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Review on Suitability of Available LCIA Methodologies for Assessing Environmental Impact of the Food Sector

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ABSTRACT

Production, processing, distribution, and consumption of a wide variety of products in the food sector have different ranges of environmental impacts. Methodologies used in environmental impact assessment differ in which set of impact categories is covered and which models are used to assess them. In the food sector, life cycle assessment results are mostly presented without any clear distinction of the principles applied to selecting the relevant methodology. In this paper, the most relevant life cycle impact assessment methodologies are determined from the list of recommended methodologies published recently in the international reference life cycle data system (ILCD) handbook. The range of the relevant impacts covered is considered as the main indicator decisive in selecting a methodology. The selection of the relevant set of impact categories is performed through an overview of more than 50 recent LCA case studies of different products in the sector. The result of the research is a short list of three LCIA methodologies recommended to be used for environmental impact assessment of products in the food sector.

Keywords: food chain sustainability, environmental impact, life cycle impact assessment (LCIA), LCIA methodologies

1 Introduction

In the published research on life cycle assessment of the food sector, final results in terms of Life Cycle Impact Assessment (LCIA) are mostly presented without any clear distinction of the methodologies or principles applied during the LCIA phase. The results of an overview of more than 50 recent LCA case studies of food products revealed that climate change followed by resource depletion, land use, eutrophication, and acidification impact categories are more frequently assessed. The result has been used to determine which LCIA methodology could be most suitable for the food sector considering the fact that different LCIA methodologies use different methods to assess each impact category. Different LCIA methodologies use quantitative methods to assess some impact categories while just qualitatively discussing the others.

In this research, LCIA methodologies which use a quantitative method for assessing the sector-specific set of impact categories have been identified as being more appropriate for the sector compared to methodologies which only utilize a qualitative method for assessing the effect of the impact categories presented above as well as those methodologies which ignore their effect. Based on this logic, three out of eleven methodologies recommended by the ILCD handbook (International Reference Life Cycle Data System handbook) were chosen as the most appropriate to be used in life cycle impact assessments of products in the food sector.

The first section is an introduction into the life cycle assessment which will be followed by a summary of the four stages of life cycle assessment (LCA) and a definition of the focus of this research in the second section. The third section is a short summary of the first part of the third stage of LCA, selection and classification of the impact categories, which is the focus of this research. In the fourth section, the results of an overview of more than 50 recent LCA studies on food products are presented which further on can be used as a base for determining a common set of impact categories specifically relevant for environmental impact assessment of products in the food sector. In the fifth section, LCIA methodologies recommended by the ILCD handbookare evaluated based on the methods they use for assessing the impact categories.

Those methodologies which better cover the identified set of impact categories are selected for being especially appropriate for use in the food sector. The resulting short list of methodologies is further discussed based on other criteria used by the ILCD handbook to further compare selected methodologies. The last section is dedicated to a review of the results and recommendations for future research.

2 Introduction to Life Cycle Assessment (LCA)

The industrial revolution in the 18th and 19th century with major changes in agriculture, manufacturing, mining, transportation, and technology gave rise to major negative impacts of human activities on the ecosystem, gradually revealing their consequences throughout the spread of industrialization all over the world. More than forty years ago, evaluating the environmental impact of industrial products with LCA took hold in business with energy and material budgets to which complementary pollution aspects were progressively added.

LCA saw a boost in the 1970s as a result of two oil crises, while the solid waste problem at the end of the 1980s accelerated the development of this methodology, leading to the announcement of the first formal framework for impact assessment in 1992 as a structured, internationally standardized method and a management tool for quantifying emissions, consumed resources, as well as he environmental and health impacts associated with products in their full life cycle from extraction of resources over production, use and recycling to the disposal of remaining waste. (EC-JRC-IES 2010a, ISO 14044 2006). For more than ten years, LCA has been applied to a broad range of agricultural products such as milk, beef, pork, chicken, salmon, wheat, fruits, wine, biofuels, etc.

LCA distinguishes four phases that are referred to as *Goal and Scope Definition*, *Life Cycle Inventory Assessment* (LCI), *LCIA* and *Interpretation* (ISO 14044 2006). Figure 1 illustrates the different stages of an LCA.

