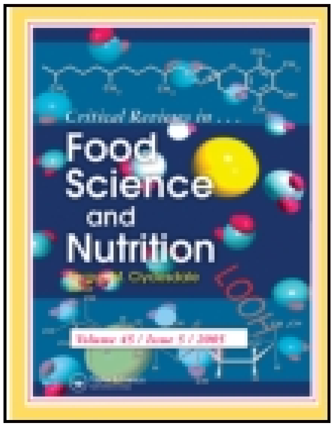

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Life Cycle Assessment (ISO 14040) Implementation in Foods of Animal and Plant Origin: Review

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The importance of environmental protection has been recently upgraded due to the continuously increasing environmental pollution load. Life Cycle Assessment (LCA), wellknown as ISO 14040, has been repeatedly shown to be a useful and powerful tool for assessing the environmental performance of industrial processes, both in the European and American continents as well as in many Asian countries (such as Japan and China). To the best of our knowledge, almost no information is provided in relation to LCA implementation in Africa apart from an article related to Egypt. Although food industries are not considered to be among the most heavily polluting ones, for some like olive oil, wine, dairy, and meat processing, their impact on the environment is a heavy burden. The introduction of LCA aimed at identifying both inputs and outputs to find out which are the most detrimental to the environment in terms of water/energy consumption and solid/liquid and gas releases. In this review, a thorough coverage of literature was made in an attempt to compare the implementation of LCA to a variety of products of both plant and animal origin. It was concluded that there is a high number of subsystems suggested for the same product, thereby, occasionally leading to confusion. An idea toward solving the problem is to proceed to some sort of standardization by means of several generic case studies of LCA implementation, similarly to what had happened in the case of Hazard Analysis and Critical Control Points (HACCP) implementation in the United States, Canada, Australia, United Kingdom, and other countries.

Keywords Life cycle assessment, ISO 14040, applications in foods of animal & plant origin, milk, dairy products, meat, fish, agricultural products.

INTRODUCTION

Food production is closely related to a substantial use of land, energy, and chemicals. As everybody purchases and consumes considerable quantities of food products on an annual basis, food production also represents a considerable physical and monetary flow in our society (Thrane, 2006). Nowadays, food production has been augmented substantially due to the introduction of new technologies, extensive mechanization, chemicals, and novel governmental policies (Coltro et al., 2006). During the last years, it has been widely accepted that the consumption processed products affects the resources and the environment. These effects can be both direct (e.g. contributions to solid waste) and indirect (e.g. pollution due to generation of electricity for using the product) (Hunt et al., 1992). The environmental impact of food production is a major issue due to a rapidly growing population and an enhanced pressure on the Earth's life-supporting systems (Berlin and Uhlin, 2003). As a result, there is a strong need to widen the knowledge of the potential long-term environmental consequences of food production in order to design a strategic methodology toward promoting sustainability (Berlin, 2002). The efficiency improvement of resource utilization in food production in conjunction with minimization of emissions and other environmental effects are vital (Berlin and Uhlin, 2003).

Life Cycle Assessment (LCA) takes into account the environmental aspects and the potential impacts of a product or a service system throughout its life – from raw material acquisition through production, use, and disposal (from cradle to grave). This information is of crucial importance and can be of great help to identifying alternatives to improve the environmental

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Table 1 Main parameters reported in LCA applications to milk and dairy products

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Swedish semi-hard cheese	■ Lime production ■ Milk production ■ Cheese making ■ Transportation ■ Waste management ■ Package	■ Water ■ Sodium hydroxide ■ Salt ■ Saltpeter ■ Retailer ■ Rennet ■ Plastic ■ Nitric acid ■ Household ■ Dairy ■ Cardboard ■ Calcium chloride	■ CO_2 equivalents ■ NH_3, NOx and SO_2 ■ O_2 ■ Ethene equivalents ■ Heavy metal *(air and water)*	⇒ Global warming *(8794 g CO_2-equiv.)* ⇒ Acidification *(136 g SO_2- equiv.)* ⇒ Eutrophication *(2134 g O_2)* ⇒ Photochemical ozone creation potentials *(2.55 g ethane- equiv.)* ⇒ Ozone depletion potentials ⇒ Eco and human-toxicity *(As = 0.066 mg, Cd = 0.7475 mg, Co = −0.001 mg, Cr tot = 0.279 mg, Cu tot = 0.0039 mg, Hg = 0.0039 mg, Ni tot = 1.268 mg, Pb = 0.273 mg, Sn = 6.740046 mg, V = 2.901 mg, Zn = 0. 36 mg)* (per 1 kg cheese wrapped in plastic)	Berlin, 2002
Milk production in Sweden *(conventional & organic farming)*	■ Production of materials ■ Production of milk ■ Transportation	■ Fertilizers ■ Feed and seeds ■ N-fixation ■ N-deposition	■ Products ■ Nutrient surplus	⇒ Global warming *(155 kg methane (con)* ⇒ Acidification *(17.98 kg SO_2 (con)/15.81 kg SO_2 (org)* ⇒ Eutrophication *(0.35 P kg ha-1 (con)/0.25 P kg ha-1(org))* ⇒ Photo-oxidant formation *(higher emissions in the organic system)* ⇒ Ozone depletion ⇒ Energy *(3350 MJ (con)/ 2511 MJ (org)* (per 1000 kg energy corrected milk)	Cederberg and Mattson, 2000
Milk production in the Nether-lands*(conventional & organic farming)*	■ Production of fertilizer, pesticides ■ Production of fossil fuel, water, electricity ■ Production farm products	■ Fixation ■ Deposition ■ Animals ■ Concentrates ■ Artificial fertilizes ■ Roughage ■ Organic mature	■ Animals ■ Milk roughage ■ Mature ■ NH_3 volatilization ■ N_2O emission **FPCM** = *(1 kg of fat & protein corrected milk)*	⇒ Energy consumption = *5.0 MJ (con) & 3.1 MJ (org)/kg FPCM* ⇒ Land use = *1.3 m^2 (con) & 1.8 m^2 (org)/kg FPCM* ⇒ Eutrophication = *0.11 kg NO_3 (con) & 0.07 kg NO_3 (org)/kg FPCM* ⇒ Acidification = *9.5 g SO_2 (con) & 10.8 g SO_2 (org)/kg FPCM* ⇒ Climate change = *1.4 kg CO_2 (con) & 1.5 kg CO_2 (org)/kg FPCM*	Thomassen et al., 2008

Galician milk production	■ Milk production (farm) ■ Animal food preparation ■ Milk processing (dairy)	■ Materials & fuels (raw milk, Tetra-brix, cardboard, film, hydrogen peroxide, nitric acid, sodium hydroxide, fuel) ■ Raw materials (water) ■ Electricity	■ Products and co-products *(packed milk and cream)* ■ Waste from treatments *(cardboard, oil, oil filters, tetra brix)* ■ Eolid emissions *(combustion waste)* ■ Emission to water *(SO_2, NO_2, CO)* ■ Emissions to water *(wastewater, COD, TSS)* ■ Emissions to soil *(sludge, Fe, Cr, Hg, Zn)*	⇒ Global warming (GWP) = *1.05 kg CO_2* ⇒ Stratospheric ozone depletion (ODP) = 5.12×10^{-8} *kg CFC_{11}* ⇒ Eutrophication (EP) = 5.31×10^{-3} *kg PO_4* ⇒ Acidification (AP) = 8.53×10^{-3} *kg* SO_2 ⇒ Photo-oxidant formation (POCP) = 3.50×10^{-4} *kg C_2H_4* ⇒ Depletion of abiotic resources (ADP) = 1.07×10^{-4} *kg Sb* (per 1 L of packaged liquid milk)	Hospido et al., 2003
Italian dairy industry	■ Raw material production ■ Manufacturing ■ Distribution ■ End of life ■ Waste management		■ H_2O (80%) ■ Energy (60%) ■ CO_2 (60%) ■ NOx (50%) ■ SOx (60%) ■ Solid wastes (35%) ■ Heavy metals (60%) (contribution from manufacturing for the production of polythene packaged butter)		Bianconi et al., 1998
Irish milk production		■ Barley ■ Wheat ■ Beet pulp ■ Oats ■ Soya ■ Rapeseed ■ Molasses ■ Vegetable oil ■ Minerals & vitamins ■ Shipping ■ Trucking ■ Processing	■ CH_4, CO_2, N_2O ■ Emissions from enteric fermentation (49%) ■ Emissions from fertilizer (21%) ■ Emission from concentrated feed (13%) ■ Emissions from dung management (11%) ■ Emissions from electricity and electricity consumption (5%)	⇒ Global warming (total GWP) = *349, 760 kg CO_2*	Casey and Holden, 2005
Commercial dairy farms		■ N, P_2O_5: clover N-fixation, deposition, import through roughage, concentrates, animals and mature	■ N, P_2O_5: animal products (milk, meat, manure or living animals) ■ Plant products (roughage or crops)	⇒ Land use *(1.60 m/̸kg FPCM)* ⇒ Energy use *(2.48 MJ/̸kg FPCM)* ⇒ Global warming *(1.81 kg* CO_2 *eq/̸kg FPCM)* ⇒ Eutrophication *(82.1 g NO_3 eq/̸kg FPCM)* ⇒ Acidification *(11.8 g SO_2/kg FPCM)*	De Boer et al., 2003

Table 2 Main parameters reported in LCA applications to meat and meat products

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Danish pork	■ Farm ■ Piglets production ■ Fertilizer production	■ Fertilizer ■ Soybean meal ■ Diesel ■ Electricity ■ Transportation	■ CO_2 = *2.5 kg* ■ NO_3 = *205 kg* ■ SO_2 = *40 kg* (of 1 kg Danish pork)	⇒ Global warming (CO_2) ⇒ Nutrient enrichment (NO_3) ⇒ Acidification (SO_2)	Dalgaard and Halberg, 2005
Pig farming systems in France	■ Litter production ■ Building production ■ Crop and feed production ■ Pig production ■ Weaning to slaughering	■ Energy use = *17.9 MJ (LR), 15.9 MJ (GAP), 22.2 MJ (AB)) per kg of pig production* ■ Energy use = *28503 MJ (LR), 29282 MJ (GAP), 22492 MJ (AB) per ha* ■ Land use = *6.28 m^2.year (LR), 5.43 m^2.year (GAP), 9.87 m^2.year (AB) per kg of pig production* ■ Pesticide use = *1.44 g (LR), 1.37 g (GAP), 0.239 g (AB) per kg of pig production* ■ Pesticide use = *2.29 kg/ha (LR), 2.52 kg/ha (GAP), 0.24 kg/ha (AB) per ha*	■ PO_4-equiv. = *0.016 kg (LR), 0.0208 kg (GAP), 0.0216 kg (AB) per kg of pig production* ■ PO_4-equiv. = *26.4 kg (LR), 38.3 kg (GAP), 22.9 kg (AB) per ha* ■ CO_2 -equiv. = *3.46 kg (LR), 2.3 kg (GAP), 3.97 (AB) per kg of pig production* ■ CO_2 -equiv. = *5510 kg (LR), 4236 kg (GAP), 4022 (AB) per ha* ■ SO_2-equiv. = *0.0226 kg (LR), 0.0435 kg (GAP), 0.0372 kg (AB)) per kg of pig production* ■ SO_2-equiv. = *36.0 kg (LR), 80.1 kg (GAP), 37.7 kg (AB) per ha* ■ 1.4-dichlorobenzene-equiv. = *0.0184 kg (LR), 0.0165 kg (GAP), 0.0304 kg (AB) per kg of pig production*	⇒ Eutrophication *(PO_4-equiv.)* ⇒ Climate change *(CO_2 –equiv.)* ⇒ Acidification *(SO_2-equiv.)* ⇒ Terrestrial toxicity *(1.4-dichlorobenzene-equiv.)*	Basset-Mens and Van der Werf, 2003
Pig production system	■ Piglet production ■ Weaning to slaughtering	■ Crop yield ■ Feed to gain ratio	■ Field emission ■ Building emission	⇒ Eutrophication (0.0208, 38.3 *kg* PO_4-equiv.) ⇒ Climate change (2.30, 4236 *kg CO_2 -equiv.)* ⇒ Climate change (2.30, 4236 *kg CO_2 -equiv.)* (of pig production expressed per kg of pig and per hectare)	Basset-Mens et al., 2006
Japanese beef cow-calf production	■ Feed production ■ Feed transportation ■ Animal management ■ Waste treatment	■ Energy use = *16.1 MJ*	■ CO_2 = *4450 kg* ■ SO_2 = *40.1 kg* ■ PO_4 = *7.0 kg* (of one beef calf)	⇒ Global warming *(CO_2)* ⇒ Acidification *(SO_2)* ⇒ Eutrophication *(PO_4)* ⇒ Energy consumption *(MJ)*	Ogino et al., 2007

Pig production systems	■ Feed production subsystem ■ Pig rearing subsystem	■ Barley ■ Wheat ■ Pea ■ Rapeseed cake ■ Rapeseed meal ■ Soybean meal ■ Synthetic amino acids	■ Feed intake ■ Nitrogen excretion ■ Slurry production ■ Dry matter content of slurry ■ Ammonium nitrogen content of slurry ■ Area for slurry spreading ■ Slurry application rate	⇒ Energy use *(6.8, 5.3, 6.3 MJ/kg pig growth)* ⇒ Global warming potential *(1.5, 1.3, 1.4 kg CO_2-equiv./kg pig growth)* ⇒ Eutrophication *(0.55, 0.55, 0.45 kg O_2-equiv./kg pig growth)* ⇒ Acidification *(24, 25, 20 g SO_2-equiv./kg pig growth)* (for the three alternative scenarios of protein supply SOY, PEA, and SAA respectively	Eriksson et al., 2005
Pig production in Bretagne	■ Production of pig feed ■ Delivery of pig feed ■ Transport	■ Pig slurry ■ N ■ P_2O_5 ■ K_2O ■ CaO ■ Pesticide ■ Diesel ■ Natural gas ■ Agricultural machinery ■ Grain dry matter yield ■ NO_3-N emitted	■ NH_3, SO_2, NO_2 ■ Zn, Cu, Ni, Pb, Cd ■ N_2O, CO_2, CH_4	⇒ Eutrophication potential *(3.8–9.3 g PO_4 – equiv.)* ⇒ Global warming *(472–792 g CO_2 -equiv.)* ⇒ Acidification *(3.0–6.3 g SO_2 .equiv.)* ⇒ photochemical ozone creation potentials *(2.55 g ethane- equiv.)* ⇒ Terrestrial ecotoxicity potentials *(0.4–8.7 g 1,4-dichlorobenzene-equiv.)* ⇒ Energy use *(3.3–6.1 MJ)* ⇒ Land use *(1.44–2.07 m^2year)* (per 1 kg of feed for finishing pigs)	Van der Werf et al., 2007
Sucker-beef production in Ireland	■ Production of concentrated feeds ■ Production of fertilizer ■ Manure management (housing, storage, spreading) electricity and diesel usage	■ Yield *(2987 kg ha yr^{-1})* ■ Nitrogen application *(135 kg N ha yr^{-1})* ■ Transport *(500 km)* ■ Diesel *(71 kg per ha)* *(for I kg of grain maize)*	■ Nitrogen production *(0.23 kg CH_4, 359 kg CO_2, 1.8 kg N_2O)* ■ Transport of N *(0.02 kg CH_4, 14 kg CO_2, 0.003 kg N_2O)* ■ N fertilizer *1.7 kg N_2O)* ■ Total diesel *(0.04kg CH_4, 252 kg CO_2, 0.05 kg N_2O)* ■ Transport on farm *(0.005 kg CH_4, 3 kg CO_2, 0.001 kg N_2O)*	⇒ Global warming (1735 *kg CO_2.equiv. and 0.6 kg CO_2.eq kg grain maize ha yr^{-1})*	Casey and Holden, 2006

Table 3 Main parameters reported in LCA applications to fish and seafood.

