Estimation of environmental impact of conversion to organic agriculture in Hamburg using the Life-Cycle-Assessment method

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Abstract

Commissioned by the Ministry of Environment of Hamburg, Germany, an environmental impact assessment using the Life-Cycle Assessment (LCA) method was carried out during 1995 and 1996. In a scenario, the effect of a complete transition from conventional to organic agriculture of about 5,674 ha and 4,669 livestock units in a rural part of Hamburg was investigated using 9 impact categories. The study was based on the analysis of 15 farms representative of the farms in the region, mainly dairy and beef cattle farms with some cash crops, in close cooperation with local advisers and other experts. Several workshops were held to integrate the local public, in particular the experts and administrative staff related to farming and nature protection.

It was estimated for the study area for the year 1995 that through the conversion to organic agriculture, the eutrophication potential could be lowered by reducing the nitrogen (N) surplus by 75% (from 311 t to 77 t) and turning the phosphate (P) surplus of 47 t into a deficit of 19 t. The ammonia emission decreased to 69% of the conventional level (from 238 t to 165 t) resulting in a similar reduction of the acidification potential (from 474 t to 328 t SO_2-equivalents). Compared to conventional farming, 55% of the primary energy was saved by organic agriculture (38,540 instead of 84,760 GJ), which also lowered the global warming potential by 31% from 26,365 t to 18,271 t CO_2-equivalents. No pesticides were used, thus saving about 22.7 t of chemical agents. This would lead to positive effects in the impact categories drinking water quality, human toxicity and ecotoxicity, especially as most pesticides were applied illegally and not in compliance with the regulations regarding minimum distance to surface water. The biodiversity impact assessed by evaluating several indicators during field visits showed a clear improvement for arable land, permanent grassland and landscape structures (such as ditches and field boundaries). No differences were determined for the categories soil protection and landscape image due to specific site conditions and cropping system effects. The study confirmed the suitability of the LCA approach for comparing different farming systems. However, the results led to strong reactions from some experts and particularly farmers and their representatives.

1 Introduction

Environmental impairment due to agricultural production has become a crucial issue worldwide. In the European Union, the agricultural sector is responsible for a large share of the pollution of surface waters and seas by nutrients, for the loss of biodiversity, and for pesticide residues in the groundwater (EEA, 2005). Furthermore, in densely populated areas, conflicts with farmers arise due to the multipurpose functions of rural areas, e.g., drinking water catchments, impact on inner city climate and the non-agricultural use of land for housing, recreation, industry and public transport. To maintain farming in such areas, agriculture has to establish environmentally and ecologically sound production methods by fulfilling regional requirements of natural resource use in line with public values.

An appropriate approach to assess the environmental impact of agriculture is the life cycle assessment (LCA) method, which has been applied at the product, process and farm level

(Audsley et al., 1997; Bentrup et al., 2001; Cederberg and Flysjoe, 2004; Haas et al., 2001; Rossier and Gaillard, 2004; Wegener Sleeswijk et al., 1996).

In this paper, the main results of a regional LCA commissioned by the Ministry of Environment of Hamburg, Germany, carried out during 1995 and 1996 are presented (Geier et al., 1998). The main objective was to quantify the effect of a complete transition from conventional to organic agriculture in a scenario based on 15 reference farms and on local expertise and investigations. Background information, needs and opinions of the local people, experts, decision makers and administrative staff were integrated by holding regular workshops and expert discussions during all project phases. The economical, political, cultural and heritage aspects and recommendations for the decision makers, which were also part of the task list and which were intensively discussed during the workshops, are not reported in this paper.

2 Material and methods

2.1 Description of study area and farming

About 28.4% of the total area of the city state of Hamburg of 75,500 ha is farmland with farmsteads, buildings, rural roads, and greenhouses (reporting year 1994). However, since 1972, its share has decreased due to continuous growth of the urban areas and areas set aside for environmental compensation measures, e.g., farmland converted to nature protection habitats. In addition, programmes to promote low intensity agriculture have led to restrictions in farm management in some areas. The investigation took place in the south-east of the Hamburg area, in the so-called "Vier- und Marschlande", where more than half of Hamburg's farmland is located, which was used by horticulture (1,100 ha, about 900 farms) and agriculture (5,674 ha, 138 farms). Of the agricultural area, 57.7% was arable land and 42.3% permanent grassland. Mixed farms with dairy or beef cattle (82% of all animals) and cash crop production (mostly wheat, barley and rapeseed) dominated. About 3,000 family workers and 540 employed farm workers were dependent on agriculture, which was 40% of all labour in the study area. Considering all other business related to agriculture, these figures indicate the great importance agricultural production still had for the local economy in that part of Hamburg, which has an 800-year history. The share of organic agriculture in Hamburg was about 5%, which was above the average for Germany.

In other parts of Hamburg, horticulture is predominant (ornamental plants, fruits, vegetables), which in total generated 90% of the production value of Hamburg's farming sector. Another LCA compares integrated, extensified and organic apple production in one of the biggest apple orchard areas of Germany located in and around Hamburg called "Altes Land" (Geier et al., 2000).

