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ECONOMIC ALLOCATION AND SYSTEM EXPANSION MODELLING GHG EMISSIONS IN DAIRY FARMING. THE IMPACT OF UNCERTAINTY

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Abstract

In this study an existing deterministic model developed to calculate greenhouse gas (GHG) emissions of confinement dairy farm systems differing in milk yield (6 000, 8 000, 10 000 kg milk/cow per year) and breed (dual purpose, milk breed) was further developed. We incorporated uncertainty to account for epistemic uncertainty (e.g. emission factors for GHG modelling, GHG emissions from suckler cow production) and intrinsic variability (e.g. variability of production traits, such as calving interval, replacement rate and variability of prices). The developed stochastic model accounts for two different methods for handling co-products of dairy farming (beef from culled cows and surplus calves): economic allocation and system expansion. In case of economic allocation GHG emissions are allocated between milk and co-products according to their economic value. Within system expansion it is assumed that beef derived from culled cows and fattening of surplus calves replaces beef from suckler cow production. The avoided GHG emissions from suckler cows are credited to the dairy farm.

Consistent with other studies results showed that the choice of method for handling co-products of dairy cow production had the highest impact on mean values of model outcomes. The inclusion of uncertainty gave insight into robustness of deterministic model outcomes and identified factors that had the highest impact on variation of model outcomes. In case of economic allocation variation of emission factor for soybean meal and nitrous oxide emissions from nitrogen input into the soil had the highest impact on variation of GHG emissions outcomes (up to 92%).

In case of system expansion emission factor for beef derived from suckler cow production had the highest impact on variation of GHG emissions outcomes (up to 54%) resulting in even negative GHG emissions per kg milk. The method of system expansion is recommended if the consequences of changes or mitigation options in dairy cow production need to be evaluated.

Whereas the choice of method for co-product handling depends on the scope of GHG modelling in dairy farming the stochastic model approach gave insight into robustness and variation of model outcomes within each method for handling co-products. This is of special importance identifying cost-effective GHG mitigation options.

Keywords

Greenhouse gas emissions, uncertainty, dairy farming, milk yield, co-product handling

1 Introduction

Dairy cow production contributes to about 23 to 70% of total agricultural GHG emissions in different countries within the EU-27 (LESSCHEN et al., 2011). Thus, a growing interest can be observed in modelling GHG emissions from dairy cow production systems and identifying cost-effective GHG mitigation options.

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As milk is the main output of dairy farms most studies express GHG emissions produced per kg milk delivered. However, beef can be considered as an important co-product of dairy farming (beef from culled cows and surplus calves sold to fattening systems) especially within dual purpose dairy cow production systems. To account for co-products from dairy farming different methods can be observed in literature (FLYSJÖ et al., 2011). Two main approaches can be distinguished: economic allocation and system expansion. In case of economic allocation GHG emissions are allocated between milk and co-products at the dairy farm gate according to their economic value. This approach is mainly used in the calculation of carbon footprints. It identifies GHG emissions at the dairy farm gate caused by milk production and allocates GHG emissions based on the value of milk and beef to the consumer. In case of system expansion allocation between milk and co-products is avoided by expanding the system and accounting for the alternative way of beef production (i.e. sucker cow production). It is assumed that the beef derived from culled cows and fattening of surplus calves replaces beef from suckler cow production. The avoided GHG emissions are credited to the dairy farm. The method of system expansion is recommended by the International Organisation for standardization (ISO, 2006). This approach is especially important if the consequences of changes or mitigation options in dairy cow production need to be evaluated (FLYSJÖ et al., 2011).

Recent determinist studies showed that the choice of method for handling co-products has a major impact on GHG emissions outcomes of dairy co-product systems (FLYSJÖ et al., 2011, ZEHETMEIER et al., 2012). Despite the impact of choice of method for co-product handling it has to be considered that assumptions and input data modelling GHG emissions from dairy cow production have known uncertainties. Many guidelines and scientific studies point out the importance of incorporating uncertainty in GHG and economic modelling (ISO, 2006; IPCC, 2006; PANNELL, 1997). The inclusion, the discussion and the reporting of model changes due to uncertainties can be important to identify robustness and variation of model outcomes and sensitive or important variables (PANNELL, 1997). It is a matter of special importance to investigate whether uncertainties of model inputs have an impact on conclusions to be drawn from the model or not.

