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Effect of choice of reference flow and energy correction formulas on results in life cycle assessment in dairy production

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Abstract

Life cycle assessment (LCA) is increasingly important for the environmental assessment of dairy systems. While efforts to standardize procedures are being made, many studies define the functional unit and reference flow in a different way even though they all refer to energy corrected milk (ECM). The reference flow should be the amount of ECM at the farm gate to account for losses and milk fed to calves. The calculation of raw milk to ECM consists of the calculation of energy of raw milk and the scaling to the energy content of ECM. While the different formulas to calculate the energy content of raw milk differ only slightly, no consensus exists on the energy content of ECM, as it has been an arbitrary choice in all instances. Calculating the feed demand based on milk yield is also sensitive to the ECM calculation. Different energy demands for the same amount of ECM can lead to different calculated feed intakes, and consequently different resource efficiencies and environmental impacts. Consequently, when no information on the definition and calculation procedure of ECM is given, LCA results may face a severe uncertainty. We evaluated the effects of different settings on carbon footprint of milk in a calculation example and found an uncertainty of 33 % to either side of the results. In order to provide valid LCA results, the definition and calculation procedure of the functional unit and reference flow must be transparently disclosed.

Key words: *Life cycle assessment, ECM, comparison, agriculture, milk*

Zusammenfassung

Auswirkungen von Wahl des Referenzflusses und der Formel zur Energiekorrektur auf Ökobilanzergebnisse in der Milchproduktion

Ökobilanzierung (Life cycle assessment, LCA) wird für die Beurteilung der ökologischen Nachhaltigkeit von Milchviehsystemen immer wichtiger. Obwohl Ansätze zur Standardisierung vorliegen, erfolgt die Definition von funktioneller Einheit und Referenzfluss unterschiedlich, auch wenn diese jeweils als energiekorrigierte Milch (ECM) angegeben werden. Der Referenzfluss sollte die Milchmenge am Hoftor sein, um Verluste und Kälberfütterung mit einzubeziehen. Die Energie-korrektur von Rohmilch besteht aus der Berechnung des Energiegehaltes der Rohmilch und der Skalierung auf den Energiegehalt von ECM. Während die Formeln zur Energiegehaltsberechnung nur wenig voneinander abweichen, existiert kein Konsens über den Energiegehalt von ECM. Dies ist in allen Fällen eine willkürliche Festlegung. Die Futteraufnahme auf Basis der Milchleistung zu berechnen, ist ebenfalls abhängig von der ECM-Berechnung. Verschiedene Energiebedarfe für dieselbe Menge ECM kann zu unterschiedlichen Futteraufnahmen führen und daraus folgend zu unterschiedlichen Bewertungen der Ressourceneffizienz und Umweltauswirkungen. Werden also keine Informationen zu Berechnung und Definition von Referenzfluss und ECM gegeben, unterliegen LCA-Ergebnisse einer großen Unsicherheit. Wir haben verschiedene Parameterkombinationen in einer Beispielrechnung für den Carbon Footprint von Milchproduktion untersucht und eine Unsicherheit von 33 % der Ergebnisse gefunden. Um sinnvolle und vergleichbare LCA-Ergebnisse zu produzieren, müssen die Definition und die Berechnung von Referenzfluss und funktioneller Einheit transparent dargestellt werden.

Schlüsselwörter: *Ökobilanz, EKM, Vergleichbarkeit, Agrarwirtschaft, Milch*

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1 Effect of Energy Correction on LCA

1.1 Introduction

Life Cycle Assessment (LCA) plays an increasing role when assessing the environmental performance of dairy production (Baldini et al., 2017). However, LCA results may face acceptance problems due to high uncertainty or lacking trust in the uncertainty assessment (Herrmann et al., 2014). Many studies tackle various aspects of uncertainty when assessing carbon footprints. These aspects include emission factor uncertainty (Chen and Corson, 2014; Schueler et al., 2018a), activity data and parameter uncertainty (Basset-Mens et al., 2009b; Wolf et al., 2017; Zehetmeier et al., 2014), or spatial or temporal variability (e.g. Guerci et al., 2013; Schueler et al., 2018b).