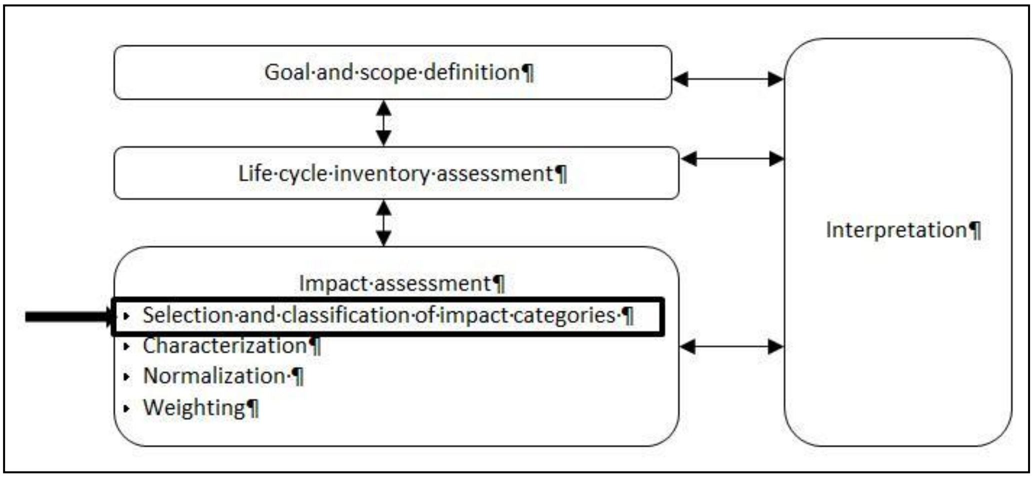

Figure1. Different stages of LCA
Source: ISO 14040:2006

Goal definition is the starting phase of any LCA, independent of whether the intention of using LCA is to monitor environmental impacts of a system or to compare different management options. In this phase, the decision context and the application intention of a study have to be identified , as they are decisive for the rest of LCA.

In the second phase, called LCI, the system boundaries have to be set. I also includes the flow diagrams of processes, the collection of data for specified processes, and the calculations of process performance. The main result of LCI is a table listing the quantified inputs from and the outputs to the environment. (EC-JRC-IES, 2010a).

LCIA is the third phase in which inputs and outputs of elementary flows are translated into impact indicators related to human health, natural environment, and natural resources. LCIA is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a production system (ISO 14044, 2006).

LCIA is divided into four steps, the *selection and classification of impact categories*, their *characterization*, *normalization* and *weighting*. In the first step, the inventory results are assigned to impact categories that are being defined. In the characterization step, the contributions of the results to impact categories are quantified and then aggregated within each impact category. In the normalization step, different indicator results are expressed on a common scale in order to facilitate comparisons across impact categories. (ISO 14044 2006)

The last phase of LCA, *interpretation*, involves an analysis of the major contributions, along with a sensitivity analysis and uncertainty analysis for determining the level of confidence in the final results and for communicating them in a complete and accurate manner. This phase leads to the conclusion whether the ambitions defined in scope and goal could be met.

The focus of this study would be on the first step of the third stage of LCA, which is the selection and classification of the impact categories.

3 Selection and classification of the impact categories

Developing an assessment methodology requires to determine 'What should be measured?'. This question would be answered through the first step of an LCIA, the selection and classification of impact categories.

Impacts are defined by the Scientific Applications International Corporation (SAIC, 2006) as the consequences that could be caused by the input and output streams of a system in three main categories, human health, ecological health, and resource depletion.

A general list of 11 impact categories has recently been recommended by EC-JRC-IES (2010a) for all sectors. These impact categories are climate change, ozone layer depletion, eutrophication, ecotoxicity, human toxicity, resource depletion, land use, acidification, radiation, ozone layer formation, and respiratory inorganics.

Impact categories are divided by definition into two groups of 'midpoint' and 'endpoint' impacts. Midpoint impacts are stated as the link in a cause-and-effect chain of an impact category while endpoints describe the relative importance of emissions. Each endpoint impact can be caused by one or more midpoints, as illustrated in figure 2. All of the impact categories mentioned above are midpoints while human health as well as natural health and resources are determined as the three main endpoint impacts (Bare, et al., 2000, EC-JRC-IES, 2010a).

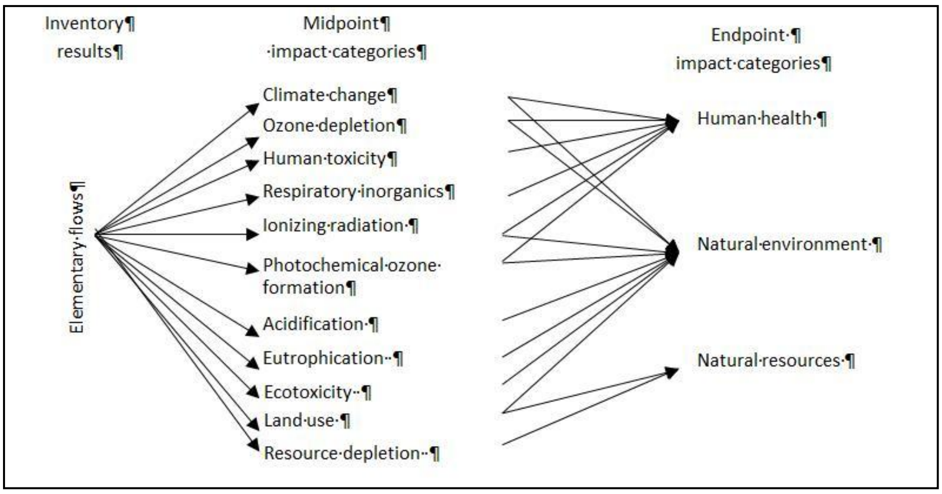

Figure 2. Framework of impact catogeries at midpoint and endpoint (Area of protection)
Source: Adapted from EC-JRC-IES, 2010a.