To show the impact of uncertainty on GHG emission outcomes a deterministic model developed to calculate GHG emissions of confinement dairy farm systems differing in milk yield and breed (ZEHETMEIER et al., 2012) was further developed. A stochastic model was established that accounts for uncertainty in various components. Compared with deterministic models, stochastic models offer the advantage of predicting not just an outcome, but also the likelihood of this outcome. Thus, stochastic modelling and scenario analysis were undertaken to answer the following questions:

- does the inclusion of uncertainty influence the ranking of modelled dairy cow production systems in terms of GHG emissions? (6 000, 8 000, 10 000 kg milk/cow)
- which uncertainties have the highest impact on variation of GHG emission outcomes?

To show the impact of uncertainty within different methods for handling co-products uncertainty modelling was undertaken for economic allocation and system expansion approach.

2 Material and Methods

A whole system model calculating GHG emissions of confinement dairy cow production systems differing in milk yield and breed have been presented in detail in another paper (ZEHETMEIER et al., 2012). In the first part of this section a short summary of the existing model is given. Economic allocation and system expansion as methods for handling co-products were included in the existing model which is described in the second part. Finally, chosen parameters and methods for stochastic simulation are described.

2.1 Description of existing model

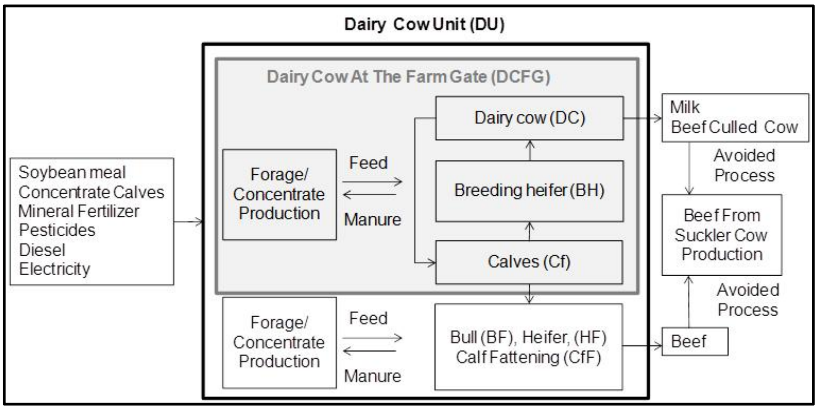
Livestock. The whole farm model incorporated dairy cows from different breeds and milk yield (6 000 and 8 000 kg milk/cow per year - dual purpose Fleckvieh (FV) breed; 10 000 kg milk/cow per year – Holstein-Friesian (H-F) breed). Representing a typical dairy farm calves and breeding heifers were combined with dairy cow production (Figure 1).

The amount of breeding heifers was equivalent to the rate of replacement to keep number of dairy cows constant. The number of calves born per year depended on calving interval and calf losses. Calves were assumed to be sold at a weight of 85 kg (FV cows) and 50 kg (H-F cows) representing typical German dairy farm production systems.

Production system and model inputs. A confinement production system with dairy cows, heifers and bulls being indoor all-year-round was assumed. Forage components were maize silage, grass silage and hay. Concentrates consisted of corn, winter wheat, barley, soybean meal, and concentrates for claves. Except soybean meal and concentrates for calves the production of all forage and concentrate components was incorporated into the model (Figure 1).

Global warming potential. Global warming potential (GWP) in the model was calculated considering all primary (occurring on farm e.g. during feed production, maintenance of animals and manure management) and secondary sources (occurring off-farm e.g. production of fertilizer, pesticides or diesel) of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions. Primary source emissions were mainly calculated according to guidelines and standard values from IPCC (2006) and HAENEL (2010). To estimate CH_4 emissions from dairy cows we followed KIRCHGEßNER et al. (1995). Emission factors for the calculation of secondary source GHG emissions were taken from literature.

