Potential of LCA for designing technological innovations – the case of organic eggs.

S.E.M. Dekker[1]
I.J.M. de Boer[2]
A.J.A. Aarnink[3]
P.W.G. Groot Koerkamp[1, 3]

[1] *Farm Technology Group, Wageningen University and Research Centre,*
P.O. box 17 6700 AA Wageningen The Netherlands
[2] *Animal Production Systems Group, Wageningen University and Research Centre*
P.O. Box 338 6700 AH Wageningen The Netherlands
[3] *Animal Sciences Group Wageningen University and Research Centre*
P.O. Box 65 8200 AB Lelystad The Netherlands
Email address: sanne.dekker@wur.nl

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Abstract
Ecological sustainability in agriculture is a concept that contains various environmental problems, which are caused by emission of pollutants and unsustainable use of limited resources, during different processes along the food chain. Technological innovations may help to improve ecological sustainability of food products. Preceding to the development of ecological sustainable technological innovations three questions need to be answered; 1) how ecological sustainable is the current production process, 2) which processes in the chain causes the highest ecological impact and 3) which production parameters significantly affect the ecological impact of these processes? The aim of this research is to demonstrate Life Cycle Assessment to the designers of technological innovations Life Cycle Assessment as a method to answer these questions, by means of a case study of the organic egg. In this study the LCA of organic eggs was calculated and compared to equivalent egg products. Ecological hotspots within the production chain were identified and the effectiveness of production parameters from the laying hen farm were identified on the LCA using sensitivity analysis. This LCA case study showed that organic eggs score worse than equivalent eggs on acidification, eutrophication and land use. Technological innovators should focus on ammonia emission from the laying hen farm to reduce the impact of acidification. Another focus should be nitrate leaching during concentrate production to reduce eutrophication. Innovative organic laying hen farmers may focus on a high feed conversion to improve the LCA of organic eggs in a broader sense. A shift from single tiered housing of laying hens to multi tiered housing with manure drying on manure belts, can reduce acidification 53% and eutrophication with 18%, almost enough to level out the 60% higher acidification and the 25% higher eutrophication of organic eggs compared to equivalent egg products.

Introduction

Use of LCA for technological innovation
Ecological sustainability in agriculture is a concept that contains various environmental problems, which are caused by emission of pollutants and unsustainable use of limited resources (e.g. land and fossil fuels), during different processes along the food chain. For example, the Dutch minister of Agriculture, Nature and Food quality (ANF), Gerda Verburg,

wrote a letter to the direction agriculture of the ministry of ANF on 16th of January 2008 in which she stated that "In 15 years the animal production sector in the Netherlands should develop to a sustainable sector with broad support in society. This implies that the animal sector has to produce with respect for humans, animals and the environment everywhere in the world". Technological innovations may help to improve ecological sustainability of food products. For example, in the past innovations such as manure belts and air scrubbers have been developed to reduce ammonia emissions from laying hen houses. However such innovations are only effective if they significantly reduce the ecological impact of a product's production chain. Therefore, preceding to the development of ecological sustainable technological innovations three questions need to be answered; 1) how ecological sustainable is the current production process, 2) which processes in the chain cause the highest ecological impact and 3) which production parameters significantly affect the ecological impact of these processes? Answering these questions ensures if ecological innovation is necessary, which process needs ecological innovation and which production parameters should be affected by the ecological innovation. To answer these questions an integral approach is necessary. Integral, in this respect, means incorporation of all relevant environmental impacts and all processes involved in the production process. LCA is a widely accepted method for integrated environmental impact assessment of agricultural products. Subsequently the LCA study can be used to evaluate the later designed ecological innovation. The aim of this research, therefore, is to demonstrate the possibilities of LCA to the designers of technological innovations by means of a case study of the organic egg.

