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Construction of different GHG accounting schemes for approximation of dairy farm emissions

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Abstract:

Whether for political aims or environmental aspects, quantification of greenhouse gas emissions stemming from agricultural production processes is demanded. But real measurement of greenhouse gas emissions from agricultural production is not practicable because of the diffuse sources of CO_2, N_2O and CH_4 at the farm level. This circumstance especially holds for dairy production systems, with their wide areas of cultivated soils, pasture and to a large extent open, fresh air stable systems. Hence, calculation schemes have to be constructed, enabling us to quantify an emission inventory knowing only limited attributes at the farm or sectoral level. This technical paper therefore describes the details of five different emission calculation schemes, named emission indicators. They differ in variables used for emission calculation, and vary from an aggregated default formulation to a highly detailed and disaggregated construction. Basically, they are derived from IPCC methodology but with several enhancements and improvements.

Keywords: *greenhouse gases, GHG calculation, GHG indicators*

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1 Introduction

This paper comprises a brief explanation of different emission accounting schemes (indicators) designed for dairy farms, adjusted to the German context. Up until now, the derived calculation schemes are only applicable on dairy farms with free stalls with slatted floors. In additional to emission accounting from husbandry, associated emissions from managed manure, cultivated acreage and pasture are implemented in the estimation procedures. The content of this paper is also subject to a broader context, dealing with the derivation of abatement and marginal abatement cost curves for emissions from dairy farms. A model approach, named DAIRYDYN (LENGERS and BRITZ, 2012) has been built to derive monetary losses due to emission ceilings. To control these ceilings, emissions have to be quantified by calculation procedures. The quantification schemes implemented in the model DAIRYDYN are explained in the following sections.

1.1 The dairy farm as the system for analysis

In dairy production systems, manifold sources of CH_4, N_2O and CO_2 exist. Whereas methane mainly stems from digestive processes as well as anaerobic processes in manure storages, nitrous oxide as well as carbon dioxide mainly originate from processes in soils or from manure management as well as application of nitrogenous fertilizers. GHG accounting schemes for dairy farms have to reflect these emitting processes, and take their interactions properly into account (MACLEOD et al., 2010: p. 200). HALBERG et al. (2005:p.43) stated that "[...] the definition of system boundaries is very important for indicator selection and for interpretation of results."

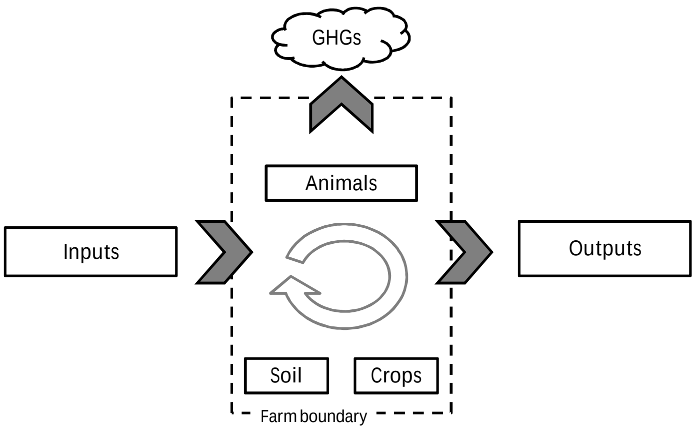

Figure 1: System boundaries for GHG emissions in a whole farm approach

(author's own illustration following SCHILS et al., 2007:p.241)

We use the farm gate as the system boundary so that only emissions directly linked to processes on the farm are recognised (Figure 1). Emissions linked to off-farm processes such as production of purchased inputs as considered in lifecycle assessments (JOSHI, 1999) are not credited to dairy production. Our system definition fits the accounting system of the Kyoto protocol and related costs-by-cause based policies.

1.2 Necessity of proper emission indicators

Due to the “non-point source” character of agricultural GHG emissions (OSTERBURG, 2004:p.209), actual total farm emissions are impossible to measure physically. That holds especially for ruminant farms, which typically combine various cropping and grazing activities with housing of animals in stables. Measurements in ruminant stables are not only quite expensive but also hindered by air exchange via various channels (stable doors, windows, vents, fresh-air systems, etc) and not, as in closed buildings, only via a “bottle-neck” (SCHEELE et al., 1993:p.302) such as an exhaust vent installation. Given the manifold types of stables used, it is also unclear to what extent existing measurements are representative. Further on, depending on the number of grazing hours, differing shares of the emissions from the herd or excreta occur outdoors. Accordingly, widespread direct measurement of GHG emissions in dairy farming is not practicable, so indicators are needed in order to include dairy farms into emission policy regimes. These indicators must rely on data which are accessible on the farm.

This necessary compromise between accuracy and practicability is also found in the indicator definition given by SAISANA and TARANTOLA (2002:p5): “Indicators are pieces of information that summarize the characteristics of a system or highlight what is happening in a system. They are often a compromise between scientific accuracy and the information available at a reasonable cost.” When referring in the following to a GHG indicator, we mean an accounting system that provides a GHG emission estimate from a dairy farm over a period of one or several years.