With 'A common carbon footprint approach for the dairy sector' from the International Dairy Federation (IDF, 2015) and the product category rules for raw milk according to ISO 14025 from International EPD® System (www.environdec.com) two guidelines exist that aim to produce reproducible and comparable results and stress their relationship to the LCA norm 14040 (ISO, 2008). While the IDF guidelines have notably been used for carbon footprinting in the dairy sector (e.g. Dalgaard et al., 2014; Daneshi et al., 2014; Gollnow, 2014; Jayasundara and Wagner-Riddle, 2014), both guidelines are not binding.

A common scope for carbon footprinting is the cradle-to-farm gate analysis where the functional unit is defined as "1 kg energy-corrected milk (ECM)". Differences in the definition and calculation of ECM have been found in Baldini et al. (2017) and Yan et al. (2011) but dismissed as "slightly different" (Baldini et al., 2017). Of the two guidelines, IDF demands energy-corrected milk (as "fat and protein-corrected milk") while the International EPD® System obtains carbon footprints per kg raw milk.

Our hypothesis is that definition and calculation of ECM as functional unit is an important source of uncertainty in LCA. We test this hypothesis by showing that uncertainty induced by definition and calculation of ECM results in relevant differences in carbon footprint of milk when assessed with different approaches.

1.2 Material and Methods

In the following, we will address three problems that arise when using ECM as a functional unit and might influence the results:

- reference flow definition
- reference flow calculation
- calculation of feed intake based on produced ECM

To check the effects different modelling choices or algorithm choices might have in carbon footprinting of milk, we used average data from 35 dairy farms from a network of organic and non-organic dairy farms in Germany (www.pilotbetriebe.de; Hülsbergen and Rahmann, 2014). The average number of cows in 2015 was 102 with 7,376 kg raw milk produced per cow. Average fat content was 3.83 % and average crude protein content was 3.37 %. These values are based on monthly milk control data, assessing each cow. Of this milk, on average only 6,169 kg were delivered, which includes private use and direct marketing. The remaining production had either been fed to calves or had been discarded due to retention periods.

For the sake of simplicity, we assumed yearly greenhouse gas (GHG) emissions of 1,200 tons CO_2-equivalents for the entire dairy system of which 1,000 tons CO_2-eq (83 %) are allocated to milk. This leaves 1.59 kg CO_2-eq per kg delivered raw milk. Comparable carbon footprints of milk production are also reported in studies of Pirlo (2012) or Guerci et al. (2013).

1.3 Results and discussion

Reference flow definition

According to ISO 14040:2006 the reference flow in LCA is defined as 'measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit' (ISO, 2008).

This definition of the reference flow, in which the *output of a product system* is used as a measure, is not ambiguous. Nonetheless, in practical use two basic options have emerged and have been used for definition of the reference flow in cradle-to-farm gate assessments: the produced amount of milk (e.g. Basset-Mens et al., 2009; Haas et al., 2001) or the delivered amount of milk (e.g. Castanheira et al., 2010; Cederberg and Mattson, 2000; Thomassen et al., 2008; van der Werf et al., 2009).

In some reports, the choice is unclear (e.g. Casey and Holden, 2006; del Prado et al., 2010; Schils et al., 2006). In case the delivered milk is defined as 'sold milk' it is still possible that private use, e.g. for direct selling or own processing, remains unaccounted for. We suggest clarifying that the functional unit includes both, sold milk and private use.

