Savoir faire

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Life Cycle Assessment of agri-food systems

An operational guide dedicated to developing and emerging economies

éditions Quæ

Part 3

Overcoming the challenges for robust agri-food LCA in developing and emerging economies

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Co-designing the study with stakeholders

The goal and scope of design is a critical first step in LCA. Key elements of the ISO 14040/44 standard should always be considered when defining goal and scope (see Appendix A p. 121). Depending on the situation, this first step may be carried out by the LCA practitioner alone or with the collaboration of stakeholders. In the following sub-sections, we describe a complete co-design approach for an LCA study.

Overview of the approach

Based on our field experience, we designed an approach to help LCA practitioners organize their LCA study with the best chance of success and build long-lasting and fruitful partnerships (Figure 8.1). In this approach, a first loop of exchanges with the commissioner (i.e. the stakeholder from whom the study originates and who defines the terms of reference) occurs, and the LCA practitioner may reject the proposal if all important conditions are not met. The study might take place in highly complex situations or the commissioner might have unrealistic requirements or not provide sufficient means. We illustrate such conditions with some real situations from the field in our "deal-breaker situations" scheme (Figure 8.2). Once realistic conditions are negotiated with the commissioner and an explicit contract is signed, we recommend designing and formally validating in a dedicated report the goal and scope of your study with the commissioner. This will help make sure that the commissioner and the practitioner agree on common and realistic achievements, and provide a clear roadmap for the LCA study.

Next, one essential part of the study will consist in building operational interactions with all stakeholders: this is what we call the "community" of the study. It is therefore of paramount importance to analyse and understand the expectations and constraints of each member of this community and to develop a strategy to work with them. Depending on the study conditions, the work may also be organized in synergy with other experts; either local technical experts or experts from other disciplines. Finally, before starting the actual data collection, as part of the study goal and scope, the system boundaries need to be fine-tuned and a typology for the studied systems must be delineated to define the best possible sampling protocol and be able to answer the questions raised by the commissioner.

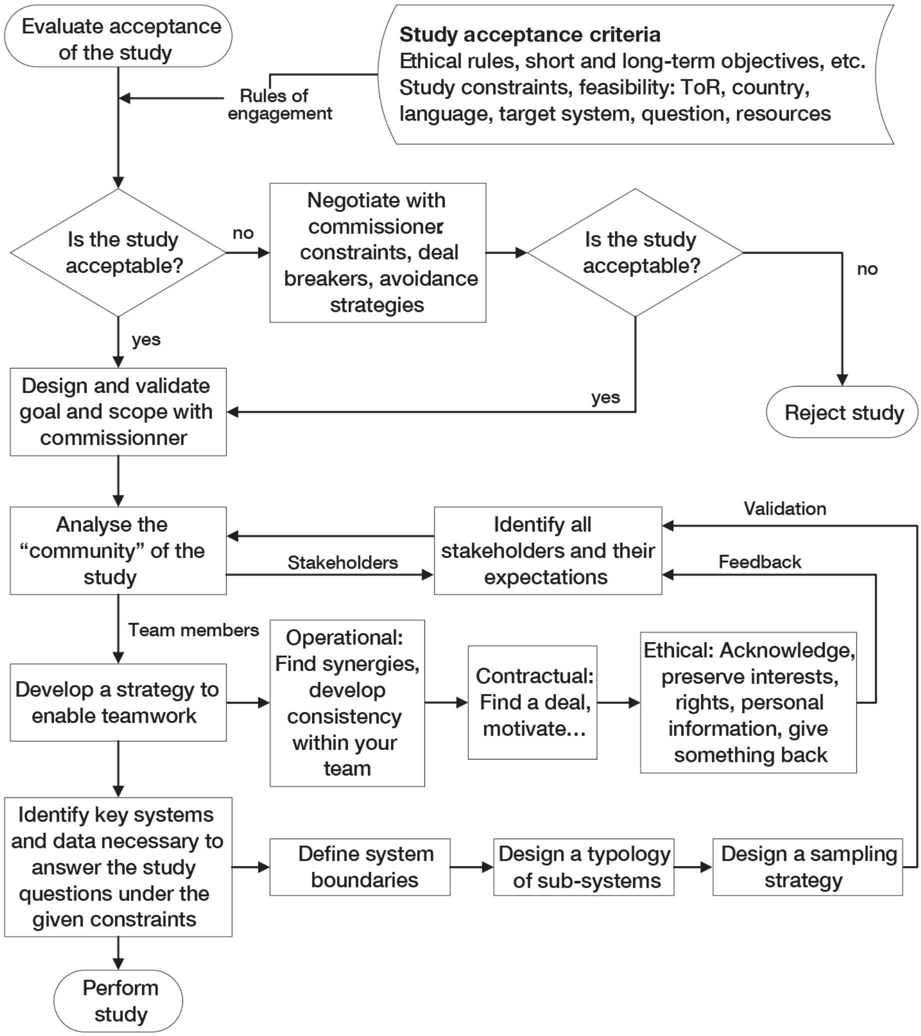


Figure 8.1. Overall approach to organize the LCA study with the different stakeholders in the best possible conditions (ToR: terms of reference).

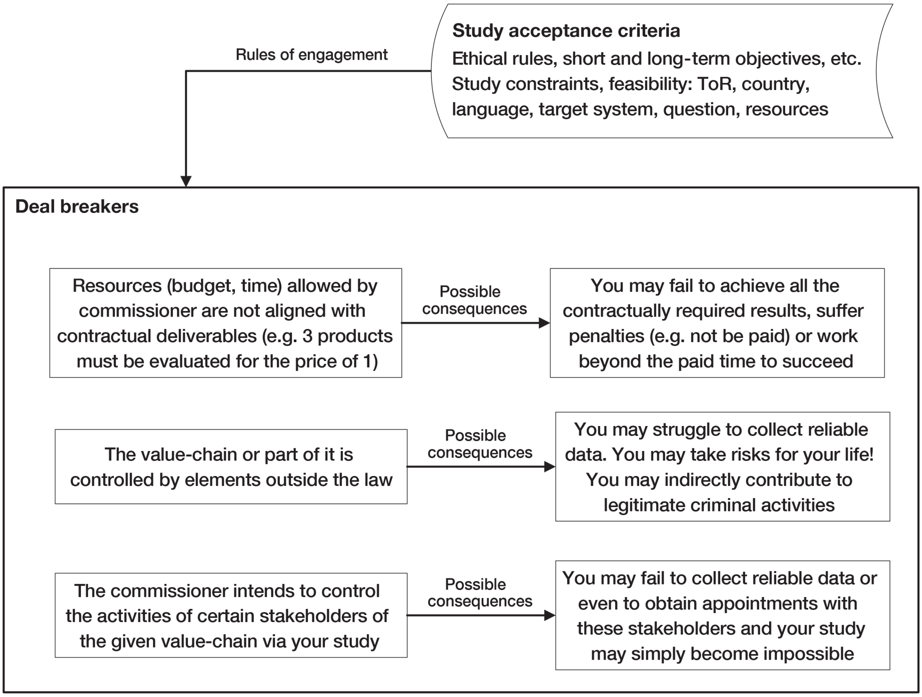


Figure 8.2. Deal-breaker situations: some examples from the field.

Critical analysis of the demand, constraints and avoidance strategies

Before starting a study, it is necessary to analyse the demand, i.e. the detailed terms of references, and assess its feasibility. The most important conditions are:

- resources allocated in terms of time, money, and access to data are adapted to the study objectives;
- the context of the study, especially that the actual commissioner and study objectives are transparent;
- the country of the study should not face important security issues (e.g. war)

In Table 8.1 and Table 8.2, main LCA study constraints are reported and adaptation strategies are provided. Table 8.1 focuses on constraints more directly related to the initial conditions of the study as determined by the commissioner's objectives, which should be clarified as much as possible before the study begins. The commissioner may or may not be the sponsor, but is considered to be the stakeholder deciding on the means allocated to the study.

Table 8.2 indicates more scenarios depending on the expectations and constraints of further stakeholders throughout the study. All other aspects including data availability and system complexity might be challenging but should be possible to address with adequate organization and the right partnerships. This is what our guide aims to demonstrate and support.

Table 8.1. Clarification of commissioners' constraints and expectations to be handled ahead of the LCA study.