1.3 Requirements of promising indicators

The most important criteria for appropriate indicators discussed in the following section are based on findings from BACH et al. (2008:p.10), ENDRES (2011:p.138), EUC (2001:p.10), KRISTENSEN et al. (2009:pp.15-16), OECD (1999:p.19) and OSTERBURG (2004:pp.210-211). They can be summarized as three criteria: *feasibility, accuracy* and *cost efficiency.*

Feasibility refers to the use of data that can actually be monitored and controlled at the farm level. As visualized in the following figure, feasibility decreases with increased requirements regarding input data.

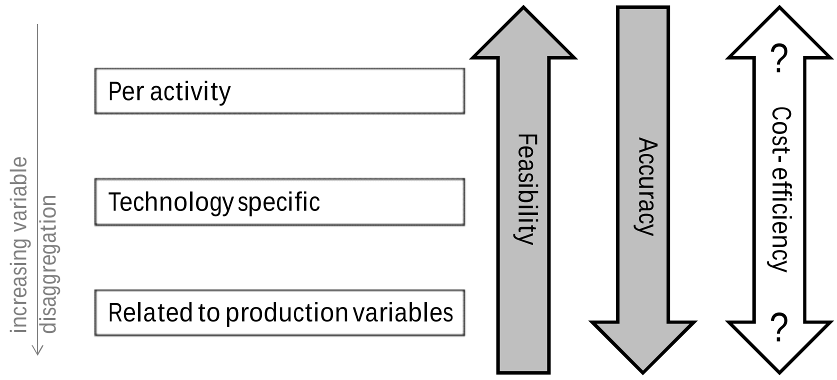

Figure 2: Trade-off concerning the complexity of indicators
(author's own illustration)

Accuracy is linked to precision in emission factors and the quality of the input data. If emission factors of one variable, for example a cow, vary with decisions made on other variables like milk yield and fodder, a more detailed model that will derive the emission factors of the cows from their determining activities is more accurate than an indicator that always presumes a default emission factor per cow. SCHRÖDER et al. (2004:p.20) underline the importance of indicator consistency (e.g. by avoiding double-counting) and accounting for all relevant GHG emissions. Consistency is highly relevant for GHG emissions from dairy farming, where different gases from highly interlinked processes and sources (animals, manure storages, soil management, fertilizer practice) need to be assessed.

Cost efficiency of indicators refers to two different dimensions, the *farm level* and the *social* perspective. A farm faced with an emission policy instrument based on an indicator faces two types of costs: (1) monitoring costs to record and report its emissions, and (2) typically more important, costs linked to emission mitigation. Both depend on the indicator chosen. Simple indicators drawing on aggregate farm attributes such as herd size offer rather limited abatement strategies, often a single one which could provoke high abatement costs (PAUSTIAN et al., 1997:p.230), a point also raised by SMITH et al. (2007:p.22) and SCHRÖDER et al. (2004:p.20). Considering additional decision variables thus could help trigger effective and cost efficient abatement options while hopefully also improving accuracy in measuring emissions.

The costs from a social perspective encompass, first, welfare changes in the narrow economic sense provoked by changes in farm management, i.e. profit losses to the farms, but probably also costs to consumers facing higher prices, or profit changes in up- and downstream industries or changes in tax revenues. Second, society faces costs to implement the legislation, to control the individual agent's efforts. Third, society benefits from the reduced GHGs emitted, the reason for implementing the policy. It is important to note here that an indicator not accurately reflecting changes in emissions will result in differences between private and social abatement costs (even if measurement, administrative and control costs are excluded). This will lead to differences between cost efficiency on the farm and actual cost efficiency at a societal level, because of differences between the indicator dependent mitigation effort and the actual quantity of abatement.

Agriculture is characterized by an atomistic and heterogeneous farm structure. Indicators must hence be applicable to different types of dairy farms to guaranty cost efficient measurement and abatement options, and should, given the dynamics in farm structural development and technical progress, reflect changes in farm attributes properly.

Figure 2 illustrates the trade-off between calculation accuracy and data feasibility, which is important for the choice of a politically relevant indicator scheme (WALZ et al., 1995). The highest level of aggregation is given when emissions are calculated via IPPC Tier 1 default values, which are linked to crop acreages and average annual herd sizes. The accuracy can be improved by disaggregation: adding further attributes such as milk yield or further processes such as fertilizer application, or by disaggregating processes, e.g. in time. But the higher the complexity and disaggregation level of indicator schemes, the less available are relevant data, which restricts the indicators' feasibility.

It is obvious that an indicator needs to be based on available - financially, technically and institutionally - and reliable data (HALBERG et al., 2005), most probably preventing the best possible indicator from the viewpoint of accuracy from being chosen. It is far less clear what level of detail in a GHG indicator should be chosen from a cost efficiency perspective. Driving up the level of detail in indicator calculations increases costs for monitoring and control, but only leads to abatement cost savings if it triggers more cost effective abatement strategies.