4 Common sets of impact categories used to assess the environmental impact of food

An investigation of over 50 recent case studies of LCA applications in the food sector on selecting impact categories, the selection method revealed that different sets of impact categories have been assessed in LCIA for different food products. For most parts, it remains unclear which principles were applied to determine the relevant impact categories (Icafood2010, 2010, Nemecek et al., 2008).

In this investigation, LCA studies are divided into two main groups identified as '*crop products*' and '*meat and dairy*'. Table 1 shows the frequency of use of different impact categories in the case studies reviewed.

Table 1.
Frequency of use of different impact categories in reviewed case studies.

Impact categories	Crop products	Meat and Dairy	Total
Climate change/global warming	26	26	52
Resource depletion	20	23	43
Land use	15	18	33
Eutrophication	9	17	26
Acidification	7	13	20
Ecotoxicity	4	5	11
Photochemical oxidant formation	7	3	8
Human toxicity	3	2	5
Ozone depletion	3	2	5
Number of studies	30	29	59

According to table 1, the impact categories with the highest frequency of use are climate change followed by resource depletion, land use, eutrophication, and acidification. The other impact categories, which are used considerably less frequently in impact assessment, are ecotoxicity and photochemical oxidant formation. Human toxicity and ozone depletion showed the lowest frequency, as they were assessed in less than 10 percent of the case studies. Figure 3 illustrates the percentage of consideration of each impact category in the case studies reviewed. For instance, in the 'meat and dairy' group 90 percent of studies considered climate change while 79 percent did so in the 'fruit and vegetables' group.

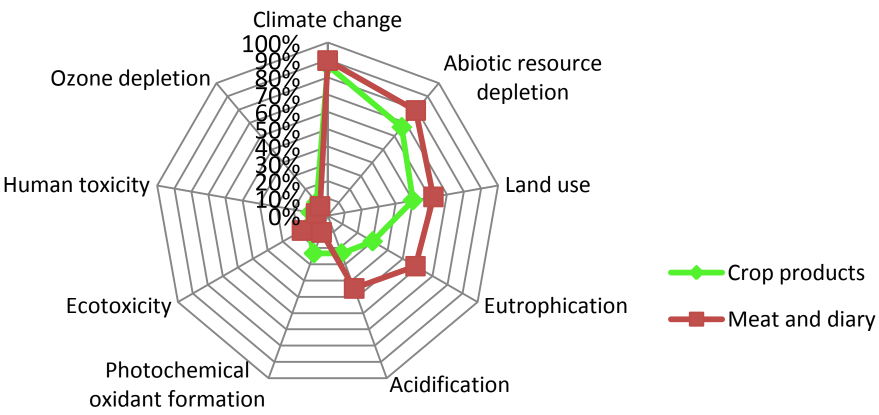

Figure 3. Frequency of use of different impact categories in reviewed case studies

Result of this study indicate that, to some extent, a consensus exists on the set of impact categories to be considered. However further international standardization in the set of impact categories used in environmental assessment of the food sector is required.

In this study, the set of impact categories is determined based on the results derived from the case studies reviewed and compared with the list of impact categories recommended by the ILCD handbook. Figure 4 illustrates the impact categories recommended by the ILCD handbook and the selected set for the food sector. These impact categories are divided into three groups of categories with high priority, low priority, and the impact categories which are ignored. Summer smog was decided to be put to the side as it was used in less than 4 percent of the studies, while the other two impact categories, radiation and respiratory inorganics, were irrelevant as they haven't been used in the case studies.

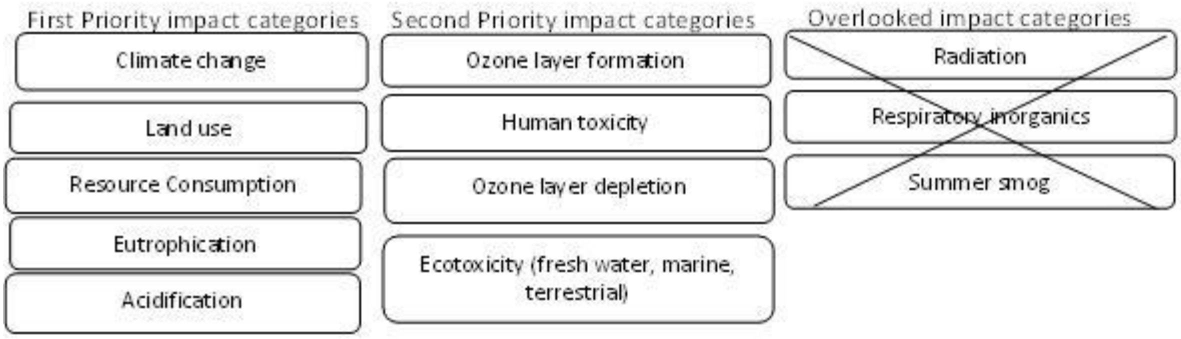

Figure 4. Selected impact categories from the list recommended by the ILCD handbook

