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Environmental Sustainability Assessment of Pig Farms in Selected European Countries: Combining LCA and Key Performance Indicators for Biodiversity Assessment

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Supplementary Material Table S1. Abbreviations.

	Abbreviation
carbon dioxide equivalents	CO_2-eq
sulphur dioxide equivalents	SO_2-eq
phosphor equivalents	P-eq
nitrogen equivalents	N-eq
Life Cycle Assessment	LCA
Key Performance Indicator	KPI
breeding unit	BU
finishing unit	FU
fossil energy depletion	FED
global warming potential	GWP
acidification potential	AP
fresh water eutrophication potential	FEP
marine water eutrophication potential	MEP
Genetic diversity	GD
Speciec diversity	SD
Ecosystem diversity	ED
megajoule	MJ
body mass net sold	BMNS

Supplementary Material Table S2. Farm-specific primary (foreground) data used for LCA calculations.

Category	Farm-Specific Data
Farm size and productivity numbers	Average number of sows (n) Average number of places for weaners/finishers (n) Number of litters per sow and year (n) Number of piglets born per sow and year or per litter (n) Number of piglets weaned per sow and year or per litter (n) Replacement rate of sows (%) Mortality rate of sows, suckling piglets, weaners and finishers (%)
Bought-in pigs	Number and weight of weaners, gilts/sows, as appropriate (n)
Sold pigs	Number and weight of weaners, finishers, gilts and sows, as appropriate (n)
Feed management	Composition of feed (% of each feed component in feed) Amount of feed used per pig and day (kg d^{-1}) Number of days in each production phase (d) Feed conversion ratio of weaners and finishers (if available, otherwise calculated; kg feed * kg live $weight^{-1}$) Average daily gain of weaners and finishers (if available, otherwise calculated; g d^{-1}) Area and yield of home-grown feed components (area, kg ha^{-1}) For home-grown feed: amount of nitrogen and phosphate fertilisers per ha (kg ha^{-1})
Manure management	Proportion of slurry/farmyard manure (%) Proportion of pigs that have access to pasture (%) Proportion of slurry covered and type of cover (roof, foil, tent, natural crust and concrete cover) (%) Proportion of farmyard manure composted (%) Proportion of manure dispatched or digested in a biogas plant outside the farm (%)
Bedding material	Amount of straw per sow and year and per weaner/finisher place (kg sow^{-1}/kg $place^{-1}$)
Electric energy	Total amount of kilowatt hours used (kWh y^{-1}) Percentages used in breeding and finishing unit (for breeding-to-finishing farms; %)

Supplementary Material Table S3. Composition of compound feed.

	Ingredients (%)									
	Corn	**Soybean meal (48)**	**Soybean meal (44)**	**Rapeseed meal**	**Sunflower seed meal**	**Wheat**	**Barley**	**Regional Soy cake**	**Fava beans**	**Peas**
Piglet feed CONVENTIONAL	60	9	1	10	10	10				
Piglet feed REGIONAL with European soybean meal	60	9	1	10	10	10				
Piglet feed ORGANIC	15					28	22	15		20
Growing pig / lactating sow feed CONVENTIONAL	50	7	3	10	9	9	12			
Growing pig / lactating sow feed REGIONAL with European soybean meal	50	5		10	10	10	15			
Growing pig / lactating sow feed ORGANIC	15					28	26	15		16
Finishing feed CONVENTIONAL	50	3	5	10	9	10	13			
Finishing feed REGIONAL with European soybean meal	50	2	5	10	9	10	14			
Finishing feed ORGANIC	15					35	30	10		10
Gestating/empty sow feed CONVENTIONAL				5	5	20	70			
Gestating/empty sow feed REGIONAL				5	5	20	70			
Gestating/empty sow feed ORGANIC						30	50	1		19
Protein mix CONVENTIONAL (30% CP, 12.5 MJ ME)	30	50	10	5	5					
Protein mix REGIONAL (30% CP, 12.5 MJ ME) with European soybean meal	30	50	10	5	5					
Protein mix ORGANIC (30% CP, 12.5 MJ ME)							30	50	20	

CP = crude protein, MJ ME = megajoule metabolisable enerergy.