Reference flow calculation

When ECM is chosen as reference flow, the output of raw milk is scaled to the energy content of ECM. The scaling factor – that is multiplied with the amount of raw milk – therefore comprises two elements: the energy content of the raw milk and the energy content of ECM. The generalized algorithm for the correction formula is found in Gaines (1928):

$$\text{Formula (1)} \quad kgECM = kg_{rawmilk}\, x \; \frac{Energycontent_{\;rawmilk}}{Energycontent_{\;ECM}}$$

For the calculation of the energy content of milk, various algorithms exist that take various components of raw milk into account. The energy content of ECM can be expressed explicitly with a unit of energy or implicitly with appropriate fat and crude protein contents. When fat and protein contents are given, these have to be inserted into an appropriate algorithm to obtain the corresponding energy content.

To compare the effect of choice of algorithm we chose four different energy calculation formulas that are frequently used. We only considered algorithms that have coefficients for both, fat and protein content of raw milk and a linear factor for all other components (Table 1). The general form of these algorithms is:

Formula (2)

$$Energycontent_{rawmilk} = x1\ x\ fat\% + x2\ x\ crudeprotein\% + x3$$

The formula from Sjaunja et al. (1991) was used numerous times in LCA and carbon footprint studies involving Scandinavian countries (Yan et al., 2011). The formula from NRC (2001) is the basis for ECM calculation in the IDF guidelines (IDF, 2015). However, in the IDF guidelines true protein is used instead of crude protein and the energy content was included implicitly into the formula, i.e. the factors x1, x2, and x3 were divided by 0.7576 Mcal kg-1 ECM, which is equivalent to 3.172 MJ kg-1 ECM. The formula from GfE (2001) is used for the German milk control system and forms the basis for feed demand calculations of dairy cows in Germany. The formula from Tyrell and Reid (1965) has been used frequently for the evaluation of feeding strategies in the Journal of Dairy Science (e.g. Bernard and Calhoun, 1997; Boyd et al., 2013).

Table 1

Coefficients for the calculation of energy content of milk adapted to the generalized form and metric units

Source	Fat coefficient x1	Crude protein coefficient x2	Linear factor x3
Sjaunja et al. (1991)	0.383	0.242	0.783
Clark et al. (2001)	0.389	0.229	0.803
GfE (2001)	0.380	0.210	1.050
Tyrell and Reid (1965)	0.376	0.209	0.948

The amount of energy in ECM has been an arbitrary choice in all correction formulas (Formula 1) used by the different authors. Sjaunja et al. (1991) justify their choice of 3.14 MJ as being the average value of other published values. The IDF guidelines provide no rationale for the choice of 0.7576 Mcal (4 % fat and 3.5 % crude protein, 3.17 MJ). Similarly, GfE (2001) does not justify the choice of 3.28 MJ (4 % fat and 3.4 % crude protein) as standard, whereas Tyrell and Reid (1965) chose 3.14 MJ kg^{-1} ECM (340 kcal pound^{-1} ECM) to reflect a fat content of 4 % as introduced by Gaines (1928). Nonetheless, the energy prediction formula of Tyrell and Reid (1965) is also often used in conjunction with fat and crude protein contents of 3.5 % and 3.2 %, respectively. Examples are Bernard and Calhoun (1997), Boyd et al. (2013), and Pagani et al. (2016). This would mean 1 kg ECM contains 2.86 MJ (Formula 2 with coefficients from Table 1). These contents are the pricing standard for milk in the United States of America (Neil Michael, Arm and Hammer Animal Nutrition, Princeton, NJ, personal communication and Jerry Cessna, Economic Research Service, USDA, personal communication), which appears to be the reason for this choice in the studies mentioned above.

With the different formulas, we calculated the energy content and the amount of ECM for milk with the different fat and protein contents from the sources and the average values from the German pilot farms (Table 2). For comparability, we changed units to SI units.

We found that the energy contents we calculated with the different standards are very similar at the same protein and fat contents, except for the results gained with the coefficients of GfE (2001). As stated above, they refer to feed energy demand per kg ECM and consequently calculations ended up in higher results. Subtracting 0.1 MJ difference between energy content and energy demand (GfE 2001) would close this gap to ~1%.