1.4 GHG mitigation options on dairy farms

As noted before, the indicator should sensitively account for low cost reduction activities (OENEMA et al., 2004:p.174; OSTERBURG, 2004:pp.210; CROSSON et al., 2011:p.41). The efficiency of different indicators can thus be determined by checking if promising abatement options such as shown in Table 2 are properly taken into account. LENGERS (2012) provides details regarding these abatement possibilities and discusses aspects their choices are based on. Only mitigating options applicable to German dairy farms with clearly identified effects on GHGs are listed and analysed in the following[1].

Table 1: Applicable options to reduce GHGs from dairy production systems.

measure	purpose
reduce CH4 emissions	
(i) variable options (flexible adaption possible)	
(a) improving feeding of animal	• increase animal productivity, improve digestibility, decrease CH4 from enteric fermentation and manure
• feeding additives	• decrease CH4 from manure and enteric fermentation
• pasture management	• possibility of improving digestibility of feed, lowering CH4 from enteric fermentation, lowering manure amounts in manure storages
• reduction of livestock number	• decrease CH4 from manure and enteric fermentation
• manure storage time	• prevent anaerobic conditions in manure by regular emptying of the storage
(ii) permanent options (investment based)	
• type of manure storage/coverage	• decrease CH4 from stored manure by fluxes
• stable type	• changing from slatted floor to straw based systems can lower CH4 emissions due to less anaerobic conditions of manure storage; also differences in tied stall, free stall and deep litter
reduce N2O emissions	
(i) variable options	
• change of crop rotation	• use of more N efficient crops
• reduction of livestock number	• decrease N amounts in manure
• animal nutrition	• increase animal productivity and decrease N in manure, N-reduced feeding
• restrict grazing	• decrease urine/dung excretion in the field
• adjusting N application to crop demand	• increase N efficiency of applied N fertilizers
• accounting for mineralization of organic N	• decrease required fertilizer N
• soil cultivation	• optimise growth and N uptake of crops, increase aeration and decrease denitrification
• reduction of urine N content	• decrease N2O production
• nitrification inhibitors	• inhibit nitrification
(ii) permanent options	
• stable type	• change from straw to slurry based systems lowers N2O emissions
• application technique with low NH3 losses	• higher N use efficiency of manure N
• storage of manure with low NH3 losses	• higher N use efficiency of manure N
• anaerobic storage of manure	• decrease nitrification and denitrification

(author's illustration following FLACHOWSKY and BRADE (2007), OENEMA et al. (2001) and OSTERBURG et al. (2009))

Variable options (*i*) comprise management strategies that can be flexibly changed over periods (weeks, months or single years) and adjusted to changes in exogenous production conditions. Permanent options (*ii*) have a more investment based character, leading to deci-

[1] E.g. antibiotics as feed additives to lower emissions is broadly discussed in literature, but nevertheless banned by German and European law.

sions which can induce path dependencies. Hence long term investments determine future abatement options and impact GHG mitigation expenditures. An optimal emission indicator leads to minimum abatement costs by considering all mitigation options and accounting for flexible adjustment of farm processes over time (e.g. monthly manure storage time).

2 Development of Indicators for the model DAIRYDYN

DAIRYDYN is a fully dynamic mixed integer linear programming model for the simulation of dairy farm development over several years, optionally confronted with emission ceilings. The bio-economic model approach has an objective function maximizing the net present value of future profits and enables the user to implement different emission accounting schemes. As the model is subject to a whole farm approach, these GHG calculation procedures may even consist of an aggregation of diverse emission calculations from different sources on the farm level (animal, soil, manure, etc.). (LENGERS and BRITZ, 2012)

The developed emission accounting schemes are based on IPCC (2006) guidelines, which offer fundamental emission parameters and calculation schemes with accounting systems for different aggregation levels; from Tier 1, the most simple, to Tier 3 with high disaggregation and implementation of very production-specific information. These are scientifically accepted and consistent (to e.g. avoid multi-accounting bias), and have been adjusted to German circumstances and enhanced by literature findings. In the following sections the different indicator schemes are described, briefly explaining the combination of GHG calculations from enteric fermentation, manure management, soil cultivation and fertilizer management to whole farm emission-accounting indicators (see Figure 5 at the end of this manuscript). I start with the simplest indicator (activity based emission calculation) and then move towards the most detailed and complex one, called the *reference indicator*. This represents the indicator with the highest degree of precision in calculating real emissions from the production portfolio of the farms. Thus it could be taken as a benchmark for valuation of the GHG accounting precision of the other indicators.