5 Selecting LCIA methodologies suitable for the food sector

LCIA methodologies are commonly based on two modeling approaches of midpoint or endpoint impact assessment (Bare et al., 2003) Midpoint impact assessment models reflect the relative strength of the stressors at a common midpoint within the cause-and-effect chain. Analysis at a midpoint helps to reduce the complexity of modeling and simplifies the communication of results by reducing the amount of *forecasting and effect modeling* incorporated into the LCIA. Midpoint analysis can minimize assumptions and value choices and be more comprehensive than model coverage for endpoint estimation (Bare et al., 2003)

Endpoint modeling might facilitate science-based aggregation across impact categories in terms of common parameters. For instance, human health impacts associated with climate change can be compared with those of ozone depletion using a common basis (Bare et al., 2000). However, endpoint modeling requires the availability of reliable data and sufficiently robust models. Besides that, an extension of the models to the endpoint might reduce the level of comprehensiveness (Bare et al., 2000).

The first of the LCIA methodologies is the *Environmental Priority Strategies* (EPS) methodology based on endpoint modeling (EC-JRC-IES, 2010b). *Swiss Ecoscarcity* or Ecopoint is mentioned as the second methodology. The next methodology identified is CML (Dutch guidelines) which was developed in 1992 based on midpoint modeling. By the mid-1990s, this methodology had been employed by most LCA practitioners worldwide (Bare, 2010).

Most recent methodologies are the results of efforts in harmonizing the mentioned methodologies. Harmonization helps to avoid different results derived by employing different approaches. The ISO 14042 includes some standardization on basic principles which is currently a part of ISO 14044 and has gained a relatively broad consensus on selected approaches and principles; for instance, some consensus has been found on the need to merge the midpoint and endpoint models (Bare et al., 1999, Bare, et al., 2000, EC-JRC-IES, 2010b, ISO 14042, 1998, ISO 14044, 2006).

A pre-selection of current LCA methodologies is made by EC-JRC-IES (2010b) based on a number of criteria. On this basis, the most recent up-to-date version of a method which appears in multiple LCA methodologies has been taken into account. Furthermore, adapting and customizing a specific method for the different regions is important. Should a method not have been improved or changed, it has been excluded from the selection (EC-JRC-IES, 2010b). LCIA methodologies recommended by EC-JRC-IES (2010b) are listed in table 2.

Table 2.

Recommended LCIA methodologies. Source: EC-JRC-IES, 2010b

Methodology	Developed by	Country of origin
CML 2002	CML	Netherlands
Eco-Indicator 99	PRé	Netherlands
EDIP (1997-2003)	DTU	Denmark
EPS2000	IVL	Sweden
Impact 2002+	EPFL	Switzerland
LIME	AIST	Japan
LUCAS	CIRAIG	Canada
ReCiPe	RUN + PRé + CML + RIVM	Netherlands
Swiss Ecoscarcity or Ecological scarcity	E2+ ESU-services	Switzerland
TRACI	US EPA	USA
MEEuP methodology	VhK	Netherlands

In selecting appropriate LCIA methodologies for the food sector, criteria and the related selection procedure needs to be determined. The criteria for selection are related to the impact categories covered by these methodologies (high/low priority impact categories) versus the method used for assessment which could be either quantitative (midpoint/endpoint) or qualitative. In general, methodologies using quantitative methods to assess the selected impact categories would have the first priority followed by those using qualitative methods. Covering both midpoint and endpoint methods would be of advantage.

Based on the set of impact categories identified in the previous section, categories with higher frequency of use are climate change following land use, eutrophication, resource depletion, energy use, and acidification. Selected methodologies are supposed to cover quantitative midpoint or endpoint methods of assessment for these impact categories. A quantitative assessment would not be required for the second group of categories including those with lower frequency of use such as ecotoxicity, ozone formation, and human toxicity. However, at least a qualitative assessment would be considered necessary related to these impact categories since ignoring these impact categories completely might negatively affect the accuracy of the final LCIA results. Only 1 out of 11 LCIA methodologies can fulfill these requirements, therefore the limitation of having a quantitative method of assessment for all impact categories with higher priority would be limited to the first three impact categories including climate change, land use, and resource depletion (including energy used). Qualitative methods would be acceptable for the rest of impact categories.