The study area Vier- und Marschlande with loamy and clayey soils is located in an alluvial floodplain of the Elbe River delta near to where the river reaches the North Sea after passing through the city of Hamburg and its harbour. A narrow grid of ditches for drainage and irrigation characterises the study area, creating a pattern of parallel fields, which are often only 15 to 25 m wide. The typical marshland landscape is formed by, beside agricultural and horticultural land, floodplain forest areas, different types of low input grassland, set-aside orchards and swamp areas creating a species- and biotope-rich countryside. The largest nature protection area in Hamburg of about 860 ha is located here. Even larger is a water protection area, among several others in the region, of about 2,250 ha that uses 216 pumps to supply 25% of the drinking water of the city. The groundwater table in that part of the project region is artificially kept close to the soil surface to recharge the aquifer, using the ditch system for infiltration, which is therefore very vulnerable to farming impacts.

2.2 Farm interviews and scenario

The scenario was based on an analysis of 8 conventional and 7 organic farms (total acreage 569 and 517 ha, respectively). All conventional and 2 of the organic farms were located in the study area and 5 organic farms around the city of Hamburg. In addition, selected average

German agricultural production data were used, e.g., amount of nutrients excreted by livestock and fuel consumption of farm machinery. The farms were selected following suggestions made by the regional state extension agents considered as being in average representative of current agricultural practice with respect to local site conditions and farming structure in the region. In-depth investigations of the farms were conducted by interviewing the farm managers using a questionnaire. The questionnaire covered all basic agricultural production data on farm structure, methods of production, performance, quality, input and output mass flow (e.g., fodder, straw, fertiliser, cattle, milk, and diesel). Data on the nutrient matter flow analyses and fossil energy use by each farm were collected. This information was subdivided by predominant types of crop and livestock systems whenever possible and meaningful. Altogether, 32 different systems of organic and conventional farming were modelled. The number of farms for each system varied because a single farm did not use all systems. Missing data or data not available at the farms (e.g., forage yield) were supplemented by the local advisers and by using statistical data. Cross checking of data and expert and workshop evaluation of the results ensured a representative database to project the mean farm model data to the Vier- und Marschlande (Figure 1).

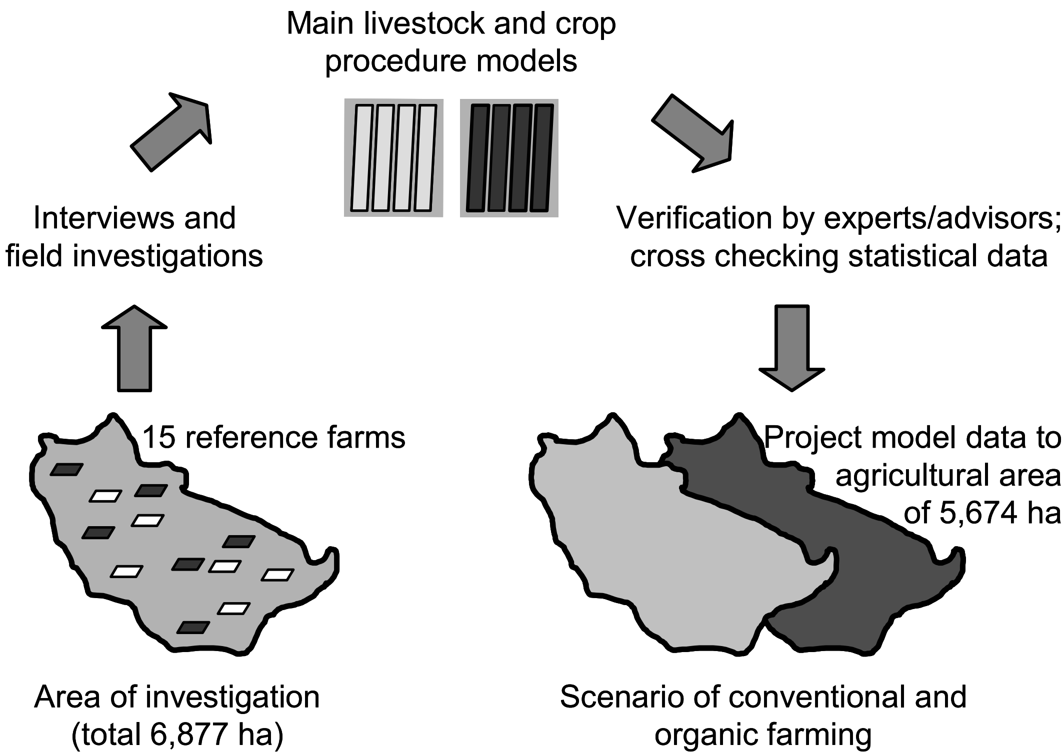

Figure 1: Working phases of the agricultural LCA scenario in the area "Vier- und Marschlande" of the city state of Hamburg

According to their importance, 6 conventional livestock production methods were derived from the reference farms. Pig fattening was assessed based on statistical extension service data, because no reliable data could be derived from the farms. Other livestock production such as sheep and poultry was negligible. Similarly, based on their relevance for the region, the conventional cropping methods were calculated. The production of rye (for bread), oats and other cereals were referred to wheat by assuming 80, 60 and 70% of the wheat intensity level (e.g., fuel consumption, fertiliser and pesticide use), respectively, whereas the environmental impact of root crops (0.7% acreage) was considered to be similar to rapeseed production.