For GHG accounting, single emission factors are used, which are linked to specific production variables and quantify the proportion of gases emitted to one unit of the variable (e.g. emissions per unit of livestock) (HAUBACH, 2009:p.172). These emission ratios can also contain formulas that calculate the material conversion from input amounts (e.g. feed) to GHG release. Following HAUBACH (2009:p.172) a kind of base formula of GHG accounting can be formulated:

(1) $em_j = \sum_k ef_{jk} x_k$; with k = 1,...,n

The different indicators j link emission factors ef_{jk} to specific decision variables x_k. ef_{jk} quantifies the amount of gases emitted per unit of the variable k (e.g. emissions per unit of livestock) to derive total emissions em_j on the farm. Indicators differ by the variables used and the emission factors attached to them. For example, an indicator that only considers the number of livestock will have a different emission factor per unit of livestock than a more complex indicator that accounts for emissions from fertilizer separately. Furthermore, emission factors for the same observed attribute might also differ depending on farm characteristics (stable type, climate zone, manure management system). Figure 3 visualizes the conceptual principle of indicator schemes that use attributes of on-farm processes to quantify overall GHG emissions.

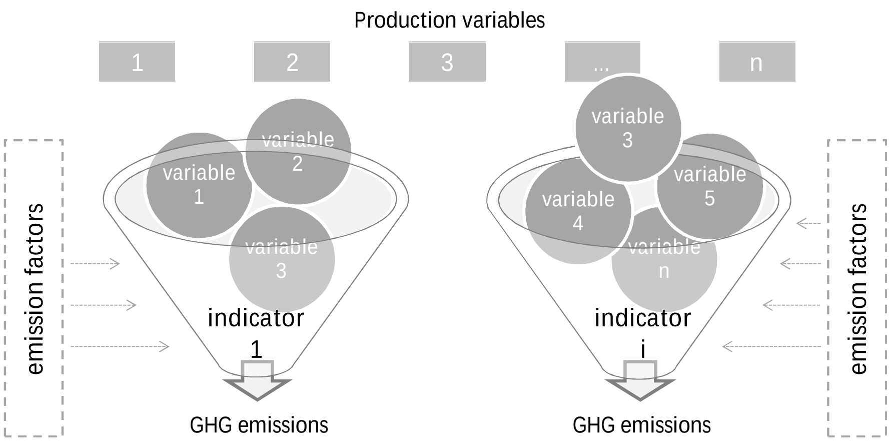

Figure 3: Indicators calculate emissions according to different production variables

(author's own illustration)

Obviously, emission calculation schemes differ in their data requirements: covering more attributes drives up the data demand and thus probably monitoring and control costs, while holding out the promise of improved accuracy and reduced abatement costs.

2.1 actBased (indicator 1)

The simplest indicator (equivalent to formula (1)) refers to the highest aggregated variable level. The single default emission factors per activity unit $ef_{actBased,k}$ in terms of arable land or livestock production are multiplied by the activity levels x_k.

(2) $em_{actBased} = \sum_k x_k * ef_{actBased,k}$

The emission parameters for CO_2, CH_4 and N_2O can be derived from the IPCC (2006) Tier 1 methodology[2]. Default CH_4 emission factors for enteric fermentation and manure management per livestock unit can be taken directly from the IPCC guidelines (table 10.11, 10.14). These are defined on a regional scale for Western Europe, assuming an average stable system and manure storage techniques. N_2O emissions from specific livestock units can also be derived from the Tier 1 approach (equations 10.25 to 10.27 and relating default parameters) implementing average animal weights into the excretion function (eq. 10.30) taken from KTBL (2010) for the German context. The resulting standard emission parameters are then transformed to CO_2-equivalents according to gas specific global warming potentials and subsumed to $ef_{actBased}$ for the specific animal category. The emissions from agricultural soils are also condensed into a single default emission factor per ha of crop category. Therefore IPCC (2006) equation 11.1, accordant sub-calculations and default emission factors are used with German-specific yield levels and N requirements. For application of manure, broad spreading is assumed. Deviating from the IPCC calculations, a lower N_2O emission factor for soil background emissions[3] is used because the underlying IPCC value is based on peat soils (8 kg N_2O-N ha^{-1} $year^{-1}$). Instead, background emissions of 0.9 kg N_2O-N ha^{-1} $year^{-1}$ are taken from a study of VELTHOF and OENEMA (1997:p.351)[4]. As an improvement of the Tier 1 methodology, CH_4 background emissions are also recognized by the *actBased* indicator. These are negative and refer to the CH_4 deposition potential of agricultural soils, quantified as -1.5 kg CH_4 ha^{-1} $year^{-1}$ for cultivated acreage and -2.5 kg CH_4 ha^{-1} $year^{-1}$ for grassland (BOECKX and VAN CLEEMPUT, 2001). As with livestock activities, calculated emissions from soils and fertilizer application are transformed to CO_2-eq. and summed up as an emission factor per ha of crop category, assuming average yield levels, average fertilizer use and broad spread application of manure N taken from engineering data collections like KTBL (2010).

2.2 prodBased (indicator 2)

The *prodBased* indicator is derived from the actBased indicator, making some adjustments concerning the variable disaggregation level. This indicator scheme also denotes differences in production output level (yield per ha or kg milk per cow) for cows and crop categories; hence, e.g. the amount of milk produced impacts the GHGs produced by one cow.