Using a different energy content of 1 kg ECM led to larger differences. Assuming 2.93 MJ kg^{-1} ECM (3.5 % fat and 3.2 % crude protein, according to Tyrell and Reid (1965)) yielded up to 9 % more ECM than assuming 4.0 % fat and 3.5 %, increasing with increasing protein content.

When different assumptions of fat and protein content of standard milk would be made, the ECM scaling may be even further off. For example, Rotz et al. (2010) assumed 3.5 % fat and 3.1 % protein without disclosing whether they mean crude protein or true protein.

To summarize, the choice of energy calculation formula is not an important source of differences but the choice of

Table 2

Energy contents (MJ) and scaling factors (kg ECM) for raw milk to ECM resulting from of the different energy correction formulas and different fat and protein contents according to different standards

Settings		Calculation results							
Fat	Crude protein	Sjaunja (1991)		Clark et al. (2001)		GfE (2001)		Tyrell and Reid (1965)	
%	%	MJ	kg ECM	MJ	kg ECM[1]	MJ	kg ECM	MJ	kg ECM[2]
3.50	3.20	2.90	0.92	2.90	0.91	3.05	0.93	**2.93**	**1.00**
3.83	3.37	3.07	0.98	3.06	0.97	3.21	0.98	3.09	1.05
4.00	3.30	3.11	0.99	3.11	0.98	3.26	0.99	3.14	1.07
4.00	3.40	**3.14**	**1.00**	3.14	0.99	**3.28**	**1.00**	3.16	1.08
4.00	3.50	3.16	1.01	**3.17**	**1.00**	3.31	1.01	3.18	1.09

[1] Assuming 4.0 % fat and 3.5 % crude protein

[2] Assuming 3.5 % fat and 3.2 % crude protein

energy content (fat and protein contents) is very important. Consequently, when neither energy content nor fat and protein contents of ECM are disclosed, the uncertainty of results will be very high.

Calculation of feed intake

In most LCA studies, feed intake of the cattle is a very important factor and will influence the results on environmental performance. The feed intake can be calculated based on the energy demands for metabolism and production (e.g. Flysjo et al., 2011; Jayasundara and Wagner-Riddle, 2014). Typically, the offered amount of some feed components and their quality are known. The quality of others, as well as the actual intake of most components are unknown. As common approach, the energy supplied by known feed components is subtracted from the feed energy demand for metabolism, live mass increase and milk production to estimate the uptake of unknown components of the ration. Consequently, any uncertainty of total energy demand has a direct impact on the estimation of the uptake of unknown components. As an example, we assume that the difference between well-known feed uptake in form of feed conserves (roughage and concentrates) and total available feed is 1042 %. These 10 % are taken in by grazing. Increasing the total feed demand of cattle 5 % with constant feed offer by the feed conserves, would increase the calculated grazing intake by 50 % This could affect the assessment of resource efficiency of pastures within a given system.

As described, depending on the availability of data, the feed demand may also serve to calculate other feed components. Then a higher estimate of feed demand could lead to higher estimations of resource use and associated emissions in the process chain of production on farms.

So, during crop production, when using an IPCC Tier 1-type approach (IPCC, 2006) for emission calculation, higher feed demand would also lead to higher estimates in yields, and consequently in crop residues and increased associated N_2O-emissions. This is also valid for higher than Tier 1 approaches for the calculation of greenhouse gas emissions during crop production when they are sensitive to crop yields (e.g., Bouwman et al., 2002). This means that, just as with IPCC Tier 1, a higher yield calculated from a higher feed demand leads to an increase in calculated N_2O-emissions from crop residues. In addition, Tier 2- or Tier 3-type approaches for estimation of methane emissions from enteric fermentation of cattle may lead to higher values, when feed demand changes by model settings. In short, the estimation of the feed demand may have significant effects on the results of a milk carbon footprint.