Similar to the conventional system modelling of the organic production methods was based on the investigation of the 7 organic reference farms. Only relevant for organic farming the production method of faba beans, peas and grass/red clover forage were modelled additionally. Because of lacking data, the use of grassland in both systems was estimated mainly referring to extension service and farm management data for Germany (KTBL, 1995) and by considering reference farm production features (e.g., number of clippings).

2.3 Method and framework

Life cycle assessment (LCA) is an internationally standardized method to comprehensively evaluate all relevant environmental impacts (SETAC, 1993; ISO, 1997). Initially developed for assessing the environmental impact of industrial plants and production systems, LCA has become common in agriculture but needs to be specifically adapted (Cowell and Clift, 1997; Geier, 2000; Haas et al., 2000), e.g., according to specific impacts on soil quality, biodiversity and landscape image (OECD, 1997; Geier al., 1999). Also, because of the high public awareness of the people of Hamburg, site-specific and regional aspects were emphasized in the framework as a central part of the assigned task (e.g., drinking water protection). In Table 1 the analysed environmental impact categories and indicators are listed.

Table 1: Categories and indicators of the impact assessment of agriculture on the environment in the "Vier- und Marschlande" of Hamburg

Impact category	Environmental indicator
Eutrophication potential	N- and P-balance, NH_3-emission
Resource depletion	Use of primary energy, use of P-fertiliser
Global warming potential	CO_2-, CH_4-, N_2O-emission (in CO_2-equivalents)
Acidification potential	SO_2-, NH_3-, NO_x-emission (in SO_2-equivalents)
Drinking water protection	N-balance (nitrate contamination); pesticide use (type, amount, impact, application time, technique and regulations); germs, soil type and ground water aquifer recharge flow paths
Human toxicity (working environment)	Impact of pesticide use on farmers health
Biodiversity (incl. ecotoxicity)	Diversity of species and biotopes, endangered and typical species and plant associations, living conditions for fauna, impact of pesticide use
Landscape image (aesthetics)	Description of landscape image in environmental programmes for landscape development by the Hamburg authorities, diversity and visual effect (e.g. flowering) of crops
Soil protection	Assessment of farming effecting heavy metals, soil compaction and humus balance

The primary functional (reference) unit of the presented investigation is the agricultural area of the Vier- and Marschlande (5,674 ha), which also defines the geographical system boundary. The Ministry of Environment of Hamburg was interested in an environmental sound farming system for that region. Choosing an appropriate functional unit is a crucial task of agricultural LCAs, because the results of a comparison can be significantly influenced (Geier, 2000; Haas et al., 2000). The most common functional unit in LCAs is a product unit. Therefore some abiotic environmental impact categories were related to the livestock unit or mass unit if meaningful and possible. However, particularly in agriculture, for some local impacts a product-related unit does not allow reasonable results if the assessment is separated from the associated unit, e.g., the evaluation of the landscape image requires the reference to the area, and waterworks are only interested in low agricultural burdens on water quality and not in yield and production efficiency. Considerations are restricted to the year 1995; some statistical data were derived from earlier years (1991, 1994).

2.4 Indicators and coefficients

Based on the farm model data, nutrient balances and emission of climate- and environment-relevant trace gases were calculated for each production method using the coefficients of several references. The nutrient matter flow and the emissions of cattle were calculated by defining stable and grassland as one production unit mainly due to the lack of reliable pasture yield data. N_2-fixation was included and assumed to be 20, 40, 50, 60 and 75 kg N ha^{-1} for conventional grassland, low intensive use of meadows (only clipping) and pasture land and for organic meadows and pasture land, respectively (Ernst, 1995; Taube et al., 1995). For set-aside areas on the organic farms (usually mulching grass/clover), 100 kg N ha^{-1} were assumed to be symbiotically fixed. All other N_2-fixation data were derived from national statistics (BML, 1996).

Fuel consumption of the tractors was computed by the primary energy content and emission of diesel (GEMIS 2.1). Emissions caused by machinery use were calculated based on total operating time (e.g., tractors 3,200 h), operating time for the production method analysed (e.g., barley) and weight of machinery. The share of energy consumption for steel production was considered to be 22.7 GJ t^{-1} (GEMIS 2.1), and the mean energy (assumed to be electricity) needed for farm machinery production of 20.5 GJ t^{-1} resulted in the value 43.2 GJ t^{-1} used for farm machinery (KTBL, 1987). To this figure, 15% was added to include repairs. For example, conventionally produced barley needed 13.8 h of tractor and machinery running time per hectare and year, 57.6 kg calculative machinery mass was used and 143.5 l of diesel consumed. Other energy consumption values (e.g., heating and ventilation in swine production, milking) were similarly derived using farm management (KTBL, 1987, 1995) and emission data (GEMIS 2.1). Purchased fodder in contrast to home-grown feed was calculated by considering a lower farming intensity (75% of the calculated winter wheat production), processing (electricity) and transport energy by assuming mean transporting distances of 2,000, 400 and 100 km by ship, train and truck, respectively (KTBL, 1987; GEMIS 2.1).