[2] Chapter 10 and 11 of the denoted IPCC (2006) guidelines.

[3] named $EF_{2CG,Temp}$ in the IPCC methodology (IPCC 2006, table 11.1).

[4] Multiplying kg N_2O-N by the term 44/28 results in the corresponding kg N_2O.

So each unit of product on the farm is loaded with a product type specific emission parameter. Other sources of emissions on farms (heifers, calves, idle) which do not vary in output intensities are loaded with activity based emission parameters per ha or head taken from the actBased indicator scheme.

(3) $em_{prodBased} = \sum_k x_k * ef_{actBased,k}$; for all $k \neq crops, cows$

$$+ \sum_k \sum_p qp_k ef_{prodBased,p} \text{ ; for all } k = cows, crops$$

The overall emissions of the farm $em_{prodBased}$ use default emission factors per activity for calves, heifers and idle. Emissions produced by dairy cows, arable crop production and grassland are derived according to their specific output level qp_k of the product p which is produced by the activity k. Specific emission factors per production quantity $ef_{prodBased,p}$ of product p (e.g. emission factor per kg of milk) are multiplied by the quantity of each product per year and summed up over all product categories of activities. The product specific emission factors per unit of product are derived by taking the default emission factors per cow or per ha from the actBased scheme and dividing them by the average milk yield level per cow[5] or average yield level per ha of the specific crop or grassland. This leads to product unit[6] emission loads for each product which are taken as output level independent, disregarding effects of production intensity level on the per unit emission factor. Within the calculation of emission factors from arable land, fixed shares of fertilizer application techniques with related parameters for leaching and outgassing are assumed (comparable to Tier 1 from IPCC (2006) equation 11.1).

2.3 genProdBased (indicator 3)

This calculation scheme also includes the impact of the production intensity level in milk production on the emissions per kg of product. This adaptation helps to consider the development of overall emission levels as well as emissions per production unit (animal, hectare) and emission amount per unit of output, pulling in opposite directions when increasing output level per production unit. Hence, the effect of using genetic potentials in breeding activities to generate higher milk yield levels per cow can be captured by this indicator. To some extent the emission derivation is based on the former indicator schemes, using the emission factors per production output of arable production from the prodBased indicator scheme ($ef_{prodBased,p}$). Equation (4) shows the emission calculation, which comprises

[5] e.g. a total emission amount of 3332 kg CO_2-eq. leads to 0.56 kg CO_2-eq. per l milk for a 6000 l cow.

[6] Product unit (e.g. kg milk, kg wheat) is not to confuse with production unit (e.g. cow, hectare).

different calculated emission formulas for cows, crops and other production activities (heifers, calves...).

(4) $em_{genProdBased} = \sum_k x_k * ef_{genProdBased,k}$; for all $k \neq cows, crops$

$+ \sum_k \sum_p qp_{k,l} ef_{genProdBased,p,l}$; for all $k = cows$

$+ \sum_k \sum_p qp_k ef_{ProdBased,p}$; for all $k = crops$

Following the first product of the above formula, emission amounts from heifers, calves and raised calves are also denoted by an activity specific emission factor per x_k. In contrast to the previously explained actBased indicator, these activity emission factors $ef_{genProdBased,k}$ are not IPCC default values, but are derived from IPCC (2006) functions basing on gross energy (GE) demand[7] from the cattle category (equations from chapters 10.3, 10.4 and 10.5) assuming average weights for heifers and calves taken from KTBL (2010). So the activity based emission factors of the *genProdBased* indicator for heifers and calves are more adapted to real feed demand and occurring manure amounts compared to the IPCC default values.

GHG levels occurring from arable production on soils (*k*=*crops*) are accounted for per product unit and equivalent to the calculations of the prodBased emission factor per kg of yield ($ef_{ProdBased,p}$) from equation (3).

The greatest advantage of the genProdBased calculation scheme is the accounting of emissions from lactating cows. Emission factors per kg of milk are not constant any more, but depend on the overall milk yield level l of the specific cow. This takes the degression effect into account, which occurs from the apportionment of produced GHG emissions from maintenance and activity energy intake to different milk outputs per cow. As illustrated by Figure 1, this leads to a non-linear decrease in GHG amounts per kg of milk when milk yield per cow increases (e.g. from 0.74 kg CO_2-eq. per kg milk from a 4000 l cow to 0.46 kg CO_2-eq. per kg of milk from a 10000 liter cow).

[7] For GE calculations an IPCC default value for feed energy digestibility of 60% is assumed.