Table 3 illustrates methods of assessment used in each LCIA methodology for each impact category.

Table 3.

Quantitative/qualitative methods of impacts assessment in LCIA methodologies

E: Endpoint, M: Midpoint, O: Qualitative discussions but no quantitative model used

Source: adapted from EC-JRC-IES (2010b)

Impact categories / Methodologies	Climate Change	Ozone Depletion	Respiratory inorganics	Human toxicity	Ecotoxicity	Ozone formation	Acidification	Terrest. Eutrophication	Aquatic Eutrophication	Land use	Resource depletion
CML 2002	O	O		M	O	M	M	M	M	O	M
Eco-indicator 99	E	E	E	O		E	E	E		E	E
EDIP 2003/97	O	M	O	M	M	M	M	M	M		M
EPS 2000	E	E	E	E	E	E	O	O	O	E	E
Impact2002	O	O	E	ME	ME	E	ME		ME	O	E
LIME	E	E	M	E	O	ME	ME	O	E	E	E
LUCAS	O	O		O	O	O	O	O	O	O	O
MEEuP	O	O	M	M	M	M	M	M	M		WATER
ReCiPe	ME	E	ME	ME	ME	ME	ME	O	ME	ME	E
Swiss Ecoscarcity 07	O	O	O	O	M	O	O	O	O	ME	WATER
TRACI	O	O	M	M	M	M	M	0	M		O

These methodologies include quantitative (midpoint and/or endpoint) and qualitative methods of assessment for each impact category. The table will later be used as basis for the selection of the recommended LCIA methodologies for food products. In this table, those impact categories which are not related to the food sector have been removed. The selection is a two-step approach. In the first step, the methodologies which offer no method of assessment for an impact category are removed from the list. In this step, four methodologies including Eco-indicator 99, EDIP 2003/97, MEEuP, and TRACI are removed. Ecotoxicity is ignored in Eco-indicator 99, and the other three LCIA methodologies put land use aside.

The result of the first selection step is illustrated in table 4. This table is derived from table 3 with some modifications. The impact categories which had been decided to be ignored in the previous section are removed. Besides that, impact categories in this table are listed based on the results of the overview in the previous section respectively from the impacts with higher to lower frequency of use.

Table 4.
First step of the selection of LCIA methodologies: removing the LCIA methodologies which offer no quantitative or qualitative method of assessment for an impact category

Impact categories / Methodologies	Climate Change	Land use	Resource Consumption	Eutrophication	Acidification	Ecotoxicity	Ozone formation	Human toxicity	Ozone depletion
CML 2002	O	O	M	M	M	O	M	M	O
Eco-indicator 99	E	E	E	E	E		E	O	E
EDIP 2003/97	O		M	M	M	M	M	M	M
EPS 2000	E	E	E	O	O	E	E	E	E
Impact2002	O	O	E	ME	ME	ME	E	ME	O
LIME	E	E	E	E	ME	O	ME	E	E
LUCAS	O	O	O	O	O	O	O	O	O
MEEuP	O		WATER	M	M	M	M	M	O
ReCiPe	ME	ME	E	ME	ME	ME	ME	ME	E
Swiss Ecoscarcity 07	O	ME	WATER	O	O	M	O	O	O
TRACI	O		O	M	M	M	M	M	O

E: Endpoint , M: Midpoint, O: Qualitative discussions but no quantitative model used

In the next step, the methodologies which don't offer any quantitative method of measurement for the first three impact categories are removed. Four methodologies are removed in this step, including CML 2002, Impact 2002, LUCAS, and Swiss Ecoscarcity 07, as they only discussed the impacts of climate change, land use, and/or resource depletion qualitatively. Table 5 illustrates the second step.

Table 5.
Second step of the selection of LCIA methodologies: removing the methodologies which offer no quantitative method of assessment for climate change, land use, and resource depletion

Impact categories / Methodologies	Climate Change	Land use	Resource Consumption	Eutrophication	Acidification	Ecotoxicity	Ozone formation	Human toxicity	Ozone Depletion
CML 2002	O	O	M	M	M	O	M	M	O
EPS 2000	E	E	E	O	O	E	E	E	E
Impact2002	O	O	E	ME	ME	ME	E	ME	O
LIME	E	E	E	E	ME	O	ME	E	E
LUCAS	O	O	O	O	O	O	O	O	O
ReCiPe	ME	ME	E	ME	ME	ME	ME	ME	E
Swiss Ecoscarcity 07	O	ME	WATER	O	O	M	O	O	O

E: Endpoint, M: Midpoint, O: Qualitative discussions but no Quantitative model used

Three methodologies including EPS 2000, LIME, and ReCiPe are selected as the most suitable for being used in life cycle impact assessment of the food sector. However, only ReCiPe offers a quantitative method of impact assessment for the whole set of impact categories. The LIME methodology only qualitatively discusses the ecotoxicity, and EPS2000 lacks a quantitative assessment for both eutrophication and acidification. Table 6 illustrates the three selected LCIA methodologies.

