Energy and Carbon Balancing in Livestock Keeping

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Introduction

In agriculture, we record a constantly growing consumption of raw materials and fossil energy due to the intensification and mechanisation of production technologies. So far, insufficient knowledge is available about the energy efficiency of production technologies in livestock keeping, their share in the total energy consumption of a farm and how targets and intensity of production may influence the energy efficiency and the entailed carbon dioxide (CO_2) emissions. Against this background, any analysis and evaluation of environmental effects and the sustainability of farming systems must consider also the energetic aspects and include a quantification of relevant CO_2 emissions. Energy and carbon balancing allows characterizing farming systems, disclose bottlenecks and elaborate optimisation strategies.

Objectives

The investigations are to contribute to the development of a method for energy and carbon balancing in livestock keeping. In this connection, not only inputs and outputs are regarded in form of a „black box“ analysis, but rather the relationships between livestock keeping and the farm levels soil and plant via internal energy and mass fluxes. The methodology will be integrated into the farm and environment management system REPRO (reproduction of organic soil matter) (Hülsbergen & Küstermann, 2005). The REPRO software allows to analyse and evaluate environmental impacts. As distinguished from other approaches, it reflects a systemic consideration and the description of interrelated mass and energy fluxes on farm level.

Results and Discussion

Energy inputs and CO_2 emissions in livestock keeping are assessed on the basis of direct and indirect energy consumption. Direct energy is used in form of fuel oil and electricity (for example in feeding, milking and manure disposal). Indirect energy includes the energy input for manufacturing machines and technical equipment (i. e. feeder-mixer wagons and milking parlours) as well as animal houses and storage facilities.

For scenario estimates a standard technology for dairy cattle has been defined: cubicle housing system for 180 cows and liquid manure disposal, feeding of total mixed rations, half-day grazing in summer, milk performance - 8000 kg FCM (Fat Corrected Milk) per cow and year. Depending on impact factors like diet composition, milk performance and service life of the cows, between 2 and 3 MJ of energy are invested in 1 kg FCM, allocating the entire energy input to milk as main product. With three fourths, the largest share of the energy demand for milk production falls to the production of feedstuffs (Berg & Scholz, 2000; Abel, 1997). Because of this high share the influence of feed-stuffs will be analysed first. For calculating the annual energy consumption with consideration of the energy amount materialized in capital goods the method and data of Kalk and Hülsbergen were used (Kalk & Hülsbergen, 1996).

Connected with the energy input are CO_2 emissions which appear in the balance sheet in form of emission factors (IPCC, 1996; Haas & Köpke, 1994). The provision of 1 kg mineral N, for example, causes 2.85 kg of CO_2 emission; when the occurring N_2O emissions are also considered, 7.82 kg CO_2/kg N arise owing to the increased greenhouse potential. The input of diesel fuel causes emissions in the range of 3.57 kg CO_2/kg, the use of machines appears in the energy balance sheet with 0.4 kg CO_2/kg machine mass (GEMIS, 2006).

As concrete example, a dairy farm with a productive area of 125 ha and a total number of 101 livestock units was analysed by use of the balancing model program REPRO. The dairy cattle are kept in a cubicle house for 61 cows with liquid manure disposal. The mean milk performance of the farm is about 8,400 kg milk/cow and year. In summer, the cattle is pastured half-day. For the provision of farm-grown feedstuffs 220 MJ/dt of dry matter are used for maize silage, 260 MJ/dt DM for grass silage and 200 MJ/dt DM for grain. This arouses CO_2 emissions in the range of 8 kg CO_2/dt DM for silage maize, 14 kg CO_2/dt DM for grass silage and 14 kg CO_2/dt DM for grain crops. All direct and indirect C emissions during the manufacturing and use of operating resources, energy carriers and capital goods were taken into consideration. If the N_2O emissions arising during the production of the consumed mineral fertiliser are also considered, the emission levels increase drastically (14 kg CO_2/dt DM for silage maize, 24 kg CO_2/dt DM for grass silage, 26 kg CO_2/dt DM for grain crops).

The energy input for forage of dairy cows and young cattle ascertained after one management year amounted to 2.7 MJ/kg of milk. Compared to the value in the standard technology, this energy input is fairly high. This might be explained by the rather low livestock numbers and a high level of feed supply.

On account of the high influence of the energy demand for the production of feedstuffs different yield classes and diet compositions are compared for the standard technology.

For the production process of field husbandry four different yield classes were investigated, which characterize different site types of North-East Germany. This division was defined by the regional department of consumer protection, agriculture and field reform of the state Brandenburg (LVLF, 2005). The difference between these yield classes is the index of land quality. The index of land quality for field husbandry amounts from yield class one to yield class four, more than 45 points, 36 to 45, 35 to 29 and 28 to 23 points. The production procedure is conventional cultivation. Four yield classes of the use of meadow land were distinguished between their yields and cultivation. The first three classes are with a conventional cultivation. Meadow with high yields (90 dt DM/ha) has accordingly excellent site conditions. The next steps have yields from 70 and 50 dt DM/ha. The fourth yield class for meadow land describes extensive cultivation with 50 dt DM/ha yield.