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Danish fish product (flatfish)	■ Use ■ Retail ■ Transport ■ Wholesale ■ Processing ■ Auction ■ Fishery	■ Materials ■ Energy (electricity: consumption of diesel for fishing, cooling, food preparation and transport) ■ Chemical ■ Other	■ CO_2: fishing, use retail ■ CFC_{11} ■ NOx: fishing and SOx: use and retail stage ■ NO_3: combustion of diesel ■ C_2H_4: production of diesel Acetone, formaldehyde, hexane: processing stage	⇒ Global warming *(20,856.00 gram CO_2- equiv.)* ⇒ Ozone depletion *(0.01 gram CFC_{11} equiv.)* ⇒ Acidification *(156.37 gram SO_2 -equiv.)* ⇒ Eutrophication *(-146.25 gram NO_3- eqv)* ⇒ Ozone formation *(24.03 gram ethane- equiv.)* ⇒ Ecotoxicity *(170182.64 m^3 water)* (for one kg consumed flatfish filet)	Thrane, 2003
Feed for farmed salmon	■ Production ■ Processing ■ Transportation	■ Crop-derived ingr. *(wheat, canola seed, canola meat, canola oil, soy meal, corn glutten meal)* ■ Fish-derived ingr. *(peruvian fish meal, peruvian fish oil, CDN by-product fish meal, CDN by-product fish oil, US fish oil)* ■ Poultry-derived ingr. *(poultry by-product meal)*	■ CO_2 *-equiv.* ■ SO_2. ■ PO_4 ■ DCB ■ C	⇒ Energy use *(18,100, 17,100, 26,900, and 9860 MJ equiv.)* ⇒ Biotic resource use *(10,600, 10,600, 45,100, and 6300 kg C)* ⇒ Global warming *(1400, 1250, 1810, and 690 kg CO_2 -equiv.)* ⇒ Acidifying *(12.6, 11.8, 24.6, and 6.9 kg* SO_2*)* ⇒ Eutrophying *(5.3, 4.9, 6.7, and 2.3 kg* PO_4) ⇒ Aquatic ecotoxiticy *(60,700, 61,100, 63,300, and 47,600 kg 1.4-DCB- equiv.)* (for conventional *(C)*, organic crop ingrendients/conventional animal meals and oils,*(OA)*, organic crop ingredients/fisheries by-product meals and oils *(OBP)* and organic crop ingredients/no poultry by-product meal *(ORF)*)	Pelletier and Tyedmers, 2007
Salmonid feeds	■ Extraction of the raw materials ■ The production and transformation of the primary ingredients ■ Production and use of energy resources		■ PO_4*-equiv.* ■ CO_2 *-equiv.* ■ SO_2*-equiv.* ■ C	⇒ Energy consumption *(21,000, 17,800, 20,500, and 20,100 MJ)* ⇒ Net primary production use *(41,300, 34,500, 19,100, and 653 kg C)* ⇒ Global warming *(1340, 1120, 1370, and 1560 kg CO_2 -equiv.)* ⇒ Acidification *(6.69, 6.25, 5.88, and 6.59 kg SO_2-equiv.)* ⇒ Eutrophication *(43.50, 50.00, 36.10, and 40.50 kg PO_4-equiv.)* (for the production of 1000 kg of rainbow trout of four feeds HF, HFBP, LF, and NF)	Papatryphon et al., 2004

Wild caught cod & farmed salmon- chicken	■ Catching ■ Breeding ■ Farming ■ Processing ■ Transportation		■ For cod fish filet *(fishing & production factory trawler = 0.08 Pt/ FU)* ■ For salmon fillet *(farming = 0.055 Pt/Fu)* ■ For chicken fillet *(chicken farming = 0.072)*	⇒ Fossil fuels ⇒ Acidification/eutrophication ⇒ Ecotoxicity ⇒ Climate change ⇒ Resp.inorganics ⇒ Carcinogens	Ellingsen and Aanondsen, 2006
Fishing Norway lobster *(Nephrops norvegicus)* in Swedish	■ Fishery ■ Seafood auctioning ■ Wholesaling ■ Retailing ■ Transport ■ Consumer phases	■ Raw materials *(electricity, fuel = 2 liters creel fishing, 9 liters conventional trawling and 4 liter selective trawling/kg of Norway lobster)* ■ Packaging materials	■ CO_2 = *14–50 kg conventional trawling, 7–15 kg creel fishing, and 8.6–16 kg CO_2 eq selective trawling*	⇒ Energy use *(80 MJ creel fishing, 320 conventional trawling, 150 selective trawling, 10 MJ wholesaler and 30 MJ consumer/kg of Norway lobster)* ⇒ Discards *(4.5 kg conventional trawling, 0.36 kg creel fishing, 1.35 kg selective trawling)* ⇒ Abiotic depletion *(90% conventional trawling, 70% creel fishing, 80% selective trawling)* ⇒ Global warming *(85% conventional trawling, 65% creel fishing, 75% selective trawling)* ⇒ Marine toxicity *(70% conventional trawling, 45% creel fishing, 55% selective trawling)* ⇒ Photochemical oxidation *(55% conventional trawling, 25% creel fishing, 35% selective trawling)* ⇒ Eutrophication *(95% conventional trawling, 70% creel fishing, 85% selective trawling)* ⇒ Acidification *(90% conventional trawling, 75% creel fishing, 85% selective trawling)*	Ziegler, 2006
Turbot farm in France *(Scophthalmus maximius)*	■ Fish farm ■ Production of farm inputs ■ Production and transformation of feed ingredients ■ Production of equipment ■ Construction and production of necessary infrastructure ■ Transportation	■ Feeds ■ Energy carrier ■ Equipment & buildings ■ Chemicals	■ Emission to water (solids, P, N) ■ Emissions to air (NH_3, N_2O, N_2)	⇒ Eutrophication *(76.96(A), 61.16(B), 62.56(C) kg PO_4-equiv.)* ⇒ Acidification *(48.28 (A,B), 54.96 (C) kg SO_2 –equiv.)* ⇒ Global warming *(6017(A,B), 10647(C) kg CO_2 -equiv.)* ⇒ Net primary production use *(60900 kg C)* ⇒ Non renewable energy use *(290.986 MJ)* (for the Marinove fish farm for 1 ton of turbot production, according to three emissions scenarios A, B, C)	Aubin et al., 2006

(Continued on next page)

Table 3 Main parameters reported in LCA applications to fish and seafood. *(Continued)*

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Turbot farm in France	■ Production and use of primary inputs to the farm ■ Production and transformation of feed ingredients ■ Production of equipment ■ Construction and production of necessary infrastructure ■ Transportation	■ Oxygen ■ Veterinary treatment ■ Feed	■ PO_4-*equiv.* ■ CO_2 -*equiv.* ■ SO_2-*equiv.* ■ C	⇒ Eutrophication *(46.3–74.8 kg PO_4-equiv.)* ⇒ Acidification *(1760–2760 kg CO_2 -equiv.)* ⇒ Climate change *(12.1–19.1 kg SO_2 –equiv.)* ⇒ Energy use *(30000–78000 MJ equiv)* ⇒ Biotic resource use *(48700–62200 kg C)* (for the production of 1 ton of rainbow trout live weight from portion trout and very large trout)	Papatryphon et al., 2003
Finnish cultivated rainbow trout	■ Feed raw material ■ Feed manufacturing ■ Hatcheries ■ Fish farm ■ Slaughtering ■ Gutting ■ Production of packaging materials ■ Transportation ■ Production of fuels	■ Raw materials ■ Fuels ■ Energy	■ $CH_4 = 1.317$ kg t^{-1} ■ $CO_2 = 651.66$ kg t^{-1} ■ $CO = 0.827$ kg t^{-1} ■ $N_2O = 0.542$ kg t^{-1} ■ $NH_3 = 0.384$ kg t^{-1} ■ NOx = 5.075 kg t^{-1} ■ SOx = 1.783 kg t^{-1} ■ VOC = 6.214 kg t^{-1} ■ N = 59.850 kg t^{-1} ■ P = 7.488 kg t^{-1} (N = 78%, P = 10%, others = 2%)	⇒ Climate change ⇒ Acidification ⇒ Ozone formation ⇒ Eutrophication ⇒ Depletion of fossil fuels	Grönroos et al, 2006
Canned tuna	■ Landing and transport ■ Reception, thawing and cutting ■ Cooking ■ Manual cleaning ■ Sterilization ■ Quality control and packaging ■ Ancillary activities ■ Transport to wholesale ■ Household use	■ Materials *(lubrication oil = 50 ml, tinplate = 350 kg, food sealer = 633 ml, copper thread = 3.88 kg, flocculants = 0.01 kg and water = 1.42 m^3)* ■ Electricity = *64.29 kWh* ■ Transport = *421.86 t km (for subsystem 8 from Ancillary Activities)*	Waste treatment ■ Wastewater *(1.42 m^3)* ■ Residual tinplate *(50 kg)* ■ Residual food sealer *(63.33 ml)* ■ Used oil and fats *(47.50 ml)* Emissions to water ■ Wastewater *(5.67 m^3)* ■ COD *(130 g/m^3)* ■ N-NO_3 *(0.5 g/m^3)* Emissions to soil ■ Sludge *(1.74 kg)* Emissions to air ■ Biogas *(360 m^3)*	⇒ Global warming *(60%)* ⇒ Acidification potential *(55%)* *(for subsystem 8 from Ancillary Activities)*	Hospido et al., 2006

Carnivorous finfish production system	■ Fish production ■ Feeds *(production of ingredients, processing and transportation)* ■ Equipment *(manufacturing, transport and use)* ■ Infrastructure of raceways, cages, buildings *(material production, transportation, construction and use)* ■ Chemicals *(production and transportation)* ■ Energy carries *(production and transportation)*	■ Protein, lipids phosphorus	■ Local emissions to water (D*issolved N, Solid N, Dissolved P, Solid, Theoretical* O_2 *demand)*	⇒ Eutrophication *(65.91, 108.85, and 76.97 kg* PO_4*-equiv.)* ⇒ Climate change *(2753, 3601, and 6017 Kg* CO_2*-equiv.)* ⇒ Acidification *(19.17, 25.30, and 48.28 Kg* SO_2*-equiv.)* ⇒ Net primary production use *(62,200, 71,400, and 60,900 kg C)* ⇒ Energy consumption *(78,229, 54,656, and 290,986 MJ)* ⇒ Water dependence *(52.6, 48,782.2, and 4.8* m^3*)* *(per 1000 kg of live fish weight for three fish farm systems (throut flow-through, sea-bass cages, turbot re-circulating)*	Aubin et al., 2009
Spanish tuna fisheries	■ Fishing vessel construction ■ Anti-fouling paint manufacture ■ Diesel production fishing vessel operational inputs	■ Fuels ■ Raw materials for vessel building ■ Anti-fouling ingredients ■ Energy	■ Emissions to the air for diesel use ■ Emissions to the water from anti-fouling use ■ Wastes *(solid and liquid)*	⇒ Global warming potential *(1600, 1700, and 1800 kg* CO_2*-equiv.)* ⇒ Ozone depletion potential *(1.4, 1.4, and 1.8 g CFC11-equiv.)* ⇒ Acidification potential *(20, 25, and 29 kg* SO_2*-equiv.)* ⇒ Eutrophication potential *(3.4, 3.6, and 4.5 kg* $PO_4{}^{3-}$*)* ⇒ Photo-oxidant formation potential *(0.12, 0.12, and 0.15 kg* C_2H_4*)* ⇒ Human toxicity potential *(180, 190, and 230 kg 1.4DCB)* ⇒ Marine toxicity potential *(56,000, 63,000, and 72,000 kg 1.4DCB)* *(for capture and delivery of 1 ton to Altantic, Indian, and Pacific respectively)*	Hospido and Tyedmers, 2005