Table 6
Selected methodologies most suitable for LCIA of the food sector

Methodologies \ Impact categories	Climate Change	Land use	Resource Consumption	Eutrophication	Acidification	Ecotoxicity	Ozone formation	Human toxicity	Ozone Depletion
EPS 2000	E	E	E	O	O	E	E	E	E
LIME	E	E	E	E	ME	O	ME	E	E
ReCiPe	ME	ME	E	ME	ME	ME	ME	ME	E

E: Endpoint, M: Midpoint, O: Qualitative discussions but no Quantitative model used

Impacts category covered and the methodology used could be regarded as two criteria to compare the LCIA methodologies. Other criteria used by the ILCD handbook for comparing different LCIA methodologies are how they handle data uncertainties, if regional validity is covered, the approximate number of substances covered, and how normalization and weighting is performed. A summary of the mentioned criteria for the three selected methodologies adapted from the ILCD handbook is presented in table 7.

Table 7
Comparing three selected LCIA methodologies based on some criteria

Methodologies \ Criteria	Regional Validity	Substances Covered	Normali-zation	Weighting	Data uncertainties
EPS 2000	Mainly Global	Approximately 200	No	Monetization method	Discussed in the text
LIME	Mainly Japan	Approximately 1000	Not required	Monetization method	Addressed in new version
ReCiPe	Mainly Europe	Approximately 3000	Partly	Monetization method	Discussed in the text

The advantage of EPS 2000 is that it could be used globally while LIME is limited to Japan and ReCiPe is developed to assess the environmental impact of systems located in Europe. Among these three methodologies, ReCiPe has the highest approximate number of substances covered. EPS 2000 at a considerable distance covers the lowest number of substances. Normalization is just partially performed in ReCiPe. All three methodologies use the same weighting approach and qualitatively considered data uncertainty but in none of them, data uncertainty is quantitatively considered in impact assessments.

6 Discussion and recommendations for future research

As a result of more than 50 recent case studies of LCA of food products five impact categories which are frequently used can be identified. The results of this overview, based on the information regarding the methods used in LCIA methodologies, has been employed to determine which methodologies could be more suitable to apply to the food sector. Different LCIA methodologies use quantitative methods to assess some impact categories while only qualitatively discussing the others. In this research, LCIA methodologies which use a quantitative method for assessing the sector-specific set of impact categories are determined to be more appropriate for the sector compared to the methodologies which only have a qualitative method for assessing the effect of the mentioned impact categories as well as those methodologies which ignore the effect of an impact category. Based on this logic, three out of eleven methodologies were chosen as the most appropriate to be used in the LCIA of the products in the food sector.

Although further international standardization in the set of impact categories used in the environmental assessment of the food sector could enable direct comparisons of different case studies and broaden their practical applications, special characteristics of the food sector need to be considered in order to avoid sacrificing accuracy and quality of the LCA results in favor of generalization and standardization. Future research could focus on incorporating specific attributes of the food sector in the selection of the set of impact categories to be assessed in LCIA of different types of products in the sector.

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Appendix I

LCA studies on crop products

Author(s)	Method	Product	Process	Alternatives	Functional units	Impact categories
Canals et al. (2008)	• Cradle to grave	• Broccoli	• Production, distribution and consumption	• Production in UK and Spain • Distribution in UK	• m3yr-1 • 1 kg Sb-eq water/kg	• Fresh water consumption, evaporation
Pfister et al. (2008)	• Eco-Indicator 99 method (EI99)	• vegetable and fruit, onion, tomato, potato, Cabbage	• Production	• production in Switzerland, Spain, China, Greece, Italy, USA, and Ethiopia.	• area of the specific activity	• Fresh water evaporation
Deimling et al. (2008)	• PE's GaBi Agrarian LCA Model to assess different farming systems, crop types, and growing locations	• Peanuts, nuts, potatoes, milk, coffee, wheat, cheese, etc.	• Juicing, spray drying, freezing, concentration, grinding, etc.	• Can model different farming systems for all types of crop anywhere in the world		• Global warming, land use changes (deforestation), carbon sequestration ,
Muñoz et al. (2008)	• CML 2000 Method (Guinée et al., 2002), all the upstream and downstream operations required for ready-to-eat food	• Eggs, meat products, fish and seafood, dairy products , etc.	• Farming, industrial processing distribution, retail, storage, cooking	• Packaging excluded • Average Spanish diet	• for a Spanish citizen in the year 2005, up to 787 kg of food	• Global Warming Potential (GWP), Eutrophication Potential (EP), and • Acidification Potential (AP) • Primary Energy use (PEU)
Soler-Rovira J. and Soler-Rovira (2008)	• multivariate statistical • method of principal components analysis (PCA)	• Apple	• Apple cultivation and transport	• Characterization CML-IA(2004). • Normalization (Van den Berg et al., 1995; Huijbregts et al.,2003; CML-IA, 2004). • Weighting AHP	• 1 hectare (ha) of orchard and for 1 kilogram (kg) of fresh apples	• global warming, acidification, eutrophication, human toxicity, ecotoxicity in fresh water, land use, photochemical oxidants formation, energy use, water resources use, abiotic resources depletion
Acosta-Alba et al. (2010)	• MGLP: Multi Goal Linear Programming • Cradle to gate	• milk	• Grass-based milk production system	• France - Brittany • Region with greatest livestock production	• A tool to add to LCA	• Land use
Audsley et al. (2010)	• Linear regression • Against factors, Using LCI systems modeling	• Pork, beef, eggs, bread wheat, rape beans, oilseed	• Producing breeding stock	• UK analyzes the impact of every sub-system, of each livestock commodity	• per ton of product	• Energy use, climate change, land use, eutrophication
Denstedt, et al. (2010)	• Cradle to consumer	• Strawberry	• Pack houses, transport: truck car to consumer	• Huelva, South Spain	• 500 g strawberry packet	• Carbon footprint [g CO2e/ 500 g]

