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CO_2-Footprints for Food of Animal Origin – Present Stage and Open Questions

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Abstract: The environmental assessment of human activities is presently a hot topic. It is not only important from an ecological perspective, but also from the view of efficient utilization of limited natural resources such as fuel, land area, water und phosphorus. The environmental impact of food of animal origin is currently quantified by so-called CO_{2eq}-footprints.

To define CO_{2eq}-footprints, emissions arising along the food chain will be calculated according to their greenhouse potentials (carbon dioxide = 1 eq; methane ≈ 23 eq, laughing gas ≈ 300 eq). For the primary production of milk, meat and eggs, emissions during crop production, transportation, the storing and processing of feeds, animal keeping, enteric losses and excrement management can be mentioned as examples.

Data for CO_{2eq}-footprints in literature for beef and pork/poultry meat presently vary between 7–30 and 2–7 CO_{2eq}/kg empty body weight, respectively.

Currently there are different gaps which must urgently be closed before CO_{2eq}-footprints can be specified correctly:

- Uniform reference basis (e.g. edible fraction or edible protein of animal origin),
- Clear definition of system borders,
- Standardisation of methods,
- further quantification of emissions along the food chain (esp. N_2O, but also CH_4 and CO_2),
- Improvement of knowledge to reduce emissions along the food chain; consequences of modern biotechnology.

At the present stage of knowledge, the ranking of food of animal origin and the introduction of CO_{2eq}-taxes on the basis of CO_{2eq}-footprints may lead to preliminary and possibly wrong conclusions for policy- and decision-makers. Furthermore, interdisciplinary cooperation between scientists working along the food chain is necessary to solve the problems and to develop better and more reliable CO_{2eq}-footprints.

Zusammenfassung: Die Bewertung der Umweltwirkung menschlicher Aktivitäten ist von großer Bedeutung. Sie ist nicht nur aus Umweltsicht wichtig, sondern auch aus Gründen einer effizienten Nutzung begrenzt verfügbarer Ressourcen, wie fossile Energie, Fläche, Wasser und Phosphor. Gegenwärtig wird versucht, so genannte CO_2-Footprints (Fussabdrücke) für Lebensmittel abzuleiten und damit die Wirkung auf die Umwelt zu quantifizieren.

Die CO_2-Äquivalenzwerte werden auf der Basis der Emissionen entlang der Nahrungskette und unter Berücksichtigung des Treibhaus-Potenzials der Emissionen (CO_2 x 1 Äq, CH_4 x 23 Äq, N_2O x ≈ 300 Äq) kalkuliert. Emissionen aus dem Pflanzenbau sowie bei Ernte, Transport, Lagerung, Aufbereitung, Tierhaltung, aus dem Verdauungstrakt der Tiere und beim Exkrementmanagement wurden bei der Kalkulation der $CO_{2Äq}$-Footprints für Milch, Fleisch und Eier berücksichtigt.

Die höchsten Werte wurden für Rindfleisch (7,0 – 30,0 kg $CO_{2Äq}$/kg Schlachttierleerkörper), gefolgt von Schweine- und Geflügelfleisch (2,0 – 7,0 kg $CO_{2Äq}$/kg) kalkuliert. Neben den Emissionen je kg Lebensmittel tierischer Herkunft wurden auch Daten je kg essbares Protein tierischer Herkunft abgeleitet.

Tab. 1 Greenhouse gas emission, global and from Germany (Isermeyer et al., 2008).

Region	CO_2	CH_4	N_2O	Total	in %
		CO_{2eq} (Bill. t/year)			
World	31.9	6.0	3.1	41.4	100
Agriculture	7.6	3.1	2.6	13.4	32
Germany	0.87	0.05	0.06	1.00	100
Agriculture	n.s.	0.02	0.04	0.06	6[1)]

[1)] 12 – 15 % under consideration of factory caused emissions

Tab. 2 CO_2-emissions from manufacturing resources of various feeds (by various authors).

Feed	CO_2-emission (kg/kg DM)	Authors
Roughages	0.07[1)]	Bockisch et al., 2000
Pasture/Grass	0.22[1)]	"
	0.10	Brunsch et al., 2008
	0.12–0.15	Kim and Dale, 2004
	0.10	Kraatz et al., 2006
Grass silage	0.24[1)]	Bockisch et al., 2000
	0.09[1)]	"
	0.12	Brunsch et al., 2008
	0.17	Kraatz et al., 2006
Corn silage	0.09[1)]	Bockisch et al., 2000
	0.15[1)]	"
	0.12	Brunsch et al., 2008
	0.15	Kraatz et al., 2006
Hay	0.09[1)]	Bockisch et al., 2000
	0.25[1)]	"
	0.12	Brunsch et al., 2008
	0.19	Kraatz et al., 2006
Concentrates	0.27	Abel, 1996
Tritical	0.19[1)]	Bockisch et al., 2000
Corn	0.21[1)]	"
Barley	0.31[1)]	"
Wheat	0.26	Brunsch et al., 2008
	0.32[1)]	"
	0.25–0.29	Kim and Dale, 2004
	0.20	Kratz el al., 2006
	0.50[1)]	Küstermann et al., 2007
	0.36[1)]	"

[1)] CO_{2eq} in organic farming

Es besteht die dringende Notwendigkeit, die Datenbasis zur Ableitung der $CO_{2Äq}$–Footprints zu verbessern. Ein Ranking der Lebensmittel tierischer Herkunft nach der Höhe der $CO_{2Äq}$-Footprints oder die Einführung von Emissionssteuern erscheint beim gegenwärtigen Kenntnisstand verfrüht und kann vermutlich zu falschen Schlussfolgerungen bei Politik- und Entscheidungsträgern führen. Zur Verbesserung der $CO_{2Äq}$-Footprints erscheinen u. a. folgende Forschungsarbeiten notwendig:

- Einheitliche Referenzbasis (z. B. essbare Fraktion oder essbares Protein tierischen Ursprungs),
- Definition von Systemgrenzen,
- Standardisierung der Methoden,
- weitere Quantifizierung der Emissionen entlang der Nahrungskette (vor allem N_2O, aber auch CH_4 und CO_2),
- intensive Studien zur Emissionsminderung entlang der Nahrungskette, Einflüsse der modernen Biotechnologie.