Table 4 Main parameters reported in LCA applications to agricultural products

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Agricultural production	■ Exploration, processing and transportation of raw materials ■ Production, packaging and transportation of farming ■ Agriculture	■ Minerals (phosphate rock, potash, limestone) ■ Fossil fuels (natural gas, oil, coal) ■ Fertilizers ■ Plant protection substances ■ Machinery ■ Seeds	■ Greenhouse gases ■ Nutrients ■ Cadmium ■ Pesticides ■ CH_4, CO, particles, SO_2. VOC	⇒ Depletion of abiotic resources ⇒ Land use ⇒ Climate change *($CO_2 = 1$ kg, $CH_4 = 21$ kg, $N_2O = 310$ kg)* ⇒ Toxicity ⇒ Acidification ⇒ Eutrophication *($N = 0.42$, $NH_3 = 0.35$, $NH_4 = 0.33$, $NOx = 0.13$, $NO_3 = 0.10$, NO_3-$N = 0.42$, $P = 3.06$, $P_2O_5 = 1.34$, $PO_4 = 1.00$)* (in kg PO_4-equiv. per kg emissions)	Brentrup et al., 2004
Integrated production of oranges in Comunidad Valencia (Spain)	■ Agrochemical production ■ Production of energy ■ Agricultural practices	■ Ammonium nitrate ■ Phosphoric acid ■ Potassium sulphate	■ Ammonia emissions ■ Rock phosphate, potassium chloride, natural gas ■ Nitrate leaching	⇒ Acidification (86% from fertilizer production) ⇒ Non-renewable resources depletion (84% from fertilizer production) ⇒ Eutrophication (99% from agricultural practices) ⇒ Global warming (52% from fertilizer production) ⇒ Photochemical oxidant formation (42% from fertilizer production) ⇒ Ozone depletion (25% from fertilizer production) Terrestrial & human toxicity (96% and 85% respectively from agricultural practices)	Sanjuán et al., 2003
Grassland farming in southern Germany *(intensive, extensified & organic)*		■ Energy *(19.1 GJ ha^{-1} &2.7 GJ t^{-1} milk -8.7 and 5.9 ha^{-1} & 1.3 and 1.2 GJ t^{-1} milk)* ■ Minerals ■ Fertilizers (P, K) (for intensive, extensified and organic farms)	■ CO_2 *-equiv. (9.4, 7.0 and 6.3 ha^{-1} & 1.3, 1.00, 1.3 t^{-1} milk)* ■ CH_4, N_2O ■ Heavy metals ■ NO_3, NOx, SO_2- emissions *(136, 119 and 107 kg ha^{-1})* ■ N *(80.1, 31.4 and 31.1 kg ha^{-1})*, P-suplus *(5.3, 4.5, and 2.3 kg ha^{-1})*, NH_3 ■ PO^4-equiv.*(54.2, 31.2 and 13.5 kg ha^{-1})*	⇒ Global warming ⇒ Soil function/strain (acidification, eutrophication) ⇒ Water quality ⇒ Human and ecotoxicity ⇒ Biodiversity ⇒ Animal husbandry ⇒ Landscape ⇒ Resource consumption (for intensive, extensified, and organic farms)	Haas et al., 2001

Grains supply chains (wheat, barley, canola)	■ Pre-farm & farming ■ Storage & processing ■ Retail & consumption ■ Transportation	■ Resources *(land use, water, phosphate, sylvinite)* ■ Materials *(grain seeds, ammonia, CO_2, limestone, sulphuric acid, water demineralized, chemical organics)* ■ Fuel *(auto diesel, natural gas)* ■ Electricity	■ Emissions to air *(methane, N_2O, NOx, SO_x, fluoride, ammonia, urea, CO_2, CO, VOC, pesticides)* ■ Emissions to water *(nitrate, phosphate, pesticides, COD, C_xH_y, fluoride, heavy metals)* ■ Solid emissions *(mining waste)* ■ Emissions to soil *(pesticides, phosphate, nitrate)* ■ Non material emission *(waste heat to air)*	⇒ Eutrophication *(0.0083, 0.18, 0.13 kg PO_4)* ⇒ Terrestrial ecotoxicity *(0.15, 3.2, 1.7 kg 1.4 DB- equiv.)* ⇒ Human toxicity *(0.16, 43.6, 0.55 kg 1.4 DB- equiv.)* ⇒ Atmospheric acidification *(0.01, 0.58, and 0.022 kg SO_2)* ⇒ Global warming *(2.3, 1.35, and 7 kg CO_2 -equiv)* ⇒ Resource energy *(74, 1300, and 220 MJ)* (for the production of 1 loaf of bread, 1 HL of beer and 1 L of canola –cooking oil)	Narayanaswamy et al., 2005
Rice straw power plant	■ Fertilizer, herbicide and pesticide production ■ Paddy cultivation and harvest ■ Rice straw collecting ■ Rice straw transportation power generation	■ 8.5–14.3 Mt rice straw→5.0–8.6 $MtCO_2$-eq→786–1325 MW of power	■ CH_4 ■ N_2O ■ CO_2	⇒ Greenhouse gas (GHG) reduction is 7.8–13.2 Mt CO_2-equiv.	Suramaythangkoor and Gheewala, 2008
Soybean meal	■ Soybean cultivation ■ Processing of oil palms ■ Processing of rapeseed ■ Processing of spring barley	Resource use ■ Fertilizer (N) ■ Fertilizer (P) ■ Fertilizer (K) ■ Lubricant oil ■ Electricity ■ Diesel	Emissions to water ■ Nitrate ■ Phosphate Emissions to air ■ Ammonia ■ Nitrous oxide ■ Nitrogen dioxide ■ Sulfur dioxide	⇒ Global warming *(721 (PO) & 344 (RSO) g CO_2- equiv.)* ⇒ Ozone depletion *(0.27 (PO) & 0.20 (RSO) mg CFC1 -equiv.)* ⇒ Acidification *(3.1 (PO) & -1.2 (RSO) g SO_2-equiv.)* ⇒ Eutrophication *(-2 (PO) & -81 (RSO) g NO_3-equiv.)* ⇒ Photochemical smog *(0.4 (PO) & 0.4 (RSO) g ethane-equiv.)* *(for 1 kg of product)*	Dalgaard et al., 2008
Sugarcane production in Australia (comparison with corn and sugar beet)	■ Cane cultivation ■ Pre-harvest burning ■ Harvesting ■ Cane transport ■ Milling ■ Juice clarification	■ Energy *(14511, 5521 and 8572 MJ)* ■ Irrigation water *(5200, 0 and 40 m^3)* ■ Planting material *(1031, 17.8 and 1.12 kg)* ■ Fertilizer and agro-chemicals *(964, 596.8 and 1417.6 kg)* ■ Transport to agricultural inputs *(5541, 5447and 188 tkm)* ■ Transport of crop to mill *(1817, 5472 and 2280 tkm* *(for the production of sugarcane, corn and sugar beet per hectare)*	■ Crop yield *(85, 9.1 49.6 t)* ■ Sugar yield *(12.1, 5.5 and 7.6 t)* ■ Field emissions to air *(N_2O, NO_x, NH_3) = 49.9 kg* ■ Emissions to water *(NO_3, P, pesticide runoff) = 77.1, 90 and 162.3 kg)* ■ Emissions from pre-harvest burning *(CH_4, N_2O, NO_x, SO_x) = 21.5, and – kg)* *(for the production of sugarcane, corn and sugar beet per hectare)*	⇒ Energy input *(4.0, 6.0, and 5.0 MJ)* ⇒ Greenhouse gas emissions *(0.1, 1.0, and 0.6 kg CO_2 -equiv.)* ⇒ Acidification potential *(4.0, 8.0, and 4.0 g SO_4 –equiv.)* ⇒ Eutrophication potential *(1.8, 2.8, and 0.8 3 g PO_4- equiv.)* ⇒ Water use *(0.4, 0, and 0 m^3)* *(for the production of sugarcane, corn and sugar beet per kilogram monosaccharide)*	Renouf et al., 2008

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Table 4 Main parameters reported in LCA applications to agricultural products *(Continued)*

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Organic and conventional wheat	■ Fertilizer production ■ Pesticide production ■ Fertilizer & pesticide transport ■ Fuel production ■ Wheat farming farm machinery production	■ Nitrogenous ■ Phosphatic	■ N_2O emissions from soil ■ GHG from manure storage	⇒ Energy consumption *(3300 –2700 J for conventional & organic wheat)* ⇒ Global warming potential*(330 – 300 g CO_2-equiv. for conventional & organic wheat)*	Meisterling et al, 2009
Swedish agriculture	■ Agriculture in Sweden ■ Food industry ■ Trade ■ Hotel and restaurant ■ Transport ■ Households ■ Waste ■ Other (forestry and fishing, energy production, industries) ■ Import ■ Export	■ Renewable fuels *(270,000 TJ)* ■ Electricity *(300,000 TJ)* and district heating *(48,000 TJ)* ■ Use of chemicals	Emissions to air ■ CO_2, NO_x, SO_2, CH_4, CO, N_2O, NH_3, NMVOC Emissions to water ■ BOD, COD, Cd, Hg, Cu, Cr, Ni, Pb, Zn, phosphates and nitrogen	⇒ Non renewable resources *(910,000 TJ)* ⇒ Global warming *(79,000/1000 ton CO_2-equiv.)* ⇒ Photochemical oxidation *(120,000 ton C_2H_2)* ⇒ Acidification *(360,000 ton SO_2-equiv.)* ⇒ Eutrophication *(5300/1000 ton PO_4-equiv.)* ⇒ Fresh water toxicity *(42,000 ton 1,4-DB-equiv.)* ⇒ Marine aquatic toxicity *(23,000/1000 ton 1,4-DB-equiv.)* ⇒ Terrestrial toxicity *(340 ton 1,4-DB-equiv.)* ⇒ Human toxicity *(450,000 ton 1,4-DB-equiv.)*	Engström et al., 2007

Table 5 Main parameters reported in LCA applications to Processed Agricultural Commodities

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Tomato Ketchup	■ Agriculture ■ Food processing ■ Packaging ■ Transportation ■ Shopping ■ Household	■ Energy use (Hudropower, biofuel, uranium, peat, coal, gas, oil) = *40.65 GJ* ■ Fertilizer (N, P, K) ■ Pesticides ■ Seeds ■ Tomatoes ■ Sugar solution, vinegar, spice emulsion, salt, citric acid (for 1000 kg of tomato ketchup consumed)	■ CO_2 = *1600 kg CO_2 -equiv.(for a 20-year time frame)* ■ CH_4 = *920 g*, N_2O = *181.6 g*, CO = 8732 g, NMHC = *3588 g* ■ H^+ = *124–239 mol* ■ BOD = *8.9 kg* ■ NOx = *4.52 kg* and other organic compounds = *4.6 g* ■ Carcinogens = *4100 g*, non carcinogens = *23016 g* and combined ranking = *28016 g* ■ Radioactive waste = *2.2–25.2 cm^3* and radon = *760 Bp* (for 1000 kg tomato ketchup consumed)	⇒ Global warming ⇒ Ozone depletion ⇒ Acidification ⇒ Eutrophication ⇒ Photo-oxidant formation ⇒ Human toxicity ⇒ Ecotoxicity	Andersson et al., 1998
Bread production	■ Crop production ■ Milling process ■ Baking process	■ Crude oil, natural gas, mineral coal, lignite, uranium (8 MJ/kg bread) ■ Land use (1.10 m^2 con, 1.70 m^2 org for 1 kg bread) (for conventional and organic system respective)	■ CO_2, NO_2, CH_4 *(700–450 g CO_2/ kg bread)* ■ N_2O *(0.50–0.020 g N_2O/kg bread)* ■ SO_2, NOx, NH_3, HCL *(2.60–1.00 g SO_2 equiv./kg bread)* ■ NOx, NH_3 *(0.40–0.10 g PO_4 equiv./kg bread)* ■ CH_4, NMHC *(ethane-equivalents)* (for conventional and organic system)	⇒ Greenhouse effect ⇒ Ozone depletion ⇒ Acidification ⇒ Eutrophication ⇒ Photo smog ⇒ Land use ⇒ Energy demand	Braschkat et al., 2003

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Table 5 Main parameters reported in LCA applications to Processed Agricultural Commodities *(Continued)*

Kind of food	System boundaries	Inputs	Outputs	Environmental impacts	References
Brazilian Green Coffee	■ Harvest ■ Cleaning ■ Separation ■ Drying ■ Storage ■ Processing ■ Classification ■ Packaging	■ Energy *(electric, wood, diesel, LPG)* = *94 Kg* ■ Land use = *0,05 hectare* ■ Water = *11,400 kg* ■ Fertilizers *(N, P, K, B, Cu, Fe, Mn, S, Zn)* = 900 Kg ■ Pesticides = *10 kg* ■ Correctives *(Ca, Mg)* = *620 kg* (for the production of 1,000 kg of green coffee)	■ Organic residue from fertilizers = *750 kg* ■ Wastewater from coffee washing = *3,000 kg* & wet route = *8,500 kg*	⇒ Depletion of fossil energy resources ⇒ Depletion of natural resources *(climate change, acidification, nitrification, human toxicity, ecotoxicity, land use)*	Coltro et al., 2006
Beer production in Greece	■ Raw material acquisition (3.1% of energy) ■ Beer production (6.1% of energy) ■ Bottle production (85% of energy) ■ Packaging (2% of energy) ■ Transportation/storage/ distribution (3.9% of energy)	■ energy use: *electricity(20.7%), diesel (67.3%), natural gas, heavy fuel oil (6.4%), lignite, propane*	■ CO_2-eq = 392.46 kg ■ CFC_{11}-eq = 0.00234 kg ■ PO_4-eq = 0.40895 kg ■ SO_2-eq = 0.00015 kg ■ C_2H_4-eq = 21.413 kg ■ Solid wastes = 57.9 kg ■ BP = 6.724E-05 kg ■ Pb 0.05161 kg	⇒ Greenhouse effect ⇒ Ozone depletion ⇒ Eutrophication ⇒ Acidification ⇒ Smog formation ⇒ Solid wastes ⇒ Human toxicity ⇒ Earth toxicity	Koroneos et al., 2005
Italian lager Beer	■ Agricultural process of barley cultivation ■ Raw material production & acquisition ■ Brewery operations ■ Beer packaging ■ Product delivery	■ Land use ($8.75-8.15 \times 10^{-5}$) ■ Fossil fuels ($2.7-1.5 \times 10^{-4}$) (1 liter of beer in bottle and keg life cycle, respectively)	■ Inorganic emissions ($6.25-3.75\times10^{-5}$) ■ Organic emissions ■ Carcinogens ($1.5-1.00 \times 10^{-5}$) ■ Mineral ($0.50-1.00 \times 10^{-5}$) (1 liter of beer in bottle and keg life cycle, respectively)	⇒ Climate change ($1.50-0.95\times10^{-5}$) ⇒ Radiation ⇒ Ozone layer ⇒ Ecotoxicity ($0.15-0.50 \times 10^{-5}$) ⇒ Acidification/eutro phication ($0.95-0.50 \times 10^{-5}$) (1 liter of beer in bottle and keg life cycle, respectively)	Cordella et al, 2008

aspects of a product at various stages in its life cycle to support decision making both in the private (industry) and public (governmental organizations) sectors. Moreover, it can be of great assistance to the selection of various environmental performance (EP) and marketing promotion of products or services. According to the Society for Environmental Toxicology and Chemistry (SETAC), LCA is defined as the: "Process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life-cycle of the product, process, or activity, encompassing, extracting and processing raw materials; manufacturing transportation and distribution; use, re-use, maintenance; recycling; and final disposal" (Arvanitoyannis, 2008).