Coefficients to calculate the indoor NH_3-emission covering, for example, dairy cows, breeding cattle and calves were 5.0, 5.9 and 5.0 kg NH_3-N LU^{-1} 182 $days^{-1}$, respectively, and for all grazing cattle 8.0 kg N LU^{-1} 183 $days^{-1}$ (Isermann, 1994). To estimate NH_3-N storage losses, different figures for slurry and manure were used depending on duration, e.g., for 2 and 6 months slurry losses were 5 and 8 % and manure losses 14 and 23 %, respectively. Application losses were assumed to be 25 and 15% of applied N for slurry and solid manure, respectively, and 3.7% of the applied mineral fertiliser N (Isermann, 1994).

Methane emissions of animal production were calculated for dairy cows using a formula by Kirchgessner et al. (1991) considering live weight and milk yield. For beef cattle and suckler cows including a calf up to 4 months old, 87 and 124.5 kg CH_4 yr^{-1}, respectively, based on that formula were calculated. A pig fattening stable unit, sow and horse led to emissions of 1.5, 1.5 and 18 kg CH_4 yr^{-1}, respectively (Heyer, 1994). Beside the emission due to digestion, annual methane coefficients for excrement by Heyer (1994) were used for a dairy cow (345 kg), suckler cow including calf (357 kg), beef cattle (120 kg), 1 pig fattening stable unit (59.9 kg), sow (59.9 kg) and horse (388 kg). The coefficient of the N_2O emissions was calculated by 1 kg N_2O-N ha^{-1} + 1.25% of applied or symbiotically fixed N (IPCC, 1996). The CO_2-equivalent factor 1 for CO_2, 21 for CH_4, and 270 for N_2O for the reference period of 100 years were used. The acidification potential was calculated using SO_2-equivalent factor 1 for SO_2, 0.7 for NO_x and 1.88 for NH_3 derived from Klöpfer and Renner (1995) and Patyk and Reinhardt (1997).

The impact on drinking water protection through pesticide use was estimated based on risk assessment, because water quality measurements were often not available or had not been appropriately performed by the water quality authorities regarding spraying time and type of pesticide. For the first time, practise and type of pesticide use were evaluated and projected for the region as part of the LCA to also assess the impact with respect to ecotoxicity and human toxicity. Ecotoxicity was assigned to the biodiversity impact category. Indicators of ecotoxicity were the hazard to beneficial organisms (BBA, 1995) and for other reported animal groups. Heavy metal loads were calculated based on data by Wilcke and Döhler (1995) and reported data of the local authorities.

The impacts on biodiversity and landscape image were evaluated during field visits in spring and summer 1995. The scientific basis and methods are described by Geier et al. (1998, p. 39 - 42) and Frieben (1998). In addition, local authorities and individual experts provided data from own investigations on fauna and flora in the area or statistical data. Though half of the project report captures the biodiversity and landscape image impact in detail (Geier et al. 1998), only a small part is presented in this paper, because many aspects are only site specific.

3 Results and discussion

3.1 Farming systems

Characteristic data for all conventional and organic farming systems are listed in tables 2 and 3. The reduction in crop yield after conversion to organic agriculture is highest for winter cereals (up to 47%) and lowest for forage production (20%), which can be explained by the restricted N supply inherent to the organic agriculture system. The difference in livestock performance is low for dairy, but very high for cattle production. Because conventional beef production is performed at a low intensity level and no other reason could be detected, important management deficits had to be stated. Relevance and market for organic pork was low as well as the management and feeding intensity, explaining to a certain extent the lower sow and pig performance in organic agriculture. Research and extension services at that time had just started to improve and overcome certain limits in organic pork production in general (e.g., limited specific amino-acid supply).

Table 2: Share of arable farming area and annual yield of crops and grassland in conventional and organic farming based on reference farm data in the "Vier- und Marschlande" of Hamburg (3,272 ha arable land; 2,402 ha grassland)

Crop	Conventional		Organic	
	Yield [1] [t ha^{-1}]	Share of area [%]	Yield [1] [t ha^{-1}]	Share of area [%]
Winter wheat	7.5	25.2	4.0	20
Winter barley	6.5	15.6	3.8	5
Winter rye	5.4	3.0	3.5	5
Oat	4.5	3.4	4.0	10
Spring wheat	-	0	4.0	10
Spring barley	-	0	3.8	10
Miscellaneous cereal		1.6	-	0
Winter rapeseed & root crops	3.2	20.1	2.0	5
Faba beans	-	0	2.5	5
Peas (fodder)	-	0	2.7	5
Maize for silage	10.6	5.6	-	0
Grass or grass/clover	9.5	4.5	7.6	20
Set aside [2]	-	21.0	-	5
Permanent grassland [3]	9.5	-	7.6	-

[1] Fresh matter for all except dry matter for maize and grass or grass/clover.
[2] Set aside in conventional farming only weed and voluntary crops, whereas in organic farming grass/clover was used.
[3] Intensively used (742 ha); 1,660 low intensive permanent grassland were considered to be managed similarly in both systems.