Eine Kooperation von Wissenschaftlern, die entlang der Nahrungskette arbeiten, ist dringend erforderlich, um die Aussagen der $CO_{2Äq}$-Footprints für Lebensmittel tierischer Herkunft zu verbessern und belastbarer zu gestalten.

1. Introduction

Efficient utilization of limited natural resources such as fuel, land area, water, phosphorus and further resources and the reduction of emission such as carbon dioxide (CO_2), methane (CH_4) or laughing gas (N_2O) are main objectives of research and production activities of men. For example the atmospheric CO_2 concentration increased from ≈ 280 (19th century) to 380 ppm (presently) and will probably increase to 550 ppm in 2050 (IPCC, 2006) because of burning of carbon from fuel and other activities. This increase is discussed in connection with global warming and climate change (IPCC, 2006). Presently the global greenhouse gas (GHG) emission is estimated to be about 41 billion tones (t) CO_2-equivalents (CO_{2eq}) per year (Tab. 1), about 32% come from agriculture.

The global growing rate is given with ≈ 1 billion tones CO_{2eq} per year presently. This increase caused considerations to assess the emissions by so-called Life Cycle Assessments (LCA), also called ecobalances or CO_2-footprints for manufacturing

Tab. 3 Methane per kg dry matter in dependence on ration composition of ruminants (by various authors).

Concentrate (%)	% of gross energy intake	g/kg DM-intake
0	8 - 10	25 - 40
50	6 - 8	20 - 25
90	4 - 6	15 - 20

Tab. 4 Methane emission by various animal species.

Animal group	Methane-emission	
	% of gross energy intake (average and range)	g/kg DM-intake (average and range)
Ruminants	6–8 (2–15)	20–25 (10–40)
Horses	2–3 (1–5)	6–8 (2–12)
Pigs[1)]	0.5 (0–2)	2–3 (0–8)
Poultry[2)]	(0–0.3)	(0–1)

[1)] Highest values in sows, lowest values in piglets
[2)] Higher values with more fibre in diets (e.g. forage for laying hens, ducks, geese)

Tab. 5 Methane emissions from food producing animals in various regions (in Mio. t/year, Steinfeld et al., 2006).

Region	Methane-Emissions	
	Digestion	Excrement-Management
Africa and West Asia	15.2	0.9
India	11.8	1.0
China	8.8	3.8
Other Asia	8.0	1.1
North America	5.0	3.4
Middle and South America	21.2	1.4
Oceania and Japan	3.3	0.4
East Europe	5.7	1.4
Others	0.9	0.1
West Europe	5.7	4.1
Total	85.6	17.6

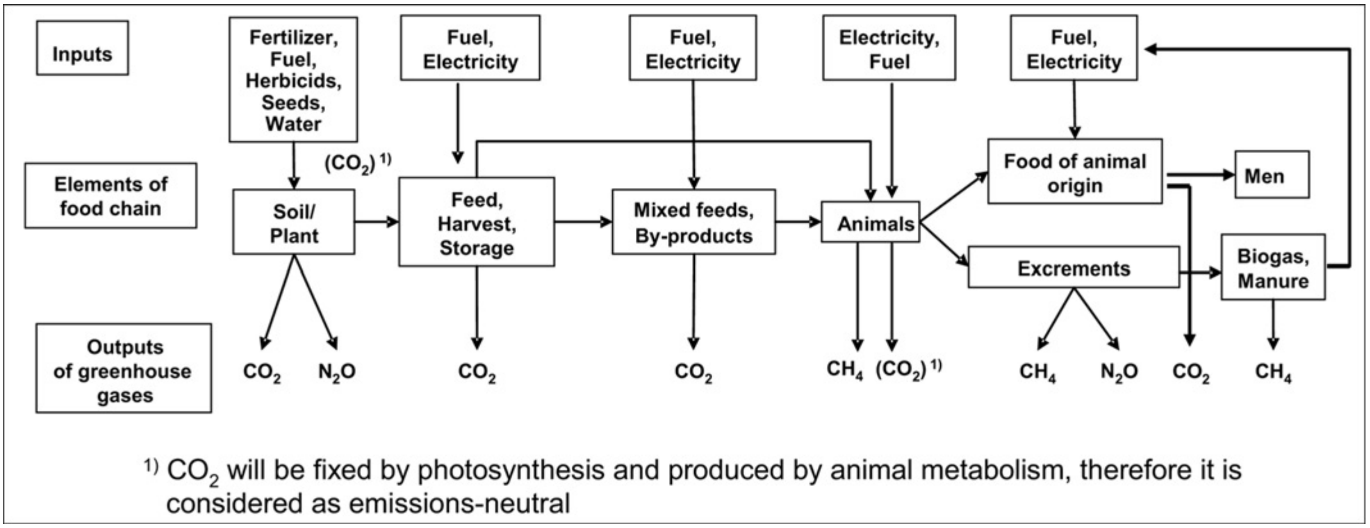

Fig. 1 Substantial elements of the chain to produce food of animal origin as well as selected inputs of resources and outputs of greenhouse gases.