Figure 1: Illustration of system boundaries composition of modelled livestock production systems



2.2 Methods for handling co-products

One method to handle co-products from dairy cow production is to allocate GHG emissions between milk and co-products according to their economic value (economic allocation) (Equation 2).

$$(2)\ GWP_{EA}\left[\frac{kg\ CO_{2eq}}{kg\ milk}\right] = \frac{GWP_{Dairy\ cow\ at\ the\ farm\ gate}\ (kg\ CO_{2eq})}{milk\ delivered\ (kg)} * AF_{EA}$$

where GWP_{EA}= Global warming potential of milk production; EA= economic allocation; AF_{EA} = allocation factor for the economic allocation method (proportion of economic value of milk on total value of milk and beef output).

One option to avoid allocation between milk and co-products would be to expand the production system by defining an alternative way to produce the co-products of dairy farming (ISO, 2006). The method named `system expansion` (FLYSJÖ et al., 2011) was incorporated into the modelling defining suckler cow production as the alternative way to produce beef. To account for the whole potential of beef production of a dairy cow dairy units were defined (Figure 1). A dairy unit goes beyond the dairy farm gate and considers the fattening systems of surplus calves. Thus, amount of beef of a dairy unit was made up by beef from culled cows, bull, heifer and calf fattening (only H-F dairy cows) (Figure 1). One dairy unit of a 6 000 kg, 8 000 kg and 10 000 kg yielding dairy cow resulted in 322, 315 and 218 kg beef, respectively. Production system and calculation of GHG emissions for suckler cow production was taken from ZEHETMEIER et al. (2012). Suckler cows were assumed to be on pasture 185 days/year. One suckler unit resulted in 318 kg beef.

In the system expansion method, GHG emissions from suckler cow production were subtracted from GHG emissions of dairy cow production based on the potential amount of beef production (Equation 3).

$$(3)\ GWP_{SE}\left(kg\,\frac{CO_{2eq}}{kg}\,milk\right)=\frac{GWP_{Dairy\,unit}(kg\ CO_{2eq})-\left(\frac{GWP_{Suckler\,unit}\,(kg\ CO_{2eq})}{b_{Suckler\,unit}\,(kg)}*\,b_{Dairy\,unit}(kg)\right)}{milk\ delivered\ (kg)}$$

where GWP_{SE}= Global warming potential of milk production using system expansion method; $GWP_{Dairy\ unit}$ = Global warming potential of one dairy unit (Figure 1); $GWP_{Suckler\ unit}$=Global warming potential of one suckler unit; $b_{Suckler\ unit}$ = amount of beef derived from one suckler unit; $b_{Dairy\ unit}$= amount of beef derived from one dairy unit.

2.3 Uncertainty modelling

Overview. A deterministic model (i.e. non-varying point estimate results - KENNEDY et al., 1996) designed to simulate different yielding dairy cow and fattening production systems (ZEHETMEIER et al., 2012) was further developed to account for uncertainty. Probabilistic simulation was carried out for main model inputs (GHG modelling, production traits, economic parameter) using @RISK (Palisade Corporation software, Ithaca NY USA). In the course of applied Monte Carlo Simulations 5000 iterations were undertaken to estimate probability distribution of output values.

Parameters estimating GHG emissions. Greenhouse gas emissions derived from enteric fermentation of dairy cows (CH_{4ent}), nitrogen application into soil (N_2O) and soybean meal production (CO_{2eq}) were subject to uncertainty modelling. Sources of emissions included in the uncertainty modelling accounted for more than 70% of total GHG emissions reported in several studies (ZEHETMEIER et al., 2012; KRISTENSEN et al., 2011). Furthermore, they are considered to have high uncertainty due to limited measurements (e.g. CH_{4ent} emissions from dairy cows), due to differences in geographical locations (e.g. N_2O emissions from nitrogen application into soil) or due to choices (e.g. incorporation of land use change calculating emission factor of soybean meal).

Uncertainty of CH_{4ent} emissions of dairy cows was included in this model using different equations from literature (Table 1) resulting in a wide range of predicted CH_{4ent} emissions.