Overview of environmental issues of organic laying hen production in NL
Organic egg production is a fast growing sector in the Netherlands. The number of Dutch organic laying hens has grown from 500,000 in 2005 to more than 900,000 in 2007. In 2007, 3% of all hens and 5.4% of all purchased eggs were organic. Over 75% of organic eggs produced in the Netherlands are exported (Biologica, 2007). According to the ecological principle of the IFOAM "organic farming should be based on living ecological systems and cycles, work with them, emulate them and help sustain them" (IFOAM, 2005). So far little research has been done to verify if organic egg production is ecologically sound, i.e., its environmental emissions and its use of natural resources can be sustained in the long term by the natural environment (Payraudeau and van der Werf, 2005). However, a few ecological issues related to organic egg production are mentioned by experts in this field: 1) energy resource depletion and carbon dioxide emission caused by long transport distances of concentrates (Bos, 2005) 2) ammonia emission from the laying hen house (Groenestein et al., 2005) and 3) eutrophication caused by a high load of nitrogen and phosphorus in the outdoor run, especially in the area close to the hen house (Aarnink et al., 2006). The reason experts mention the first issue is that organic hens are fed with concentrate ingredients that originate from all over the world. This is a general tendency in organic farming as can be seen by world statistics on organic farming (Willer and Yussefi, 2005). Reducing transport by regionalizing organic production is mentioned as a possibility to improve ecological sustainability of organic products (Bos, 2005). The second issue is based on Mollenhorst et al.(2006), who concluded in his LCA study of conventional egg production that ammonia emission from manure in single tiered floor housing as well as in multi tiered floor housing is the main contributor to acidification. In addition, unlike conventional farmers, organic farmers in the Netherlands are not forced by law to built housing systems with low ammonia emissions. Regarding the third issue Aarnink (2006) measured nutrient load and ammonia emissions in the first 20 m of two organic outdoor runs and concludes that "…ammonia emission from the outdoor run of laying hens was relatively small compared to the emission from the hen house and that the nutrient load in the outdoor run near the hen house by far exceeded maximum

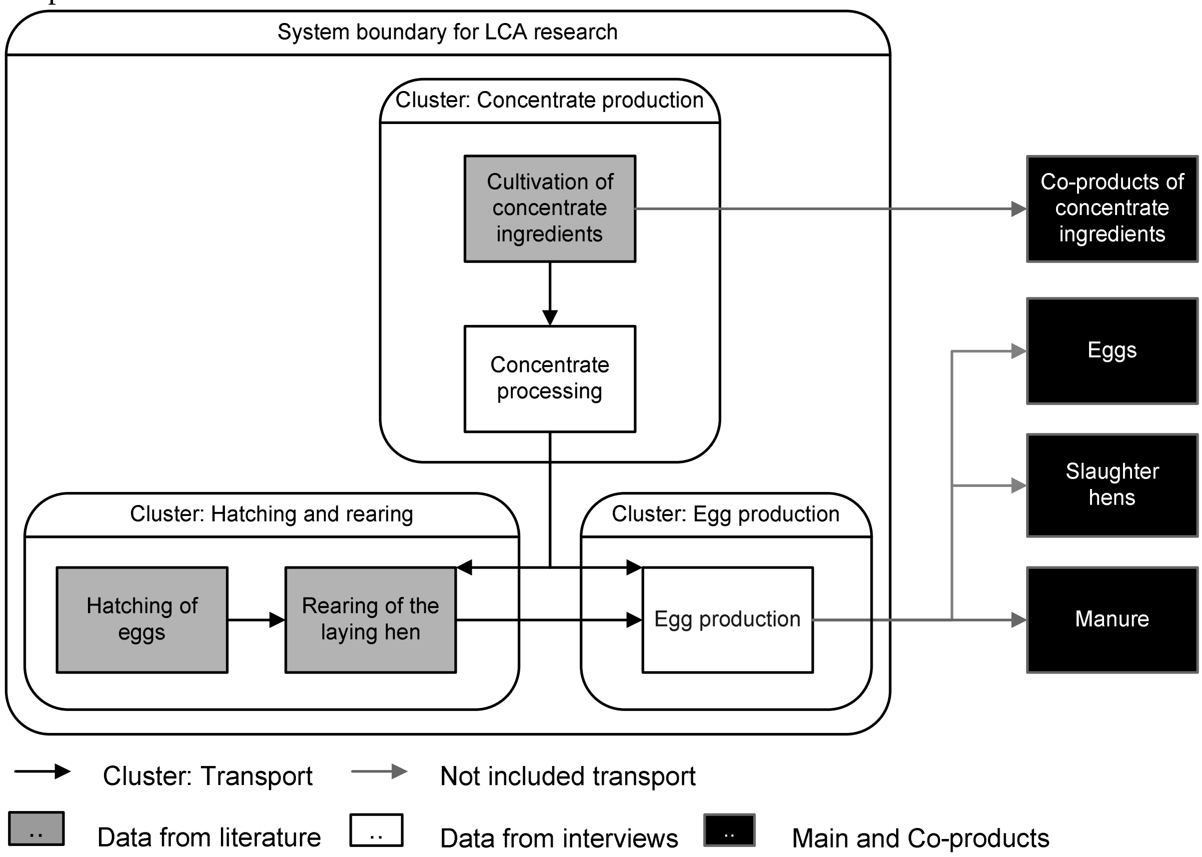
acceptable levels." This LCA research calculates the relative importance of the above described problems. Further on the most damaging processes are identified by means of hotspot identification and the production parameters of the organic laying hen farm that have the biggest influence on the LCA are identified by means of a sensitivity analysis.