Main constraints and/or expectations of commissioner	Avoidance and adaptation strategy	Practical implementation
The commissioner wants quick results and/or is not aware of LCA complexity: not enough time or resources are allocated to the LCA practitioner in the terms of reference Or The commissioner or another affiliated beneficiary expects unrealistic outputs from the study such as the decision he or she should make (see Box 8.1 and Box 8.2)	Clarify in advance the needs for a proper LCA study. Clarify in advance the limits regarding potential LCA coverage, data completeness and representativeness. In all cases, after negotiations and the study, issue a reminder to put final results into perspective with initial context and means.	Ahead of study start, propose a presentation to the commissioner on LCA methodology with an example of necessary datasets and explanation about result consistency and quality. It is key to find suitable ways to explain the importance of the constraints and to detail the methodological challenges faced by the practitioner. Propose an inception mission ahead of the actual study, without a set engagement for carrying out the study, in order to gather concrete field information to justify either the narrowing of study objectives to fit the proposed means or to negotiate better alignment among the study scale, allocated means and potential scope for the outputs.
Lack of transparency on who the commissioner is and what the expected outcomes are	Clarify in advance the study context, i.e. the commissioner's expectations and intended use of LCA outputs.	Check the study terms of references to know who the designated parties are and make sure you are properly introduced to all potential commissioner levels. Make sure objectives are clearly defined in the study terms of references and/or the LCA study contract.
Lack of objectivity from the commissioner who expects "good" results	Explain in advance what "good" or "bad" results could be; stress issues of trade-offs; exemplify how all of these can be useful to improve the production systems. Clarify in advance the publication policy to make sure that results can be made public independently from initial expectations. If the LCA is meant to be used for a public comparison with other products or published results, anticipate the need for a peer-review as required by the ISO standard.	Provide feedback and showcase success stories of LCA. Make sure the publication policy is clearly stated in the contract. Propose a "non-responsibility" clause in the contract for the practitioner, if the LCA results are not used properly (not in agreement with the study validity domain) and/or results are modified. Make sure that a budget is allocated for an external ISO-compliant LCA review when the objective is to publish the LCA results compared with previously published LCA results.

The commissioner and one or more stakeholders are bound by contractual or funding relationships that complicate the collection of information	Clarify in advance potential contractual relationships between the commissioner and other stakeholders. Clarify in advance the commissioner's objectives (link with the constraint on "lack of transparency").	Make sure objectives are clearly defined in the study terms of references and/or the LCA study contract. Discuss with the commissioner the potential implications of his/her relationships with the stakeholders regarding potential issues on data collection, etc. Depending on the outputs, ask for transparent information communicated to relevant stakeholders on the study objectives (e.g. through mails to stakeholders with a copy to the LCA practitioner).

Box 8.1 Expectation management in Zambian aquaculture study (A. Avadí, CIRAD)

In the context of the VCA4D project on Zambian aquaculture, certain stakeholders such as the local European community (EC) Delegation and the Zambian government (Ministry of Fisheries) expected direct advice on where to invest in the supply chain (e.g. priorities). The experts explained that the purpose and scope of the study was to describe the current supply chain situation, and to evaluate the consequences of investing in each element of the value chain, but not to recommend specific investments. Therefore, the project team's role was to inform and support their decision-making, not to make decisions.

Project data brief: https://europa.eu/capacity4dev/value-chain-analysis-for-development-vca4d-/wiki/207-zambia-aquaculture

Box 8.2. The notion of "environmental sustainability" from a LCA perspective (Y. Biard, CIRAD)

The study carried out on the mango commodity chains in Burkina Faso was one of the first studies of the VCA4D programme. At that time, the question explicitly formulated by DG DEVCO and Agrinatura was: Are these commodity chains sustainable?

With regard to LCA, the question had to be reformulated, to make it clear to the sponsor that the word "sustainable" is a non-prescriptive word and does not include anything quantitative. As such, LCA could not answer yes or no to the question asked, but could provide data and information on the potential impacts of each sub-sector.

Second, these potential impacts could be benchmarked by comparing the values obtained for the mango commodity chains with those of other agricultural commodity chains, or even other sectors of the Burkina Faso economy, although as a non-predictive cross-view given the unmatched functions.

The detailed synthesis of the study is freely available online via the following link: https://europa.eu/capacity4dev/value-chain-analysis-for-development-vca4d-/wiki/202-burkina-faso-mango

The community of the study

An LCA study involves many stakeholders with whom the practitioner must exchange information and data (Figure 8.3). Stakeholder categories include:

- the commissioner (public or private, individual or institutional, etc.);
- local experts who cooperate with your study;
- local institutions (e.g. ministries);
- actors involved in the value chain to be interviewed (producers, processors, carriers, retailers, who can be industrial players or smallholders, etc.);
- actors involved indirectly (local authorities, statistics offices, central decision-makers, etc.);
- sometimes observers from the civil society (NGOs, academics, consultants, etc.).

The quality of the LCA depends substantially on the quality of the data collected, which in turn depends on the willingness from stakeholders to share information and data, and from their potential direct interest in participating, since doing so requires time. It is paramount to make sure that expectations and constraints related to stakeholders are well understood and managed to the fullest extent possible. We differentiated two main situations that influence interactions between the LCA expert and the community of the study:

- a situation where the LCA expert is local;
- a situation where the LCA expert is a foreigner.

For each situation, we proposed a formalization of the expectations from the various stakeholders (Figure 8.3). The commissioner (or funder) orders and pays for the study. This stakeholder must have clear expectations and requirements. As already mentioned, the LCA practitioner must explain clearly what an LCA study can and cannot do and negotiate with the commissioner to ensure adequate conditions to produce realistic deliverables. In the country of the study, all stakeholders have their own expectations. Local institutions may seek useful information and support for decision-making as well as more personal recognition as individuals. Local experts may expect financial benefits, future projects, visibility or publications. Farmers might hope for some technical advice and future subsidies based on the study results. Processors and exporters might expect favourable feedback on their businesses, etc. All along the value chain, the stakeholders must manage their day-to-day activities and will need to see a benefit in contributing to the study.

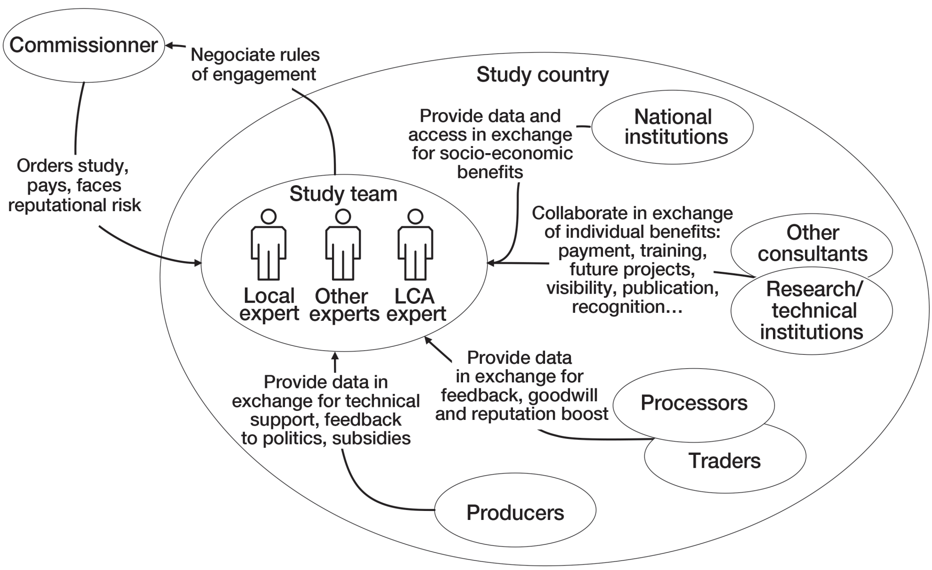


Figure 8.3. Community of the study and stakeholder expectations: the LCA expert may be local or a foreigner. The main difference between the two situations is that when the LCA expert is a foreigner, she or he will need to collaborate with a skilled local expert who can facilitate meetings with the relevant contact and ensure proper social usages and language.

Overall, the golden rules to ensure good working conditions with stakeholders are: listening skills, transparency, awareness raising, explaining, respect, trust, protection of interests and sensitive data. These main rules are presented and illustrated in Figure 8.4.