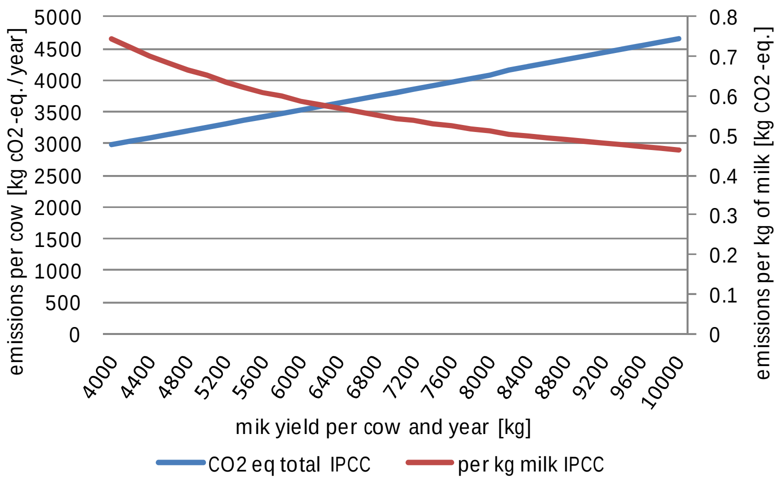

Figure 4: GHG emissions per cow and per kg of milk depending on milk yield potential

(author's own calculation and illustration following KIRCHGESSNER (2004) and IPCC (2006))

For GE dependent emission calculations of methane from enteric fermentation, IPCC equations 10.19 and 10.21 are used. Methane from manure management is derived from equations 10.22 to 10.24 for the output level, depending on the GE requirements of the different cow categories. For calculation of N_2O from manure management the relevant GE demand-dependent equations of IPCC (2006) subchapter 10.5 are used, assuming an average storage time of six months for manure. Following this systematic, total GHG emissions of single cows with specific genetic potential are calculated and divided by their potential milk yield per year to obtain the output level l specific emission factors $ef_{genProdBased,p,l}$ per output quantity of milk.

2.4 NBased (indicator 4)

The *NBased* indicator scheme describes a further disaggregated emission calculation compared to the former three indicators. Additionally, this one also accounts for differences in storage type and time and considers various manure application methods with their specific costs and impacts on emission rates of individual GHGs. In contrast to the other indicators described up to now, calculations of the NBased indicator derive GHG amounts separately for the different sources of enteric fermentation, manure management and soil management as shown by the following formula.

(5) $em_{NBased} = \sum_k \sum_l qGE_{k,l} ef_{NBased,k}$; for all k = *cows, heifers, calves*

$+ \sum_m \sum_s qN_{m,s} ef_{NBased,s}$

$+ \sum_m \sum_k \sum_{apl} qN_{m,apl,k} ef_{NBased,apl} + \sum_k x_k ef_{NBased,back}$; for k = *crops*

In the first line of the equation (5), the emissions from enteric fermentation are calculated in CO_2-eq. following equation 10.21 of IPCC (2006). For the NBased indicator, $qGE_{k,l}$, the GE demand quantity[8] by each livestock category k and each level of genetic potential l are implemented into the calculation scheme. The livestock category specific emission factor $ef_{NBased,k}$ is therefore derived by IPCC guidelines using a category specific conversion factor for methane multiplied by the global warming potential of methane (21) to yield CO_2-equivalents. Summing up over all levels of genetic potential l and livestock categories k (cows, heifers, calves) leads to the overall emissions from enteric fermentation. Variations in feed digestibility are not considered by the NBased calculation.

The CO_2-eq. resulting (from CH_4 and N_2O) from manure management before application is expressed by the second line of the above equation. Here $qN_{m,s}$, monthly (m) quantities of liquid slurry N (qN) in the different storage types s (subfloor, surface liquid storage systems without or with different coverage) are recognized to account for the manure residence time and the impacts of different storage techniques on emission quantities. The storage type s specific emission factor $ef_{NBased,s}$ is calculated on the basis of IPCC equation 10.23 to implement CH_4 emissions. Therefore an average N content of cattle slurry of 4.7 kg per m³ (KTBL, 2010) is assumed to assess the amount of liquid manure (m³) on the basis of the model given information on kg N in storage. Because IPCC formula 10.23 demands storage type specific manure quantities expressed in dry matter, an average dry matter content of 11% (KTBL, 2010) for cattle slurry is used. In order to also add N_2O emissions to the NBased emission factor for stored manure, information from IPCC equations 10.25 to 10.29 are taken to account for direct emissions and also indirect fluxes from outgassing and leaching.