Tab. 6 N_2O-emissions in Germany from arable land and grassland in dependence of fertilising (Jungkunst et al., 2006).

Form of cultivation	Fertilizer	Number	Average	Minimum	Maximum
				kg N_2O-N ha^{-1} a^{-1}	
Arable Land	-	9	1.35	0.04	2.50
	+	50	4.85	0.07	17.10
Grassland	-	16	1.18	0.10	3.40
	+	28	2.15	0.30	10.00

various products including food. CO_{2eq}-footprints means the sum of all climate relevant emissions under consideration of their greenhouse potential such as 1 for CO_2, 23 x CO_2 for CH_4 and ≈ 300 x CO_2 for N_2O (IPCC, 2006). The footprints are given as CO_{2eq} in gram or kilogram per product. The objective of the footprints is to sensitize producers and consumers for an efficient use of fossil carbon sources and to reduce greenhouse gas emissions per product. Presently some companies label already their products with such footprints. The objective of the paper is to introduce to footprints, to deduce CO_{2eq} footprints for selected food of animal origin and to come to open questions and to further research need.

2. Fundamentals for CO_{2eq}-footprints

Knowledge about the emissions of greenhouse gases along the food chain (value-added chain, Fig. 1) is the most important prerequisite for calculation of CO_{2eq}-footprints. In the case of food of animal origin knowledge on emissions from manufacturing resources (plant production, harvesting, transportation, storage, conservation, processing in feed mills, animal keeping, etc.) and animal caused emissions from the digestive tract and the excrement management are fundamentals for further calculations.

2.1 Emissions from manufacturing resources

The value of CO_2-emission from fuel depends on the intensity of farm management esp. from type and amount of fertilizer, but also from the plant yields and the expenditures for transportation, feed processing and animal keeping.

Tab. 2 summarizes some values of CO_2-emissions from manufacturing resources for various feed by different authors. There is a considerable variation between feeds and authors. In most case organic farming shows lower CO_2-emissions than conventional agriculture.

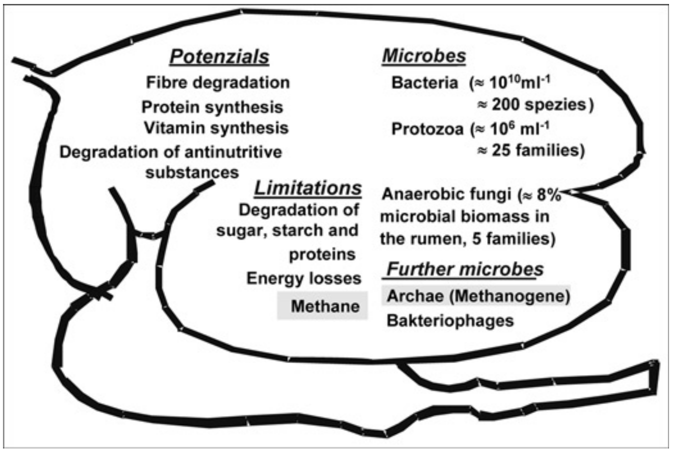

Fig. 2 Potentials, limitations and microbes in the rumen.

Tab. 7 Calculation of emissions per cow and year (Parameters: body weight: 650 kg per cow, milk yield: 8000 kg per year, 1 calf per year, Daemmgen and Haenel, 2008).

	Emissions (kg per cow per year)		
Source of emissions	CO_2	CH_4	N_2O
Fertilizer	210	5.5	1.1
Feed	83		1.2
Transport Treatment	43		
Rumen fermentation		119	
Fermentation of excrement management		19	0.9
Emissions from soil		- 1	1.8
Total	336	143	5
CO_2-Equivalents (kg/cow and year)		5200	
(g/kg milk)[1)]		650	
CO_2- Equivalents of emission (kg/cow)	336	3290	1500
(% of total emission)	6	65	29

[1)] without calf and heifer

Tab. 8 CO_{2eq} per kg milk in dependence on type of production (by various authors).

Type of production: Conventional (kg CO_{2eq}/kg milk)	Organic	Authors
0.40 (40 kg milk/day)		Own data (2008)
0.55 (20 kg kg milk/day)		
1.00 (10kg kg milk/day)		
0.65 (not given)		Dämmgen and Hänel (2008)
0.83	0.84	Woitowicz (2007)
0.85	0.78	Hirschfeld et al. (2008)
0.89	1.13	Iepema and Pijnenburg (2001)
0.94	0.88	Fritsche und Eberle (2007)
0.97	1.13	Zijpp (2001)
0.99	0.94	Cederberg und Mattsson (2000)
1.06	1.23	DEFRA (2006)
1.30	1.30	Haas et al. (2001)
1.40	1.50	Thomassen et al. (2007)

0.12 kg CO_2 per kg dry matter (DM) of roughage and 0.22 kg CO_2 per kg DM of concentrate (average of some reviews, see Tab. 2) were used for further calculations of CO_{2eq}-footprints.