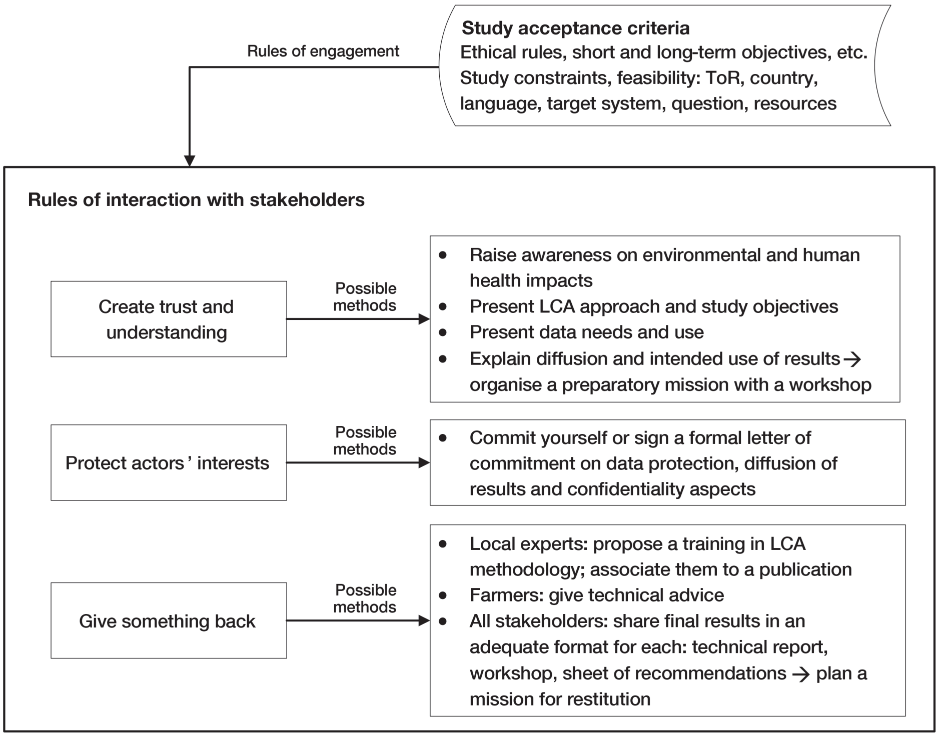


Figure 8.4. Golden rules of interactions with stakeholders.

Some stakeholders might fear drawbacks or reputational risks from the study, or simply see it as a waste of time with no foreseeable benefits. It is impossible to make an exhaustive list of all potential situations and expectations. However, we did list the main situations and proposed ways to avoid obstacles and ensure positive collaboration with stakeholders and effective data collection (Table 8.2). Ideas are not listed by stakeholder type, as one constraint may be faced by several stakeholders. Instead, they are listed by type of constraint and/or expectation. Avoidance and adaptation strategies may still depend on the stakeholder. Generally speaking, it is important to remain attentive to the actual willingness of the local partners and stakeholders. Some may prefer very official interactions while others may feel uncomfortable signing formal agreements. Local expert advice is of great help in determining the most suitable ways of collaborating with each stakeholder.

Table 8.2. Possible avoidance and adaptation strategies to some of the main constraints and expectations of stakeholders involved in an LCA study.

Main constraints and/or expectations of stakeholders	Avoidance and adaptation strategy	Practical implementation
Lack of objectivity from the stakeholders involved in the study who expect "good" results	Show ahead what "good or bad" results could be; stress issues of trade-off; exemplify how all of them can be useful to improve the production systems. Highlight that bad aspects from a study are levers for progress and should not be feared. Communication can even be targeted on these margins of improvement, valuing the effort of transparency of the company.	Provide feedback and showcases on success stories of LCA. Propose a "non-responsibility" clause in the contract for the practitioner, if the LCA results are not used properly (not in agreement with the study validity domain) and/or results are modified.
Stakeholders directly or indirectly involved in the value chain are not interested in the study and its results and/or fear getting "bad" results about their own business	Recall the importance of quantifying impacts and assessing systems with real datasets to be able to design appropriate and improved practices; i.e. demonstrating that they are the actual final beneficiaries of the results. Based on previous LCA studies, try to shed some light on potential good/bad results. Highlight the potential positive consequences for the value chain/sector and the various stakeholders, including positive economic feedback, access to labelled markets, etc.	Provide feedback and showcase success stories of LCA and positive evolutions of production systems and value chains by integrating environmental impact reduction and enhanced performances. When possible, provide demonstration in the field about system improvements investigated with the LCA (e.g. demonstration of residue recycling in the field, etc.). Include both agro-environmental and economic perspectives. Ultimately, inform reluctant stakeholders about which default worst-case values will be used for key data in the absence of real data from them, preventing them from getting any direct use of results.

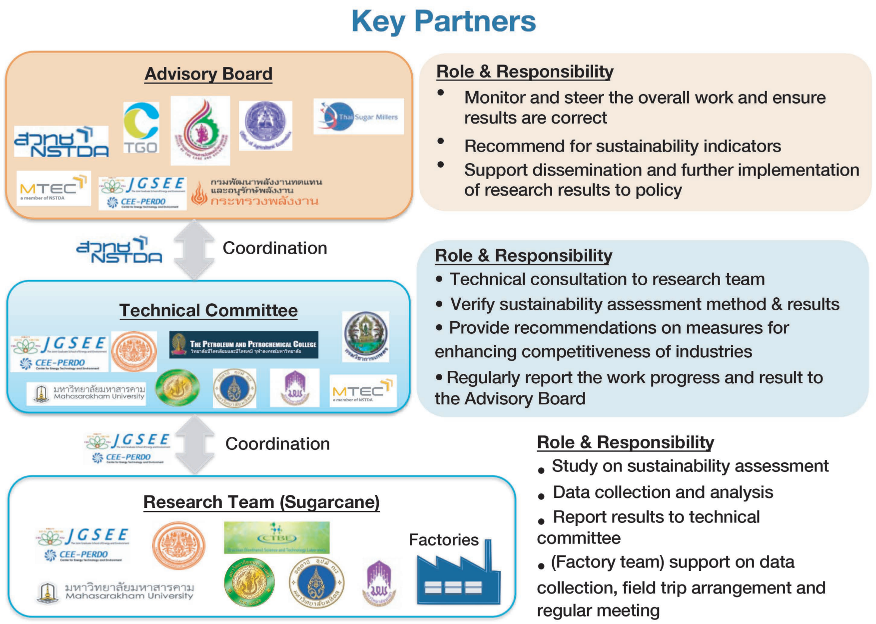
Main constraints and/or expectations of stakeholders	Avoidance and adaptation strategy	Practical implementation
Stakeholders directly or indirectly involved in the value chain are not willing to participate if the results are public and/or are reluctant to share sensitive information	Clarify in advance what will and will not be made public. Define a strategy to make individual data anonymous. Create trust and secure the confidentiality of exchanges and the non-transmission of the raw sensitive information. For sensitive matters, it is particularly important to rely on a local expert to know how to manoeuvre. In extremely sensitive contexts, whether political or simply technical with very critical access to data, practitioners should try to avoid, as far as possible, that LCA results could severely discredit stakeholders or create any unnecessary controversy. The practitioner should keep in mind that LCA embeds various uncertainty sources whose influence on results might be particularly critical in the context of lack of data. Decisions based on very uncertain results should be limited/avoided in sensitive contexts, where such decisions could have severe consequences.	Specify the deliverables that are planned, including the detail level of these deliverables. An official document may be provided by the commissioner to introduce the study and install trust by clearly presenting planned deliverables and data property and confidentiality. Depending on the sensitivity of the context, one may either simply clarify the publication issue within the contract, so that it can be properly traced and parties reassured, or also provide a "confidentiality document/contract clause" for the data collection and the protection of sensitive information. Involve stakeholders, notably public institutions, in a steering committee so that they are informed about the progress of the study can help to install trust. Those stakeholders could then see the results before they go public and could also contribute to co-building the results in an objective and participative way (see Box 8.3).
Stakeholders directly or indirectly involved in the value chain do not have time to answer or participate	Define work plan in the field according to seasonality (when it comes to agricultural activities) and potential best moments for the stakeholders to be available. Adapt data collection to the various constraints of each stakeholder. Think of compensation mechanisms for the time given by the stakeholders (e.g. money, technical advices, field demonstration, capacity building, references, etc.)	Gather information in advance about the local context in order to identify suitable periods during which the various stakeholders may be the most available. If needed, split your field mission in two or three shorter missions to meet the various stakeholders at different times of the year. Combine several modes of data collection: – Field surveys by the practitioner – Field surveys carried out by external interviewers who can visit stakeholders at different points in time – Questionnaires sent per email – Questionnaires through Internet tools, etc. Pay attention to cross-checking of data to assess potential bias linked to such combinations. Allocate time and budget resources for compensating activities.