Materials and Method

Goal and scope definition

An LCA is an inventory of the ecological impact caused by a production chain of a product. An LCA study starts with the location of system borders. The functional unit defines the end of the production chain. In this research the functional unit (FU) is one kg of organic egg leaving the farm gate. LCA lists the ecological impact caused by one FU. The system boundaries for this research are visualized in Figure 1. Often a production chain produces more than one product. To allocate the ecological impact between main and co-products economic allocation was used. Main and co-products are visualized in Figure 1.

Figure 1: System boundaries of the LCA research, included processes, in- and excluded transportation, main- and co-products, data origin and the division in four clusters as used for hotspot identification.



Inventory analysis

In the inventory analysis data concerning relevant inputs, outputs and environmental losses for each included process, as specified in Figure 1, were collected. Based on this information, a Life Cycle Inventory (LCI) for each process was computed. This inventory analysis included land use of the hatchery, the rearing hen farm, the laying hen farm, the concentrate industry and concentrate cultivation. Also included were ammonia, methane and nitrous oxide emissions, the leaching and accumulation of nitrate and phosphate on the field during concentrate cultivation and from the hen house and outdoor run during rearing and egg production. Electricity use during hatching, concentrate production and concentrate cultivation was included. Natural gas use for hatching was included. Transport of hatchers, rearing hens, concentrate ingredients and concentrates was included. Water, methanol and formaldehyde use of the hatchery were included. Hatchers originate from conventional hatcheries. Concentrate cultivation and processing, rearing and laying hen farms produce conform regulation EC 2092/91 for organic farming (EG, 1991), as specified by Skal (Skal, 2008). In Table 1 the production characteristics of the laying and rearing hen farm are visualized. Laying hen concentrate consisted for 19.3% of ingredients outside the European Union and for 80.7% of ingredients from inside the European Union. Main ingredients of the laying hen concentrate were organic maize (31.9%) and organic wheat (33.5%). Arable ingredients may contain a maximum 10% non organic ingredients. Resources were transported by lorry, or transoceanic freight ship.

Table 1: Mean and SD of production parameters of the interviewed organic laying hen farms and literature based mean production parameters of the organic rearing farm.

Production parameter	Unit	Laying hen farm	Rearing hen farm
		Mean (SD)	Mean
Purchased hens	hen/farm	7,604 (4,281)	-
Single tiered floor housing	%	85	100
Multi tiered floor housing	%	15	0
Stocking density house	hen[b]/m^2	5.55 (0.78)	5.55
Stocking density outdoor run	hen[b]/m^2	0.22 (0.04)	1
Length of round	Days	398 (44)	119
Purchased concentrates	kg/hen[b]	43(7)	6
Purchased wheat	kg/hen[b]	4.6	0.6
Hens in outdoor run [a]	%	9 (4)	5
Mortality rate	%	13 (5)	3.9
Egg weight	G	63 (2)	-
Egg production	kg/hen[b]	276 (39)	-
Egg price	euro/kg	1.83 (0.2)	-
Start weight hen	Kg	1.52	0.035
End weight hen	Kg	1.94 (0.09)	1.52
Slaughter price	euro/kg	0.18 (0.12)	-
N-excretion	kg N/hen[b]	0.96[c]	0.11
P-excretion	kg P/hen[b]	0.20[c]	0.02

[a] Average amount of hens the farmer estimated to be present in the outdoor run during the day.
[b] Amount of reared hens the farmer purchased.
[c] No SD available because N- and P-excretions are LCA model output values.