Supplementary Material Table S4. Impact factors of bought-in feed components.

Unit per kg BMNS		FED MJ	GWP CO_2-eq.	AP SO_2-eq.	FEP P-eq.	MEP N-eq.
Bought-in feed components 1 (conventional)			***10^{-1}**	***10^{-3}**	***10^{-5}**	***10^{-4}**
barley	Ecoinvent	4.5	5.2	4.8	12.4	95.2
maize (CCM)	Ecoinvent	2.9	3.5	3.7	13.9	26.4
maize (corn)	Ecoinvent	5.0	5.5	5.3	21.7	37.9
horse/faba been	Ecoinvent	2.1	3.9	1.4	14.9	98.5
lucerne (alfalfa) and forage (incl. grassland) AS SILAGE	Ecoinvent	1.5	3.2	3.1	8.4	135.9
pseudo cereals, e.g. sorghum	Ecoinvent	4.5	5.2	4.8	12.4	95.2
oats	Ecoinvent	4.6	7.0	11.1	56.8	450.4
protein peas	Ecoinvent	2.1	3.5	2.6	15.9	83.2
rye	Ecoinvent	5.2	6.4	5.0	19.3	154.7
soybean	Ecoinvent	14.5	37.2	3.0	22.6	83.0
triticale	Ecoinvent	5.7	8.9	10.1	32.1	139.7
wheat	Ecoinvent	5.5	7.0	7.6	54.2	76.7
other feed	[average of Ecoinvent data sets]	4.8	8.0	5.2	23.7	123.1
Bought-in feed components 1 (organic)			***10^{-1}**	***10^{-3}**	***10^{-5}**	***10^{-4}**
Organic barley	Ecoinvent	2.3	2.9	11.6	13.9	182.1
Organic maize/corn	Ecoinvent	1.0	2.8	10.3	9.0	104.2
Organic wheat	Ecoinvent	2.5	3.4	14.8	14.7	214.0
Organic protein peas	Ecoinvent	2.8	5.5	13.2	18.3	150.6
Organic faba beans	Ecoinvent	2.0	5.4	11.4	15.0	157.5
Bought-in feed components 2 (conventional)			***10^{-1}**	***10^{-3}**	***10^{-5}**	***10^{-4}**
HP soybean meal (extracted)	Ecoinvent	11.2	24.5	3.1	18.5	61.7
soy cake Europe	Agribalyse	2.2	1.8	1.6	52.3	75.6
soybeans (toasted) Europe	Agribalyse	2.1	2.6	2.4	50.0	94.9
rapeseed meal (extracted)	Ecoinvent	3.8	4.4	7.1	11.8	64.4
sunflower meal (extracted)	Ecoinvent	2.3	3.3	2.8	7.2	81.3
distillers dry grains with solubles	Agribalyse	3.1	3.4	5.4	10.5	39.7
fish meal	Agri-footprint	10.4	8.2	4.5	0.2	22.0
yeast	Ecoinvent	9.6	15.1	7.6	22.7	66.4
potatoe protein	Agribalyse	8.5	9.9	16.0	26.6	144.7
whey	Ecoinvent	0.9	1.5	0.8	2.0	7.5
milk powder	Agribalyse	74.8	153.1	110.8	113.0	2062.0
minerals	Ecoinvent & Agribalyse	8.7	7.1	6.0	81.5	8.2
wheat middlings	Agribalyse	4.6	5.0	8.9	16.7	65.9
(wheat) bran	Agribalyse	5.1	5.3	9.0	17.0	66.5
fibre mix	Ecoinvent	1.4	2.0	3.1	6.3	32.1
beet pulp, dry	Ecoinvent	5.0	4.6	10.2	12.4	49.6
potatoe pulp	Ecoinvent & Agribalyse	6.1	4.9	5.8	17.9	52.8
animal fat	Ecoinvent & Agri-footprint	13.1	7.0	1.1	3.6	5.7
(old) bread	Agri-footprint	4.3	5.5	6.0	42.7	60.5
whole / maize corn silage	Ecoinvent	0.4	0.5	1.0	1.8	12.6
Corn cob mix CCM	Ecoinvent	2.9	3.5	3.7	13.9	26.4
alfalfa-hay meal/pellets	Ecoinvent	29.7	8.1	4.4	22.1	192.6
soybean/rapeseed oil	Agribalyse	22.9	41.2	20.1	53.3	226.0
other feed	[average of Ecoinvent, Agribalyse and Agri-footrpint data sets]	5.0	5.0	5.4	17.0	61.7