Main constraints and/or expectations of stakeholders	Avoidance and adaptation strategy	Practical implementation
Stakeholders directly or indirectly involved in the value chain fear being dispossessed of the results, having no feedback, no benefits from their given time and data, etc.	Commit to providing feedback adapted to the audience (from a results document to a dedicated in-country workshop).	Allocate time and budget resources in the initial contract for the feedback mission/deliverables. Feedback needs to be adapted to both the public and the medium-term partnership perspectives.
The LCA is done within a research project without specific expectations from any stakeholder (see Box 8.4)	It is paramount to create interest among stakeholders, inform them about the objectives and try to develop partnerships. Try and engage public institutions, academics and observers to reach a wider audience and connect with stakeholders. It can be an opportunity to conduct capacity building activities related to LCA.	In the research project budget, plan for time and activities dedicated to developing stakeholders' interest in the LCA study: e.g. inception mission, presentation workshop, etc. When possible, plan a conference in an academic institution to present the research project and the LCA methodology.
The practitioner has specific constraints as a stranger not knowing the local context well and/or Stakeholders do not provide accurate information (either to please/displease the practitioner, to hide sensitive information or involuntarily, etc.)	Being accompanied by local experts is a good solution, but the practitioner should be aware that some local experts can create both trust and mistrust and can influence data collection. Moreover, work with interpreters always implies an added uncertainty source. Cross-checking information with other data sources, including literature, etc. is needed to secure data quality	It is important to enquire about the local situation and to make sure that the method and goal of the study are clearly explained to the stakeholders and people surveyed. It is also important to get information about the culture of the countries/regions where the LCA study takes place, as well as to have an idea on how foreigners are perceived in the country of the study (distrust, positive view, etc.). First visiting institutions and meeting with local representatives is key to introducing the study and enable the survey with local partners. Whenever possible, training of interviewers and interpreters should be implemented to reduce bias and uncertainty in data collection.

Box 8.3. Sustainability assessment of sugarcane biorefineries to enhance the competitiveness of the Thai sugar industry (S. Gheewala, King Mongkut's University of Technology Thonburi, Thailand)

Thailand is one of the world's leading sugarcane-producing and sugar-exporting countries where this industry is relatively mature. However, there is relatively little scientific information on the sustainability of the sugarcane supply chain considering all environmental, economic and societal aspects. This study aimed to assess the sustainability of sugarcane biorefineries in Thailand in view of environmental, economic and social hotspots (Gheewala *et al.* 2016; Silalertruksa *et al.* 2017).

To monitor and steer the overall work and support dissemination and further implementation of research results into policy, an advisory committee was officially assigned through the National Science and Technology Development Agency (NSTDA) by engaging the relevant stakeholders in the sugarcane value chain, including government bodies, industry players, the cane growers association and researchers. The government sector included the Office of the Cane and Sugar Board (Ministry of Industry), Office of Agricultural Economics (Ministry of Agriculture and Cooperatives), Department of Alternative Energy Development and Efficiency (Ministry of Energy), Ministry of Science and Technology, and the Thailand Greenhouse Gas Management Organization. The private sector included representatives from the sugar mills and ethanol companies, as well as the sugarcane growers association. In addition to the advisory committee, a technical committee from various research institutes provided technical advice to the research team, verified the sustainability assessment method and results, and provided recommendations.



Box 8.4. Expectation management in a research study: coffee in Colombia (I. Acosta-Alba, EvaLivo)

In the context of a post-doctoral research project, an LCA of farms was carried out including all the crops and livestock of coffee producers in Colombia (Acosta-Alba *et al*. 2020). The participative research enabled several field visits and trust development with farmers who were actively participating in other research projects. A launch meeting was held to explain the LCA's expected outcomes to partners and farmers. In the beginning, partners and farmers did not understand why different researchers asked the same questions. After explaining the level of detail needed for LCA, farmers were more receptive. The multicriteria nature of LCA was also warmly welcomed by academic and technical partners. A participative workshop was organized with farmers to ask them about the main environmental issues for them, and to share the LCA results. They were very satisfied to have the full picture including off-farm impacts of coffee production. Meetings and discussions with researchers resulted in the LCA study being introduced into a larger methodological framework for co-designing climate-smart farming systems with local stakeholders (Acosta-Alba *et al*. 2019; Andrieu *et al*. 2019).

Working as a team in the field

How to best organize fieldwork

Figure 8.5 summarizes important steps to best organize fieldwork, especially for foreign LCA experts. The first step is the preparation of the study before the data collection in the field. It is crucial to document the product system to be assessed, the region and the value chain sufficiently in advance for the proposed solutions to be appropriate and achievable. When the LCA expert is a foreigner, relying on a national or regional expert is a huge asset to quickly identify key stakeholders, inconsistent or reliable data sources, etc. Language mastery and understanding the local culture and specific constraints such as administrative difficulties, etc. by at least one member of the team is a second compulsory element. It is particularly important when the studied systems include small-scale producers to establish quality contact with them. This will also help identify and gain data from potentially important actors who only can speak in local dialect or language (Box 8.5, Box 8.6).