Required data were collected from literature and interviews with egg producers and concentrate industries. We used statistic averages from hatcheries and conventional rearing farms (ASG-WUR, 2004; Hemmer et al., 2006). Where necessary we adapted data to differences in regulation between conventional and organic rearing farms. The data for the organic laying hen farm were collected by the conduction of interviews with 20 out of a total of 68 Dutch organic laying hen farmers with over 1,500 hens. We collected data on production rounds of 2006 to 2007. Two organic concentrate industries were interviewed. The transport distance and type of distance of resources was known from interviews with laying hen farmers and the concentrate industry. The LCI of electricity, natural gas, different types of transport, methanol, formaldehyde and the concentrate ingredient monocalciumphosphate originated from the Ecoinvent V 2.1 database (Ecoinvent Center, 2008). Data on the emission of ammonia, nitrous oxide and methane from the hen house and outdoor run and eutrophication caused by phosphorus and nitrate from the outdoor run of all farm types were based on literature for conventional farming (Oenema et al., 2000) and modelled to depend on the following farm characteristics: housing system, storage time, nitrogen and phosphorus excretion and manure excretion in the outdoor run. Due to practical reasons the concentrate composition was simplified in the LCA model into one concentrate type for rearing as well as laying hens and 8 concentrate ingredients. Data on cultivation and processing of the ingredients were derived from Dekkers (2002) and Thomassen (2008).

Impact Assessment
Based on the LCI of all included processes the LCA was computed. Each process produces a number of substances that influence ecological sustainability. The substances were multiplied with a weighing factor. A weighing factor is used to cluster substances into impact categories. An impact category represents a group of substances that effects on a certain ecological issue, for example climate change. The used unit for an impact category was derived from one of the substances. Logically this substance has a weighing factor of one. Weighing factors for LCA are internationally fixed based on the current state of knowledge. In Table 2 the impact categories, included substances and weighing factors of this study are listed. Finally the substances of each impact category were added up to calculate the LCA. The outcome is then compared to other (future) products. To be able to judge the ecological sustainability of organic eggs, the LCA output of this study is compared to that of an earlier LCA executed by Mollenhorst (2006).

Table 2: Specification of the selected impact categories, equivalent units, contributing elements and weighing factors.

Impact category (unit)	Contributing substances (weighing factors)
Climate change (kg CO_2 eq.)	CO_2 (1), CH_4 (23) , N_2O (296)
Acidification (kg SO_2 eq.)	SO_2 (1), SO_x* (1.2), NH_3 (1.9), NO_x (0.7)
Eutrophication (kg PO_4^{3-} eq.)	PO_4^{3-} (1), P_2O_5 (1.3), H_3PO4 (1.0), P (3.0), NH_3 (0.35), NH_4^+ (0.33), NO_x (0.13), NO_3^- (0.1), N (0.42)
Land use (m^2 eq.)	land occupation (1)
Energy use (MJ eq.)	Oil (43.4), gas (40.1), uranium (1.4 10^6), coal (18.7)

Hotspot identification
In the results the LCA was split up into four clusters i.e. ; 1) hatching and rearing, 2) concentrate production, 3) egg production and 4) transport (Figure 1). We decided to identify a cluster-substance combination as a hotspot if it contributed more than 40% to the total of the impact category.

Sensitivity to production parameters
To identify the sensitivity of the LCA to the production parameters of the laying hen farm, we executed a sensitivity analysis. We ran scenarios of the LCA model with the mean plus and minus the standard deviation of each production parameter of the laying hen farm. For mean and SD of the tested parameters see Table 1. We also calculated the LCA for the two

occurring housing systems single tiered floor housing and multi tiered housing with manure belts and manure drying.

Results

Impact Assessment

The results in Table 3, show that organic eggs have a 5% lower ecological impact on climate change, a 60% higher impact on acidification, a 25% higher impact on eutrophication a 2% lower impact on energy use and a 28% higher impact on land use, than the average of the four other types of egg production.

Table 3: Results from the LCA of eggs from an organic (this study), an average egg based on a mix of a free range, a deep litter and a battery cage production system (Mollenhorst, 2006), and the relative impact of an organic egg.

Impact category (unit)	Organic egg	Average egg	Organic/Average
Climate change (g CO2-eq./kg egg)	4,038	4,240	95%
Acidification (g SO2-eq./kg egg)	80	50	160%
Eutrophication (g $PO4^-$-eq./kg egg)	40	32	125%
Energy use (MJ eq./kg egg)	13.1	13.4	98%
Land use (m^2 eq./kg egg)	6.4	5.0	128%

Ecological hotspot identification

The hotspot for climate change is nitrous oxide emission from the concentrate production cluster. The hotspot for acidification is ammonia emission from the egg production cluster. No hotspot was identified for eutrophication. However nitrate leaching from the concentrate production cluster contributed most to this impact category. The hotspot for energy use is the use of oil by the concentrate production chain. The concentrate production cluster accounts for the hotspot land use. In Table 4 the contribution of the hotspots is visualized.