Less data are available for CO_2-emission for feed transportation and processing (Bockisch et al., 2000, Feil, 2005) as well as animal keeping (Bockisch et al., 2000; Brunsch et al., 2008; HEA, 1996; Hirschfeld et al., 2008).

2.2 Animal caused emissions

Methane is one of the most important greenhouse gas emissions from livestock production. Especially ruminants emit CH_4 as unavoidable natural by-product of rumen fermentation, because of their microbial settlement in the rumen (Fig. 2). On the other side and caused by the microbes, ruminants have very important potentials to convert cellulose and other low quality roughages as well as non-protein-nitrogen-compounds (Fig. 2) in food of animal origin (e.g. milk and meat).

The methane amount depends on ration composition (Tab. 3) and added supplements with methane reduction potentials. Apart from ruminants nonruminants emit also methane, but to a much lower extend than ruminants (Tab. 4). About 40 % of the global methane emission ($\approx$ 240 Mio t) falls to animal husbandry. There are large differences between various regions (Tab. 5). Methane emissions arising from excrements may be reduced by utilization of excrements in biogas-fermenters.

Many papers were published about origin of methane, methane emission and influencing factors recently (e.g. Beauchemin et al., 2008; Flachowsky and Brade, 2007; Jouany, 2008; Kreuzer and Soliva, 2008; Tamminga et al., 2007). Therefore no further details should be discussed here.

Food producing animals do not excrete laughing gas. They excrete various N-sources with different propensity to ammonia (NH_3)-formation (Fig. 3). For example ammonia is much faster coming from urea than from uric acid. Ammonia is a very important precursor for N_2O-formation (Fig. 4), which depends mainly on microbial activities in the soil. Furthermore N_2O-formation is influenced by source of N, soil quality, moisture, temperature and management of soil as summarized by Flachowsky and Lebzien (2007).

Normally the N_2O-emission depends on amount of N-fertilization (Tab. 6), but there exist also studies, where the N-emission is independent on level of N-fertilization (Jungkunst et al., 2006; Roelandt et al., 2005). The N_2O-emission may vary between 0 and about 10% of N-amount given to the land (Bockisch et al., 2000; Hirschfeld et al., 2008). Normally the IPCC-value of 1.25 % of N is transferred to N_2O-N in the soil (IPCC, 2006) is used for calculation of N-emissions from the soil. In some cases this average value may be wrong (Bockisch et al., 2000; Crutzen et al., 2007).

3. CO_{2eq}-Footprints

The level of CO_{2eq}-footprints for food of animal origin depends primarily on the system borders (Fig. 1); that means which emission sources will be considered for calculations. The intensity of production (e.g. conventional and organic farming) and the level of emissions also influence the CO_{2eq}-footprints. Tab. 7 shows calculations for CO_{2eq}-footprints for milk under consideration of fertilizer production, feeds, transport, processing, rumen fermentation and excrement management. Reproduction of cows, emissions from the previous achievements (e.g. machinery, cowshed etc.), further processing and trade of milk have been not considered in the calculation of Tab. 7.

All the factors mentioned above and further variables influence the level of CO_{2eq}-footprints and their range as shown in Tab. 8 for milk by various authors (0.4–1.5 kg CO_{2eq}/kg milk). In fact of the wide impact possibilities and the high variability the precisions of the data are unexpected.

Much higher variations are described for beef (Tab. 9 and 10). The values are influenced by body weight gain, feeding

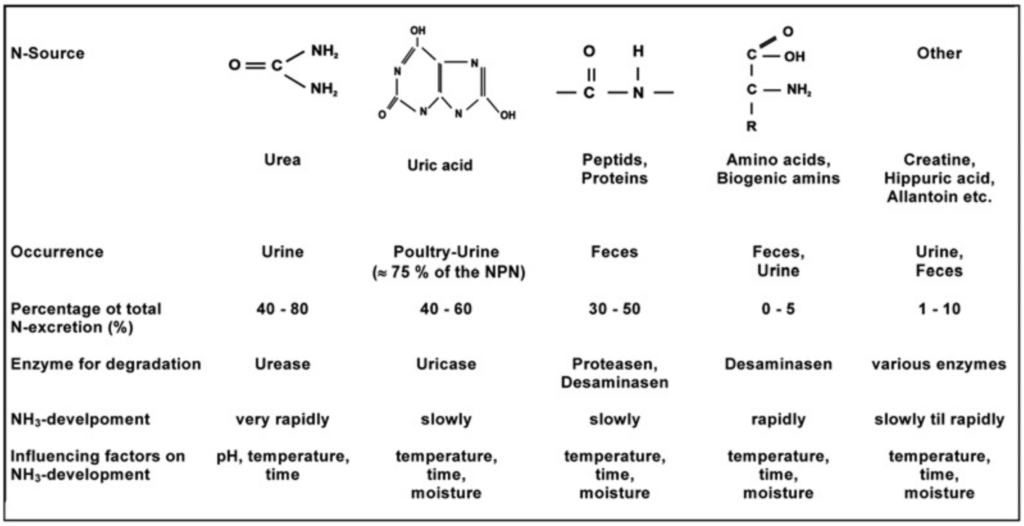

Fig. 3 Important N-sources in excrements and their propensity to NH_3 – formation.

Tab. 9 Calculations of CO_{2eq}-footprints for beef (150 – 550 kg body weight) in dependence on weight gain, feeding, Methane- and N-emissions (Flachowsky, 2008).