Uncertainty of N_2O emission factor was included in the modelling assuming an uncertainty range of 0.003 - 0.03 kg N_2O–N/kg N (representing 95% confidence interval) for all nitrogen input into the soil (IPCC, 2006).

Soybean meal is of particular interest since it is an important feed providing high quality protein especially within high yielding dairy cow production systems. In 2010 EU-27 imported 34.5 Mio tonne of soybeans, soybean cake and soybean meal. Over 90% of imports to EU-27 countries were derived from Brazil (53%), Argentina (34%) and USA (7%) (EUROSTAT, 2011). Many studies discuss the contribution of soybean production especially in Brazil in terms of GHG emissions due to direct land use change (dLUC) (FLYSJÖ et al., 2011a; DAL-

GAARD et al., 2008) and indirect land use change (iLUC) (ARIMA et al., 2011). Emission factors chosen for soybean meal production (Table 1) represent different assumptions of soybean meal production. Minimum value includes emissions only from soybean meal production and transport to Europe while no land use change was assumed. A mixture of previous land use being converted to produce soybean meal was assumed for the calculation of most likely value. Maximum value represents a worst case as it is assumed that forest was converted to arable land for the production of soybean meal (FLYSJÖ et al., 2012).

Triangle distribution function was used to describe probability distribution of CH_{4ent} and emission factors included in uncertainty modelling. Minimum, maximum and most likely values of this function are shown in Table 1.

Table 1: Values for uncertainty modelling of CH_{4ent} and emission factors

	Most Likely	Miniumum	Maximum
CH_{4ent} ferm (kg CH_4) (6 000/8 000/10 000)*	128[1)]/135[1)]/138[1)]	105[2)]/116[2)]/127[2)]	140[3)]/152[3)]/157[3)]
EF N_2Odir N_{input} (kg N_2O-N/kg N)	0.01[4)]	0.003[4)]	0.03[4)]
EF soybean meal (kg CO_{2eq}/kg)	3.1[6)]	0.34[5)]	10[6)]

* kg milk/cow per year yielding dairy cow production systems; EF=emission factor;

Sources: [1)] KIRCHGEßNER et al. (1995); [2)] DAMMGEN et al. (2009); [3)] JENTSCH et al. (2009); [4)] IPCC (2006); [5)] DALGAARD et al. (2008); [6)] LYSJÖ et al. (2012)

Emission factors for GHG emissions from suckler cow beef production were taken from CROSSON et al. (2011). In their study CROSSON et al. (2011) showed an overview of GHG emissions from beef production systems of different countries and models. Based on the study of CROSSON et al. (2011) we included 15 values for GHG emissions of beef from suckler cow production using cumulative probability function. Emission factors per kg beef varied from 15.6 to 37.5 kg CO_2eq.

Production traits. Three different production traits of dairy cow production systems were investigated in terms of variability uncertainty (i.e. intrinsic variability): (1) yearly milk yield per dairy farm (kg milk/cow per year), (2) calving interval and (3) replacement rate. Data from LKV BAYERN (2011) and LKV WESER EMS (2011) for a time period of 2004 to 2010 (LKV Bayern)/ 2009 (LKV Weser Ems) was used to identify variability within (variation of average yearly milk yield/ farm from one year to another) and between (variation of calving interval and replacement) dairy farms with equivalent milk yield/cow. Data included 19 070 dairy farms breeding FV cows and 3200 dairy farms breeding H-F dairy cows. To calculate year to year variation of average yearly milk yield/farm (kg milk/cow), milk yield/farm (kg milk/cow) for the observed time period was detrended (LANOUE, 2010). This was necessary to eliminate increase in milk yield due to progress in breeding. A weighted (farms size) linear regression model was used to estimate trends. Taking into account the influence of different farm sizes, standard deviation was standardized to a farm size of 35 (FV) and 48 (H-F) dairy cows.

Weighted (farm size) linear regression models were calculated consecutively with detrended milk yield as dependent variable and standard deviation of yearly milk output per farm, average calving interval and replacement rate per farm as independent variables. The method of quantile regression was used to calculate standard deviation of calving interval and longevity between different dairy farms as a function of detrended milk yield. Resulting production trait figures for different yielding dairy cow production systems are shown in Table 2. Normal distribution was assumed for all considered production traits.