Author(s)	Method	Product	Process	Alternatives	Functional units	Impact categories
Blonk et al. (2010)	• Recipe ecosystems score (Goedkoop et. Al 2009), cradle to gate	• Beef • Pork • Pork organic		• Inventory based on Dutch animal production systems	• Per Kg of product • (m2*years)	• Land use, climate change animal welfare
Bos, et al.(2010)	• LBP GaBi • Environmental impacts of fresh fruit and vegetable packaging and transport	• Wooden boxes, cardboard boxes, and plastic crates	• Utilization and end-of-life of packaging • Transport and Distribution	• Producer (fruit & vegetables): Spain, Italy, France, The Netherlands, Germany • Consumer (fruit & vegetables): France, The Netherlands, Germany, Great Britain	• 1,000 tons of fruit/vegetables • or 3,333,350 filled boxes/crates	• Primary energy use, separated into renewable and non-renewable energy use, Global warming potential, ozone depletion, acidification, eutrophication, photochemical ozone creation
Brandão (2010)	• “What are the global environmental consequences of diverting wheat from food to fuel purposes in UK?”	• Food wheat • A combination of palm oil, soymeal and feed wheat	• Wheat for food and feed (Canada) • Argentina (soymeal) • Indonesia (vegetable oil)	• Consequential approach, • Foreground system (UK wheat cropland) • Background system (marginal production, thereby avoiding allocation)	• 1 ha	• Indirect Land Use Change (iLUC) • – Climate Change (GWP100), including biogenic C flows and temporary storage • – Ecosystem Services (Net Ecosystem Carbon Balance)
Cellura, et al.(2010)	• The district is characterized by: high level of specialization • cradle to consumer (with consumption)	• Tomatoes, cherry • Peppers, melons, zucchinis.	• The production of greenhouses.	• Southern Italy (Sicily). • Production of seeds is neglected	• 1 ton of protected crops	• Energy requirement, global warming, ozone depletion, photochemical oxidation, acidification, eutrophication, water consumption, wastes production
Coltro.(2010)	• Water use in the life cycle of food products from Brazi • Cradle-to-gate	• Coffee and oranges	• Production of oranges for FCOJ up to processing plants	• Brazil	• production of 1,000 kg of product	• Water footprint: 1) the evaporative water 2) the non-evaporative water = polluted water resources
Ingwersen(2010)	• Product category range of environmental performance for EPDs: • Ecoinvent Database • Farm-to-shelf (for consumers)	• Pineapple	• Farm, packing, transport, distribution to US retailer	• Costa Rica • uncertainty estimated based on sensitivity analysis of the model (here Monte Carlo simulation)	• 1 serving at US Servings in 1 kg fruit = % edible/USD serving size (kg)	• Soil erosion, carbon footprint, virtual water/stress-weighted water footprint, standard pesticide toxicity, energy use, eutrophication, acidification, smog formation
Jefferies(2010)	• assess impact of water use, cradle-to-grave	• Tea bags	• Production and Transport	• Gabi, Ecoinvent	• 25 LYL tea bags	• Water Footprint • Blue water, Grey water
KHOO et al. (2010)	• Evaluating the Global Warming Potential • From “farm land” to “food”	• Beef, chicken, tofu, milled rice, tomatoes	• Feed cultivation • Slaughtering etc.	• Singapore	• 1 kg-protein for all food types	• Climate change, Carbon Footprint, Land Use
Jungbluth (2008)	• ESU-services Ltd • EDIP 2003	• BTL-fuels	• producing and using BTL-fuels	• sensitivity analysis with the CML 2001	• leaf weight • (kg/ha)	• NMVOC (non-methane volatile organic compounds), ozone formation, photochemical smog