Consumption of products includes several processes such as extraction, manufacturing, treatments, use-application, transportation, and disposal operations. A thorough analysis of these operations, called "life-cycle" or "cradle-to-grave" analysis, documents the inputs (water, energy, raw materials) and outputs (products, transportation, and wastes) for these various steps (http://www.istc.illinois.edu/info/library_docs/tn/99-031.pdf).

The food production industry demands high inputs of resources and leads to several negative environmental effects. Most food production systems have been optimized to meet economic requirements and the nutritional needs of a rapidly augmenting world population. Although environmental issues have not been given proper attention, one should bear in mind the various intricacies in conducting life-cycle studies of food products. A fully fledged study should comprise separate sections, as subsystems, such as agricultural production, transportation, industrial processing, storage, distribution, packaging, consumption, and waste management, all of which make up a quite complicated system. One of the major hindrances in the collection of suitable data is the lack of public databases. Another serious obstacle is that life-cycle studies require interdisciplinary interactions. As a result, the majority of food life-cycle studies carried out so far focus exclusively either on agricultural production or industrial refining (Koroneos et al., 2005).

Tools are required to assess the environmental aspects of a business, irrespectively of whether it is an individual firm, an entire sector, or even economy at national or international level. In environmental systems, the widely recognized powerful and effective tools for collection of detailed information on environmental aspects are Life Cycle Assessment (LCA), Multi-Criteria Analysis (MCA), and Environmental Performance Indicators (EPIs).

Life Cycle Assessment (LCA) is considered a systematic tool to evaluate the environmental impacts occurring throughout the entire life cycle of a product, process, or activity. One of the major strengths is the comprehensiveness of this approach and the avoidance of problem shifting between impacts or areas. On the other hand, the large amount of detailed data, long time required, and expert knowledge to apply it are the main weaknesses of LCA. MCA is a decision-making tool often applied in environmental systems analysis to evaluate a problem by providing by order of preference several alternatives on the basis of well-established criteria pending on the individual unit. The goal of MCA is to compare and rank alternative options and to evaluate their (environmental) consequences in compliance with the criteria established. One of its greatest advantages is the possibility to use the criteria with their own dimension. One of the most important difficulties of MCA is the subjectivity of the weighing step for evaluating the various criteria. EPIs determine quantitatively the current or past environmental performance of an organization's management. One of their main strengths is their use in benchmarking within the sector whereas one of the main weaknesses of EPIs is that they often only collect data for aspects about which data are readily available. Their main difference *vis-a-vis* other approaches is that they do not target to comprehensiveness, but rather a representation of key characteristics of an enterprise (Hermann et al., 2007).

The history of LCA dates back approximately 40 years since it first focused on energy and material budgets to which complementary pollution aspects were gradually added. With the advent of two oil crises on the 1970s, interest in LCA was boosted, but mainly for the aspect related to energy effectiveness. With the growing solid-waste issues at the end of the 1980s, the development of the methodology moved at a higher pace. The first formal framework for the impact-assessment phase was proposed in 1992 in an attempt to convert inventory data into potential impacts on ecosystems and human health. A first international norm for quantifying the environmental impacts of products and services was set up in 1997 describing the principles and the general framework of LCA, in terms of a "cradle-to-grave" methodology (http://www.eoearth.org/article/Life_cycle_assessment_of_farming_systems).

The LCA framework is applied to inventory the energy, the materials input, the emissions and waste released to the environment, and also to categorize these terms according to environmental impact category (Pelletier and Tyedmers, 2007). The entire life cycle is included in the assessment, which means that the product under study must be investigated from the very beginning, that is, from extracting and processing of raw materials through manufacturing, storage, transportation and usage, up to final disposal (Berlin, 2002). Each substance consumed or emitted is allocated to different impact category indicators, on the basis of its potential environmental effects. A model is used to convert the inventory data contributing to each environmental impact (taking into account in the LCA), into potential impact results. This is carried out by multiplying the emissions of each substance with a conversion factor per impact category to which it may potentially contribute (Aubin et al., 2006). In the study of Baumann and Rydberg (1994), three different methods for impact analysis and evaluation were compared. Specifically, two sets of environmental indices were calculated according to the 'ecological scarcity method' and the 'environmental theme method' and compared with indices from the method for 'environmental priority strategies in product design'. The relative importance of CO_2, SO_2 and NO_x in the three evaluation methods, expressed as index ratios $CO_2:SO_2:NO_x{}'$ was calculated as 1:200:250, 1:220:350 and 1:150:6100, respectively. It was suggested that the differences in the results may depend on effects considered, the construction of the algorithms, and other background data.

LCA was developed to take into account issues not addressed by other environmental management tools. It proved itself particularly useful as a technique for comparing two or more alternative options in terms of their combined potential environmental impacts and ecological sustainability (Lundie and Peters, 2005). For example, Tangsubkul et al. (2006) studied the LCA of microfilration, a particular step of the manufacturing process of several products. Different membrane chemical cleaning options were compared. It was demonstrated that processes that operate at a low flux with a high maximum transmembrane pressure lead to the most environmentally favourable results.

In some industrial sectors in terms of "eco-balancing", "resource and environmental profile analysis", or "cradle-to-grave assessment", LCA has displayed a wider methodologic development since the early 1990s when its relevance as an environmental management tool in both corporate and public decision making became more evident (Hospido et al., 2003). An important review of several LCA applications was published by Azapagic (1999), who identified the major axes as follows:

- Identification of environmental improvement opportunities,
- Environmental strategic planning development,
- Product and process optimization, design and innovation,
- Environmental reporting and marketing.

The performance of LCA can be distinguished into four main parts: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA), and interpretation of results. Both goal and scope definition constitute the stage in which initial choices are made to determine the working plan of the entire LCA (Thomassen et al., 2008). This stage defines the reasons for the LCA study and the intended use of results. The selected system boundaries are bound to depict the boundary between the systems (natural and/or technical) under study. Most often, the starting point is extraction of raw materials whereas the final stage is the waste treatment.

The inventory analysis compiles all required resources and all emissions released by the system under investigation and relates them to the functional unit (Brentrup et al., 2004). This presupposes that the production system is divided into unit processes to facilitate the data collection. In the inventory analysis it is of great importance to determine the issues that play a crucial role in assessing reliability, such as acceptability of data sources and calculation rules of assessing environmental interventions (Grönroos et al., 2006).

The impact assessment is the stage in which data collected during the inventory analysis are processed, and environmental effects are allocated qualitatively to the selected impact categories. Furthermore, environmental effects are not quantified with regard to a common unit for that category (Thomassen et al., 2008). LCA is typically divided into five phases: selection of impact categories classification, characterization, normalization, and weighing (Grönroos et al., 2006). All in- and out-flows are calculated on the basis of a unit called the functional unit. Such a unit is chosen based on the product function. As some activities may involve more than one product, the total environmental impact is often divided among the main product and the by-products. This procedure known as allocation is based on the relationship between the main product and by-products with regard to parameters like mass, energy content, or economic value. According to another approach, the by-products must be included in the system, thereby, separately evaluating the production system per by-product. Thus, it will be possible to subtract the latter from the initial system, thus, obtaining results for the main product. This approach is called "system expansion" and is strongly recommended by the ISO. The first result of an LCA is a matrix of inventory results in which the calculated values per phase of the life cycle as well as the total values are represented for a number of substances, categorized as resources from ground, water, emissions to air, emissions to water, and products. Matrix simplification is feasible by applying determination methods that weigh together all emissions responsible for global warming, acidification, toxicity, eutrophication, photochemical ozone formation, and stratospheric ozone depletion. This determination in combination with qualitative assessment of environmental impacts that cannot be described make up the impact assessment. Qualitative assessment is only applicable when no reliable method is available for quantifying a category of environmental impact or data are lacking (Arvanitoyannis, 2008).

Following the completion of impact assessment, analysis, interpretation, and evaluation of results occurs, thereby resulting in statement of conclusions and recommendations of the study. A contribution control in the interpretation phase determined the elements mainly responsible per specific impact category (Thomassen et al., 2008).

LCA must be effectively combined with trade-off rules, boundaries, and critical thinking. Comprehension of the purpose of analysis and service effectiveness delivered places the foundations for an efficient comparative analysis. At this instance, it is noteworthy to refer to latent problems that must be addressed to ensure the validity of the conducted LCA.

- The reliability and quality variance data must be understood and acknowledged
- Unequivocal description of uncertainty can only be minimized if more and better quality data are used in LCA
- "Decent" comparisons between studies are hardly feasible because of the greatly differing assumptions made in the first place
- There is no unanimously accepted method for LCA

Although several methodologic aspects are still under discussion, the applicability of LCA is continuously gaining ground and is considered an effective approach for numerous greatly differing situations. Foods are definitely among the products whose overall environmental performance can be effectively investigated with the aid of LCA (Cordella et al., 2008).

An agricultural activity is regarded as ecologically sustainable if its polluting emissions and its use of natural resources can be supported in the long term by the natural environment (Thomassen et al., 2008). LCA is a promising tool for evaluation of environmental impact caused by agricultural products and, in extrapolation, for the entire production chain (Dalgaard and Halberg, 2005).

One should bear in mind that the uncertainty and variability of LCA outcome can greatly affect the credibility of this methodology. Calculating LCA impacts requires the use of several parameters, models, and scenarios which necessarily introduce uncertainty, in their attempt to simulate real-life situations. Uncertainty quantification of LCA is feasible by means of sensitivity analysis per individual parameter. The uncertainty of LCA results can be effectively quantified by applying stochastic and scenarios analyses (Basset-Mens et al., 2006).

Consumption rates underwent a tremendous increase because of a series of recent technological advances in sectors like manufacturing and production systems, life style, increase in world population, and changes in social systems have led to higher rates of energy consumption. There are several approaches to meet the coverage for current and future energy needs with parallel maintenance of cleaner production systems. LCA is applied in an attempt to look into design and functional/operational parameters that have either direct of indirect environmental impacts throughout the life cycle of the underlying product or service. Moreover, LCA can be effectively used to make comparisons of the environmental impacts of two or more potential operational scenarios that perform the same function. The majority of industrial organizations apply a well-defined LCA-standardized process or management policy to reach the minimal environmental impact. Among the undesired environmental impact of the emission of greenhouse gases (GHG) such as CO_2, NOx, and CO, which heavily contribute to global warming and are involved in other social and health risks. Moreover, one comes across other ecological and sustainability problems when investigation goes through the overall cycle of natural resources (Feng et al., 2007). In the study of Mahgoub and colleagues (2010), the environmental effect of Alexandria's urban water is evaluated. LCA method was applied and modeling of the urban water system was achieved through SimaPro software. It was shown that the most pronounced impact was due to the disposal of primary processed wastewater (68% of the total impact) and enhanced energy-consuming water-treatment plants (18% of the total impact). Decentralization was found to be the most effective technique for the decrease of the environmental effects.

Ecolabeling is used worldwide in industrialized countries as a means to promote more sustainable products in two complementary ways: by providing information enabling consumer to choose produces with the best environmental performance; and by 'benchmarking' environmental performance and, thereby, guiding product development. According to the ISO 14020 series, the criteria for award of an ecolabel must mainly depend on life-cycle considerations. Therefore, it was only rational to use LCA as a basis for developing ecolabeling criteria. However, LCA has been heavily criticized for lack of transparency and austerity. Furthermore, ecolabeling unfortunately is neither well established nor strongly encouraged in developing countries (Mungkung et al., 2006).

The main target of LCA application in agriculture has been to record the environmental impacts of production processes and to further place them in a global context or to compare production processes considerably varying from each other (Papatryphon et al., 2003). The impacts categories taken into account are the following:

- Eutrophication Potential (EP) comprises all potential impacts of high environmental levels of nutrients in particular N and P.
- Acidification Potential (AP) includes all negative effects on soils and surface water and any ecosystems of acidifying pollutants.
- Global Warming Potential (GWP) refers to the potential impact of gaseous emissions on the heat radiation absorption in the atmosphere.
- Net Primary Use (NPU) covers the use of NNP as a biotic resource, in the sense of it being unavailable for other purposes, and
- Non Renewable Energy Use (NREU) refers to the depletion of non-renewable energy resources (Aubin et al., 2006).

Awareness of environmental problems, such as water pollution and eutrophication both at local and global level, has displayed a strong increase in animal production. Because of the enhanced concern society is advocating over environmental issues, the animal industry has recognized the need to undertake action on environmental problems. The industry can solve its environment-related problems if it identifies and quantifies the impacts the present livestock production systems have on the environment, and then develops methods for quantitative assessment of these impacts (Ogino et al., 2007).