Table 3: Number of livestock units (LU) per species or type of production per annum and their annual performance in conventional and organic farming based on reference farm data in the "Vier- und Marschlande" of Hamburg (4,669 LU 1) in total for both systems)

	Conventional		Organic	
Species / type of production [performance unit in parenthesis]	Perfor-mance	Number of LU	Perfor-mance	Number of LU
Dairy cows [kg milk cow^{-1}]	6,115	1,400	5,850	1,400
Suckler cows [kg meat LU^{-1}]	244	852	-	-
Suckler cows & oxen [kg meat LU^{-1}]	-	-	134	1,440
Beef cattle [kg meat LU^{-1}] [2)]	737	587	403	1,091
Intensive beef cattle [kg meat LU^{-1}] [2)]	737	1,091	-	-
Horses (only recreation purposes)	-	426	-	426
Sows [number of young pigs 25 kg in weight LU^{-1}]	30.5	141	20.2	141
Pig fattening [kg meat LU^{-1}]	2,411	172	1,908	172

[1)] LU - livestock unit equals 500 kg live weight
[2)] Differentiation in conventional farming according to grassland area use: 1.0 and 0.32 ha for intensive and low intensive beef cattle, respectively.

According to its importance, the nutrient balance and emissions of the main production methods are presented in detail. Nutrient balance remainders of the predominant crops at the field level as well as the overall crop average indicate high surpluses in conventional farming and deficits in organic agriculture (Table 4). The balances for the livestock production models were indifferent (Table 5).

Table 4: Nutrient field balance of predominant crops and overall mean (3,272 ha including set aside) in conventional and organic farming in the "Vier- und Marschlande" of Hamburg

[kg ha^{-1} yr^{-1}]	Nitrogen	Phosphorus	Potassium
Conventional mean [1)]	*86.4*	*15.7*	*94*
Winter wheat	125	24	149
Winter barley	148	28	162
Winter rapeseed	93	9.2	126
Organic mean [1)]	*-17.7*	*-4.0*	*-25.3*
Winter wheat	-1.2	5,2	44
Spring cereal [2)]	-24	-2.5	15
Grass/clover	-95	-23	-196

[1)] Mean of all crops including set aside related to total arable area
[2)] Mean of wheat, barley and oat.

Table 5: Nutrient stable-grassland unit balance of the predominant types of livestock and overall mean (4,669 LU) in conventional and organic farming in the "Vier- und Marschlande" of Hamburg

[kg LU^{-1} yr^{-1}] [1)]	Nitrogen	Phosphorus	Potassium
Conventional mean [2)]	*57.1*	*1.2*	*-18.2*
Dairy cows	69.6	2.0	-3.1
Suckler cows [3)]	31.5	-3.4	-23.9
Intensive cattle	60.7	-0.4	-10.7
Low intensive cattle	30.2	-8.3	-68.3
Organic mean [2)]	*39.2*	*0.8*	*3.7*
Dairy cows	56.4	1.0	31.2
Suckler cows & oxen	22.2	-3.7	-24.8
Beef cattle	42.7	1.0	11.5

[1)] LU - livestock unit equals 500 kg live weight
[2)] Mean of total livestock in the area
[3)] Including calves until 4 months of age

The main reason for high nutrient surpluses in crop production in conventional farming was the use of mineral fertiliser without proper assessment of the amount of N applied via manure, as shown by the winter wheat data set (Table 6). In arable production (2,583 ha) and intensive grassland (742 ha), 160 and 171 kg ha^{-1} N fertiliser were used, respectively. Mean stable output of excrement and bedding material N was 102 kg N per LU (gross, NH_3 losses not deducted). To arable land, 94 kg N ha^{-1} of manure in conventional farming were applied (volatile losses of about 36 kg NH_3-N LU^{-1} already deducted).

Table 6: Nutrient balances of winter wheat in conventional (conv.) and organic farming (org.) in the "Vier- und Marschlande" of Hamburg

[kg ha^{-1} yr^{-1}]	Nitrogen		Phosphorus		Potassium	
	Conv.	Org.	Conv.	Org.	Conv.	Org.
Manure	144.0	90.8	37.5	24.4	198.0	113.4
Mineral fertiliser	165.3	0	23.1	0	91.6	0
Input total	*309.3*	*90.8*	*60.6*	*24.4*	*289.6*	*113.4*
Grain	144.6	72.0	26.8	14.0	36.0	19.9
Straw	39.8	20.0	9.5	5.2	105.1	49.8
Output total	*184.4*	*92.0*	*36.3*	*19.2*	*141.1*	*69.7*
Balance remainder	*124.9*	*-1.2*	*24.3*	*5.2*	*148.5*	*43.7*

As shown in Table 7, the main livestock system dairy production did not show similar higher surpluses in conventional farming for N and P, and was even negative for potassium (K), whereas the organic dairy balance indicated a K surplus. Though mineral fertilisers were only used in conventional farming, similarly high N and K surpluses occurred in both systems as a function of high amounts of nutrients that were imported via purchased feed.

Table 7: Nutrient balances of the dairy stable-grassland unit in conventional (conv.) and organic farming (org.) in the "Vier- und Marschlande" of Hamburg

[kg LU^{-1} yr^{-1}] [1)]	Nitrogen		Phosphorus		Potassium	
	Conv.	Org.	Conv.	Org.	Conv.	Org.
N_2-fixation	19.3	23.7	-	-	-	-
Mineral fertiliser	49.6	-	6.5	-	15.8	-
Purchased feed	41.4	19.4	6.2	2.8	16.7	5.8
Purchased regional feed [2)]	18.5	55.3	2.8	6.4	17.0	54.7
Straw	4.4	3.4	0.8	0.9	8.3	4.3
Animals	0.5	-	0.1	-	0.1	-
Input total	*133.7*	*101.8*	*16.4*	*10.1*	*57.9*	*64.8*
Manure	30.6	20.1	7.5	4.4	44.2	25.1
Sold manure	6.6	-	2.0	-	9.8	-
Milk, calves and culled cows	26.9	25.3	4.9	4.7	7.0	8.5
Output total	*64.1*	*45.4*	*14.4*	*9.1*	*61.0*	*33.6*
Balance remainder	*69.6*	*56.4*	*2.0*	*1.0*	*-3.1*	*31.2*

[1)] LU - livestock unit equals 500 kg live weight
[2)] Purchased within the project region, mainly roughage.

