LCA Methodology

Framework in Agriculture on the Farm Level

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Abstract. Life Cycle Assessment (LCA) is a method that can be used to assess the environmental impact of agriculture, but impact categories and the functional unit of classical LCA's must be adapted to the specific agricultural production process. Serving as an example, the framework of a LCA of 18 grassland dairy farms covering three farming intensity levels and carried out in the Allgäu region in southern Germany is presented. By focussing on the chosen impact categories and the respective, suitable functional units, the specific needs and backgrounds of conducting an agricultural LCA are discussed in general.

Keywords: Agriculture; eco-balance; farm level; functional unit; impact category; Life Cycle Assessment; methodology

Introduction

The impact of agriculture on the environment is a major issue because the ecological health of natural resources is already overstrained. In general, the agricultural impact on nature is well known (Haber and Salzwedel 1992, RBS 1994) and a set of agri-environmental indicators has been developed for national monitoring systems (OECD 1997, Rudloff et al. 1999). But efficient methods to comprehend and assess agricultural impacts on the environment by combining suitable indicators are very much needed. One of the methods considered in the last years is the Life Cycle Assessment (LCA) (Audsley et al. 1997, Ceuterick 1996, 1998, Diepenbrock et al. 1997, Wegener Sleeswijk et al. 1996).

Because the single farm is the nucleus of agricultural production, it is the main starting point for identifying and reducing negative environmental impacts. To identify and assess the environmental impact on the farm level, an LCA in the Allgäu region in southern Germany was conducted in the year 1998 (Haas et al. 2000, Wetterich and Haas 1999). In the project region, intensive use of permanent grassland by dairy farms is predominant. After a pre-selection of 35 farms using the support of local experts, 18 representative farms – six for each of the three farming intensities – 'intensive', 'extensive' and 'organic' – were analysed in detail by on-farm investigation, an examination of the farmers by using a questionnaire and consultation with advisors and local experts (e.g. water authorities).

In this paper, the framework of the Allgäu-LCA is emphasised, especially the selection of appropriate impact categories and functional units to fit specific agricultural and regional requirements in order to compare the impact of farms as well as farming intensity levels.

1 Framework

1.1 Goal

Until now, agricultural LCA's have been mainly carried out for single crops or production processes (e.g. winter wheat, non-food-crops, weed control). The central objective of the study was to adapt the LCA method, developed for assessing the environmental impact of industrial plants and production processes, to agriculture on the whole farm level, efficiently and feasibly assessing all relevant environmental impacts. Weak-point analyses followed and optimising measures for the farms (Haas and Wetterich 1999) and for creating a more efficient agri-environmental programme in the Bavarian State (Haas and Wetterich 2000) were suggested. The intended audience included farmers, agricultural advisers, politicians and scientists.

1.2 Scope – agricultural LCA

Agriculture as part of the primary economic sector – including forestry and fisheries – commonly does not use nature in the meaning of consuming it, because it also creates and ensures nature and its functions. The agricultural use of nature has a different background compared to industrial production processes. Acquisition of raw material through production, use and disposal, for which the environmental impact is assessed in classical LCA's, is a production chain which does not properly describe the agricultural production process. Central agricultural production resources, for example soil fertility, seeds and cattle, are self-produced. Farmyard manure, the main 'waste' product of livestock keeping, is a valuable fertiliser for plant production (as long as livestock-units are adjusted to the farmed area).

Agricultural production is not a pure 'cradle-to-grave' process. Therefore, LCA's in agriculture must be more than a method "...to evaluate environmental burdens ... by identifying and quantifying energy and materials used and wastes released to the environment..." (definition by LCA Journal). For agricultural application, the term 'Life Cycle Assessment' could be misleading because the main agricultural life cycle in mainstream mixed farming systems is taking place within a farm

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and based on renewable resources using, enhancing and ensuring nature's processes. The term 'eco-balance' used for LCA in French or German is regarded to fit more accurately.

1.3 Impact categories

Beside the specific agricultural background, the difference between classical product-LCA's and process-LCA's of enterprises (farms) or production systems (e.g. intensive, extensive and organic farming) causes problems with classical impact categories. In classical LCA's, 'land use', 'waste' and 'photo-oxidants' are impact categories considered as essential (Klöpffer and Renner 1994), but they are not generally appropriate for agricultural LCA's (Geier et al. 1998, Geier 2000) because they do not function as central environmental impacts of agriculture (Haber and Salzwedel 1992). Man-made landscape and biodiversity of wildlife and crops in agroecosystems are heavily dependent on the kind and intensity of the agricultural production process. Consequently, biodiversity, wildlife habitats and landscape are identified as key agri-environmental issues (OECD 1997, Rudloff et al. 1999). The impact on these natural resources should be represented by individual impact categories in agricultural LCA's (**Table 1**).