Cleaning is of great importance to the dairy industry to ensure production of safe produces of high quality and added value. However, the cleaning operations do have strong environmental impacts; cleaning is a both water- and energy-demanding process, requiring the addition of cleaning agents as well. To meet both the hygienic and the environmental requirements, it is recommended to use the lowest possible amounts of water, energy, and cleaning agents. Moreover, there are emissions due to cleaning operations and product losses, which adhere to tanks and pipes after processing. Whenever there is loss of milk products to wastewater, an increase in chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrogen, and phosphorus is recorded (Eide et al., 2003).

The environmental impacts of fish catching or farming, processing, and transport to the market are gradually becoming important issues apart from fish quality. Enhanced pressure from strong consumer groups and retailer organizations is "building up" in the direction of a more sustainable food production chain supplied with documentation. Furthermore, introduction of various environmental labels in conjunction with requirements for traceability and safety of foods is anticipated (Ellingsen and Aanondsen, 2006).

Waste management is a complicated phenomenon having a range of consequences for the involved stakeholders and the society. One of the many parameters to evaluate is the environmental impact of various treatment options or technical solutions. Although there are many tools for environmental impact assessment, one of the most commonly applied is LCA. The latter helps to expand the perspective beyond the waste management system. The environmental consequences of waste management are often related to the impacts on neighboring systems except for the emission from the waste management system, (Ekvall et al., 2007). Quantitative environmental life cycle assessment of products can be effectively used for product-oriented environmental management. In this sense, the environmental effects of a product during its entire life cycle are attributed quantitatively to the functioning of the product (Guinée et al., 1993).

There are two major approaches to analyze the impacts of the underlying production process or service: i) source analysis (primarily focused on the analysis of each source of GHG with quantitative measures regarding the impact on environment, health, or social systems). The endpoint is a complementary approach applied to determine the impact and related costs on human health, society, and ecology. ii) another approach to environmental quantitative assessment is to use the life-cycle impact-assessment method (LIME; ref. Feng et al., 2007).

LCA STUDIES ON FOODS AND FOOD PACKAGING MATERIALS

Implementation of LCA on Milk and Dairy Foods

The dairy industry has been thoroughly studied to determine its environmental impact in many European countries. Milk is one of the most important dairy products in European countries and it has been reported that organic milk production can considerably decrease the pesticide use and mineral surplus in agriculture, but requires much more arable land compared with what conventional production does (Cederberg and Mattsson, 2000).

Berlin (2002) published an environmental LCA to investigate the environmental consequences of the life cycle of Hushallsost semi-hard cheese. The results obtained revealed that all the activities of the production of cheese, starting with extraction of ingredients up to waste management, contribute to the environmental impact. Milk production was shown to have the greatest environmental impact, followed by cheese making at the dairy, retailing, and the production of polymeric packaging for wrapping purposes. A decrease in the wastage of milk and cheese throughout the life cycle could be a potential solution for decreasing the environmental impact, without any effect on product quality. From a dairy perspective, the most effective action would be to lessen the requirements of milk in the cheese; this would automatically reduce the milk production at the farm.

An LCA on organic and conventional milk production at the farm level in Sweden was carried out by Cederberg and Mattsson (2000). The different feeding strategies applied in the two forms of production were shown to affect differently several impacts categories. The feed by conventional dairy farms, where feed is made from co-products (vegetable oils and starch), often resulted in a considerable input of phosphorus and nitrogen. Although organic milk production can clearly reduce the pesticide use and mineral surplus in agriculture, this production method also demands much more farm land than conventional production. For Swedish conditions, however, the extensive use of grassland for grazing ruminants is considered positive because this type of arable use falls in line with the domestic environmental goals of biodiversity and aesthetic values. This study revealed that even in the case of a low-input agricultural system (i.e., organic milk production), there can be obvious environmental benefits such as the considerably lesser application of pesticides and fertilizers.

Thomassen et al. (2008) conducted LCA to compare the assessment of the environmental impact of conventional and organic milk production systems in Netherlands and to identify crucial points in the conventional and organic milk production chains. This LCA case study, based on ten and 11 conventional and organic farms, respectively, displayed better environmental performance with regard to energy use and eutrophication potential per kilogram of milk for organic farms than for conventional farms. Moreover, higher on-farm acidification potential and global warming per kilogram organic milk implies that higher ammonia, methane, and nitrous oxide emissions occur on farm per kilogram organic milk than for conventional farm. Total acidification potential and global warming hardly revealed any difference between the selected conventional and organic farms. Moreover, results displayed lesser land use per kilogram of conventional milk compared with organic milk.

According to Xie et al. (2011), an LCA methodology was applied for the comparison of the environmental effects in the life cycle of two different milk-packaging methods (1: paper–polyethylene–aluminum laminate and 2: polyethylene). According to the data obtained after application of LCA, it was shown that the composite packaging is characterized by increased environmental impact in comparison with plastic packaging. Furthermore, it was shown that the impact of raw material extraction is the strongest among all life-cycle stages, except for the disposal stage. The environmental effects caused by the use of composite packaging are basically derived from fossil fuels, land use, and respiratory inorganics categories, while the corresponding effects of the plastic packaging are basically derived from the fossil fuels. Nevertheless, the composite packaging is characterized by enhanced environmental impact due to the limited recycling and reuses possibilities. This environmental impact can be effectively limited by targeting to the use of methods for the separation of polyethylene and aluminum from the packaging.

A simplified LCA methodology was applied to assess the total life-cycle processing of milk to quantify the potential environmental impact by Hospido and colleagues (2003). Two dairies and two farms were selected as typical representatives of Galician milk production to determine both production and processing scenarios. Several subsystems were identified and thoroughly studied; farms, fodder factories, and dairies and, although the collection of their inventory data was carried out over one complete year, some values were shown to vary substantially. The analysis of the data by LCA quantified the potential impact associated to milk production and also the reductions obtained by the application of various corrective actions, such as better formulation of cattle feed and the implementation of treatment systems for water and air emissions. The consideration of the above-mentioned actions can result in the maximal reduction of almost 22% of the global normalized impact.

Bianconi et al. (1998) reported on the application of LCA to an Italian medium-size dairy. The main target of this approach was to pinpoint the major difficulties occurring in SMEs (small- and medium-sized enterprises) while applying LCA and to develop a simplified methodology. Two alternative primary packaging materials for butter, one of coupled paper and polyethylene and another of coupled aluminum foil and grease-proof paper, were studies. The inventory evaluation data on water, energy consumption, and quantity of CO_2, SO_2, heavy metals, and solid waste released to the environment per phase of the life cycle (raw material production, manufacturing, distribution, and end of life) were considered, as well.

Casey and Holden (2005) applied the LCA methodology to derive a scientific framework for calculating emissions and to assess emissions management scenarios with regard to kg CO_2 eq emitted per unit of milk production. The total GHG emission per kg (ECM) produced in one year, in Ireland was 1.50 kg CO_2 eq; the main contributors were enteric fermentation (49%), fertilizer (22%), concentrates (13%), dung management (11%), and diesel/electricity (5%). Analysis of the obtained results reveals that, having taken into account the largest contributors to kg CO_2 eq, it is also crucial to examine the smallest ones, that is, concentrated feed, manure management, and diesel consumption for potential amplifying and attenuating effects.

The environmental impact of eight commercial organic dairy farms, using input–output accounting (IO), ecological footprint analysis (EFP), and LCA was investigated by De Boer and colleagues (2003). In total, 11 environmental indicators (EIs) were quantified and correlated. The following impact categories were assessed: land use, energy use, global warming potential, eutrophication potential, and acidification potential. Results showed beyond doubt that IO of nutrients yields effective indicators with respect to eutrophication and acidification. As regards land and energy use, both EFP and LCA led to similar indicators, thereby confirming the potential of this technique toward deriving effective environmental indicators. Table 1 presents the most important factors related to LCA applications on milk and dairy products.

Implementation of LCA on Meat and Meat Products

In a study by Dalgaard and Halberg (2005) the LCA methodology was applied to estimate impact (eutrophication global warming and acidification) from a product of one kilogram of pork. The results revealed that subsystems such as farm, the piglet production and the fertilizer production are the major contributors to global warming. The highest contribution to global warming from the farm is nitrous oxide. The highest contribution of greenhouse gases come from the farm and comprises emissions from stable, mature storage, fertilizer application, fossil fuel, and crop production. Some of the emissions from the farm cannot be directly related to the pork production, but only to the crop production. Production of piglets in other farms and fertilizers were found to contribute considerably to the global warming as well.

Basset-Mens and Van der Werf (2003) made an attempt to explore the diversity of pig-farming systems using LCA, and resulted in a multicriteria environmental assessment of three contrasting pig farm systems: conventional Good Agriculture Practice (GAP), 'Label Rouge' (LR), and Agriculture Biologique (AB), known as Organic Farming (OF). Average, favorable, and unfavorable scenarios were defined and evaluated per production mode for seven impact categories (eutrophication, climate change, acidification, energy use, land use, and pesticide use). When LR and AB were expressed per hectare, it had lower impacts than GAP for eutrophication and acidification, a higher (LR) or similar (AB) impact for climate change, and was less productive (14% and 45%, respectively). This comparison of the three contrasting and relatively optimized scenarios of pig production provided useful knowledge to decisionmakers at different levels and crucial points identification per scenario studied.

Calculation of LCA outcomes is feasible only through the use of parameters, models, and scenarios which introduce uncertainty, as they imperfectly account for the variability of both human and environmental systems. The analysis of uncertainty of LCA results made possible its reduction with an improved estimation of key parameters and application of models used to convert emissions into regional impacts, such as eutrophication in a pig production system. The quantification of the intra-system uncertainty, requires determination of: i) the variability if the technical performance (crop yield, feed efficiency); ii) emission factors (for NH_3, N_2O, and NO_3); and the iii) effect of the functional unit. For farming systems, the intersystem variability was investigated through changing the production mode and the farmer practices. However, for natural systems, the theory that variability due to physical and climatic characteristics of catchments is anticipated to modify the nitrate fate was explored. The results obtained revealed the main sources of uncertainty which were the estimation of emission factors due to variability of environmental conditions and lack of knowledge. Another important issue is the model used for assessing the regional impacts such as eutrophication (Basset-Mens et al., 2006).

The environmental impacts of the Japanese beef cow–calf system were assessed, and the impacts of the whole beef production system were estimated and integrated with those of beef-fattening by Ogino and colleagues (2007). Both inputs and outputs involved in the cow-calf production, such as food production, feed transport, and animal management, biological activity of animal and waste treatment were calculated. Two approaches for the reduction of environmental impacts were examined. The first was a scenario based on shortening the calving intervals by one month, thereby reducing the environmental impacts by 5.7–5.8% in all categories. In the second approach, the number of calves per cow on each environmental impact category was investigated. It was found that an increase in the number of calves per cow led to decrease of environmental impacts in all categories. However, the repercussion was rather minimal because an increase of one calf dropped the environmental impact a meager 3.0%.

According to Beauchemin and colleagues (2011), an LCA methodology was applied in western Canada to evaluate the emitted GHG during the entire production process of beef. The effect of different mitigation methods applied was based on feed alterations aiming at the reduction of emitted CH_4 and improvement of animal husbandry. The investigated system was a farm of 120 cows, four bulls, and their progeny. It was shown that GHG emissions from beef production amounted to approximately 22 kg CO_2 equivalent/kg carcass, and GHG emissions from cow half and feedlot systems were approximately 80% and 20%, respectively. Significant reduction (8%) of GHG intensity values was reached with strategies applied to the cow–calf herd. Several strategies could enhance this percentage by up to 17%. However, strategies adopted in the feedlot had a nonsignificant impact of up to three and four percent. It was clearly shown that the whole system was of high efficiency; however, there are still some mitigation strategies the implementation of which can maintain GHG emissions at even lower levels.

Van der Werf and colleagues (2007) implemented LCA to assess the major environmental impacts linked to production and on-farm delivery of concentrated feed for pigs. The recorded impacts differed greatly based on feed type; differences were smallest for acidification and largest for energy use. For all impact categories, except for terrestrial ecotoxicity, the highest values were recorded for piglet feed. Impact values far the weighed mean of the six feed types fell in the same range with those of the feeds for growing and finishing pigs. The environmental burdens in conjunction with the production and delivery of pig feed can effectively drop by optimizing the fertilization of its crop-based ingredients: employing more locally produced feed ingredients, lowering concentration of Cu and Zn in the feed, and employing wheat-based rather than maize-based feeds.

An LCA was applied to determine quantitatively the emissions of GHG from Irish suckler-beef production and assess a number of alternative management scenarios (Casey and Holden, 2005). Scenarios were put forward to study both beef-bred animals (Charolais, Simmental, and Limousin) and dairy-bred animals (Hostein–Fresian). The obtained results revealed that the cow phase had considerable contribution to emissions and the highest impact in this field. The typical suckler-beef system was estimated to produce 11.26 kg $LWyr^{-1}$. The results of the maize sub-LCA analysis showed that an emission of 1735 kg CO_2 (eq) ha^{-1} yr^{-1} corresponding to 0.6 kg (eq) kg $^{-1}$ grain maize per year could be anticipated from the production of main grain, with 84% of the emission coming from nitrogen used for production and husbandry products. As regards the dietary supplementation for GHG emissions reduction, a broad range of supplement combinations were evaluated. The obtained results showed no major potential reduction compared with, or within, the grass-dominated system.

Casey and Holden (2005) made an effort to assess the GHG emissions from suckler-beef units, including conventional, Rural Environment Protection Scheme (REPS), and organic production and to assess whether adopting more extensive methods of production could minimize the GHG emissions per kilogram of live weight leaving the farm and per area used for production. Fifteen units versed in suckler-beef production (five conventional, five in an Irish agri-environmental scheme, and five organic units) were assessed in terms of emissions per unit product and area. The obtained results revealed that moving from conventional suckler-beef production to an agri-environmental scheme (AES) production system would substantially decrease GHG emissions. However, an ever greater reduction in emissions could be reached for organic suckler-beef production but at the cost of large drop in live weight (LW) production per hectare, which could inevitably result in increase of organic meat price. Table 2 presents the most important parameters related to LCA applications on meat and meat products.