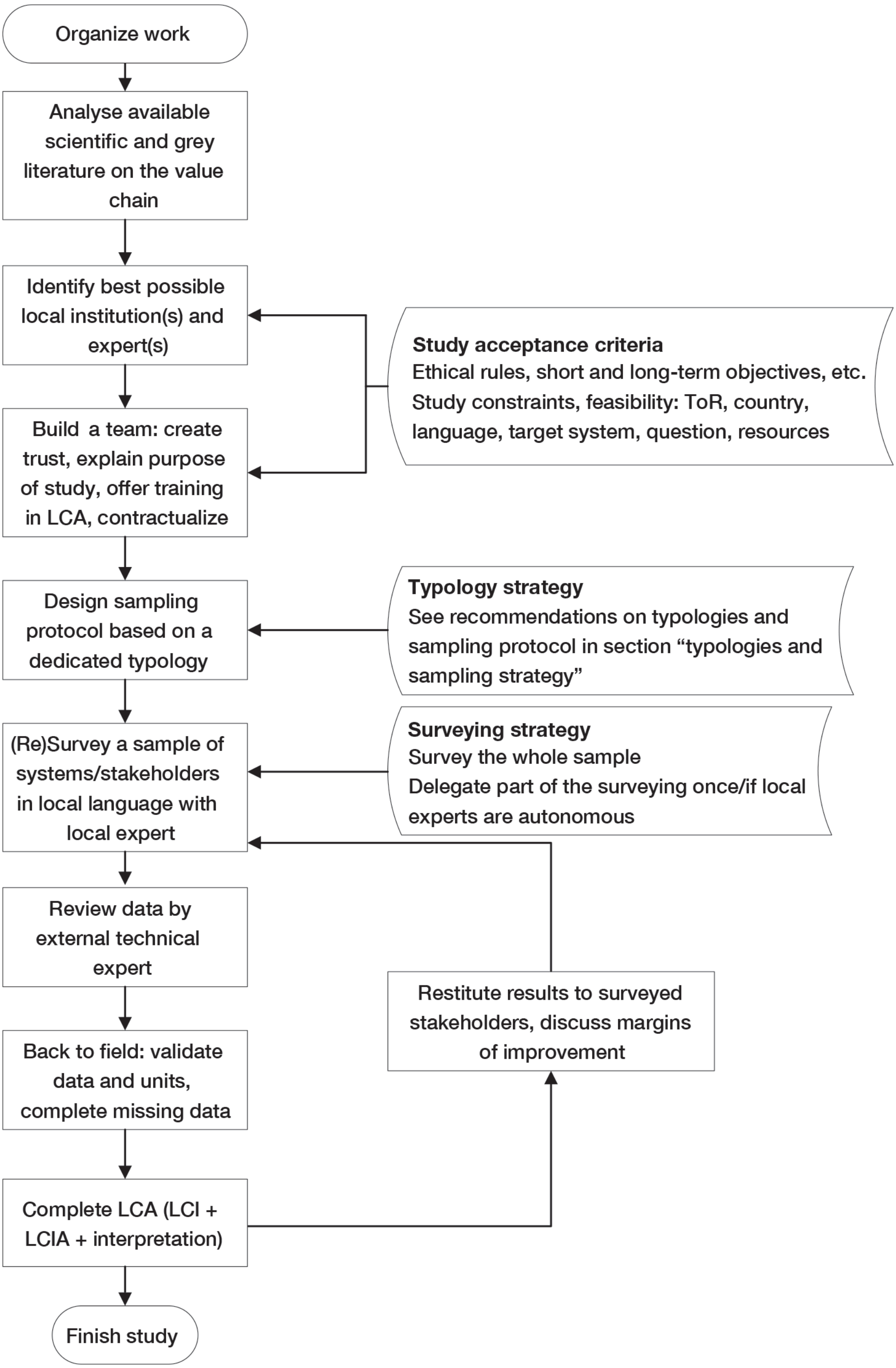


Figure 8.5. Recommendations for optimal fieldwork organization for foreign LCA practitioners.

Box 8.5. Study of the Malian value chain of artisanal continental fisheries in Mali, linguistic and cultural barriers (I. Acosta-Alba, EvaLivo)

In Mali, more than half of the fish caught is processed into smoked fish mostly by the fishermen's wives. To limit travel within the country because of security risks, a workshop was organized in one of the main fishing areas. Actors were invited to participate; more than 50 participants attended. The seats were occupied by the men while the women remained seated next to them on the floor. Men understood French and spoke Bambara unlike the women who spoke only Bambara. In general, fishermen's wives are more familiar with the quantitative data about fished yield, the allocation between consumption and sales, the prices, the quantities of wood, the technical aspects of smoking and even the prices of fishing equipment because their sales partially finance them. Without an experienced translator and a female interlocutor on the team, the critical access to the data and knowledge from the wives would have been impossible.

Box 8.6. Gender division of labour and direct access to the people concerned – mango from Burkina Faso (Y. Biard, CIRAD)

The dried mango sub-sector particularly involves women, especially for fruit preparation tasks (selection and washing, peeling and cutting, and packaging). Meanwhile, oven management and permutation of mango slices racks are mainly carried out by men. Depending on the information to be collected and the associated technical activities, it is important to be able to identify the right people, if possible in the language used in practice to coordinate the work in an operational manner, in this case the Dioula language.

The detailed synthesis of the study is freely available online via the following link: https://europa.eu/capacity4dev/value-chain-analysis-for-development-vca4d-/wiki/202-burkina-faso-mango

How to best work as part of a multidisciplinary team

If the LCA study is part of a sustainability study including environmental, economic and social evaluations of a common system or value chain, a common and efficient working method must be adopted. This is especially important when it comes to designing a consistent protocol and interacting with stakeholders. However, in projects subject to time constraints, the presence of several experts in the field to understand and collect data from the systems studied can be difficult to organize and the actors interviewed may feel uncomfortable. All experts should clearly explain their specific objectives to the team and try to build bridges and develop synergy as much as possible. We summarized our field experience in Figure 8.6. When surveying stakeholders, the multidisciplinary team should not hesitate to split into two sub-teams: a "social" team (including a local expert and the social expert) and a "technical" team (including a local expert, the economist and the LCA expert) and meet specific key people in the organization or company. The team may organize turns if all members must discuss with the same people to avoid creating competition for asking the questions and confusion for the people surveyed.

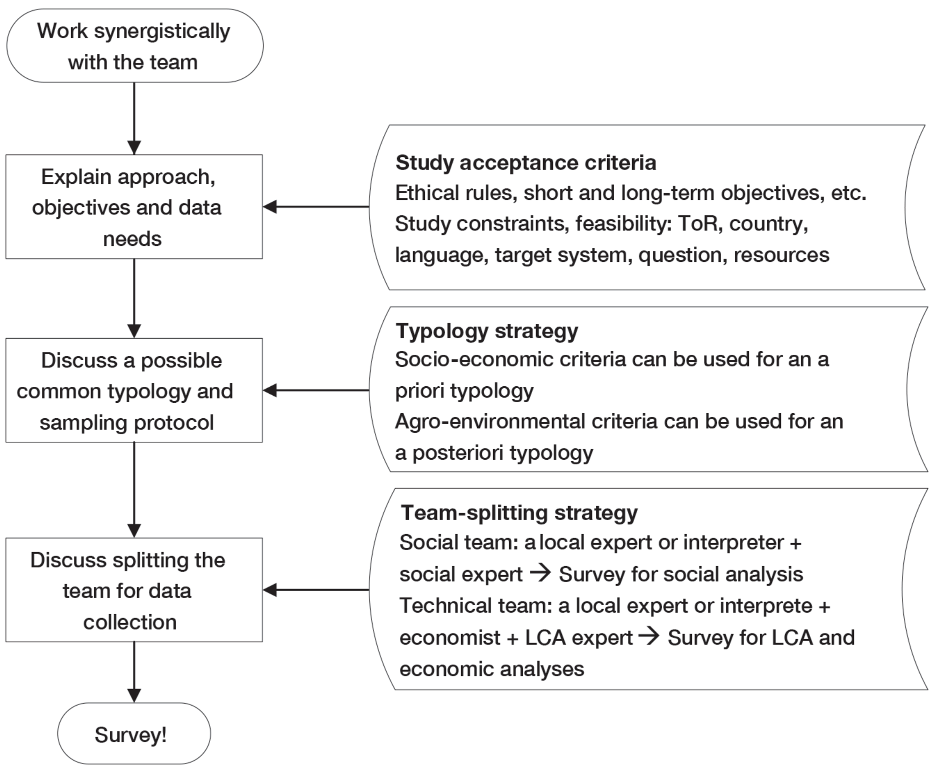


Figure 8.6. Recommendations for optimal fieldwork as a multidisciplinary team.

When the LCA expert works with an economist, part of the data collection can be mutualized. Indeed, both analyses have a common need for detailed data from all operations and products used. Therefore, it is crucial to have a common definition of the system, as previously mentioned. With sociologists, it is also possible to find anchorage points for mutualized data, especially when focusing on working conditions and food production and consumption patterns.

If LCA is not part of a sustainability assessment, support from a technical expert of the studied system is always recommended. The technical expert can be the local expert or another expert such as an agronomist for a given cropping system or a technical expert of aquaculture or livestock production. The technical expert can play a key role in identifying the right partners and experts in a given country on a specific product system. He or she can provide valuable input to design the protocol and when validating the field data, thereby identifying potential inconsistencies in a dataset, anomalies or mistakes and guide the validation effort among the stakeholders in the field (see Chapter 9 section “Foreground data collection”).

Management of ethics and rights for stakeholders

This section is mainly based on the European legal and institutional frameworks with explicit references to them, particularly where European regulations have spread and influenced jurisdictions in other geographical areas of the world. However, a complementary analysis would be needed to adapt to countries whose legal development is based on other frameworks such as the common law-based systems (UK, US, Australia, etc.), which differs significantly on copyright issues from these European frameworks.

Data and database legal framework

According to the harmonized European legal frameworks, a “single data unit” is not protected by law. However, it is possible to limit its dissemination, use or exploitation by a contract (data availability contract, confidentiality contract, exploitation contract, etc.). It is also possible to disseminate it and make it available to the scientific community in particular, while indicating conditions for reuse and citation and respecting an embargo period if necessary.

However, some data may be subject to specific protection by intellectual property rights, such as photos and videos that may be protected by copyright. In this case, the data cannot be used freely without the written permission of the author, who should have prior consent from any people who are filmed or photographed. In the context of data collection for LCA, photos and videos can be very useful, especially for easily collecting technical information on devices and infrastructure (technical data sheets, model numbers) but also for scanning monitoring documents. Special care must therefore be taken with this data and permission must be obtained prior to their use in a study.

A database can be protected by two types of mechanisms: copyright as a creative/original work and/or by a *sui generis* database right. These two types of protection are presented in Box 8.7.