Table 1 shows the results of the determination of cumulative energy demand (CED) and the CO_2 emissions for the production of selected feed-stuffs presenting the main parts of diets for dairy cattle. The calculation of the CED was realized with REPRO (Hülsbergen, 2003).

Table 1: Cumulative energy demand (CED) and carbon dioxide emissions for different feed-stuffs and yield classes

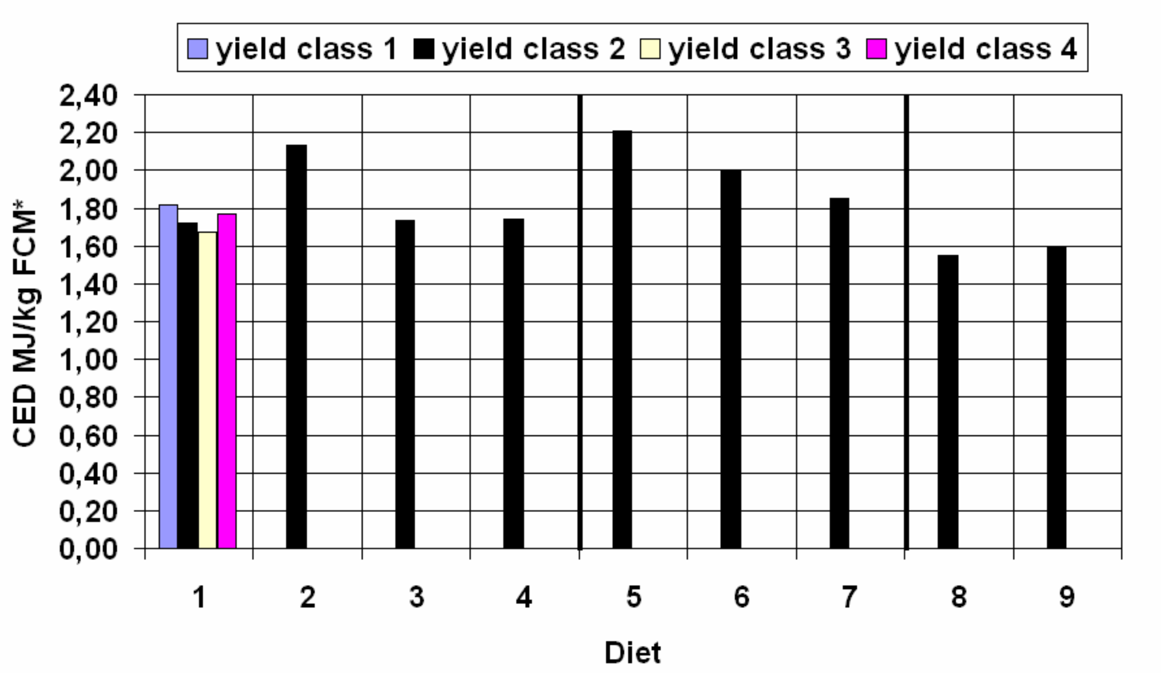
Crop	Yield-Class	fertiliser kg N ha^{-1}	DMY[a] dt ha^{-1}	CED[b] MJ kg DM^{-1}	CED[b] MJ MJ NEL^{-1}	CO_2 kg kg^{-1} DM^{-1}
Maize silage	1	144	120	1,68[d]	0,262[d]	0,15[d]
Maize silage	2	132	110	1,66[d]	0,259[d]	0,14[d]
Maize silage	3	114	95	1,69[d]	0,264[d]	0,15[d]
Maize silage	4	90	75	1,83[d]	0,287[d]	0,17[d]
Triticale	1	149	55	2,57	0,310	0,18
Triticale	2	135	50	2,64	0,318	0,19
Triticale	3	104	40	2,84	0,342	0,20
Triticale	4	80	30	3,28	0,395	0,22
Grass silage, conventional	1 (4 cuts)[c]	141	90	2,37[e]	0,388[e]	0,20[e]
Grass silage, conventional	2 (3 cuts) [c]	65	70	1,99[e]	0,326[e]	0,17[e]
Grass silage, conventional	3 (2 cuts) [c]	30	50	1,84[e]	0,301[e]	0,15[e]
Grass silage, extensive	4 (2 cuts) [c]	0	40	1,92[e]	0,315[e]	0,17[e]
Pasture, conventional	1	140	80	0,95	0,148	0,12
Pasture, conventional	2	80	60	0,84	0,131	0,10
Pasture, conventional	3	20	40	0,65	0,102	0,08
Pasture, extensive	4	0	30	0,83	0,129	0,10
Hay, conventional	1 (3 cuts)	140	90	2,14[f]	0,404[f]	0,21[f]
Hay, conventional	2 (2 cuts)	74	70	1,78[f]	0,336[f]	0,19[f]
Hay, conventional	3 (2 cuts)	50	50	2,03[f]	0,382[f]	0,20[f]
Hay, extensive	4 (2 cuts)	0	40	1,58[f]	0,299[f]	0,17[f]

[a]DMY- dry matter yield main product [b] CED-cumulative energy demand [c] with forage harvester
[d] including 15% losses (REPRO) [e] including 20% losses (REPRO) f including 30% losses (REPRO)

The CED and the CO_2 emissions of the single feed-stuffs differ in dependence on the yield classes. The production of grass silage needs a higher CED indebted with higher CO_2

emissions than the production of maize silage. The main reasons for this are the multiply share of machines, because of the multiple cuts and the lower yield of the grass silage. The comparison between maize and grass silage related to the CED of feed energy shows the same result. The pasture has a lower CED and lower emissions than the other feed-stuffs, because machines are only used for fertilisation and for cultivation operations. It is to mention, that the excrements of the animals during grazing amount to zero.