The impact category 'land use' in the meaning of land consuming is not appropriate and must be more specifically adapted to the agricultural background defined as 'landscape image'. Landscape image as an aesthetic resource, as well as animal welfare, both depend on the kind of agriculture practiced. Although negative agricultural impacts in these categories normally do not cause obvious ecological burdens, these categories do have a high public awareness and are governed by the agri-environmental policies of the European Union. Therefore, they have been considered as single impact categories of the Allgäu-LCA (Table 1). An impact category 'water use' meaning 'water consumption' creates similar definition problems and would be only appropriate in regions with a shortage of water, which in north-west Europe is usually not the case. Especially when assessing arable farms, 'land use' with the specific meaning of 'soil use' (e.g. soil fertility, soil erosion, soil protection, soil function, soil strain) should also be included as a separate impact category, which in the Allgäu-LCA was done for the impact category of soil function.

Table 1: Impact categories and indicators of the Allgäu LCA

Impact category	Environmental indicator
Resource consumption energy minerals	 Use of primary energy Use of P- & K-fertiliser
Global warming potential	CO_2, CH_4, N_2O-emission
Soil function/strain grassland of other ecosystems (N-eutrophication, acidification)	 Accumulation of heavy metals NH_3, NO_x, SO_2-emission
Water quality ground water (nitrate leaching) surface water (P-eutrophication)	 N-fertilising, N-farmgate-balance, potential of nitrate leaching, P-fertilising, P-balance, % of drained area
Human and ecotoxicity	Application of herbicides and antibiotics, potential of nitrate leaching, NH_3-emission
Biodiversity	Grassland (number of species, date of first cut), hedges & field margins (density, diversity, state, care)
Landscape image (aesthetics)	Grassland, hedges & field margins (see above), grazing animals (period, breed, alpine cattle keeping), layout of farmstead (regional type, buildings, garden)
Animal husbandry (appropriate animal welfare)	Housing system & conditions, herd management (e.g. lightness, spacing, grazing season, care)

Cederberg and Mattsson (1998) used the impact category of land use with the meaning of land consuming in a similar study comparing conventional and organic dairy farming in Sweden. Although they – as well as Cowell and Clift (1997) – mentioned that it is not sufficient to evaluate the land resource in quantitative terms because indirect effects of land use must be considered, the preservation of scenic beauty, open landscape and cultural heritage must also be taken into account. The lack of grazing ruminants preserving valuable biotopes, for example, became an important problem in Sweden. These indicators were part of the impact category 'landscape image' in the Allgäu-LCA (Table 1).

The impact category 'nuisance' (smell, noise) was not included because agricultural smell and sound are part of the rural image in rural areas and perceived indifferently by the people. Slurry can be an offensive smell, whereas hay is usually a pleasant odour. Cowbells can either bother people or calm them down. Cowbells as well as horned, in contrast to hornless, cattle were included and evaluated in the category of landscape image.

By selecting an appropriate list of impact categories and indicators, site-specific and regional aspects were integrated into the framework to fit the regional demands (e.g. typical regional layout of the farmstead, keeping of the regional dairy breed 'Brown Swiss'). The selection of suitable indicators for the impact category landscape image was based on the interests of the people in the region, for example as expressed as main characteristics in tourist information booklets ("how do people in the region see or define the region?").

Oriented on the main environmental problems in the region caused by farming, some of the impact categories are subdivided and named by the natural resource to achieve a high transparency for the local target group, for example naming water-related impact categories ground and surface-water instead of by the intended purpose 'drinking water' or impact process 'eutrophication' (of water resources).

Estimation schemes based on self-defined criteria and assumptions were used in the impact categories of biodiversity, landscape image and animal husbandry for efficiency, accessibility of data, feasibility, practicability and integration of regional aspects. The scientific background for these estimation schemes comes from the much more detailed but time-consuming methods of assessing animal welfare (Sundrum et al. 1994, Sundrum 1997) and biodiversity (Frieben 1998).

1.4 System boundaries

The geographical coverage of the Allgäu-LCA was the area of the farms. Input industry was only considered for energy and mineral fertiliser production, whereas the output industry (dairy) was not part of the assessment. A purely agricultural LCA was carried out rather than an LCA of food products by assembling agricultural and food processing processes (Cowell and Clift 1997). The environmental impact, for example the primary energy needed for constructing farm buildings, stable and machinery was not included either, because there were no differences between farms and the farming intensity expected. Considerations were restricted to the year 1997; single or rare events (e.g. every 10 years) compared with other years were excluded.

1.5 Functional units

Depending on the environmental impact and aim of the investigation, different functional units can be chosen. Most impacts of the Allgäu-LCA were referenced to the farmed area, i.e. to a hectare of grassland. Within the biodiversity (except number of species per area), landscape image and animal husbandry categories, however, the whole farm is the only meaningful unit (**Table 2**). Only abiotic categories can also be related to the livestock unit (stocking rate), that is a common comparative figure in agriculture, or to the product unit of milk (kg).