Implementation of LCA on Fish and Seafood

Thrane (2006) presented the main results and conclusions with regard to environmental impacts derived from Danish fish Products (fish caught by Danish fisherman). Although the main focus was on LCA results for flatfish, an overview of screening other fish species was included as well. Moreover, it comprised a thorough analysis of the energy consumption in the fishing stage. The results from the quantitative LCA revealed that the fishing and usage stage remained the spots for flatfish and for Danish fish products as such. It was further argued that fuel consumption has a strong potential impact and that further improvements in fuel effectiveness are closely linked to other objectives such as a reduction of discard, overexploitation, and seabed impact. Moreover, it was suggested that more attention should be paid to the development and promotion of cleaner production methods preferably in the fishing stage.

Pelletier and Tyedmers (2007) implemented LCA to evaluate the comparative environmental performance of both conventional and organic salmon-feed ingredients and feed formulations in terms of cumulative industrial energy use and contributions to global warming, acidification, eutrophication, marine aquatic ecotoxicity, and biotic resource use, and to identify the feed-related environmental profits (if available) that might be capitalized in the case of a potential transition to organic salmon aquaculture. Fish- and poultry-derived ingredients had considerably greater impacts than crop-derived ingredients. Despite the substantially lower life-cycle impacts of organic crop ingredients compared with their corresponding conventional ingredients, replacing conventional with organic crop ingredients led to very minor reductions to the impacts of feed production. In contrast, when fish meals/oils from dedicated reduction fisheries were substituted by by-product meals/oils, the environmental impacts of feed production displayed a pronounced increase. Environmental impacts were considerably lower when feeds contained lesser proportions of fish- and poultry-derived ingredients. These results clearly showed that the application of organic crop ingredients and fisheries by-products hardly affected the environmental impacts of feed production.

LCA was used in France to evaluate the effects of massive feed process of rainbow trout on the environment. All the procedures involved in fish production (crop, fishery, feeds, and fish processing) were taken into account. The investigation for the effects on the environment was mainly focused on energy requirements, production capacity, contribution to global warming, acidification phenomena, and eutrophication. It was found that by limiting the main nutrients (N and P) and resource use on farms, the highest percentage of targets in aqua-feed processing and application was reached. With the use of plant feed of enhanced qualitative value and fish meal products produced by other procedures, a significant decrease of the environmental impact of aqua feeds was observed. Another important output of LCA implementation was the better management of the units which increased efficiency and minimized nutrient-wastes (Papatryphon et al., 2003).

LCA was applied to investigate the environmental impact of two alternative methods for the production of trout. The study evaluated an aquaculture unit that used either flow-through system (FTS) or recirculating flow system (RFS). Water requirements, eutrophication phenomenon, and energy requirements were all taken into account. RFS proved to be more effective except for energy requirements. The water requirements of this method decreased by 93% in comparison with FTS and eutrophication potential dropped by 26–38%. Nevertheless, for 57,659 MJ/t of fishes (16 KWh/kg), the consumption of energy was 24–40% higher. Significant energy savings could be made by improving airlift and biofilter systems. In addition, it was shown that LCA can be effectively applied on aquaculture field to evaluate and improve the existing systems (d'Orbcastel et al., 2009).

Moreover, Ellingsen & Aanondsen (2006) applied LCA to assess the environmental impacts of Norwegian cod fishing and salmon farming. They reported that the fishing phase for the cod and the feeding phase for both salmon and chicken dominated all environmental impacts considered. In fact, it was shown that chicken was, by far, the most energy effective, followed by salmon and cod. The area of sea floor affected by bottom trawling was approximately 100 times greater than the land area required to produce the chicken feed for production of the 0.2 kg fillet. The potential for improvement of environmental performance, both for salmon farming and cod fishing, resided mainly in the energy use.

According to Ziegler (2006), a substantial effort was made aiming at determining both resource consumption and the effects on the environment due to the capture and consumption process of Norway lobsters collected with creels and trawls, by applying the LCA method. The effect of creeling, conventional trawling, and species selective trawling on the environment was evaluated. It was found that the highest percentage of energy is spent for carrying out the fishery procedure. The energy expenditure after landing the catch is only 10%, 19%, and 32% of the total energy needs, as concerns conventional trawling, selective trawling, and creeling, respectively. It was revealed that creeling efficiency was higher than the respective conventional one as concerns seafloor effect and discarded fishes. Moreover, the selected method showed the lowest percentage of discarded and landed by-catch fishes and, as a result, it was significantly more effective. However, the operation of this method required the use of higher percentage of resources compared with creeling. It was finally shown that better results could be obtained through a gradual replacement of conventional trawls with creels or trawls that use catching methods only of selected species.

The LCA method was applied to investigate the environmental effects of a systematic procedure used to re-circulate water for aquaculture of turbot in Brittany, France. The emitted nutrient compounds and the suspension of N, P, and other solid substances were investigated using two methodologies; nutrient measurement accounting and nutrient balance modelling. Both methods were in accordance as concerns the emitted solids and P, whereas model-based methodology presented twice the emissions of N compared with the other method. Total farm emissions (total solids: 11,352 kg, PO_4-P: 454 kg, P_2O_5-P: 438 kg, total P: 892 kg, nitrogen/NO_2-N: 48 kg, NO_3-N: 397 kg, NH_3-N: 397 kg, and total N: 3168 kg) were calculated. Furthermore, total emissions of solids, P, and N reached at 17,560 kgDM, 900 kg, and 5830 kg, respectively. It was disclosed that both methods had several disadvantages. To be more specific, the nutrient–measurement-accounting method was characterized by several uncertain factors including the potential gaseous N_2 emissions (Aubin et al., 2006).

LCA was applied with the aim to assess the environmental impacts of two different valorization types for mussel by-products: mussel shell valorization (targeting to the production of calcium carbonate) and mussel organic remains valorization (targeting to the production of pâté). Propane and electricity requirements, sludge, and ash management haulage, and atmospheric releases were detected as the most important factors to be improved. Further action should be undertaken in the pâté-production stage as concerns formulation of the final product, energy requirements, and transportation. The main inputs during mussel shell valorization were: mussel shell and debris (100 t), coagulant (55 t), diesel oil (57 t), polypropylene big-bags (17 u), fresh water (60 m^3), cooling water (35 m^3), and transportation of raw materials and products (216.3 and 299.7 km, respectively). On the other hand, the main outputs in the operation of the same process were: dispatched $CaCO_3$ products (65 t), emitted water (35 t), emitted NO_x (32.3 kg/NO_2), and emitted CO (22 kg). The main inputs during mussel organic by-product valorization were: mussel organic waste (100 t), water (111.8 t), oil (23.6 t), aromas and spices (15.3 t), cardboard (15.1 t), and transportation of mussel pâté (1.8 10^5 t km). In addition, the most significant output to the techno sphere was of mussel pâté (277.8 t) while the most important output to the environment was the released treated wastewater (1.3 10^3 m^3). As a concluding remark, it can be said that the assessment of the Galician mussel field included the valorization of the implementation of mussel shells and by-products. The contribution of these products to environmental impact was lower in comparison with mussel culture, purification procedure, and canning processes (Iribarren et al., 2010).

Furthermore, in the study of Papatryphon and colleagues (2003), LCA was applied to compare the effects of different farms on the environment and as a method of studying and evaluating the impact of different management strategies. Several records were collected from eight trout farms during the production of goods. The main factors studied in this investigation included eutrophication phenomena, acidification, impacts on global warming, energy requirements, and biotic resource usage. Comparing the aquacultures, an important variation was found as regards the effects of every system on the environment. It was concluded that more factors, such as feed efficiency and the production intensity should be taken into account, to have a more global insight of the involved parameters both qualitatively and quantitatively.

Grönroos and colleagues (2006) investigated the application of LCA on rainbow trout aquaculture in Finland. The effects of several stages, emissions, and application of fossil fuels on the environment were evaluated. Several variables including feeds with varying contents of nutrients, and methods of limiting the emitted compounds, were taken into account. It was shown that the basic airborne emissions from rainbow trout farming were derived from the manufacture of basic products and animal feed. On the other hand, the most important waterborne emitted products came from farming itself. The transport of the goods had a high impact on environmental pollution because of gases released from vehicles. A new different farming methodology can considerably reduce the disposal of emitted substances. According to this methodology, usage of improved and more effective feeds can minimize the environmental cost by decreasing the concentration of N and P in the water.

The effects on the environment during the production of canned tuna were studied by Hospido and colleagues (2006) in an attempt to estimate the average environmental impact starting with the installation up to operation of such a farm. The investigation was conducted in an industrial plant in Galicia, with a capacity of 26,000 tons per year. It was clearly shown that the processing stage was responsible for most effects except for human toxicity. However, inside the enterprise, the management of tinplate was evaluated as the most important factor and, as a result, corrective measures must be undertaken with regard to this factor either to minimize or to keep it under control. Some of these actions could include the use of larger quantities of recycled tinplate and the taking of required actions to gradually replace this metal with other more environment-friendly materials.

Three aquaculture units, two in France (rainbow trout reared in freshwater raceways and turbot in an inland re-circulated system) and one in Greece (sea bass farming in sea cages) were examined by applying LCA. The examined aquacultures were described by different intensities as concerns the production efficiency. Specifically, the basic differences were detected in the provision of feed and energy requirements. Dissolved N emissions to water of trout, sea-bass, and turbot farms were about 57.8, 83.2 and 68.8 kgton^{-1} of fish, respectively. The respective solid N emissions reached at 7.2, 18.5, and 12.7 kg ton^{-1} of fish, while the corresponding dissolved P emissions amounted to 4.0, 4.7, and 2.6 kg ton^{-1} of fish, respectively. Finally, the theoretical O_2 demand of trout, sea-bass, and turbot farms was about 135.7, 347.7, and 147.8 kg ton^{-1} of fish, respectively. The sea-bass cage unit was shown to be well-distinguished by lower efficiency in comparison with trout raceways unit, with an enhanced potential for eutrophication and net primary production use (NPPU). The turbot unit was found to be the most energy-demanding. Moreover, high-energy demand was directly connected to a greater contribution to global warming and higher acidification effects (Aubin et al., 2009).

In an article published by Phong and colleagues (2011), the environmental impact of integrated agriculture–aquaculture (IAA) units in the Mekong Delta was investigated. The evaluation of these farms was carried out taking into account the different types of intensification. Inputs and outputs for rice, fruits, vegetables, pigs, poultry, and fish were recorded every day from 11 units, for a two-year period. The farms were classified by rice-dependence and high-input fish method (R-HF), rice-dependence and medium-input fish method (R-MF), or orchard-dependence and low-input fish method (O-LF). After the completion of LCA, it was shown that land usage/kcal fish had no difference among the three types of farming. Global warming, energy requirements, and eutrophication effects per kilogram of fish fluctuated at slightly increased levels, whereas the acidification factor was significantly enhanced in O-LF in comparison with R-HF and R-MF. Farm calories calculated for R-HF, R-MF, and O-LF were 0.016, 0.015, and 0.023 m^2kcal^{-1}, respectively. Calories calculated for energy use of R-HF, R-MF, and O-LF were 17.415, 14.246, and 27.068 kJkcal^{-1}, respectively, while the corresponding GWP values were 11.256, 10.096, and 27.662 gCO_2-eq Kcal^{-1}, respectively. One kilogram of product treated by O-LF units was characterized by 28%, 35%, 54%, 45%, and 52% augmented land usage, energy requirements, global warming effect, eutrophication effect, and acidification, respectively, compared with one kilogram of product produced in the other two types of farms.

LCA was implemented by Hospido and Tyedmers (2005) to quantify the scale and importance of emissions that result from industrial activities associated with contemporary Spanish purse seine fisheries for Skipjack *(Katsuwonus pelamis)* and Yellowfin *(Thunnus albacares)* tunas. The obtained results revealed that the production and use of diesel fuel while fishing accounts for more than half of the total impacts in six of the seven impact categories analyzed. In contrast, the use of anti-fouling paint was a substantial contribution to marine ecotoxicity potential. On comparison of the performance of fisheries in the three oceans, Pacific-based operations resulted in the highest emissions across all impact categories modelled. Finally, two scenarios were applied to quantify the environmental benefits linked with improving tuna abundance and availability.

According to Vázquez-Rowe and colleagues (2010), the LCA methodology was applied to evaluate the environmental impacts of Atlantic horse mackerel fishing in two different Galician coastal fisheries. All the required machinery, fuels, anti-fouling paints and others were taken into account. As concerns fishes landed by coastal bottom trawlers, it was shown that, among the inputs from the techno sphere, diesel (496 kg), steel (5.1 kg), and seine net (2.4 kg), marine lubricant oil (2.2 kg) and ice (323 kg) can be referred. Moreover, the outputs to the techno sphere were only the horse mackerel products (1 t) while the main outputs to the environment were: emitted nylon (189 kg), CO_2 (1571 kg), NO_x (35.7 kg), and SO_2 (5 kg). As regards fishes landed by coastal purse seiners, it was shown that, among the inputs from the techno sphere, diesel (176 kg), steel (2.7 kg), anti-fouling (365 kg), marine fabricant oil (447 g), ice (321 kg), and seine net (10.2 kg) were the most important. In addition, outputs to the techno sphere were only the horse mackerel products (1 t), while the main outputs to the environment were: nylon (1.03 kg), CO_2 (558 kg), SO_2 (1.8 kg), and NO_x (13 kg). It was shown beyond doubt that basic environmental impacts were strongly correlated with diesel production, transportation, and energy consumption by machinery. Moreover, cooling agent-leakage cases from the corresponding chambers had a very important impact affecting the ozone layer and global warming phenomenon. The use of purse seiners was linked to lower environmental severity (reduced by 49–89%) compared with the use of bottom trawlers. Discard rates of trawlers were found to have a significant impact as well. The reduction of the environmental impacts could be reached by revising all fishing quotas and methods, reducing the energy requirements, and using new types of fuels and improving operations. The main factors related to LCA applications on fish and seafood are presented in Table 3.