To identify which feed-stuffs cause a low CED different diets were investigated. The starting point of this investigation was a “standard diet” (diet 1) as a mixed ration. Typical of this diet is the balanced proportion between the ration ingredients maize silage, grass silage, pasture and concentrate. Figure 1 shows different diets in dependence on one yield class. The basic conditions of this three diet groups are the same but the share of one ration ingredient is always maximized.



* Cumulative Energy Demand in MJ per kg Fat Corrected Milk

Diets: 1 - standard diet; The basic conditions of the diets are the same but the share of one ration ingredient is always maximized. 2 – concentrate and balance feed, 3 – grass silage, 4 – maize silage, 5 - concentrate and balance feed without pasture, 6 – grass silage without pasture, 7 – maize silage without pasture, 8 - grass silage full time pasture, 9 - maize silage full time pasture; diet 1 to 4 half-day grazing in the summer, diet 5 to 7 without pasture, diet 8 and 9 full time pasture in the summer

Figure 1: Cumulative energy demand of different diets

The CED of the standard diet in influence of the different yield classes is shown in Figure 1. It demonstrates, that the CED of the diets has an optimum in dependence on the yield level. Yield class two represents an average yield class for Germany, therefore it is choosen to demonstrate the differences between the energy demand of the diets.

The CED and the CO_2 emissions of the variant “concentrate and balance feed” (diet 2) are 25% higher than the “standard diet”. The reasons for this difference are the high CED and CO_2 emissions for the supply of the concentrate and the balance feed. The values of the CED and the CO_2 emissions for these feed-stuffs are based on GEMIS (GEMIS, 2006). According to it the CED for extracted soya bean meal amount to 4.25 MJ/kg DM, for the CO_2 emissions 0,29 kg CO_2/kg DM, for extracted rape-seed meal the CED is 5.26 MJ/kg DM and the CO_2 emissions are 0,34 kg CO_2/kg DM. Assuming that an CED for soya bean meal is 3 MJ/kg DM (Kim, S. & Dale, B.E., 2004) and for rape-seed meal 4 MJ/kg DM (own calculations with REPRO) the CED of diet 2 still would be a quarter higher than that for diet 1. The comparison between the variants “grass silage” (diet 3), “maize silage” (diet 4) and the “standard diet” shows that with maximized share of grass or maize silage the CED approximate stay the same.

Further examinations focus at the influence of the pasture feeding. Three diet variants for house feeding without pasture feeding are shown in Figure 1. The CED of these variants is higher than the CED of the diet variants with half-day grazing. The energy demand of the variant “concentrate and balance feed without pasture” (diet 5) is higher compared to all other variants. The CED of diet 7 is comparatively low, because of the self-assertion of the lower CED for the production of maize silage.

Two diet variants with full-time pasture feeding in the summer are shown in Figure 1. The CED and also the CO_2 emissions (not shown) of these diets are smaller than all other variants, half-day grazing and house feeding. Diet 9 “maize silage full time pasture” has a slightly higher CED than diet 8 “grass silage full time pasture” because of the higher entry of concentrate and balance feed during the whole year. In comparison with the CED of the diets 3 and 4 exist a difference between the CED of diet 8 and 9. The reason for this subtle difference, in spite of the higher CED for the production of grass silage, is that with a growing up share of maize silage the share of balance feed increase, too.

Conclusions

Feed-stuff cropping has a strong influence on the cumulative energy demand (CED) and the CO_2 emissions in dairy production. The investigations of the CED and CO_2 emissions for the supply of different feed-stuffs have shown, that in dependence of the considered yield classes, which represent typical conditions of Germany, variations of the same feed-stuffs as far as 50% exists. Based on these results the CED and the CO_2 emissions were calculated for different diets. Diets with a high share of concentrate and balance feed have a higher

CED and also higher CO_2 emissions than diets with a high share of roughage. With a growing up share of pasture in the diet the CED and the CO_2 emissions are decreasing.

The total energy input and the resulting CO_2 emissions were allocated to the main product, the milk. The CED and the CO_2 emissions would decrease, if the by-products (milk, meat, calves, excrements) would be incorporated in the calculations, in which size will be researched in future investigations. The CED combined with the resulting carbon emissions (biologically caused carbon emissions and relevant N emissions) allow characterizing farming systems and are condition for an emission inventory on farm level.

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