Use of fossil energy and emission of trace gases in conventional crop production were more than double those in organic farming (Table 8). In particular, the production of mineral N fertiliser is energy intensive, emitting large amounts of CO_2. Data derived for the cereal crops in both systems match average data calculated for Germany by Bockisch et al. (2000), Haas and Köpke (1994) and Haas et al. (1995), but are lower for conventional winter rapeseed and higher for organic grass/clover.

Table 8: Annual area-related abiotic environmental impact of predominant crops in conventional and organic farming in the "Vier- und Marschlande" of Hamburg (3,272 ha arable land)

	Fossil energy use	Global warming potential	Ammonia emission [1)]	Acidification
	[GJ ha^{-1}]	[t CO_2-equiv. ha^{-1}]	[kg NH_3 ha^{-1}]	[kg SO_2-equiv. ha^{-1}]
Conventional mean [2)]	*12.22*	*2.80*	*20.7*	*44.1*
Winter wheat	17.88	3.87	33.6	70.9
Winter barley	16.32	3.62	32.9	68.7
Winter rapeseed	12.68	2.93	17.1	37.2
Organic mean [2)]	*4.95*	*1.20*	*9.8*	*21.3*
Winter wheat	6.18	1.32	17.3	36.0
Spring cereal [3)]	5.05	1.03	12.6	26.6
Grass/clover	6.13	1.47	0	3.5

[1)] Ammonia emission due to manure, slurry and mineral fertiliser application
[2)] Mean of all crops including set aside related to total arable area
[3)] Mean of oat, wheat and barley

Fossil energy use in livestock production was also higher in conventional farming, mainly due to the mineral N fertiliser applied to grassland. However, because methane emissions were similar, the difference in global warming potential was smaller than in crop production (Table 9). Differences in ammonia emission and therefore acidification potential can be observed in crop and livestock production, because of a longer grazing time, shorter manure storage and no use of mineral N fertiliser on the organic farms.

Table 9: Annual livestock-unit (LU) -related abiotic environmental impact of predominant types of livestock-grassland units in conventional and organic farming in the "Vier- und Marschlande" of Hamburg (4,669 LU)

	Fossil energy use [GJ LU^{-1}]	Methane emission [kg CH_4 LU^{-1}]	Global warming potential [t CO_2-equiv. LU^{-1}]	Ammonia emission [kg NH_3 LU^{-1}]	Acidification [kg SO_2-equiv. LU^{-1}]
Conventional mean [2]	*9.59*	*92.1*	*3.68*	*36.5*	*70.7*
Dairy cows	12.61	107.5	4.54	37.6	75.5
Suckler cows [3]	7.97	126.2	4.18	37.7	75.2
Intensive beef cattle	8.51	92.8	3.33	40.4	80.5
Beef cattle	8.16	92.8	3.87	33.7	67.4
Organic mean [2]	*4.79*	*93.7*	*3.07*	*28.5*	*55.5*
Dairy cows	6.39	128.1	3.91	30.1	58.7
Suckler cows & oxen	2.76	97.9	3.00	22.1	43.1
Beef cattle	4.76	92.8	3.24	36.6	71.1

1) LU - livestock unit equals 500 kg live weight
2) Mean of total livestock in the area
3) Including calve until 4 months of age

Even the product-related environmental impacts on winter wheat and milk indicate a superior performance of organic agriculture in all listed categories, though yields were lower (Table 10). Similar relationships were obtained and are cited by Bockisch et al. (2000) and Haas et al. (1995) for fossil energy use of wheat and are reported by Cederberg and Flysjoe (2004), De Boer (2003) and Haas et al. (2001) for certain milk-related environmental impacts, however, for dairy farms in total.

Table 10: Product-related abiotic environmental impact of winter wheat and dairy-grassland production in conventional (conv.) and organic farming (org.) in the "Vier- und Marschlande" of Hamburg

		Winter wheat		Milk	
	Unit	Conv.	Org.	Conv.	Org.
N balance	g N kg^{-1}	16.65	-0.302	11.37	9.637
P balance	g P kg^{-1}	3.242	2.605	0.334	0.162
Fossil energy use	MJ kg^{-1}	2.384	1.546	2.062	1.092
Global warming	kg CO_2-eq. kg^{-1}	0.516	0.330	0.567	0.449
Ammonia emission	g NH_3 kg^{-1}	4.486	4.333	6.157	5.144
Acidification	g SO_2-eq. kg^{-1}	9.453	9.004	12.35	10.04