Also, in cases of emissions occurring from soil cultivation (arable land, grassland) profound differences are made by the NBased indicator compared to the former ones. Background emissions from soils $(\sum_k x_k ef_{NBased,back})$ are excluded from the detailed derivation, taking standard emission factors per ha of crop or grassland quantified by -1.5 kg CH_4 ha^{-1} $year^{-1}$ for acre and -2.5 kg CH_4 ha^{-1} $year^{-1}$ for grassland (BOECKX and VAN CLEEMPUT, 2001). The other GHG emissions occurring from soil cultivation and fertilizer use (organic and synthetic) are derived from the first summand of the third line in equation (5). Monthly applied synthetic and manure N amounts to single crop categories k with different application techniques apl (broad spread, drag hose and injector, sprayer for synthetic N) are

[8] GE demands calculated following accordant IPCC (2006) equations 10.2 to 10.16 with fix digestibility of feed.

collected for emission calculation. The applied N quantities qN in month m are then multiplied by an application type specific emission factor $ef_{NBased,apl}$ and summed up over all application types, months and crop categories. This is an advantage with respect to the former indicators because manure application (time and type) can effectively diminish emissions (CHADWICK et al., 2011). Therefore, differences in emission factors for applied N to grass or arable land are also recognized. The NBased emission factor for GHG emissions from manure and synthetic fertilizer application $ef_{NBased,apl}$ is derived following IPCC (2006) equation 11.1 and relating auxiliary calculations and emission conversion factors for direct and indirect emissions[9]. To differentiate between gas release depending on manure application type (N volatised/N applied), the IPCC standard value of 0.2 (Table 11.3 from IPCC (2006)) for broad spread is changed by using assumptions from the RAINS model (ALCAMO et al., 1990) methodology to obtain lower volatilisation rates for drag hose and injector application.

2.5 refInd (indicator 5)

The digestibility (KIRCHGESSNER, 2004:p.33) of the feed consumed by each animal is also recognized by the final reference indicator (*refInd*), as digestibility is noted as being the major emission reduction factor in feeding pattern (HELLEBRAND and MUNACK, 1995). Of relevance is here prevalently the energy digestibility of the ration and single supplements because IPCC enteric emissions (equation 10.21) base on gross energy demand/intake. The higher the energy digestibility, the less feed has to pass the rumen to satisfy GE demand. Furthermore, the refInd emission calculation scheme accounts for the addition of feed additives as fats and oils, as they significantly impact the energy level and digestibility of the feed ration and influence the enteric methane production potential (BENCHAAR and GREATHEAD, 2011; MACHMULLER and KREUZER, 1999).

(6) $em_{refInd} = \sum_k \sum_l \sum_f qFE_{k,l,f} ef_{refInd,k,f,di}$; for k = *cows, heifer, calves*

$+ \sum_m \sum_s qN_{m,s} ef_{NBased,s}$

$+ \sum_m \sum_k \sum_{apl} qN_{m,apl,k} ef_{NBased,apl} + \sum_k x_k ef_{NBased,back}$; for k = *crops*

In general, the reference indicator is constructed equivalent to the NBased indicator, dividing emissions according to their different sources (enteric fermentation, manure storage, soil cultivation and fertilizer N use). For the accounting of GHGs from manure manage-

[9] taken from table 11.3 in IPCC (2006) guidelines.

ment and arable production, the same methodologies are used as with the NBased indicator scheme (see lines 2 and 3 of equation (6)).

An enhancement is made by the reference indicator for the emission calculation from enteric fermentation. Line one of equation (6) visualises that the basic principle is the same as that of the NBased indicator scheme but with minor modifications. To calculate emissions from enteric fermentation following the refInd, the derived GE demand (GE) for each animal isn't used but rather the real feed intake (FE) of several feed supplements f. GE demand, which is derived from theoretical valid demand functions, can deviate from the actual GE intake by feed in reality because of variations in feed quality and fodder availability or even if animals are reduced in intensity level so as not to fully exhaust their genetic potential (for e.g. cost efficient intensity level when prices change). Thus, $qFE_{k,l,f}$ displays the real feed intake of livestock category k with genetic potential l of feed compound f. For emission calculation the feed digestibility (di) is also recognized, leading to lower ruminant emissions for fodder rations with higher digestibility values, because less feed has to pass the animal metabolism to meet the energy demand. The emission factor $ef_{refInd,k,f,di}$ is the emission amount of methane occurring from enteric processes by implementing one kg of feed type f to the ration of animal category k. Hence, enteric emissions are also calculated following the IPCC (2006) principle in equation 10.21 but with recognition of the variability in feed digestibility and real feed intake of different compounds instead of a theoretical proper GE demand. The feed content of fats and oils, supplemented to the existing feed components, should not exceed 8% of feed dry matter (DUGMORE, 2005).

3 General hints

As seen from the above stated indicator explanations, they are partly equivalent to each other in the calculation of emissions from different sources. Some of the less aggregated emission parameters are derived from the default ones used in the highly aggregated calculation schemes (e.g. the per kg milk emission factors of the prodBased indicator are derived from the default per cow emission factors from the actBased calculation scheme). Other indicator calculations constitute simplifications of more detailed aggregation schemes (the NBased calculation is a simplification of the refInd). In the case of accounting for background emissions from soils, the quantification is similar for all indicator schemes. These dependencies between the indicators´ emission calculations are visualized in the following figure (Figure 5). The five indicators are plotted on the vertical axis, dividing the emission calculation from different sources on the farm along the horizontal axis.