Implementation of LCA on Agricultural Products

According to Brentrup and colleagues (2004), a novel methodology was established aiming at the integration of the environmental impacts related to crop industry, mainly focusing on plant nutrition. Moreover, the method targeted to the combination of the optimal processes within the assessment stage of effects. One of the most positive characteristics of this method is its taking into account all practices related to crop production, including the process of cultivation and fertilizers, farm machinery, fuel, etc. An innovative process was established to assess the use of land and the consumption rate of the resources. This process included aggregation to identify indicators for resource depletion (RDI) and effects on the environment (EcoX), normalization, and weighing. It was revealed that enhanced EcoX level resulted in increased environmental impact.

The objective of the work by Sanjuán and colleagues (2003) was to evaluate the environmental effects of orange production (Comunidad Valenciana). The agricultural technique was assessed to develop and apply the LCA method to this economically important productive sector in Spain. The use of fertilizers and pesticides, the energy requirements of the crop (for use of machinery and watering system), and all agricultural practices were taken into account. The potential effects investigated included acidification, non-renewable resource use, eutrophication phenomena, global warming, photochemical oxidants production, risks to human health from toxic substances, and environmental pollution. It was shown that production of fertilizers highly contributed to acidification (86% of total impact) and to depletion of non-renewable resources (84%). In addition, the same factor had a great contribution to greenhouse effects (52%), photochemical oxidant formation (42%), and ozone depletion (25%). Eutrophication was basically (99%) caused by agricultural practices.

Haas and colleagues (2001) applied LCA methodology to assess the environmental effects of several farming productive methods. Eighteen grassland farms differing in terms of production intensity (intensive, organic, and intensified) were evaluated in Allgau, in the south part of Germany. In was shown that both extensified and organic systems could effectively limit the environmental degradation, preserving at a higher level the abiotic factors, reducing the energy demand, and, thus, contributing lightly to global warming and usable ground-water depletion. Moreover, by analyzing all impact factors (biodiversity, landscape image, protection of wild animals), it was shown that organic farms have considerably less disadvantages in terms of indicators like grassland diversity, grazing cattle, layout of farmstead, and herd management. LCA can be effectively applied to compare farms and different production intensities, but there is still great potential for improvement.

LCA was also applied for the identification of environmental effects along the food chain and the assessment of the mechanism by which pre-farm processes and farming are contributing to the effects of different factors during the production of foods (wheat-to-bread, barley-to-beer, and canola-to cooking oil) in Western Australia. The impact factors investigated included energy requirements, resource depletion, global warming, eutrophication phenomenon, acidification, and production of toxic substances. The key production steps to reduce the environmental impact in order of importance were canola production, cooking canola oil, wheat, and, finally, barley production. It was shown that pre-farm and farming stages constitute approximately 90% of the total supply chain for these products (Narayaswammy et al., 2005).

The basic conclusions derived from a LCA application to three commercial apple orchards as well as to reference orchard in New Zealand, were compared and commented by Jones (2002). The study was mainly focused on the primary environmental disadvantages of apple agriculture and the improvement possibilities. It was found that more than the half of the impact group data taken into account in this investigation was strongly linked to energy requirements. Moreover, the energy consumed for the arm machinery operation was shown to be the most energy-demanding part of the process, while the most important toxic substances were derived from the use of synthetic pesticides.

Suramaythangkoor and Gheewala (2008) applied LCA methodology to production and burning of rice straw plant, aiming at the evaluation of the possible reduction of GHG (from avoiding burning these products) as well as at the use of the straw as a biofuel. The main finding of this review was that rice straw power plant could effectively substitute the conventional electricity-generation methods. It was concluded that, apart from a serious source of environmental pollution, field-burning of this product deprives population from a major energy source.

In the study of Blengini and Busto (2009), LCA was implemented to evaluate the life cycle of rice (from cultivation to consumers) in Italy. According to the obtained results of the investigation, the impact per kilogram of delivered rice after the milling procedure was 2.9 kg of emitted CO_2 equivalent, consumed energy of 17.8 MJ (16.6 MJ non-renewable), and water requirements of 4.9 m^3. Water irrigation level was calculated at approximately five cubic meters per kilogram of exported rice. However, inclusion of indirect requirements of water could increase it to eight cubic meters per kilogram. The use of fertilizers required the highest percentage of energy (30%) in comparison with refining and packing (25%) and transportation (17%). The global warming factor is highly affected by field emissions (68%), production of fertilizers (9%), and transportation purposes (6%). Several potential improvements were carried out, including different rice farming (organic, upland farming) and processing procedures (parboiling), in an attempt to limit the environmental impact. It was found that both organic and upland methods can considerably diminish the impact of the cultivation, but because of the decreased grain yields, the advantages per kilogram of the final products were very limited as concerns upland production systems, and tended to be eliminated in organic cultivations. Therefore, LCA can be effectively used to evaluate the above type of cultivations, and as a valid communication tool along the rice supply chain.

In the study of Breiling and colleagues (1999), the field of rice production was evaluated in an effort to limit the Japanese greenhouse gas emissions using the LCA. The introduction of more environment-friendly techniques during the production and the protection of the environmental resources were the main issues concerning the application of LCA. The LCA implementation for rice implies the re-examination of different procedures such as preparation, sawing, cultivation, harvesting, and post-harvesting techniques. It was shown that rice value of one million yen is characterized by approximate emissions of approximately 2.3 tons CO_2. It was finally proved that the total emitted CO_2 of Japan in 1990 was about 920 million tons (7.7 tones per person). The contribution of rice to the produced GHG of Japan was estimated at 0.9%.

Dalgaard and colleagues (2008) applied LCA to soybean meal for the estimation of the environmental impact from its consumption. A soybean/ palm loop (PO) and a soybean/ rapeseed loop (RSO) for the soybean meal were used to investigate the effectiveness of high soybean meal demand on palm oil and rapeseed oil production, respectively. A decreased level of environmental effects (apart from photochemical smog) was obtained for RSO, while enhanced effects were recorded for PO. It was clearly shown that the most important impact factors were global warming, eutrophication phenomenon, and acidification.

Enhancing need for transport fuels has led China to the use of biodiesel. The evaluation of the potential environmental effects due to the production and use of biodiesel formed by soybean, jatropha, and microalgae was achieved through the application of LCA methodology. The proper use of the solar energy and CO_2 uptake as well as the decreased application of fossil fuels improved the abiotic depletion potential (ADP), GWP, and ozone depletion potential (ODP) in the life cycle of biodiesel in comparison with conventional fuel. On the other hand, no effects were observed on eutrophication, acidification, photochemical oxidation, and toxicity phenomena. Numerous sensitivity tests were also used showing that the adoption of different allocation techniques, transport distances, yield, and oil concentrations, can significantly affect the life-cycle environmental impact of biodiesel (Hou et al., 2011).

An LCA methodology was applied to evaluate the potential use of sugarcane as a raw material for the manufacture of bio-products. Specifically, the production of sugar-fermented products was assessed and in comparison with data from other productive processes, such as US corn and UK sugar beet production, and the negative environmental impact was determined and recorded. It was also shown that sugar was characterized by significantly diminished fossil-energy demand, reduced emission of GHGs, and lower acidification, compared with corn and sugar beet. On the other hand, enhanced water demands and eutrophication possibilities were reported (Renouf et al., 2008).

The investigation of Contreras and colleagues (2009) was carried out to identify and assess the most important environmental impacts of different ways of using by-products and wastes from the cane sugar processing. Another purpose of this study was to improve the currently applied methods in a cane sugar mill in Cuba. The methods investigated were: 1) conventional production (application of synthetic fertilizers, pesticides, bagasse combustion); 2) use of wastewater, filter cake, and ashes to substitute the use of the above-mentioned fertilizers); 3) biogas production through the use of filter cake and wastewater; and 4) integration of alcohol and biogas processing into the sugar production procedure. According to LCA-obtained results, the mill could process 216 tons of sugar/day. It was disclosed that the agricultural stage had the greatest impact because of the enhanced land (48 ha/year), fuel (8743 kg diesel/day), and chemical (Diuron: 0.0040 kg/ha year, Glyphosate: 0.0097 kg/ha year, Gesapox 80: 0.0048 kg/ha year, MSMA 72: 0.0072 kg/ha year, Amine salt 72: 0.0025 kg/ha year, Isoctilic ester 48: 0.0116 kg/ha year, Asulox 40: 0.025 kg/ha year, Gramoxone: 0.0003 kg/ha year, etc.) requirements. As concerns the industrial processing, the electricity in combination with bagasse exhibited the most severe respiratory effects. During this process, emitted particles (N_2O: 5.7 kg/day, N_{total} to water: 0.4 kg/day, pesticides to water: 0.0015 kg/day, pesticides to soil: 0.03 kg/day) were released thus increasing the significance of the related impact. Finally, the production of alcohol (11.66 t/day), biogas (10–16 t/day), feeds, and chemical substances from by-products led to significantly lower energy requirements.

The needs for sugar continue to increase and India is the second biggest producer worldwide. It is estimated that over 12 million tons of sugar are produced annually in this country. As a result, the sugar industry is one of the most important industries in India. LCA and waste management methodologies were essential for analyzing and limiting the environmental impacts of this industrial field. For the improvement of sugarcane field, many parameters can contribute to the surplus electricity production such as bagasse% of cane, fiber% of cane, moisture% of bagasse, boiler efficiency, process steam consumption, and energy consumed in mill. As regards dry bagasse, lower heating value (LHV) is estimated at 16 MJ/kg whereas, for dry ligneous residue, LHV is about 18 MJ/kg. In India, most sugar industries form bagasse characterized by 50% moisture concentration and density value of about 150 kg/m^3. Oil, coal, gas, hydropower, bagasse, and rice husk are mainly used as fuels. The increased production of pollutants by this industrial field leads to enhanced greenhouse and global warming impact. Specifically, for the formation of one ton of sugar, emission of 0.002 kg CH_4, 1.7 kg total suspended particles (TSP), 1.21 kg SO_2, 1.26 kg NOx, 1.26 kg CO, and 160 kg CO_2 has been observed. Furthermore, 1.7 kg N_2, 19.1 kg COD and 13.1 kg total soluble salts (TSS) are emitted into water systems (Chauhan et al., 2011).

According to Eriksson and colleagues (2005), LCA was applied to examine how different types of feed can affect the environment during the operation of an aquaculture. Each examined feed was formulated to include proteins from one of three different protein sources: imported soybean meal (SOY), peas, and rapeseed cake (PEA) or Swedish peas and rapeseed meal with addition of synthetic amino acids (SAA). It was revealed that feed manufacture had greater contribution to the environmental impact than fish husbandry in terms of global warming and eutrophication phenomena. However, effects of lesser intensity were detected as concerns acidification. The SAA alternative was shown to be the most effective in reducing environmental degradation.

Organically and conventionally grown wheat produced in the United States was assessed with the use of a streamlined hybrid life cycle. The aim of the investigation was the evaluation of the primary energy requirements and GWP alterations between the two types of products. The different impacts (agricultural inputs, grain farming and transportation) were recorded and evaluated. It was found that the GWP value of a one kilogram loaf of organically cultivated wheat bread was decreased by approximately 30 g CO_2-eq compared with the conventional loaf. After shipping (420 km) for commercial purposes, both types of wheat were characterized by the same impacts (Meisterling et al., 2009).

In the study of Engström and colleagues (2007), the environmental impact of Swedish agriculture was assessed. In the investigation any upstream and downstream effects were taken into account, while the main impacts from this industry field included global warming, eutrophication, and biodiversity decrease. Furthermore, it was clearly shown that indirectly occurring impacts were also of high importance. Eutrophication, global warming, and resource depletion were determined as the most severe impact factors. Specifically, global warming reached 79,000 ton CO_2 eq (18% of food-chain contribution), eutrophication was measured at 5300 ton PO_4 eq (49% of food chain contribution), while depletion of non-renewable resources amounted to 910,000 TJ (10% of food-chain contribution).

The environmental impact of winter wheat cultivations carried out with several intensities (scalable depending on the percentage of used fertilizers) was examined by Brentrup and colleagues (2004). During the application of LCA methodology, the impact of resource and land use, global warming, toxicity, acidification, and eutrophication phenomena were taken into consideration. It was shown that, at N levels of 48, 96, 144, or 192 kgN/ha, the EcoX presented almost the same levels per weight unit. At N values of 0, 240, and 288 kgN/ha, the EcoX values increased by 100–232% (lowest N level = 96 kg/ha). It was also concluded that there was no conflict between agronomical optimal arable farming and commercial and environmentally relevant circumstances.

Mattsson and colleagues (2000) assessed the application of LCA methodology for the evaluation of agricultural land usage. Both environmental factors and qualitative characteristics of indicators of land usage were carefully analyzed. The methodology was implemented to cultivations of vegetable crops, the Swedish rapeseed, the Brazilian soybean, and Malaysian oil palm. Erosion, soil organic matter, soil structural characteristics, soil pH, P, and K, and their effect on biodiversity were taken into account. Several other indicators were not included because data collection for these indicators was extremely difficult (e.g., data related with the accumulation of heavy metals). Finally, another problem complicating the process was the assessment of the impact of a given crop on aesthetic landscape level.

Mouron and colleagues (2006) investigated the potential economic and environmental factors in homogenous integrated fruit farms in Switzerland. The abovementioned apple-growing factors were compared by means of an income analysis, mainly characterized by full-cost principle assessment of all potential environmental impacts (LCA). The empirically obtained data revealed that environmental impacts (ecotoxicity, eutrophication phenomenon, consumption of non-renewable energy sources) did not present higher values after increase of the farms' income. Enhanced use of pesticides, fertilizers, and mechanical equipment hardly affected yields and receipts. The extracted data were schematically presented in a pyramid-form managerial model that comprised the most important factors for successfully cultivated orchards. It was disclosed that thinking ways (distributional, conditional, and non-linear) were of high importance, given that integration of evaluations from orchards managerial pattern at a farm level took place.