3.2 Scenario

Individual farming system models were projected to the total farming area of the Vier- und Marschlande with 138 farms. Because livestock production formed an essential part of farming in the region and investments in housing systems were made, the number of livestock units was kept at the same level. Only the type of beef production was varied (Table 3). In general, livestock production density in organic compared to conventional farming is lower in Germany (Haas, 2005), but in the study area the density was already comparably low (0.82 LU ha^{-1}). At the conventional and organic farms, livestock density was 0.66 and 0.53 LU ha^{-1}, respectively. Spectrum and acreage of crops had to be changed for the organic agriculture scenario (Table 2), because crop yields were lower and system-immanent needs had to be considered, e.g., among others fulfilling the amount of home-grown feed needed, ensuring sufficient N supply via legume N_2-fixation, weed control and nutrient management aspects (higher share of spring instead of winter cereals). As a consequence, organic forage production on arable land was extended at the expense of cash crop acreage. The total organic cereal (-54%) and beef (-45%) production was half that in conventional farming in contrast to almost similar amounts of milk (Table 2), which was not representative for Germany, indicating a deficit of management skills.

Projecting the nutrient-balance data of each system to the farmed area of the Vier- und Marschlande, a regional nutrient balance was calculated (Table 11). The N surplus in conventional farming was twice as high as in the organic scenario. In organic agriculture, the P and K balances indicate a slight deficit. The N surplus in conventional farming was as high as the N input via mineral fertiliser, indicating an inefficient use, though higher yields and therefore nutrient outputs were achieved. No straw or roughage was imported from outside the study area. Therefore, in organic agriculture only a small amount of nutrients was imported via purchased feed (e.g., concentrates).

Table 11: Regional nutrient balance scenario of conventional (conv.) and organic farming (org.) in the "Vier- und Marschlande" of Hamburg (5,674 ha, 4,669 LU 1) in the year 1995)

[kg ha^{-1}]	Nitrogen		Phosphorus		Potassium	
	Conv.	Org.	Conv.	Org.	Conv.	Org.
N_2-fixation	15.4	44.2	-	-	-	-
Mineral fertiliser	95.0	-	14.3	-	50.2	-
Purchased feed	25.8	7.7	5.2	1.7	9.8	2.6
Animals	2.7	0.5	0.7	0.1	0.2	0.1
Atmospheric deposition	15.6	15.6	-	-	-	-
Input total	*154.5*	*68.0*	*20.2*	*1.8*	*60.2*	*2.7*
Sold crops	42.4	14.3	8.9	2.9	11.0	4.3
Sold animals	15.3	11.0	3.1	2.2	3.0	3.5
Output total	*57.7*	*25.3*	*12.0*	*5.1*	*14.0*	*7.8*
Balance remainder	*96.8*	*42.7*	*8.3*	*-3.3*	*46.2*	*-5.1*

[1)] LU - livestock unit equals 500 kg live weight

According to recommendations given by scientific organisations involved in water quality issues, a surplus of 50 and 5 kg ha^{-1} N and P, respectively, should not be exceeded in Germany (DVWK, 1995). However, in conventional farming in the study area as well as on average for Germany in 1995 it still was 111 N kg ha^{-1}, 11 P kg ha^{-1} and 29 K kg ha^{-1} (Bach and Frede, 1998). Deficits for P and K in organic agriculture indicate that there is no environmental impairment (e.g., eutrophication). Mean P and K balances close to zero in organic agriculture are likewise reported in other investigations (Bengtsson 2005; Haas, 1995; Haas et al., 2001; Watson et al., 2002). After converting to organic agriculture, no fertilisation is needed for many years if previous conventional farming caused nutrient-rich soils, which still is often the case in many European countries (Tunney et al., 2003).

Table 12: Regional environmental impact scenario comparing conventional and organic farming in total amounts of the "Vier- und Marschlande" of Hamburg (5,674 ha, 4,669 LU in the year 1995)

Impact category	Environmental indicator	Reduction of ... if organic
Eutrophication potential	N-surplus without NH_3-emission P-balance NH_3-emission	75%: from 311 t to 77 t: from surplus of 47 t to a deficit of 19 t 31%: from 238 t to 165 t
Resource depletion	Energy use P-fertiliser use	55%: from 84,760 to 38,540 GJ 100%: from 81.1 t
Global warming potential	CO_2-equivalents (CO_2-, CH_4-, N_2O-emission)	31%: from 26,365 t to 18,271 t
Acidification potential	SO_2-equivalents (SO_2-, NH_3-, NO_x-emission)	31%: from 474 t to 328 t
Drinking water protection	N-surplus (to estimate nitrate contamination) Pesticide use	75%: from 311 t to 77 t 100%: from 22.7 t, no risk of contaminating any water body
Human toxicity (working environment)	Pesticide use	No risk of contamination for farmers
Biodiversity (incl. ecotoxicity)	Typical species diversity of biotopes, number of endangered species, endangered and typical plant associations, living conditions for fauna, pesticide use	Arable land: clear improvement Grassland: improvement Structures (ditches and boundaries): clear improvement
Landscape image (aesthetics)	Local landscape image description, diversity and visual effect of crops	No difference between organic and conventional
Soil protection	Accumulation of heavy metals, soil compaction, humus balance	No difference between organic and conventional farming