Table 4: Hotspot identification: Substance-cluster combinations that contribute most to each impact category

Impact category (unit)	substance	Cluster	impact	Contribution
Climate change (g CO2-eq./kg egg)	N_2O	concentrate	2475	61%
Acidification (g SO2-eq./kg egg)	NH_3	egg production	45.7	57%
Eutrophication (g $PO4^-$-eq./kg egg)	NO_3^-	concentrate	14.4	36%
Energy use (MJ eq./kg egg)	Oil	concentrate	5.4	41%
Land use (m^2 eq./kg egg)	Land	concentrate	6.1	95%

Sensitivity to production parameters

From the sensitivity analysis it appears that the most sensitive parameters on an organic laying hen farm are the number of produced eggs, the amount of concentrates consumed and the housing system. Effect of the scenarios compared to the current LCA is listed in Table 5.

Table 5: Reduced percentage of the LCA in three different scenarios; 1) an increase of egg production with the SD from the interviewed laying hen farm interviews, 2) a reduction of concentrate consumption with the SD from the interviewed laying hen farm interviews, 3) A shift from a single to a multi tiered housing system with manure drying on manure belts

Production parameter	Egg production	Concentrate consumption	Housing
	#/hen*year	kg/hen	Type
Current situation	276	42.9	100% single tiered

Scenario	+39	-7	100% multi tiered
Impact category (unit)			
Climate change (g CO2-eq./kg egg)	-13%[a]	-14%[a]	-11%[b]
Acidification (g SO2-eq./kg egg)	-15%[a]	-17%[a]	-53%[b]
Eutrophication (g $PO4^{-}$-eq./kg egg)	-13%[a]	-15%[a]	-18%[b]
Energy use (MJ eq. /kg egg)	-12%[a]	-14%[a]	-?[c]
Land use (m^2 eq./kg egg)	-12%[a]	-13%[a]	0%[a]

[a] Reduction of LCA compared to originally calculated model.
[b] Reduction compared to 100% single tiered floor scenario.
[c] No representative results available, since no data were available on differences in energy use between single tiered and multi tiered housing systems.

Discussion

To be able to use an LCA for the evaluation of the ecological sustainability of a (furure) product there has to be a reference product. In this case the organic egg production system can be compared to other egg production systems. However care has to be taken when comparing products. Between studies differences can exist in methodological choices such as system borders, functional units, included resources and emitted substances, impact categories, weighing factors and allocation method. As far as could be detected no methodological choices existed between this study and Mollenhorst (2003). Ecological hotspot identification is capable of identifying the most polluting substances-cluster combinations. After identifying these hotspots it is necessary to identify the source of these hotspots within the clusters. Identification of these sources can be the starting point for ecological innovation. Since this is a demonstrative case study, only a sensitivity analysis of the production parameters of the laying hen farm was executed. However, a full sensitivity analysis includes all production parameters of the production chain. We recommend to include an uncertainty analysis of the models' parameters, such as emission factors. The actual emission can vary widely in practice, depending on local circumstances. It is not always possible to find region specific parameters for the entire production chain of the LCA. One should always bear in mind that an LCA is a model estimating ecological sustainability of a product, based on the scientific information that is available at that moment.

Conclusion

LCA is suitable as a method to evaluate the ecological sustainability of a product, identify hotspots and production parameters that affect on specific impact categories. This LCA case study showed that organic eggs score worse than equivalent eggs on acidification, eutrophication and land use. Land use also has a qualitative aspect, which should be assessed before further concluding on this impact category. Technological innovators should focus on ammonia emission from the laying hen farm to reduce the impact of acidification. Another focus should be nitrate leaching during concentrate production to reduce eutrophication. Innovative organic laying hen farmers may focus on a high feed conversion to improve the LCA of organic eggs in a broader sense. A shift from single tiered housing of laying hens to multi tiered housing with manure drying on manure belts, can reduce acidification 53% and eutrophication with 18%, almost enough to level out the 60% higher acidification and the 25% higher eutrophication of organic eggs compared to equivalent egg products.

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