Table 2: Options of functional units of the Allgäu LCA

Indicator / Impact category	Functional unit			
	Farm	Area [ha]	Livestock [LU*]	Product [t milk]
Global impact				
Primary energy (resource use)	X	X	X	X
P-fertiliser (resource use)	X	X		X
Emission of CO_2-equivalents (global warming potential)	X	X	X	X
Regional to international impact				
Emission of SO_2-equivalents (acidification)	X	X	X	X
N-balance (groundwater) P-balance (surface water)	X	X		(X)
Local to regional impact				
Biodiversity estimation score	X	(X)		
Landscape image score	X	(X)		
Animal husbandry score	X		(X)	

*LU livestock-unit (each 500 kg live-weight of cattle)
(X) restricted, only for certain indicators possible or in general not very meaningful

However, different figures may result depending on the functional unit chosen. For example, the emission of greenhouse gases aggregated as CO_2-equivalents of the Allgäu farms is referenced to all four optional functional units (**Table 3**). Emissions related to the farm, area and livestock were calculated as much higher in intensive compared to extensive production and were lowest in organic farms. The product (milk)-related emission, however, shows advantage for extensive farming compared to the organic production because of lower milk production in the organic farms.

Table 3: Emission of CO_2-equivalents (mean, lower range) of different farming intensities depending on the functional unit chosen – impact category 'global warming potential' of the Allgäu LCA

Functional unit	Unit	Farming intensity		
		Intensive	Extensive	Organic
Farm	t	306 205-514	239 118-404	165 90-236
Area	t/ha	9.4 7.5-11.2	7.0 5.7-8.3	6.3 5.6-7.3
Livestock	t/LU*	138 88-223	129 59-252	86.5 53-113
Product (milk)	t/t	1.3 1.1-1.7	1.0 0.9-1.2	1.3 1.2-1.4

*LU livestock-unit (each 500 kg live-weight of cattle)

By relating the emission to the unit of milk produced, both the production efficiency and the environmental impact are considered. Environmental impacts on a regional or local level, which are mainly caused by agricultural production, have a strong area-related aspect. For example, the input of nitrate or phosphate in a watershed or a lake must be minimised despite the yields or production efficiency the farmers are able to achieve. Therefore, it must be carefully determined if production efficiency is an appropriate goal of a specific agricultural LCA (see Audsley et al. 1997, p. 59, Wegener Sleeswijk et al. 1996, p. 28).

Product-related figures in the Allgäu-LCA were only calculated for the use of primary energy and the emission of CO_2-equivalents, because these indicators are commonly stressed in agri-environmental discussions. In these cases, a product-related functional unit serves as an additional interpretation basis.

Product-related functional units might be appropriate for environmental impacts that contribute on a global scale (Table 2), such as global warming potential (CO_2-equivalents) and resource depletion (see Geier 2000). Due to the small share of a single farm in total national energy consumption, the emission of climatically relevant trace gases as well as the acidification and eutrophication by trace gases, according to classical product-LCA, the functional unit can be related to the product unit milk. From a national point of view, the production efficiency combined with minimising negative environmental impacts might be relevant to be focussed. However, milk production efficiency can be seen as a subordinate goal regarding improvements in environment performance because there is a surplus of milk production in the Allgäu region as well as in the European Union.

The investigated farms were all permanent grassland farms with the main product being milk, besides some beef produced. Therefore, the functional unit product can be calculated with hardly any allocation problems. However, performing a single product-LCA to compare the environmental impact of different agricultural production systems or intensities (e.g. solely wheat, Audsley et al. 1997, Gaillard and Hausheer 1997) barely allows an adequate assessment if different types of mixed and/or arable farming with or with-

out livestock keeping are investigated. Both interaction processes of production system and agri-ecosystem, as well as the arising allocation problems, are still not taken into account sufficiently.

2 Conclusions

LCA in agriculture must cover all central environmental impacts. Suggested impact categories for classical LCA's either must be adapted or cannot be applied. Particularly the term 'land use' must be specially defined. In the Allgäu-LCA, 'land use' was converted to 'landscape image', 'soil function/strain' and 'biodiversity' as separate impact categories.

The selection of appropriate functional units is essential when assessing impacts and interpreting the results, because in certain impact categories several functional units can be used. In general, in the Allgäu-LCA, the functional unit 'area' and 'farm' were used. The product-related functional unit served only in some abiotic impact categories as an additional figure when often used in the agri-environmental discussion or if international and global impacts are focussed from a national point of view. However, the functional unit product in agricultural LCA's should solely be used if a reasonable cause exists and allocation problems are satisfactorily solved, which will rarely be the case.

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