BMNS = body mass net sold. FED = fossil energy depletion; GWP = global warming potential; AP = acidification potential; FEP = fresh water eutrophication potential; MEP = marine eutrophication potential. MJ = megajoule; CO2-eq = carbon dioxide equivalents; SO2-eq = sulphur dioxide equivalents; P-eq = phosphorous equivalents; N-eq = nitrogen equivalents.

Supplementary Material Table S5. Impact factors of bought-in compound feed.

		FED	GWP	AP	FEP	MEP
Unit per kg BMNS		MJ	CO_2-eq.	SO_2-eq.	P-eq.	N-eq.
Compound feed			***10^{-1}**	***10^{-3}**	***10^{-5}**	***10^{-4}**
Piglet feed CONVENTIONAL	Calculated mixtures	5.3	7.2	5.2	22.2	51.1
Piglet feed REGIONAL	of feedstuffs using	4.5	5.5	5.6	25.3	54.9
Piglet feed ORGANIC	Ecoinvent, Agri-	1.9	4.4	11.8	13.6	157.8
Growing pig / lactating sow feed CONVENTIONAL	balyse and Agri-	5.2	7.2	5.2	20.9	57.2
Growing pig / lactating sow feed REGIONAL	footrpint data sets	4.5	5.4	5.5	22.5	60.4
Growing pig / lactating sow feed ORGANIC		1.6	3.2	9.7	10.9	132.5
Finishing feed CONVENTIONAL		5.1	6.8	5.3	21.2	57.7
Finishing feed REGIONAL		4.5	5.4	5.5	23.3	60.6
Finishing feed ORGANIC		2.2	3.2	11.7	17.7	167.8
Gestating/empty sow feed CONVENTIONAL		4.5	5.4	5.4	20.5	89.2
Gestating/empty sow feed REGIONAL		4.5	5.4	5.4	20.5	89.2
Gestating/empty sow feed ORGANIC		2.4	3.5	12.8	15.4	184.6
Protein mix CON: 30% CP, 12.5 MJ ME		8.5	16.8	3.9	18.6	55.7
Protein mix REGIO: 30% CP, 12.5 MJ ME		4.0	6.4	6.0	37.1	78.0
Protein mix ORGANIC: 30% CP, 12.5 MJ ME		2.1	2.9	6.6	33.3	124.0

BMNS = body mass net sold. FED = fossil energy depletion; GWP = global warming potential; AP = acidification potential; FEP = fresh water eutrophication potential; MEP = marine eutrophication potential. MJ = megajoule; CO2-eq = carbon dioxide equivalents; SO2-eq = sulphur dioxide equivalents; P-eq = phosphorous equivalents; N-eq = nitrogen equivalents.

Supplementary Material Table S6. Characteristics of the agricultural fields managed by the pig farmers.