Author(s)	Method	Product	Process	Alternatives	Functional units	Impact categories
Pascual et al. (2010)	• Calculation of CO2 equivalent emissions cradle-to-gate	• Mediterranean tomato	• Production, and • Transportation,	• US	• one food calorie in the U.S.	• Global annual emissions of • anthropogenic GHGs
Marton et al. (2010)	• Lower global warming potential of cucumbers and lettuce, cradle-to-gate (waste handling)	• cucumbers and • lettuce	• Usage of waste heat improves, efficiency of generators	• Swiss Comparison of products from a waste heat heated and a fuel oil heated greenhouse	• - 1kg cucumber • - 1kg lettuce	• Global warming potential
Jeanneret et al. (2008)	• method for assessing impacts of agricultural • activities on biodiversity	• winter wheat systems • Grassland	• Conventional, intensive integrated, extensive(integrated),organic production	• field management options (intensity level) and (cropping system) Switzerland,	• gradient for • grasslands DM/ha and year	• biodiversity
Nemecek and Kägi (2008)	• Ecoinvent-based	• wheat	• crop production, crop management, • intensive integrated production	• Switzerland • •	• 1 kg of product	• Land use, Energy demand • Global warming pot. Ozone formation, Eutrophication • Acidification, Aquat./Terr. Ecotoxicity, Human toxicity
Audsley and Williams (2008)	• Cranfield models of agricultural and horticultural commodity production	• non-organic bread • wheat and milk	• arable production, • Animal production	• produced for British systems	• 1 t bread wheat • •	• Land use, Fertilizer, Manure , Arable returns, Atmospheric deposition, global warming, • eutrophication and land ccupation
Deimling et al. (2008)	• PE's GaBi Agrarian LCA Model •	• Peanuts, coffee, wheat, etc.	• Juicing, spray drying, freeze drying, grinding, etc.	• Can model different farming systems •	•	• Global warming, land use changes (deforestation), Carbon sequestration ,
Léis et al. (2010	• Two dairy systems in Brazil South, SimaPro, Ecoinvent®, CML 2001 • Cradle to gate	• Milk	• Food production • Grain drying • Burning diesel • Electric power	• Brazil South	• produce 1 kg of cooled milk in the farm	• Acidification, eutrophication • Climate change, terrestrial ecotoxicity, land occupation • energy consumption
Dolman et al. (2010	• Economic versus LCA indicators, Cradle to gate	• Pig	• Feeding and production	• Netherlands	• 100 kg slaughter	• Non-renewable energy, ozone depletion
Farine et al. (2008)	• Comparing other researches	• Sugar, Wheat	• Farming	• Australia • Uncertainty choice of emission factor	• per hectare, or per tone of production	• GHG emission
Muñoz et al. (2008)	• CML 2000 Method (Guinée et al., 2002)	• Bakery products	• farming, industrial processing, distribution, storage, and cooking, etc.	• Packaging excluded • Average Spanish diet	• supply of food for a Spanish citizen	• Global Warming Potential (GWP); Eutrophication Potential (EP); and Acidification Potential (AP) Primary Energy use (PEU)

Author(s)	Method	Product	Process	Alternatives	Functional units	Impact categories
Brandão (2010)	• Environmental consequences of diverting wheat from food to fuel purposes in UK	• Food wheat • Combination of palm oil, soymeal, and feed wheat	• Wheat for food and feed (Canada), Argentina (soymeal), Indonesia (vegetable oil)	• Consequential approach, • Foreground system (UK wheat cropland) • Background	• 1 ha	• Indirect Land Use Change (iLUC) – Climate Change (GWP100), • Ecosystem Services (Net Ecosystem Carbon Balance)
Hayer et al. (2010)	• Multi-criteria comparison of eco-toxicity models focused on pesticides	• Wheat • Apple	• comparison based on scientific soundness, practical feasibility • stakeholder utility	• toxicity models EDIP97, USESLCA,IMPACT2002, EI99, databases: SYNOPS, Footprint		• Pesticide application toxic effects
Kägi et al. (2010)	• LCA of rice: ecoinvent LCI database • Cradle to consumption	• Rice	• Cooking, transport • Packaging (incl. disposal), refining • Parboiling, etc.	• Zürich conventional and organic rice from Italy, conventional rice from USA, upland rice from Switzerland	• 1kg processed rice in dry condition (as it is available in the store)	• Global warming, method of ecological scarcity • software EMIS • (Environmental Management and Information System)
KHOO et al. (2010	• An LCA approach for evaluating the GWP • "farm land" to "food"	• Milled rice from Thailand	• Feed, cultivation • Harvesting, milling grinding, drying, etc.	• Singapore	• 1 kg-protein for all food types	• Climate change, carbon Footprint, land Use