When calculating feed demand from different ECM formulas, different assumptions of energy content for the same amount of ECM can occur. For 4.0 % fat and 3.4 % protein both Sjaunja et al. (1991) and GfE (2001) assume 1 kg of ECM (Table 2). However, the energy content of Sjaunja et al. (1991) is 3.14 MJ while GFE assumes 3.28 MJ. The reason is that GfE (2001) distinguishes between energy content of milk (3.18 MJ kg^{-1} ECM) and feed energy demand for the same amount of milk (3.28 MJ feed demand kg^{-1} ECM) while Sjaunja et al. (1991) claim that 3.14 MJ kg^{-1} ECM 'seems to be accepted for application for feeding purposes'. In return, this means that for the same amount of milk with 4.0 % fat and 3.4 % protein Sjaunja et al. (1991) accept 3.14 MJ energy requirement while GfE (2001) assume an energy requirement of 3.28 MJ. This is an increase of 4.5 %, which may have the system-wide effects described above.

Calculation example

We calculated the carbon footprint of our simple example (milk with 3.37 % fat, 3.07 % crude protein) with different reference flow definitions (milk delivered, milk produced) and with the different energy contents for ECM as given in Table 2 resulting from the different formulas. The lowest energy content of 2.86 MJ kg^{-1} ECM produced the lowest carbon footprint in this comparison when produced milk is addressed (Table 3). Whereas sold milk with 3.17 MJ kg^{-1} ECM had the highest carbon footprint. That means that for the same dairy system we could arrive at values between 1.23 kg CO_2-eq kg^{-1} ECM and 1.64 kg CO_2-eq kg^{-1} ECM, i.e. a difference of 33 % just from the different definitions of the reference flow. Of these, around two thirds come from the definition of the reference flow and one third from the energy content of ECM. As mentioned above the different parameters for the energy content calculation lead to very similar results.

This difference directly translates into results' uncertainty. When identical results from two studies are given without any context on the definition and calculation of the reference flow or calculation, one of the systems could have 33 % higher product-related GHG emissions than the other. Vica versa, dairy systems with similar environmental performance could be judged to be far apart, due to lack of transparency in the calculation process.

This uncertainty does not apply, when two different systems are compared within the same study. Multiple studies

Table 3

Calculation example for the effect of choices of reference flow and energy correction formula with different assumptions of energy content in ECM

Reference flow	Unit	Sjaunja (1991)	Clark et al. (2001)	Tyrell and Reid (1965)	No correction
		1 kg ECM ≙ 3.14 MJ	1 kg ECM ≙ 3.17 MJ	1 kg ECM ≙ 2.86 MJ	1 kg raw milk
1) Produced milk 7,376 kg cow^{-1} yr^{-1}	kg CO_2-eq kg^{-1} ECM	1.36	1.38	1.23	1.33
2) Sold milk 6,169 kg cow^{-1} yr^{-1}	kg CO_2-eq kg^{-1} ECM	1.63	1.64	1.47	1.59

could consistently find relevant differences between different farming strategies, e.g. organic versus non-organic farming. However, when comparing different results across different studies, e.g. for deriving regional differences, the scaling of the functional unit may lead to false conclusions.

2 Conclusion

The method of scaling to the reference flow does not prohibit improving the understanding of a production system, as can be an aim of LCA (Hellweg and Canals, 2014). However, when the aim is to provide results for use in comparative assertions, the scaling to the reference may significantly alter the interpretation. Hence, it is of upmost importance to provide a high transparency on the methods and data and not assume terms such as ECM to be sufficiently self-explanatory.

We suggest defining the functional unit and reference flows as follows: "The functional unit is 1 kg energy corrected milk (ECM) at the farm gate (including private use, if applicable). The energy correction is performed using the formula given by IDF (2015) and scales to 3.17 MJ per kg ECM."

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