Van der Werf and colleagues (2007) used five evaluation methods (Dialectic, Ecological Footprint, Environmental Management of Agriculture, Farmsmart, and LCA) to assess three different types of farms manufacturing crops and pigs in Bretagne and western France. The aim of this investigation was to assess the different impacts and properties of every method. The pig farms patterns cited were: conventional Good Agricultural Practice (GAP), a quality-label scenario (RL), and organic agriculture (OA). Farm size (GAP: 68 ha, RL: 38.3 ha, OA: 52.8 ha),% weight of pig feed (GAP: 40, RL: 40, OA: 70), necessary surface per pig (GAP: 0.85 m^2, RL: 2.6 m^2, OA: 2.3 m^2), feed consumed (GAP: 275 kg, RL: 312 kg, OA: 340 kg), and other characteristics were measured. Moreover, nitrate emissions per hectare of land used (GAP: 203 kg, RL: 181 kg, OA: 127 kg), carbon dioxide emissions per hectare (GAP: 1625 kg, RL: 1783 kg, OA: 1408 kg), nitrate emissions per 1000 kg of pig (GAP: 110 kg, RL: 114 kg, OA: 125 kg), and carbon dioxide emissions per 1000 kg of pig (GAP: 882 kg, RL: 1120 kg, OA: 1390 kg) were the most important factors examined. These patterns were characterized by great disparities both in terms of input and output. As a result, OA can be defined as "low input–low output" (eutrophication impact: 21.9 kg PO_4-eq, climate change: 4022 kg CO_2-eq and nonrenewable energy use: 22492 MJ LHV), and GAP as "high input–high output" (eutrophication impact: 38.3 kg PO_4-eq, climate change: 4236 kg CO_2-eq and nonrenewable energy use: 29282 MJ LHV). RL presented values placed between the other two patterns. Table 4 presents the main parameters reported in LCA applications on agricultural products.

Implementation of LCA on Processed Agricultural Commodities

The study of Andersson and colleagues (1998) was among the first investigations citing data on application of LCA in the evaluation of an integrated food system. In this article, LCA was applied to evaluate the environmental impact of manufacture of tomato ketchup, attempting to highlight the main points of this process. Agricultural production process, industrial refining, packaging procedure, transportation, consumption, and disposal of effluents were all assessed. Furthermore, emitted and required energy was estimated. Agricultural CH_4, N_2O, CO, and NMHC emissions were about 21, 130, 370, and 420 g per FU, respectively, while the respective food processing emissions were approximately 620, 38, 62, and 540 g per FU. Packaging and ketchup processing were detected to be the most important stages. As concerns toxicity, the agricultural processes, food processing, and packaging were characterized as the most crucial stages. Finally, product refrigeration was the most energy-expensive process.

The LCA methodology of eight distinct methods of bread manufacture was assessed by Braschkat and colleagues (2003). Several factors such as crop-growing processes (conventional, organic), milling procedures (industrial, domestic milling), and baking methodologies (industries, bakeries, domestic bread production) were examined. Bread formed from wheat cultivated with organic methods, processed in industrial mill and industrially produced was found to be the most appropriate method of bread production. Nevertheless, the cultivation of organic wheat can only be carried out in large land areas, compared with conventionally cultivated products. Moreover, it was revealed that baking procedure was the most energy-demanding stage of the whole process (approximately 64% of total energy requirements).

According to Coltro and colleagues (2006), LCA of Brazilian green coffee of two years of crops was applied in an effort to quantify any possible environmental impact, obtain detailed production records, reduce impacts, and make the product more environmentally sustainable. The inputs and outputs in relation to the coffee tillage were only taken into consideration. It was revealed that the LCA formation of agricultural products is a crucial stage for evaluating the environmental impacts per tillage, thereby leading to the establishment of a sustainable production.

The evaluation of the environmental impacts of three different types of coffee (spray-dried soluble coffee, drip filter coffee, and capsule espresso coffee) through the whole life cycle of the products was carried out by Humbert and colleagues (2009). All energy requirements of emitted GHG and water requirements were taken into account for calculation purposes. More impacts were examined by applying the IMPACT 2002+ impact-assessment methodology. According to LCA-extracted data, one deciliter cup of spray-dried soluble coffee required 1 MJ of primary nonrenewable energy consumption, emitted cases of 0.07 kg of CO_2 equivalent, and three to ten liters of water. The inputs required per deciliter cup of coffee were as follows: water for the coffee, coffee, machine used, and heating were approximately two deciliter, two gram per cup, one water boiler, and 0.125 kWh/L, respectively for spray-dried soluble coffee, 1.5 dl, 13.5 g of R&G, one drip filter machine, and 0.125 kWh/L, respectively for drip-filter coffee, and one deciliter, 6.5 g of R&G coffee/capsule, one espresso machine, and 0.028 kWh/cup, respectively for capsule espresso. Both pouch and metal could be used as packages because they display reduced environmental impacts in comparison with glass or sticks. The main environmental factors of spray-dried soluble coffee were the percentage of extra water boiled, the water use for cup cleaning, the application of irrigation or not, and the usage of fertilizers during cultivation. Packaging consisted of 10% of the total impacts. It was found that spray-dried soluble coffee required lower levels of energy consumption in comparison with the other two types of coffee. Finally, a detailed application of LCA methodology was required to reduce the environmental impacts.

In the study of Koroneos and colleagues (2005), LCA was applied to record and evaluate the environmental impact during manufacturing and transporting beer products in Greece. The investigated factors were: raw material production, refining, packaging, transportation, consumption, and disposal of effluents. Emitted and applied energy quantification, as well as several possible effects on the environment were examined. The impact factors of the greatest effect included toxicity, disposal of heavy metals, and smog formation. It was clearly shown that several impacts, such as bottle manufacture, packaging processes, and beer formation had the highest contribution to severe environmental impacts. Therefore, the minimization of the environmental impacts should be based on the reduction of the emitted products formed during the abovementioned procedures.

In the study of Cordella and colleagues (2008), LCA was conducted with the aim to define and evaluate the environmental impact of beer production by a small industry in Italy. Two different packages were assessed; a 20 L returnable stainless steel keg and a 33 cL conventional glass bottle. Inorganic emitted substances, land usage, and fuel demands were the most important factors in both cases. It was shown that product stored in keg displayed decreased environmental effects in comparison with beer stored in bottles. Furthermore, consumption stage, glass bottle manufacture, and barley production were identified to be the most significant sections of the product life cycle.

LCA methodology was applied in the aim to investigate and compare three environmental impacts of three differently processed feeds obtained from food residues. The residues were sterilized with thermal processing (LQ), dehydrated (production of dehydrated FFR; DH), or disposed with incineration (IC). Among the boundaries of system, collection of food residues, and production of feed from food residues were included. It was revealed that the average emitted GHG from LQ, DH, and IC were 268, 1073, and 1066 g of CO_2 equivalents, respectively. Emitted GHG from LQ fluctuated at very low levels, exhibiting that LQ effectively reduced the environmental impact of animal production process. FFR process was characterized with significantly lower levels of consumed water, compared with IC, because, during the latter, enhanced levels of water were disposed in forage crop production (Ogino et al., 2007).

Li and colleagues (2006) conducted LCA methodology to evaluate the soybean oil production. The purpose of this study was the comparison of different extraction methodologies and the gradual process optimization. The carried out examination comprised three stages of soybean oil processing. In terms of extraction, hexane (industrial scale procedure), and supercritical CO_2 (laboratory scale procedure) cases were analytically evaluated. It was shown that improved laboratory-scale methods were significantly less energy-demanding. According to the same methods "Hexane extraction was more environmentally attractive based on several Eco-indicators, except for summer smog and cancer". Furthermore, extraction stage required the highest percentage of energy in overall GTG (Cradle-To-Gate) energetic pattern as concerns both CO_2 and hexane methodologies.

In the study of Jones and colleagues (2008), the capacity of input–output LCA and the evaluation of all environmental impacts of more than 600 types or products and services were examined. It was estimated that approximately 23 tons of CO_2 equivalent GHG were included in foods and services in United States. With a cost of around \$10/t CO_2, it was shown that the incorporation of CO_2 mitigation cost would increase price of foods and services by 0.5% and 1%, respectively. The obtained results can stimulate the formation of foundations for more sustainable manufacture and better usage of products.

The environmental effectiveness of the Norwegian beverage sector has been examined and analyzed in a Factor 10 perspective (Hanssen et al., 2007). The main aim was to determine the strategies that could enable the beverage sector to become more effective from an environmental and resource perspective. The study revealed substantial differences between the drinking products with respect to energy consumption and emissions that can contribute to global warming. It is also noteworthy that, for the impact categories under study, production of raw materials was found to be the most crucial part of the life cycle for most potable products.

Landis and colleagues (2007) looked into the agro-ecosystem materials flow in conjunction with Monte Carlo Analysis (MCA) for future bio-product LCAs relying on corn or soybeans as feedstock. The inventory comprised C, N, P major pesticides, energy, and U.S. EPA criteria of air pollutants resulting from agricultural processes. Results clearly revealed that the dominant air emissions resulted from crop farming, fertilizers, and on-farm nitrogen flows. Because the contribution of seed production and irrigation was lower than 0.002% to the inventory emissions and/ or energy flows, it was suggested to be left out from any future LCAs of corn or soybeans as feedstock. In contrast, lime had a significant contribution (17% of total emissions) to air emissions and must be taken into account in bio-product LCAs. Table 5 presents the main parameters reported in LCA applications on Processed Agricultural Commodities.

CONCLUSIONS

In recent years, the prevailing idea is that planning methods and techniques must be based on the sustainability concept. This perspective necessarily comprises a comprehensive evaluation of all upstream and downstream effects of human activity or product manufacture to assess all the cumulative and synergistic effects on the environmental over space and time. From this viewpoint LCA is the most internationally accepted methods for examining the global impact of activities or products (Hospido et al. 2003).

The enhanced concern for environmental protection and a greater awareness of sustainable development issues proved to be the triggering factors for extra attention to be paid to the environmental impacts of products throughout the various phases of their life cycle (processing transportation use). Therefore, the concept of life cycle (from cradle-to-grave) is implemented to facilitate both strategic and operation choices for products and services (Cordella et al., 2008).

LCA is an effective tool to identify potential environmental impacts of a product's life cycle earth-to earth. Without this analysis, reduction in one aspect may result in increased pollution in other aspects of production. Despite LCA studies limitations, they still continue to be the most effective to assure a complete product impact evaluation.

For more than ten years, LCA has been applied to a whole range of agricultural produces such as milk, pork, beef, chicken, salmon, trout, wheat, apple, wine, kiwifruit, and biofuel. The majority of studies are focused on the "cradle-to-farm-gate" part of the life cycle. The latter was found to be the most important factor in all impacts involved. As for the next stages (processing, distribution, consumption, and final disposal), it can be generally accepted that they display many common points for most investigated scenarios. In terms of assessment, the farm stage is very difficult because of the numerous interactions involved between farming systems and their environment (http://www.eoearth.org/article/Life_cycle_assessment_of_farming_systems).

The intensification of agricultural production processes has led to greater environmental burdens thereby triggering discussions for the necessity of sustainable farming. Conversion of conventional and/or intensive agriculture into organic farming will most probably result in environmentally friendly agriculture, improved landscape image, and animal welfare.

Although LCA methods were first developed for land-based industrial applications, and the methodology has not so far been brought to the same level when it comes to food products, especially not for fish (Ellingsen and Aanondsen, 2006). LCA is a rapidly developing area of applied environmental science. One of the recent activities in the field of LCA is the development of a methodologic framework. Five components may be distinguished within this framework: goal and scope definition, inventory, classification, valuation, and improvement analysis.

The most obvious advantages of LCA are: a) investigation of the most apparent cost savings over the entire life cycle of a product, process, or services; b) assessment of the environmental impacts of a product, process, or service. When the impacts have been determined, the product, process, or service can be properly modified to minimize the impacts. Along the same line, another option would be to make a comparison with a "similar" product to deduce which is of lowest cost and has the smallest impact on the environment (Carpenter et al. 2007).

The environmental impact assessment of aquatic production systems is often focused on the effect of emissions of nutrients and suspended particles/solids in water both at local or regional scale. Unfortunately, several other important environmental impacts such as energy use, biotic resources depletion, or GHG production are frequently not taken into account because their effect is only evident at global scale. Integration of all impacts (local and global scale) is imperative to comprehend and interpret the effects of fish farming on the environment (Aubin et al., 2006).

As a concluding remark could be said that the further proper development of LCA by means of modeling and standardization of main inputs (raw materials, water, energy, packaging, and secondary materials) and outputs (liquid and solid waste, gas releases) in conjunction with some guidance with regard to subsystems (requirements) with most likely result in more effective and uniform implementation of LCA.

ABBREVIATIONS

AB = Agriculture Biologique
ADP = Depletion of abiotic resources
AES = Agri-Environmental Scheme
AP = Acidification potential
BOD = Biochemical Oxygen Demand
COD = Chemical Oxygen Demand
CTG = Cradle to grave
EcoX = Environmental impacts
EFP = Ecological footprint analysis
EI = Environmental indicators
EP = Eutrophication potential
EPIs = Environmental performance indicator
FTS = Flow Through System
FU = Functional unit
GAP = Good agricultural practices
GHG = Greenhouse gases
GWP = Global warming potential
IO = Input–output accounting
IP = Integrated production
ISO = International Organization for Standardization
LCA = Life Cycle Analysis/Assessment
LCI = Life Cycle Inventory Analysis
LCIA = Life Cycle Impact Analysis
LIME = Life Cycle Impact Assessment Method
LR = Label Rouge
LW = Live weight
MCA = Multi-Criteria Analysis
NPPU = Net Primary Use
NREU = Non-renewable energy use
OA = Organic agriculture
ODP = Stratospheric ozone depletion
OF = Organic farming
RDI = Resource depletion indicators
REPS = Rural Environment Protection Scheme

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