Weight gain (g/day)	Feed intake (kg/DM/ animal and day)	Portion concentrate (% of DM-intake)[1)]	Methane Emissions (g/kg DM)	N-excretion (g/day)	N_2O-synthesis (% of N -excretion)	CO_{2eq} (kg/kg)		
						Weight gain	Empty body gain	Edible fraction
500 (Pasture, no concentrate)	6.5	0	26	110	2	11.5	23.0	28.0
1000 (Indoor, grass silage, some concentrate)	7.0	15	24	130	1	5.5	11.0	13.8
1500 (Indoor, corn silage, concentrate)	7.5	30	22	150	0.5	3.5	7.0	9.0

[1)] CO_2-Output: 120 kg/t roughage – DM
[2)] 220 kg/t concentrate – DM

Tab. 10 CO_{2eq} per kg empty body gain of beef cattle in dependence on type of production (by various authors).

Type of production		Authors
Conventional (kg CO_{2eq}/kg empty body gain)	Organic	
8.5	29.0 (Beef cows)	Reitmayr, (2005)
8.7/10.1	10.2	Woitowicz, (2007)
7.0 (1500 g daily weight gain)		
11.0 (1000g daily weight gain)	not given	Own data, (2008)
23.0 (500g daily weight gain)		
11.5	not given	Wechselberger, (2000)
13.3	11.4	Fritsche and Eberle, (2007)
15.8	18.2	DEFRA, (2006)
23.6	20.2	Casey und Holden, (2006)
36.4 (Beef cows, fattening bulls, 40% meat yield)		Ogino et al., (2007)

and the system borders (Tab. 9). The highest values were measured with beef cows. The base for calculations such as body weight gain, empty body weight, edible fraction, meat or edible protein has an important influence on the CO_{2eq}-footprints. Once again, the grade of accuracy of the data race to questions.

Similar calculations were done for pork, poultry meat and eggs (e.g. DEFRA, 2006; Fritsche and Eberle, 2007; Heissenhuber, 2008; Hirschfeld et al., 2008). The authors compared conventional with organic farming (Fig. 5). The results are characterized by a high variation between food sources and authors. There is no clear tendency concerning production system. Fritsche and Eberle (2007) calculated always lower CO_{2eq}-footprints for organic farming, but there were no clear trends in the studies of all other authors (Fig. 5).

The main objective of animal husbandry in Europe and some other countries is the production of edible protein in milk, meat and eggs. Food of animal origin contains apart from important amino acids also many essential trace nutrients and is characterized by a high enjoyable value. Therefore animal protein may be considered as a base for calculation of CO_{2eq}-footprints. From the scientific view edible protein seems to be a suitable parameter to compare various ways of animal production from the view of feed/resource efficiency and emissions. Tab. 11 summarizes protein yields of different

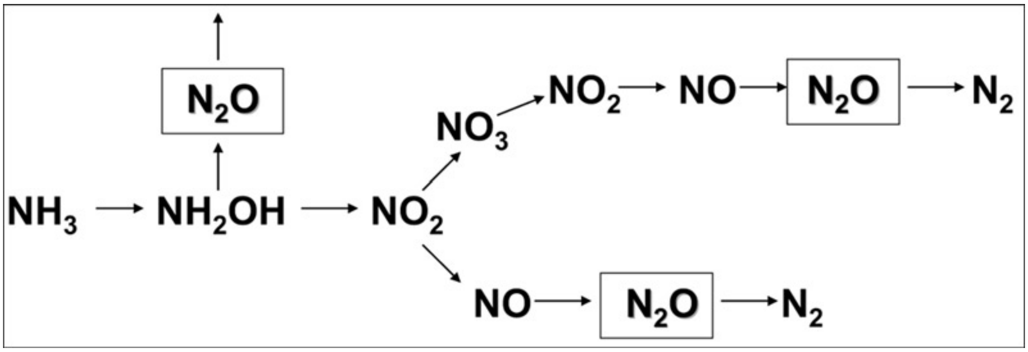

Fig. 4 Laughing gas (N_2O) from ammonia (NH_3) (Wrage et al., 2001).