Box 8.7. The two mechanisms of database protection (Y. Biard, CIRAD)

• "The rules of international law – Berne Convention, the WTO/TRIPs Agreement and under the WIPO Copyright Treaty (WCT), original and creative databases enjoy copyright protection as literary works."
• "The Directive 96/9/EC on the legal protection of databases, which creates a specific property right for databases that is unrelated to other forms of protection such as copyright. This new form of *sui generis* protection applies to those databases, which are not 'original' in the sense of an author's own intellectual creation ('non-original' databases), but which involved a substantial investment in their making."

Source: European IP Helpdesk (https://www.iprhelpdesk.eu/home)

These two types of rights only apply to the arrangement of data – neither database copyright nor the *sui generis* right create an additional protection for the individual elements of the database.

Questions and recommendations on data

When setting up the LCA study, there are key questions about data collection, as well as at the end of the project regarding the use of the data. We prepared the following checklist with the main questions to be addressed by the LCA practitioner (Box 8.8).

Box 8.8. Questions directed to the LCA practitioner (as "you") when designing the study and preparing data collection

1. Will you be using existing databases? Can you trace back their origin? Is it possible to identify the producer? Do you have permission to reuse these databases (structure and content)?
   • The use of the main reference LCI databases is foreseen and indicated in the conditions of use of these databases. However, this question becomes very important if you plan to mobilize other databases (such as on inputs).
2. For the development of your own databases, especially in files external to the LCA software you use, do you plan to extract from third-party databases (content)?
   • If so, do you have the authorization to perform these extractions?
   • If not, you must formally request such authorization.
3. Will you produce an original database (structure and content) with several partners?
   • In this case, a co-production contract must be drawn up and the rights and obligations of each party with regard to the database during and after the project must be defined.
   • This may be the case in particular when quantitative or semi-quantitative surveys are planned in connection with a typology of systems. These questions must be addressed as soon as the study starts, as they should be explained to your partners and contacts.
4. Will you use existing datasets?
   • If yes, are these datasets covered by a contract (partnership agreement, confidentiality agreement, service agreement, license agreement, other)?
   • If they are covered by a contract, check the conditions of use in the contract.
5. What is the purpose of the data and databases resulting from the project? Open data? Valuation through expertise? Paid licenses for restricted access databases?
   • Whenever possible, it is strongly recommended to discuss these points with the partners at the start of the project.

At the end of the LCA study, it is important to revisit these elements to verify that what is planned for the dissemination or exploitation of LCA results is in line with what was originally agreed with all stakeholders. The first step is to check what is included in the partnership or consortium agreement regarding the use of the data or databases produced. The best tool to manage data is called a data management plan (DMP), which is presented in Box 8.9.

Box 8.9. A DMP: a convenient tool to manage the data of a LCA project (Y. Biard, CIRAD)

A DMP is a tool to help scientists manage their data within a project. Writing a DMP at the beginning of a project allows for the implementation of good data management practices, facilitates exchanges between partners and saves time for the publication and reasoned sharing of data at the end of the project. This document is increasingly required by most funders.

The drafting of a DMP makes it possible, among other things, to:
- implement good data management practices and documenting data,
- guarantee the quality of research and the production of reliable and understandable data,
- contribute to the transparency, scientific integrity and reproducibility of research,
- reduce the risk of data loss or non-reusable data,
- clarify the roles, responsibilities and rights of each contributor,
- anticipate legal, ethical or technical problems,
- ensure the security of personal, sensitive or strategic data,
- facilitate the sharing of data within the collective,
- predict the needs and costs to generate, process, store and share data,
- respond to donor demand.

The return on investment is the simplification of subsequent recovery work since these data will be ready to be deposited in a data warehouse, published, and reused.

Here is a list of free tools for creating a DMP:
- DMPonline (Digital Curation Centre – UK): https://dmponline.dcc.ac.uk/
- Easy.DMP (EUDAT European data infrastructure): https://easydmp.eudat.eu/
- DMPTool (University of California Curation Center – US): https://dmptool.org/
- ezDMP (Interdisciplinary Earth Data Alliance 2011): https://ezdmp.org/index

In Figure 8.7, the data flow and data transformation mapping in the DMP of the LCA-CIRAD platform is presented for information. Appendix D (p. 135) proposes a checklist to help LCA practitioners account for confidentiality in their inventory.

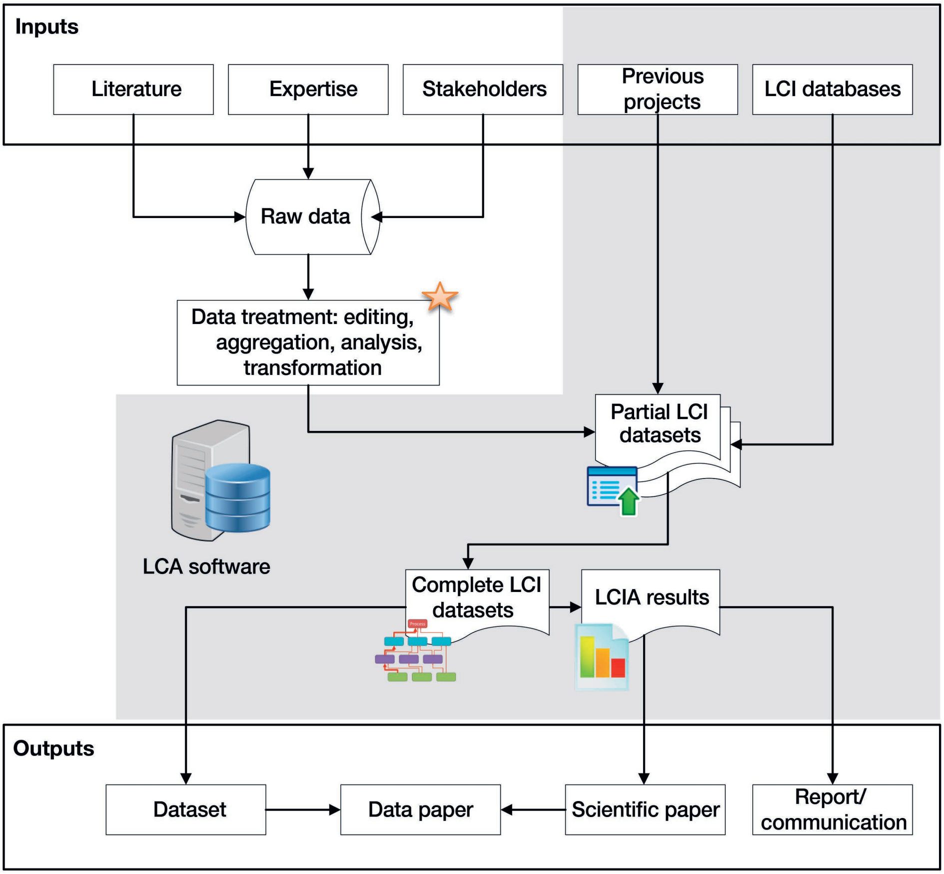


Figure 8.7. Data flow and data transformation mapping identified in the DMP of the LCA-CIRAD platform.

A closer look at personal data protection

The General Data Protection Regulation (GDPR) is a European regulation applicable since 25 May 2018. This regulation aims to strengthen the protection of personal data and has inspired substantial developments regarding their protection in other countries around the world. Indeed, it applies to any company operating in the EU and to any company outside the EU that processes data on European citizens.

The production of LCIs generally does not require personal data, which is why LCA is generally not directly concerned by this legal framework. However, for specific cases where personal data is required, a generic template was created (Box 8.10). This template must be adapted (parts in square brackets are to be completed using the explanations below) and integrated in full to any form used either for internal or research purposes. It may be inserted directly within consent forms.

In general, for an LCA study carried out as part of a scientific project, raw personal data may be retained, in paper or electronic form, for the duration of the project and the time required for publication. Beyond that period, the data must be deleted or anonymized on all media (personal computers, external hard drives, databases, etc.).

Box 8.10. Personal data template (Y. Biard, CIRAD)

The information collected [on this form / …] is processed by [DATA CONTROLLER] as data controller, in order to / for the research project … [PURPOSE(S)[1]]. This data processing operation is based on [LEGAL BASIS[2]].

Your personal data is stored only for [RETENTION PERIOD[3] / the necessary duration to achieve said purpose(s)], without prejudice to applicable regulation. It is destined to [INTERNAL RECIPIENT] and can be transferred to [EXTERNAL RECIPIENT[4]].