Table 2: Mean and standard deviation (SD) of data input for stochastic modelling of production traits (milk output, calving interval and replacement rate)

System milk yield (kg milk/cow/yr)	Milk yield (kg/cow/farm/yr) Mean	SD	Calving interval (days) Mean	SD	Replacement rate (%) Mean	SD
6000	6000	280	405	22	32.6	7.6
8000	8000	342	389	15	36.7	7.6
10000	10000	373	416	17	30.3	6.4

Economic parameters. Uncertainty of beef from culled cows and calf prices was incorporated into the modelling when calculating allocation factor of economic allocation method. No parametric distribution for prices was found. Thus, a nonparametric approach based on the empirical cumulative probability function using the RiskCumul function implemented in @RISK of prices over a period of 10 years (2000-2010) was chosen (ZMP, various volumes; AMI, 2011) (range is shown in Table 3). Greenhouse gas emission inputs parameters were assumed to be independently distributed. Statistically significant correlations between prices were modelled.

Table 3: Prices for beef from culled cows and calves

Dairy cow		Calf entering bull fattening		Calf entering heifer fattening	
FV	HF	FV	HF	FV	HF
(€/kg carcass weight)		(€/kg live weight*)	(€/calf**)	(€/kg live weight*)	(€/calf**)
2.2 (1.7-2.6)	1.7 (1.3-2.1)	4.7 (4.2-5.4)	113 (80-147)	3.2 (2.9-3.7)	48 (32-68)

FV= Fleckvieh; H-F= Holstein-Friesian; Live weight: *85kg/**50 kg;

Sources: AMI, 2011; ZMP, various volumes, minimum and maximum value in parenthesis

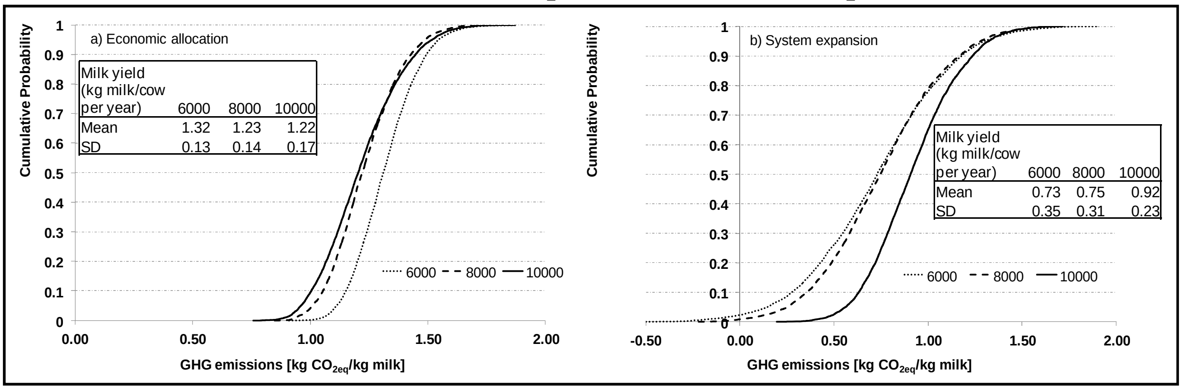
3 Results

3.1 Probabilistic simulation of all parameters

Probabilistic simulation was undertaken for all considered parameters simultaneously. Figure 2 shows cumulative probability of GHG emissions for both scenarios of handling co-products (economic allocation and system expansion). In case of economic allocation the 6 000 kg yielding dairy cow production system showed highest GHG emissions at each level of probability. Greenhouse gas emissions varied from about 1.1 to 2.4 kg CO_{2eq}/kg milk (Figure 2a). Probability that the 10 000 kg yielding dairy cow production system resulted in higher GHG emissions than the 8 000 kg yielding dairy cow production systems was 77% (Figure 2a).