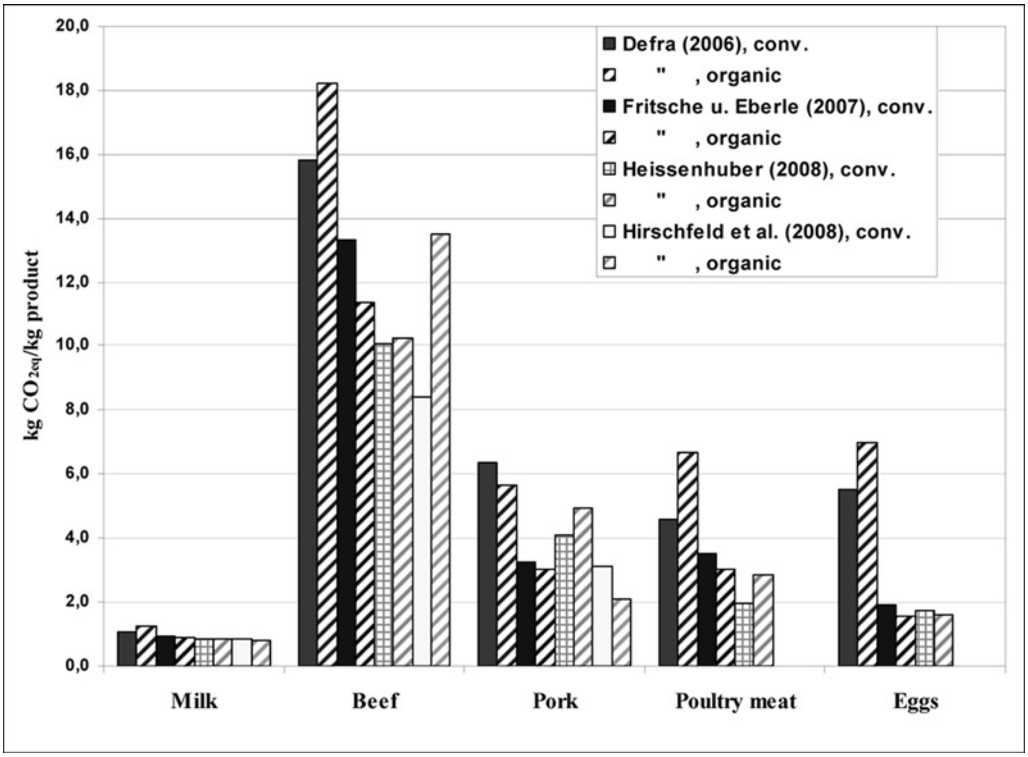

Fig. 5 CO_{2eq}-footprints of food of animal origin from conventional and organic farming by various authors.

animal husbandry depending on their performances as well as their emissions per kg edible protein.

4. Research need

The assessments and rankings of foods of animal origin on the base of CO_{2eq}-footprints on the present stage of knowledge (Fig. 5) may lead to preliminary and possible wrong conclusions for policymakers and deciders. Furthermore there could be the impression that all things are clear and there is no need for any further research. Therefore the following research activities can be seen to qualify and improve the CO_{2eq}-footprints:

– Further quantification of emissions along the food chain under consideration of influencing factors such as:
  ■ Quantification of laughing gas emissions,
  ■ Quantification of manufacturing caused emissions,
  ■ Improvement on knowledge on enteric and management caused methane emission,
  ■ Standardization of methods, clear definition of system borders.
– Improvement of knowledge to reduce emissions along the food chain:
  ■ Lower CO_2-emissions,
  ■ Reduction of N-excretion (esp. urea-excretions by animals),
  ■ Reduction of enteric methane emissions, using of excrements in biogas fermenter.
– Assessment and consequences of "modern" biotechnology on emissions.

A cooperation of animal scientists (e.g. nutritionists, breeders, veterinarians etc.) with scientists working in the fields of ecology and economy seems to be necessary to solve the problems and to develop better and loadable CO_{2eq}-footprints.

Tab. 11 Production of edible protein of animal origin of various animal species/categories in dependence on animal performances (Flachowsky, 2002) and emissions per kg edible protein.

Protein sources (Body weight)	Performance per day	Parameters of feed intake: Intake (kg DM per day)	Parameters of feed intake: Roughage: Concentrate, Ratio (on DM base, %)	Edible fraction (%)	Protein in edible fraction (g/kg fresh matter)	Edible protein (g/day)	Emissions in kg per kg edible protein: N	CH_4	CO_{2eq}
Dairy cow (650 kg)	10 kg milk	12	90/10	95	34	323	0.65	1.0	30
	20 kg milk	16	75/25			646	0.44	0.6	16
	40 kg milk	25	50/50			1292	0.24	0.4	12
Dairy goat (60 kg)	2 kg milk	2	80/20	95	36	68	0.5	0.8	20
	5 kg milk	2.5	50/50			170	0.2	0.4	10
Beef cattle (350 kg)	500 g[1)]	6.5	95/5	50	190	48	2.3	3.5	110
	1000 g[1)]	7	85/15			95	1.3	1.7	55
	1500 g[1)]	7.5	70/30			143	1.0	1.2	35
Growing /Fattening pig (80 kg)	500 g[1)]	1.8	20/80	60	150	45	1.0	0.12	16
	700 g[1)]	2	10/90			63	0.7	0.08	12
	900 g[1)]	2.2	0/100			81	0.55	0.05	10
Broilers (1.5 kg)	40 g[1)]	0.07	10/90	60	200	4.8	0.35	0.01	4
	60 g[1)]	0.08	0/100			7.2	0.25	0.01	3
Laying hen (1.8 kg)	50%[2)]	0.10	20/80	95	120	4.8	0.6	0.03	7
	70%[2)]	0.11	10/90			5.1	0.4	0.02	5
	90%[2)]	0.12	0/100			6.6	0.3	0.02	4

[1)] Daily weight gain
[2)] Laying performance

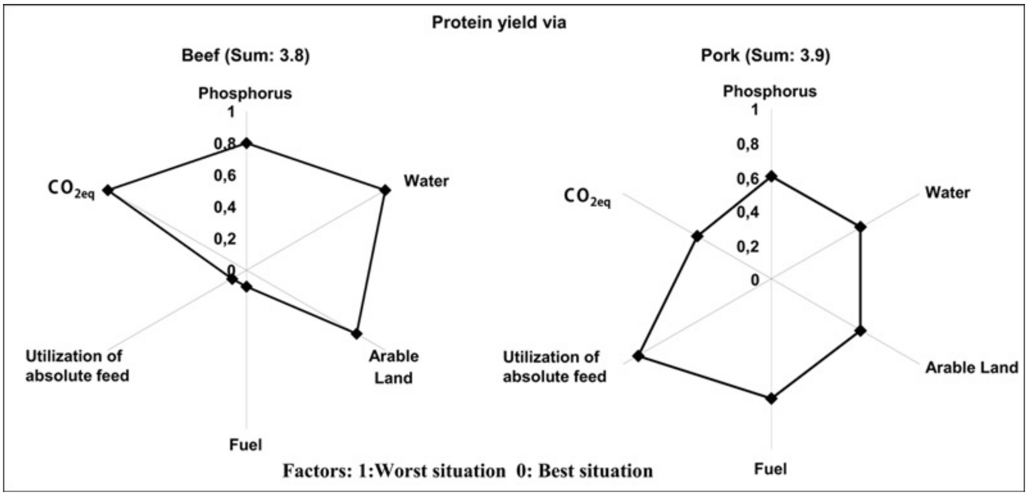

Fig. 6 Proposal of complex assessment of production of protein of animal origin on the base of beef and pork under consideration of various parameters.