In accordance with Regulation (EU) 2016/679 (GDPR), you are entitled the rights of access, modification, erasure and portability (when applicable) of your personal data, and of limitation and opposition of its processing, with the right to withdraw your consent at any time. You can claim those rights writing to our Data Protection Officer. You also have a right to submit a complaint directly to the appropriate data protection Supervisory Authority.

[1] PROCESSING PURPOSE(S): The processing purpose is the reason why personal data need to be collected and processed, and what are the planned use for it.

[2] LEGAL BASIS: GDPR allows processing operations on personal data when justified by one of six legal bases:

- Specific, informed, and unambiguous consent of the data subject, which must be given freely and prior to the processing (for instance, collecting sensitive data such as health data is normally subject to the person's consent)
- The necessity of the processing operations in order to satisfy a contract or pre-contractual steps taken at the request of the data subject
- The compliance of the data controller with a legal obligation that requires it
- The necessity to protect the vital interests of the data subject or another natural person
- The necessity of the processing in order to accomplish a task carried out in the public interest, or as regards the official authority of the controller
- The necessity for the purposes of the legitimate interests pursued by the controller or a third party, provided said interests are not overridden by the interests or fundamental rights and freedoms of the data subject (for instance, the protection of minors' personal data)

[3] RETENTION PERIOD: In accordance with the principle of minimization, personal data must not be retained any longer than necessary to accomplish the determined purpose or comply with legal obligations. A retention period must therefore be defined, informed, and implemented.

[4] RECIPIENT AND DATA TRANSFER: Whenever personal data are bound to be transferred outside of Europe, complementary obligations apply.

Ethical dimension and scientific integrity

Respect for the privacy of respondents, the intellectual property of the data mobilized, and the quality and integrity of the data are part of a broader definition of the ethical dimension of data management. The European Code of Conduct for Research Integrity identifies four fundamental values: responsibility, respect, honesty and reliability.[6]

When applied to primary data collection required to perform LCA, it is clear that developing strong partnerships is one of the cornerstones of the working method. The approach, based on mutual trust between partners, aims to build up LCA win-win situations: partners in developing countries build their capacity in LCA methodology and are well informed about the implications of the study on which they are collaborating, while an LCA practitioner can benefit from the best existing data on agricultural systems in these contexts and deliver reliable LCA studies for all parties. This approach requires taking into account ethical and legal considerations on the collection and use of LCI data with different partners presented above.

The LCA-CIRAD team decided to go further than the legal framework, putting more emphasis on trust and partnerships in their set of ethical rules, acknowledging the fact that strong partnerships are particularly important in the context of LCI data collection and sharing. The details of the implementation of this data quality charter were published in the proceedings of the LCA Food conference (Biard *et al.* 2016) and its main rules are described in Box 8.11.

Box 8.11. Main rules of CIRAD's ethical charter (Y. Biard, CIRAD)

The charter is based on two pillars: the quality of the relationship with the partners and scientific development. No data dissemination is allowed without considering the impact this could have on the interests or reputation of the partners and their relationship with LCA-CIRAD or CIRAD as a whole. The dissemination of datasets for direct commercial exploitation to strict dataset buyers is not a strategic priority for CIRAD.

These principles are specific to CIRAD and its long-term partnership strategy. LCA practitioners are free to establish their own policy, taking into account the imperatives of the project as well as their institution's strategy. This policy should then be explained in a document that summarizes commitments with regard to the datasets collected from third parties. If the dissemination of the full LCI dataset or LCIA results is required, those conditions should be thoroughly explained to partners right from the beginning of the study. Partners' validation of such conditions should be written out to the fullest extent possible in the collaboration agreement. Moreover, if external demands for LCI datasets or LCIA results

6. https://www.allea.org/wp-content/uploads/2017/05/ALLEA-European-Code-of-Conduct-for-Research-Integrity-2017.pdf

arise after the end of the project, the further long-term impact on the relationship with the partners must be considered in addition to the contractual clauses concerning the data dissemination agreed at the beginning. The scientific team leader is generally perceived as the most convenient decision-maker to exercise the *sui generis* right. She or he is encouraged to decide based on the advice from practitioners who worked on the concerned data. The data dissemination timeframe can include an embargo period, i.e. a delay to allow for scientific publication, provided that all partners agree.

An effective way to strengthen the trust and cooperation between partners is also to include, right from the initial project design, activities dedicated to LCA capacity building in the studied regions. This helps partners fully understand the ins and outs and potentially contribute to the LCA building itself rather than act only as data providers. This entails building medium- or long-term partnerships offering LCA trainings at novice and expert levels as well as specific trainings on LCA database quality management systems.

System boundaries, typologies and sampling strategies

To finalize the co-design of the study with stakeholders, a clear definition of the system boundaries and typologies associated with a transparent sampling strategy in accordance with the goal and scope of the study is crucial.

System boundaries

A key component of the goal and scope definition is the setting of system boundaries, coupled with cut-off criteria. In the case of a single system LCA, the limits of the system are usually straightforward to define, and several approaches for cut-off criteria exist. For instance, typical cut-off criteria include a mass or an economic threshold, but more elaborate approaches such as cumulative contribution to impacts have been proposed (e.g. Fréon *et al.* 2014b). A generalized practice in LCA consists of excluding certain inventory items (typically infrastructure) under the assumption that their contribution to impacts, per FU, is marginal. This practice is risky, as stated in Suh *et al.* (2004): “many excluded processes have often never been assessed by the practitioner, and therefore, their negligibility cannot be guaranteed”. Nonetheless, in many situations, a system type is well known and there is consensus on key inventory items that should be considered (see Chapter 9 section “Foreground data collection”, and especially Figure 9.1).

Even if the system boundaries are pre-defined, the data collection stage may inform refinements, as unforeseen sources of emissions for atypical systems may be discovered only by visiting them and interviewing the local stakeholders. Refinements through iterative loops are often needed in LCA and must be anticipated in terms of time allocation for the study.

Typologies and sampling strategy

The level of representativeness is linked to the goal and scope definition. Published LCA studies tend to exaggerate their representativeness in the very title (e.g. soybeans from Brazil), potentially misguiding readers when the study is actually representative of only a fraction of the whole system. LCA users should also be aware that LCI at country level available in databases, such as the WFLDB, also are too often not representative of very diversified systems, especially for tropical agriculture in developing and emerging countries. The conscientious LCA practitioner should choose a title fitting to the study's representativeness, e.g. specifying a type of agricultural system or a representative area.

Except in rare occasions, such as when the study is intended for pedagogic or research purposes, designing a representative sample of individuals of the studied population/product system may be a prerequisite. This is especially true when the scope of the study includes several typical systems, a regional or national scope, and if various systems ought to be compared regarding their environmental impacts. The feasibility of defining and surveying a representative sample of individuals will depend on both internal characteristics of the studied population, such as its size, variability and heterogeneity, and external parameters including the question asked and the resources allocated but also the knowledge and data available on the studied system.

A typical approach consists in classifying several systems into types, by means of a typology, in order to make comparison among types of systems rather than among individual systems or to account for the internal diversity of the studied population. The construction and use of a typology is based on the key assumption that systems belonging to different types are (i) homogeneous within a type, and (ii) sufficiently different among types to the extent that environmental impacts (or their key drivers) are also sufficiently different. Comparisons based on typologies require careful uncertainty management and understanding of the intrinsic variability among systems.

Typologies can be established a priori or a posteriori to the first field mission. If the addressed question is "Are the environmental impacts across pre-defined product system types significantly different?", the LCA study and sampling protocol will be based on an a priori typology relevant to these pre-defined types. If the addressed question is "What are the key drivers explaining the environmental impacts of a given product system?" then the sampling protocol could be based on a priori expert-based typology and cross-referenced with a posteriori typology using principal component analysis (PCA) and clustering if possible.

According to Bélières *et al.* (2017) the creation of typologies requires both theoretical and practical knowledge. Several approaches can be used for a priori typologies such as:

- structural-based typologies based on means of production;
- functional-based typologies based on the chain of decision-making by the farmer;

• performance-based typologies, although this criterion is often coupled with the previous two typologies;
• analytical typologies, which are constructed from the selection of discriminating indicators whose information comes from the farms themselves;
• statistical typologies;
• expert-based typologies; and
• mixed typologies.