The ranking of cumulative probability graphs changed if system boundary was expanded from the dairy farm gate to the whole system of milk and beef production (system expansion). Depending on the amount of beef as a co-product, modelled dairy cow production systems were credited with a certain amount of GHG emissions from suckler cow production (the alternative way producing the same amount of beef). In case of system expansion modelled production systems including 10 000 kg yielding dairy cows resulted in highest GHG emissions at each level of probability. Probability that dairy cow production system 6 000 had lower GHG emissions than dairy cow production system 8 000 was 60%. Total level of GHG emissions decreased considerably for all modelled dairy cow production systems. Greenhouse gas emissions ranged from negative values of minus -0.5 to 1.9 kg CO_{2eq}/kg milk for the 6 000 and from 0.2 to 1.7 kg CO_{2eq}/kg milk for the 10 000 yielding dairy cow production system.

Figure 2: Cumulative probability of GHG emissions considering uncertainty of GHG emission factors, production traits and prices.



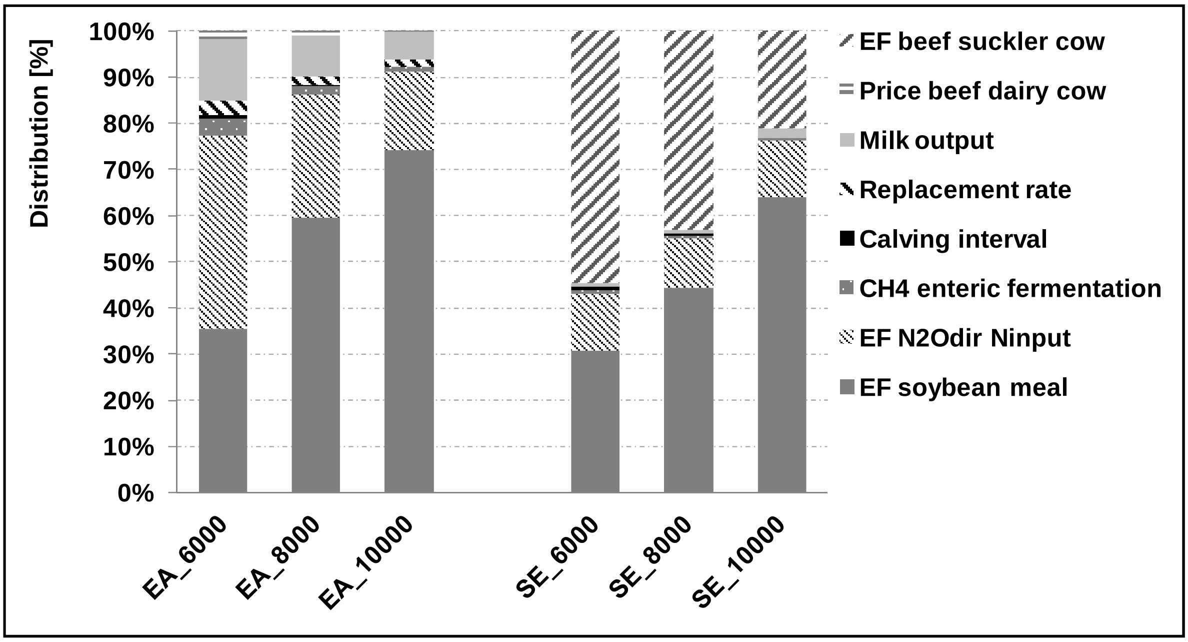
a) Economic allocation, b) System expansion

3.2 Parameter influencing variation of GHG emission outcomes

Multivariate linear regression was undertaken calculating the impact of each input variable considered in the uncertainty modelling. In the case of uncorrelated input variables squared standardized regression coefficients sum up to r-squared value of the whole model (MURRAY and CONNER, 2009) giving insight into the proportion of total variation of GHG emissions which can be explained by the variation of each variable (BORTZ and WEBER, 2005). In case of economic allocation the impact of emission factors for soybean meal and direct N_2O emissions dominated total variance accounting for 79% for the 6 000 kg yielding dairy cow production system to 92% for the 10 000 kg yielding dairy cow production system. Furthermore, the variation of yearly milk output had an impact on variation of GHG emissions outcomes especially for the 6 000 kg yielding dairy cow production system (13%). The impact of replacement rate on total variance of GHG emissions ranged between 3-2%

In case of system expansion variation of emission factor for beef from suckler cow production had the highest impact on variation of GHG emission outcomes especially within dual purpose dairy cow production systems (54% for the 6 000 and 43% for the 8 000 yielding dairy cow production system). Impact of replacement rate could be negated (0.9 to 0.2%).