But footprints are only one side to assess and compare various foods of animal origin. Apart from low emissions there is also a need for a more efficient use of limited natural resources such as arable land, water, fuel, phosphorus etc. Furthermore many products such as grass, straw and other by-products from agriculture and food industry may be effective used as feeds in animal nutrition. Therefore a more complex assessment of various forms to produce food of animal origin seems to be helpful and necessary. Fig. 6 shows on the base of a simple calculation such an example for beef and pork. Six factors were considered in the spider web (fuel, area, water, phosphorus, CO_{2eq}-footprints and “absolute” feed). Situation 1 is considered as unfavourable, 0 would be the best situation. There is an urgent need for improvement of such models (considering of further factors, evaluation of factors, way of calculation for total assessment etc.). A total assessment would be possible by addition of individual values (0 to 1) or by calculation of the area in the spider web. Coming back to the examples in Fig. 6 nearly the same total assessment value could be calculated for beef and pork under consideration of the values assumed in the simple model.

5. Conclusion

At the present stage of knowledge, ranking of food of animal origin on the basis of CO_{2eq}-footprints may lead to preliminary and possibly wrong conclusions. Especially the precision of the already stated CO_{2eq}-footprints needs to questions. The data base for CO_{2eq}-footprints needs to be further improved before they may contribute to the assessment of greenhouse gas emissions during the primary production of food of animal origin. Further factors as limited natural resources or utilization of grassland or agricultural/industrial by-products should be considered for a complex assessment of various production systems in future.

6. References

Abel, H.-J. (1996) Energieaufwand und CO_2-Ausstoß bei verschiedenen Formen der Lebensmittelerzeugung. Schriftenreihe der Schaumann-Stiftung zur Förderung der Agrarwissenschaften, Hülsenberger Gespräche 16:153–161.

Beauchemin, K. A., Kreuzer, M., O'Mara, F., and McAllister, T. A. (2008) Nutritional management for enteric methane abatement: a review. Austral J Exp Agricul 48:21–27.

Bockisch, F.-J., Ahlgrimm, H.-J., Böhme, H., Bramm, A., Dämmgen, U., Flachowsky, G., Heinemeyer, O., Höppner, F., Murphy, D. P. L., Rogasiki, J., Röver, M., and Sohler, S. (2000) Bewertung von Verfahren der ökologischen und konventionellen landwirtschaftlichen Produktion im Hinblick auf Energieeinsatz und bestimmte Schadgasemissionen. Landbauf Völkenrode, SH 211, 206 S.

Brunsch, R., Kraatz, S., Berg, W., and Rus, C. (2008) Ermittlung der Energieeffizienz in der Tierhaltung auf der Grundlage von Energiebilanzen. KTBL-Schrift 463:115–125.

Casey, J. W., and Holden, N. M. (2006) Greenhouse gas emission from conventional, agri-environmental scheme and organic Irish Suckler – Beef Univ J Environm Quality 35:231–239.

Cederberg, C., and Mattson, B. (2000) Life cycle assessment of milk production – A comparison of conventional and organic farming. J Cleaner Prod 8:250–260.

Crutzen, P. J., Mosier, A. R., Smith, K. A., and Winiwarter, W. (2007) N_2O-release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmos Chem Phys Discuss 7:1191–11205.

Daemmgen, U., and Haenel, H.-D. (2008) Emissions of greenhouse gases and gaseous air pollutants – a challenge for animal nutrition. Proc Soc Nutr Physiol 17:163–167.

DEFRA (August 2006) Determination the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report ISO 205. Cranfield Univ. Silsoe Inst., http://www.cranfield.ac.uk

Feil, A. (2005) IFF-Kolloquium 2005 – Sind Maßnahmen zur Reduzierung der Energiekosten denkbar? Aufbereitungstechnik 46:52–56.

Flachowsky, G. (2002) Efficiency of energy and nutrient use in the production of edible protein of animal origin. J Appl Anim Res 22:1–24.

Flachowsky, G. (2008) Treibhausgase und Ressourceneffizienz. Aspekte der Erzeugung von Lebensmitteln tierischer Herkunft. Ernährungsumschau 55:414–419.

Flachowsky, G., and Brade, W. (2007) Potenziale zur Reduzierung der Methan-Emissionen bei Wiederkäuern. Züchtungskd 79:417–465.

Flachowsy, G., and Lebzien, P. (2007) Lebensmittel liefernde Tiere und Treibhausgase – Möglichkeiten der Tierernährung zur Emissionsminderung. Übersicht Tierern 35:191–231.

Fritsche, R., and Eberle, U. (2007) Treibhausgasemissionen durch Erzeugung und Verarbeitung von Lebensmitteln. Arbeitspapier, Öko-Institut e.V. Darmstadt, 13 S.