Obviously, the different indicator schemes differ in their level of detail in implemented data for emission calculation. The more detailed the indicator scheme, the more disaggregated information from the on-farm production processes are demanded for an emission approximation, in procedural as well as time resolution. Hence, differences in the feasibility of calculation-relevant data and the resulting accuracy of emission accounting can be assumed. The feasibility and applicability of indicator schemes can be assumed to be high for very disaggregated and simple indicators. This is influenced by the availability of the required farm level data as well as the possibility of controlling the accuracy of the collected information. Accuracy as well as induced cost efficient abatement of emissions will probably increase with increasing level of detail and incorporated information used for emission approximation. The application of highly detailed emission schemes enables recognition of small differences in farm attributes and production-relevant variables. Therefore, further research must be done to quantify the emission accounting bias of the different indicator schemes. Further on, as various production variables and parameters are implemented in the calculation schemes, the indicator construction may even have decisive impacts on farm reactions to emission ceilings, which have to be explored. Overall, indicators have to be validated concerning their fulfilment of the above stated mutual requirements *feasibility*, *accuracy* and *cost efficiency* to be able to draw conclusions concerning their applicability from a political and a farm level perspective.

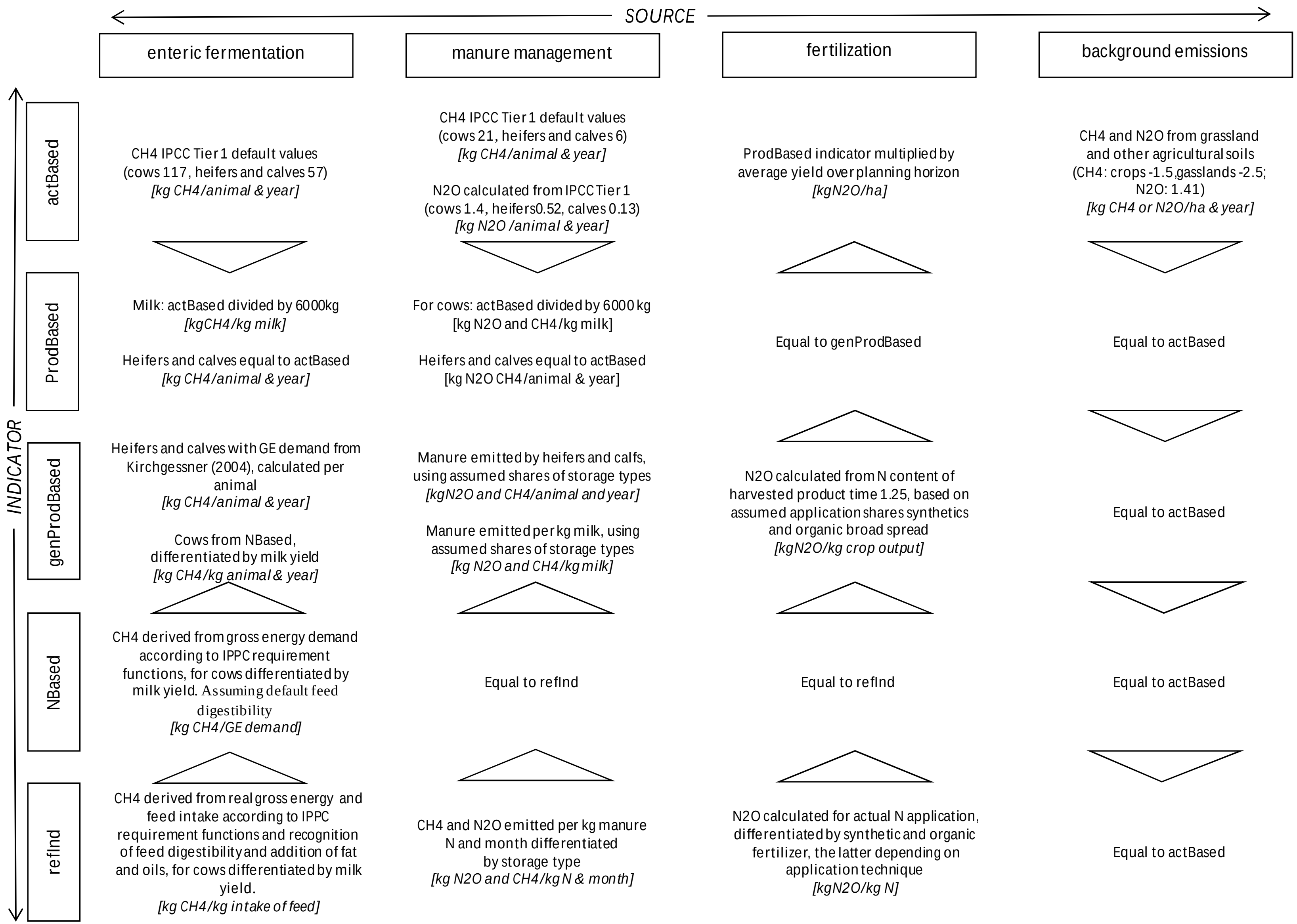

Figure 5: Overview on emission indicators

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