for their production. The reason for this are relatively low emissions from other sources (e.g. short transports, no LUC), low yields, a relatively high amount of N left as crop residues and no further co-products which would account for a part of the emissions. However, residues of FB leave N in the soil and therefore allows for a reduction of mineral fertilizers to be applied in the next year(s), thereby exerting a mitigating effect of about -0.168 kg CO_2-eq per kg (DM) of FB. If this effect was taken into account, GHGE for FB would be 0.277 kg CO_2-eq per kg (DM).

Generally, where nutrients cycles are better closed, N_2O emissions are potentially lower because less nutrients circulate in the system. Similarly, the effect of biological N-fixation can help to lower GHGE from a crop rotation.

Energy (fuels and industrial processing)

For all APRFs, fuels for transports and agricultural production accounted for only 15% of GHGE. However, in absolute terms emissions from fuel consumption is high for SBME due to the long transport distance as compared to regionally produced feedstuffs. For all feedstuffs considered herein, GHGE from transports accounted on average for 57% of total emissions from fuels with a range from 24% (FB) to 84% (SBME), the rest was related to agricultural activities (43% on average).

Except for DDGS where the share of GHGE from industrial processing was found to be high (52%), industrial processes accounted for only 1% to 3% (e.g. from pressing and extraction of oil seeds).

If dairy farms cultivate their (protein-rich) concentrates themselves, they improve the GHGE-balance of feeds not only by reduced transports, but also by better closed nutrients cycles where manure (excreta) is returned to the fields again. Thereby, substantial amounts of GHGE (10% on average, with peak values of 20% for RSC) can be mitigated where the manure replaces mineral fertilizers which otherwise contribute to GHGE.

Mitigation of overall GHGE by substituting SBME by APRMs

As could be expected, a replacement of SBME by mixtures of APRFs decreases GHGE significantly (Fig. 2). A replacement rate of about 50% (APRM 1 and 2) decreases GHGE by about 36% in comparison to SBME. A complete substitution of SBME (APRM 3 and 4) decreases GHGE on average by about 74%. Figure 2 shows GHGE of the four APRMs as compared to one kg SBME. The reduced substitution rate of 50% (APRM 1 and 2) is most likely relevant for feeding high yielding dairy cows which require high amounts of protein. However, all four APRM allow for a relatively high level of performance and especially APRM 3 and 4 emphasize the high potential of mitigation effects in connection with feeding management.

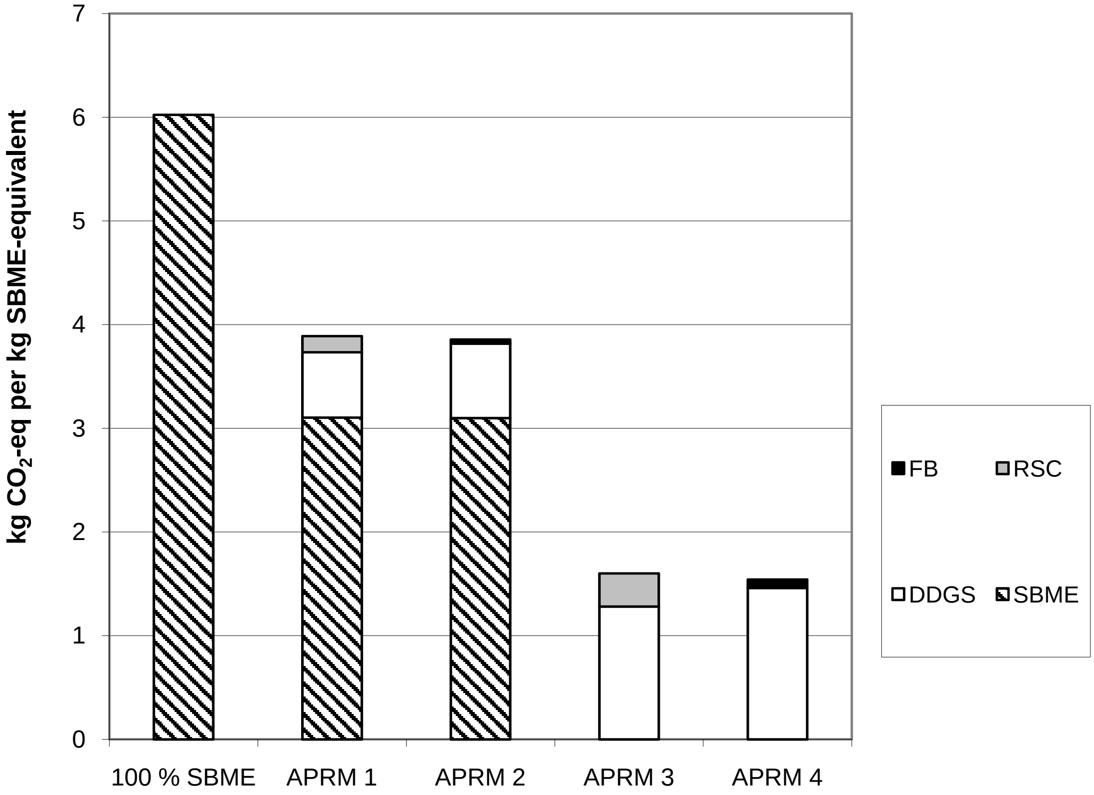

Figure 2. GHGE of SBME and four mixtures of APRFs (kg CO_2-eq per SBME-equivalent).

Conclusions

Because of the LUC-related high GHGE of SBME, a partial or complete substitution of SBME by regionally produced, high-protein concentrates is an important option in mitigation strategies addressing GHGE from dairy production systems. Formulating mixtures from regionally produced feedstuffs allows to maintain a high nutritive value, while at the same time significantly reducing GHGE from the supply chains of protein-rich concentrates.

LUC is by far the dominant source of GHGE for SBME originating from South-America, but may also be relevant – although to a much lesser degree – in the production of alternative concentrates.

The relevance of single sources of GHGE is quite different for different feedstuffs: although quantitatively varying, the most important sources were industrial processes, LUC and N_2O-emissions from the soil for DDGS, RSC and FB, respectively. This calls for a thorough analysis of GHGE and the identification of the most important sources in order to define strategies for their reduction.

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