Haas, G., Wetterich, F., and Köpke U. (2001) Comparing intensive, extensified and organic grassland farming in Southern Germany by process life cycle assessment. Agricult Ecosyst & Environm 83:43–53.

HEA (Hauptverwaltungsstelle für Elektrizitätsanwendung e.V.) (1996) Strom – Tips für Landwirte. HEA (Hrsg.), Energieverlag GmbH, Heidelberg, S. 14 ff.

Heissenhuber, A. (2007) Ökonomische Aspekte einer energieeffizienten Landwirtschaft. KTBL-Vortragstagung, 08./09. 04. 2008, Fulda, KTBL-Schrift 463:42–53.

Hirschfeld, J., Weiß, J., Preicht, M., and Korbun, T. (2008) Klimawirkungen der Landwirtschaft in Deutschland. Schriftenreihe des IÖW 186/08, Berlin, 188 S.

Iepema, G., and Pijnenburg, J. (2001) Conventional *versus* organic dairy farming. A comparison of three experimental farms on environmental impact, animal health and animal welfare. MSc thesis, Animal Production Systems Group, Wageningen University, The Netherlands.

IPCC (Intergovernmental Panel on Climate Change, 2006) (IPCC) Guidelines for National Greenhouse Gas Inventories. Vol. 4, Agriculture, Forestry and other Land use. http://www.ipcenggip.iges.or.jp/public/2006/gl/vol4.htm.

Isermeyer, F., Otte, A., Christen, O., Frohberg, K., Hartung, J., Kirschke, D., Schmitz, M., and Sundrum, A. (2008): Nutzung von Biomasse zur Energiegewinnung – Empfehlungen an die Politik, Gutachten. Berichte über Landwirtschaft, SH 116: 198 S.

Jouany, J.-P. (2008) Enteric methane production by ruminants and its control. In: Andrieu, A., and Wilde, D. (eds.) Gut efficiency; the key ingredient in ruminant. Wageningen Academic Publ., 35–59.

Jungkunst, H. F., Freibauer, A. Neufeldt, H., and Bareth, G. (2006) Nitrous oxide emissions from agricultural land use in Germany – a synthesis of available annual field data. J Plant Nutr and Soil Sci 169:341–351.

Kim, S., and Dale, B. E. (2004) Cumulative energy and global warming impact from the production of biomass for biobased products. J. Industrial Ecol. 7:147–162.

Küstermann, B., Kainz, M., and Hülsenbergen, K. J. (2007) Modelling carbon cycles and estimation of greenhouse gas emissions from organic and conventional farming systems. Renewable Agriculture and Food Systems 23:1–16.

Kraatz, S., Berg, W., Küstermann, B., and Hülsbergen, K. J. (2006) Energy and carbon balancing in livestock keeping. Proc World Congress: Agricultural engineering for a better world congress Bonn, 03.-07. 09. 2006, VDI-Berichte Nr. 1958, VDI-Verlag Düsseldorf, 417–418.

Kreuzer M., and Soliva C. R. (2008) Nutrition: Key to methane mitigation in ruminants. Proc Soc Nutr Physiol 17:168–171.

Ogino, A., Orito, H., Shimada, K., and Hirooka, H. (2007) Evaluating environmental impacts of the Japanese beef cow-calf system by the life cycle assessment method. Anim Sci J 78:424–432.

Reitmayr, T. (1995) Entwicklung eines rechnergeschützten Kennzahlensystems zur ökonomischen und ökologischen Beurteilung von agrarischen Bewirtschaftungsformen – Dargestellt an einem Beispiel. Agrarwirtschaft, Frankfurt/Main, SH 147.

Roelandt, C., van Wesemael, B., and Rounsevelli, M. (2005) Estimation annual N_2O-emissions from agricultural soils in temperature climates: Global Change Biol 11:1701–1711.

Steinfeldt, D., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., and de Haan, C. (2006) Livestock's long shadow. Environmental issues and options. Food and Agric. Org. of the UN (FAO), Roma. http://www.virtualcentre.org/on/library/key.pub/longshad/AO701EOO.pdf.

Tamminga, S., Bannink, K., Dijkstra, J., and Zorn, R. (2007) Feeding strategies to reduce methane loss in cattle. Animal Science Group, Wageningen, UR, Rep. 34:44 p.

Thomassen, M. A., van Calker, K. J., Smits, M. C. J., Iepema, G. L., and

de Boer I. J. M. (2007) Life cycle assessment of conventional and organic milk production in the Netherlands. Agricult Systems.
Wechselberger, P. (2000) Ökonomische und ökologische Beurteilung unterschiedlicher landwirtschaftlicher Bewirtschaftungsmaßnahmen und –systeme anhand ausgewählter Kriterien. FAM-Bericht, Shaker-Verlag, Aachen, 502 S.
Woitowicz, A. (2007) Auswirkungen einer Einschränkung des Verzehrs von Lebensmitteln tierischer Herkunft auf ausgewählte Nachhaltigkeitsindikatoren – dargestellt am Beispiel konventioneller und ökologischer Wirtschaftsweise. Diss., TU München, 237 S.
Wrage, N., Velthof, G. L., Van Beusichem, M. L., and Oenema, O. (2001) Role of nutrifier denitrification in the production of nitrous oxide. Soil Biology Biochemy 33:1723–1732.
van der Zijpp, I. A. J. (2001) Animal production systems: on intigration and diversity. Habil.schrift, Univ. Wageningen, The Netherlands.

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