	Breeding Farms			**Breeding-to-Finishing Farms**			**Finishing Farms**		
	Q25	**M**	**Q75**	**Q25**	**M**	Q75	Q25	M	Q75
Total number of farms		**13**			**27**			**23**	
Farms with agricultural land[1] (n)		9			26			21	
Area (ha)	35	80	120	51	86	170	28	53	88
Farms with arable land (n)		9			24			21	
Area (ha)	35	80	119	51	84	142	28	44	82
Farms growing own pig feed (n)	4				21			12	
Area (ha)	32	52	88	30	50	100	29	45	71

[1]including arable land and grass land. n = number; Q25 = lower quartile, M = median, Q75 = upper quartile.

Supplementary Material Table S7. Scaled Key-Performance-Indicators.

Values of KPI to assess biodiversity. Values are between 0 (worst/lowest) and 100 (highest/best value).

	Breeding Farms			**Breeding-to-Finishing Farms**			**Finishing Farms**		
n farms		9			26			21	
	Q25	M	Q75	Q25	M	Q75	Q25	M	Q75
Cultivating and harvesting crops on riparian strips	0	100	100	0	100	100	100	100	100
Access of animals to surface water bodies and/or riparian strips	100	100	100	100	100	100	100	100	100
On-farm cultivation of GMO crops	100	100	100	0	100	100	0	100	100
Feeding GMO crops	0	100	100	0	0	100	0	0	100
High precision application of nitrogen (N) fertiliser	0	0	0	0	0	100	0	0	100
Amounts of nitrogen (N) fertiliser abased on demand on soil- or plant analyses	0	100	100	0	100	100	0	100	100
P- and K-fertilisers amounts based on the results of soil or plant analysis	100	100	100	50	100	100	100	100	100
Proportion of agricultural land with chemical synthetic pesticides	15	70	100	0	0	100	0	20	100
Average pesticide treatment frequency	50	50	50	50	50	50	50	50	50
Calculation of humus balances for farmland	0	0	0	0	0	0	0	0	0
Arable land with leguminous crops or leguminous grassland	0	10	40	0	0	2	0	7	26
Conversion of substantial proportion of permanent grassland or pasture to arable land in the past 20 years	0	100	100	90	100	100	100	100	100
Cultivating catch crops	0	5	25	4	25	40	0	13	33
Ecological focus areas	0	0	13	0	0	8	0	0	8
Agricultural land on drained moorland	100	100	100	100	100	100	100	100	100
Growing rare or endangered agricultural crops	0	0	0	0	0	0	0	0	0
Woodland on farm	3	43	95	0	17	63	0	9	43
Woodland deforested and converted to grassland, arable land or buildings in the past 20 years	100	100	100	100	100	100	100	100	100

n = number; M = median, Q25 = lower quartile; Q75 = upper quartile.

Supplementary Material Table S8. Spearman correlations (r_s) between environmental impacts calculated using LCA (rows) and the biodiversity theme and its three sub-themes (ecosystem, species and genetic diversity; columns) for breeding units and finishing units of crop-livestock farms. No correlation was significant ($p < 0.05$).

		Sub-Theme			Theme
		Ecosystem diversity	**Species diversity**	**Genetic diversity**	**Biodiversity**
Breeding units (n)		35	35	35	35
Fossil energy depletion	MJ	−0.23	−0.17	−0.04	−0.10
Global warming potential	kg CO_2-eq	−0.21	−0.12	−0.02	−0.07
Acidification potential	g SO_2-eq	0.08	0.11	0.24	0.18
Fresh water eutrophication potential	g P-eq	−0.10	−0.01	0.10	0.05
Marine eutrophication potential	g N-eq	0.12	0.16	0.36	0.32
Finishing units (n)		47	47	47	47
Fossil energy depletion	MJ	0.10	0.12	0.20	0.17
Global warming potential	kg CO_2-eq	0.15	0.16	0.23	0.19
Acidification potential	g SO_2-eq	0.04	0.06	0.21	0.13
Fresh water eutrophication potential	g P-eq	0.17	0.19	0.22	0.22
Marine eutrophication potential	g N-eq	0.19	0.16	0.27	0.23

n = number; r_s = spearman rank correlation coefficient.