Figure 3: Parameters influencing variation of GHG emission outcomes



EA = economic allocation, SE=system expansion, EF=emission factor

Higher culling rates resulted in higher amount of beef from culled cows per year which reduced the amount of suckler cows needed for beef production. Thus, the effect of reduced GHG emissions due to lower amount of replacement heifers was reversed.

4 Discussion and Conclusions

The main objective of this study was to incorporate uncertainty of main assumptions and parameters from a deterministic model modelling GHG emissions from different dairy cow production systems. Two different methods for handling co-products were used.

In consistence with other studies using deterministic model approaches (FLYSJÖ et al., 2011; ZEHETMEIER et al., 2012) our study showed that the method for handling co-products had the highest impact on total value of GHG emissions. Mean values decreased up to 56% when system expansion was applied in comparison to economic allocation. FLYSJÖ et al. (2011) discussed different methods for handling co-products comparing New Zealand and Swedish dairy cow production systems. Study results showed that GHG emissions per kg milk decreased 37% when system expansion was applied compared to allocating 100% of impacts to milk. However, in their study different allocation methods did not influence the ranking of modelled systems.

Due to the high uncertainty of emission factor for beef from suckler cow production standard deviation of GHG emissions were higher within system expansion in comparison to economic allocation. Considering uncertainty of emission factor for beef from suckler cow production even negative GHG emissions per kg milk were calculated for the dual purpose dairy cow production systems. This shows that if surplus calves from dairy cow production systems replace calves from suckler cow production systems GHG emissions from the dairy farm could be reversed. The finding that system expansion could result in negative GHG emissions emphasizes the recommendation that this method is not suitable to calculate e.g. carbon footprints of dairy farms. However, despite the high degree of uncertainties the method of system expansion gives insight if changes of GHG emissions at the dairy farm could be reversed by changes in other systems affected.

Stochastic models offer the advantage to give insight on the robustness and probability of model outcomes (PANNELL, 1997). This is especially important in case of system expansion where changes of production systems are evaluated. In case of system expansion the stochastic model showed that dairy cow production system 6 000 has lower GHG emissions than dairy cow production system system 8 000 in only 60% of model runs. In contrary the increase in milk yield ongoing with a change in breed (8000 to 10000 kg milk/cow per year) resulted in higher GHG emission for the 10 000 kg yielding dairy cow production system at each stage of probability.

In case of economic allocation the main purpose of stochastic modelling was to identify factors which have an important impact on GHG emissions of milk production at the dairy farm. Stochastic models have advantage to give insight into the variation of GHG emissions outcomes and can identify most important factors. In our study regression analysis showed that uncertainty of soybean meal emission factor had the largest single impact on variation of total GHG emissions especially within high yielding dairy cow production systems. This is confirm with the study of FLYSJÖ et al. (2012) who showed that the inclusion of LUC to emission factor of soybean meal resulted in an increase of 12 up to 82% of total GHG emissions for investigated dairy cow production systems. Thus, the calculation of carbon footprints of dairy products is mostly influenced by the knowledge of production and origin of soybean meal. While the influence of dLUC e.g. from soybean meal production is already included in guidelines for carbon footprint calculations of dairy products as IDF (2010) the inclusion of iLUC in GHG modelling of dairy cow production systems is still to be discussed (FLYSJÖ et al., 2012). This should be focused in further research studies.

Uncertainty of some other parameters was not included in the modelling however being discussed in other studies: model assumption for GHG emissions from slurry storage (HINDRICHSEN et al., 2006) or carbon sequestration on grassland (SOUSSANA et al., 2010).

Whereas the choice of method for handling co-products depends on the scope of GHG modelling in dairy farming the stochastic model approach gave insight into robustness and variation of model outcomes within each method for co-product handling. This is of special importance identifying cost-effective GHG abatement options.

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