Resuming all environmental impacts investigated, converting to organic agriculture can improve farming effects or reduce emission in 7 of 9 impact categories (Table 12). Beside the quantitative indicators already presented in detail, 22.7 t of pesticides could be saved. On average, the amount of pesticides used in conventional farming was 7, 5 and 2 kg ha^{-1} annually for cereal (wheat and barley), rapeseed and maize, respectively. According to own investigations, conventional farmers did not care about the regulation concerning minimum distances to surface water when spraying pesticides (usually 10 to 20 m for 75 and 15%, respectively, of all pesticides used), which was also the case in other parts of Germany (Fischer 1996). For example, the application of herbicides in winter cereals was not allowed within a 20-m distance to surface water. Similar to pesticide use, for mineral fertiliser and manure application a minimum distance of 5 m was recommended. Because average field width in the study area was only 15 to 30 m, while the average width of the pesticide sprayer was 12 m, spraying itself was already illegal and there was a high risk of water contamination for all applied fertilisers and manure. The risk of germ contamination of surface water due to grazing animals could also not be prevented, since excrement dropping always occurs, at least when the animals drink ditch water. Within the water protection area of 2,250 ha used for drinking water pumping, there were 800 km of ditches for recharging the aquifer, indicating a very vulnerable area. As more surface water analyses by the local authorities were performed specifically looking for the pesticide agents applied during this study, as more findings were realised. With respect to ecotoxicity, completely avoiding the use of pesticides in organic agriculture would also be positive for the environment, because 90% of the active agents were harmful to algae, fish and other water fauna.

Though the N surplus of 96.8 kg ha^{-1} in conventional farming (Table 11) indicated a high nitrate leaching potential, nitrate concentration in the upper aquifer was low. Due to high soil organic matter, loamy and clayey soils, often anaerobic conditions because of a high groundwater table close to the soil surface, high denitrification rates and buffering capacity by incorporating N in the soil were assumed but not calculated.

Organic agriculture showed improvements compared to conventional farming in all three investigated areas of biodiversity (Table 12). In 9 pairs of organic and conventional cereal fields, a higher abundance and total number of wild plant species numbering 53 and 22 within the fields and 59 and 36 on the field boundaries were detected, respectively. Medians were 19 and 4 within the fields and 22 and 9 on the field boundaries, respectively. The number of typical companion weed plants was also clearly higher in organic farming including some endangered species only found here. The main reasons for the differences were assumed to be a higher diversity of crops, longer periods without tillage (mainly when growing grass/red clover), lower N supply and no pesticides in organic agriculture, favouring a higher diversity of wild plants. A very rich diversity of flowering plants could be detected within 90% of the investigated organic crop fields, whereas in conventional fields this was very poor.

The same relationship was detected when comparing permanent grassland, where amongst others, in organic agriculture the species richness of herbs and legumes was twice that of conventional grassland. Habitat conditions in field boundaries particularly along the narrow grid of ditches were also positively affected by organic land use, mainly due to the non-use of pesticides. In all fields and field boundaries, living space for the fauna were also secured and enhanced in organic agriculture due to the higher number of diverse inner-field and field-margin habitats. A clear superior biotic performance of organic compared with conventional farming is also frequently reported in other investigations (reviews by Azeez, 2000; Frieben and Köpke, 1996; Hansen et al., 2001).

In two impact categories, i.e., landscape image and soil protection, no difference were detected between the farming systems. The marshland structure of the area was determined by the placement of fields and the ditch grid. The aspects of landscape image depending on farming were positive in conventional farming due to the high share of yellow flowering rapeseed and in organic farming due on the one hand to the higher percentage of flowering wild herbs in the arable and permanent grassland fields and on the other to the diverse crop rotation. No differences concerning humus balances could be determined, because both farming systems had the same livestock density and solid dung management. The differences in soil compaction potential were only small due to a very low share of problematic row crops (e.g., sugar beet, maize and potatoes), which are often harvested with heavy machinery in autumn when the soils are wet. Sewage sludge and other municipal waste were not used. Heavy metal input due to mineral P fertiliser in conventional farming were negligible (48 g ha^{-1} yr^{-1} of Cd, Cr, Cu, Ni and Pb) compared to the calculated and reported high loads of annually 143 t of heavy metals in the atmospheric deposition of 40,880 t dust for total Hamburg (in average 1.9 kg ha^{-1} yr^{-1}) caused by local commercial and municipal emitters and the transport sector.

4 Conclusions

The LCA approach was suitable to efficiently and comprehensively compare the environmental effects of organic and conventional farming on a regional level. The scenario of a complete conversion of the region Vier- und Marschlande led to considerable environmental improvements compared to the ongoing conventional agriculture, but total product output was significantly lower (particularly for cereal and beef). However, in congested urban areas, the ecological effects of agriculture are in principle the most favourable compared to any other typically irreversible urban use of former cultivated land.

The LCA results and recommendations derived caused strong reactions from the farmer organisations in Hamburg for several reasons. Farmers in urban areas are under permanent pressure through urban sprawl. The clear results of the LCA were interpreted as another threat, particularly the finding that farmers do not follow pesticide spraying regulations (i.e., minimum distances to surface water). Many participants involved in the study found it difficult to accept environmental impact assessment results that did not consider economical aspects simultaneously. Thus, to overcome the already existing conflicts between the farming and the nature protection parties, the farmers, extension agents and Hamburg authorities could not sufficiently be supported, despite the numerous workshops. However, discussions in Hamburg are now based on scientifically derived facts and data including recommendations also considering economic and social aspects.

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