According to our field experience there is often a mix of approaches depending on the goal of the project, time, resources, and available data. To build a typology, for instance of agricultural systems or fish farming systems, various criteria should be considered, including the existence of legal, administrative or ad hoc classifications of systems based on previous experiences or documents. Examples of a priori typologies:
• crop systems may be segregated into field crops vs. prairies vs. perennial crops, or into conventional vs. organic, or into open-field versus greenhouse production;
• animal systems are often classified depending on farming conditions and time spent in the building or in the open air;
• cattle systems are often classified into dairy vs. suckler systems;
• fishing fleets are generally divided into segments based on dominant fishing gear, target species or holding capacity;
• aquaculture systems are usually separated into land-based and water-based or intensive vs. extensive, or by size (which is often correlated with management intensity);
• for all product systems, a technical typology can be combined with a spatial typology accounting for the different regions or soil and climate conditions of production.

If such an a priori typology is retained, its validity should be confirmed by comparing the overall difference in environmental impacts among types. Other, more complex approaches are available for building typologies, including the use of statistical tools such as PCA (e.g. Avadí *et al.* 2016; Abdou 2017; Basset-Mens *et al.* 2019).

Criteria and recommendations for typology construction, based on key drivers of environmental impacts per agri-food system category, are summarized in Table 8.3. Although the existence of a legal, de facto or expert-based typology can be highly valuable in designing a sampling protocol in an LCA study, it should always be cross-checked and validated by the field experience, as illustrated in some of our case studies (see Box 8.12, Box 8.13, Box 8.14). In particular, the importance and the performance of the informal sector are often underestimated (or denied) by official typologies and knowledge.

Table 8.3. Criteria and recommendations for constructing the system typologies.

Criteria	Crop systems	Livestock systems	Aquaculture systems	Fisheries	Agri-food processing	Distribution
Existence of a legal, administrative or de facto typology	General advice: If contractually obliged or limited by resource availability, use it "as is", otherwise challenge/confirm it by statistical methods, e.g. PCA and hierarchical clustering of principal components (HCPC) (Avadí *et al.* 2016, 2017; Basset-Mens *et al.* 2019)					
Existence of recommendations, guidelines on system classification	General advice: Check the existence of either of the following:					
	Specific advice: FAOSTAT (FAO 2020b), national agricultural reports, agricultural census data, etc.		Specific advice: FishStatJ, historical data from 1950 on global capture and aquaculture production (FAO 2017b)		Official statistics, expert advice, literature	
Absence of any official or de facto widely accepted classification	Common practice: Segregate by practices (e.g. conventional vs. organic, artisanal/usually manual labour-based smallholder vs. industrial/usually large mechanized estates), by cropping system type (e.g. open field vs. greenhouse)	Common practice: Segregate by practices (e.g. conventional vs. organic), by feed specialization (e.g. in-farm feed or grazing vs. commercial feed), by product type (e.g. eggs vs. poultry, dairy vs. suckler) or by level of integration (e.g. combined reproduction and finishing vs. finishing only)	Common practice: Segregate by technology (e.g. ponds, cages, recirculating systems) and production thresholds (small, medium, large) (Guinée *et al.* 2010; Abdou *et al.* 2017; Avadí *et al.* 2021)	Common practice: Segregate by dominant fishing gear and by holding capacity (Fréon *et al.* 2014a; Avadí and Vázquez-Rowe 2019a; Acosta-Alba and Avadí 2021)	Common practice: Segregate by type of process (e.g. primary vs. secondary; freezing, canning, salting, smoking, etc.) and by size of factories, technological level (degree of mechanization) and type of technology (e.g. artisanal vs. industrial) (Avadí *et al.* 2014, 2020a)	Common practice: Segregate by type of products handled (e.g. unprocessed, processed) and by size or geographical scope (e.g. local, national, regional, global). Type of vehicles is also key. Processors buy raw materials by the full load (for cost-efficiency), and the type of vehicle becomes like a crop-specific unit of measurement for trading.

Box 8.12. Milk value chain in Colombia: an example of important produce categories omitted by existent typologies based on local extension services (I. Acosta-Alba, EvaLivo)

In developing countries, the share of informality can be very high even for export products. Often, this informality is a source of unawareness and preconceptions about the real importance of some actors even when surveying local extension services within the country.

In Colombia, a study on the milk value chain and processed products was carried out in 2016. During discussions with partners and technical services about the producers' typology, the choice of excluding the milk produced by the informal sector was recommended. The suggestion was in particular for smallholders having no official records nor technical monitoring since they were considered as not economically sustainable and fated to disappear. However, during the field interviews, experts from producers' cooperatives estimated the informally produced and marketed milk at around 40% of total Colombian milk and 80% of total Colombian milk was produced by small farmers having fewer than 15 animals. After several field visits, which confirmed the importance of small producers, this type of producers was modelled on the basis of a few interviews to at least represent them within a dedicated scenario.

Box 8.13. Fishing value chain in Mali: an example of the importance of iterative fieldwork to catch the occasional fishers (I. Acosta-Alba, EvaLivo)

In Mali, the fisheries value chain was particularly difficult to model. Official fishing data do not correspond to the reality of this sector. Only 1% of artisanal fishermen have a fishing license. This fact is known by state services, who correct fishing volumes and rate the self-consumption to account for this. A relevant and acknowledged typology of fishermen exists since the 1970s. Given the travel difficulties linked to the security conditions in the country, the experts had a limited data collection period and the system definition was based on the official typology. However, after discussions and interviews on the ground, it turned out that the fishing activity, formerly reserved for traditional professional fishermen, had become very widespread and that now "everyone fishes". These occasional and opportunistic "new" fishers caught about 30% of Malian fish. This category of fishermen could not be thoroughly surveyed due to the lack of time and they had to be modelled in a very simplistic scheme. This illustrates the interest of iterative fieldwork.

Box 8.14. Study of the Dominican Republic value chain for processed mango: bias from systems and products identified by sponsors and partners (I. Acosta-Alba, EvaLivo)

A type of bias can arise when defining the system, even by actors from the field. For example, in the Dominican Republic, during an evaluation of processed mango, the regional variety *criolla* was described by the sponsors and technical partners as negligible for the study. The production was described as "*palos de mango en el patio*" (a few trees in private gardens). However, after interviews with the main industry players in the country, it turned out that only this variety was used at industrial level. Sourcing and production are little known and very different to commercially grown varieties which focus on export varieties for fresh fruits based on the taste demanded by importing countries (United States, European countries, Japan). Despite the difficulty, it was possible to find farmers who produced the *criolla* mango and to include it in the analysis.

Figure 8.8 presents recommendations on sampling protocol design following the choices regarding the extension of systems to be studied and their typology. Depending on the constraints associated with the LCA study, the number of achievable samples may vary considerably, and the robustness of the study's conclusions may vary accordingly. In a context of limited resources (time, money), only limited sampling may be possible, and thus the heterogeneity among systems and within a system may be considerable. The level of heterogeneity can be determined by expert opinion, as local experts usually have a good idea of it. For instance, in Africa, smallholder pond systems farming herbivorous fish, or smallholder crop systems producing staple foods such as maize or tubers or commodities such as cotton, tend to be rather homogenous (regarding practices and yields) within each country. If the scope of the LCA study is regional or value-chain oriented, the representativeness of sampling is key.

Many sampling strategies exist. They may include random or non-random selection of actual production units which will be based either on snowballing sampling or random sampling designs. Snowball sampling represents non-probability sampling where individuals are recruited by experts or between themselves based on their acquaintances, while in simple random sampling of a given size, all individuals have an equal probability of being selected. In Appendix E (p. 137), a table from PAS 2050-1 is provided with sample sizes depending on the population size, with or without grouping into types. However, these sample sizes are indicative and will be influenced by the constraints of the study.

Alongside sampling strategies, building virtual representative production units can constitute an effective strategy (Vayssières *et al.* 2011; Avadí *et al.* 2016, 2020a, b, 2021). A virtual representative production unit is a scenario designed to represent a given type. They are widely used in LCA, especially when the goal is to compare system types. An alternative to the use of these virtual representative production units is to use a real individual system that is very representative of each type. When a solid typology exists, these representative individuals may have been previously identified and are called paragons.

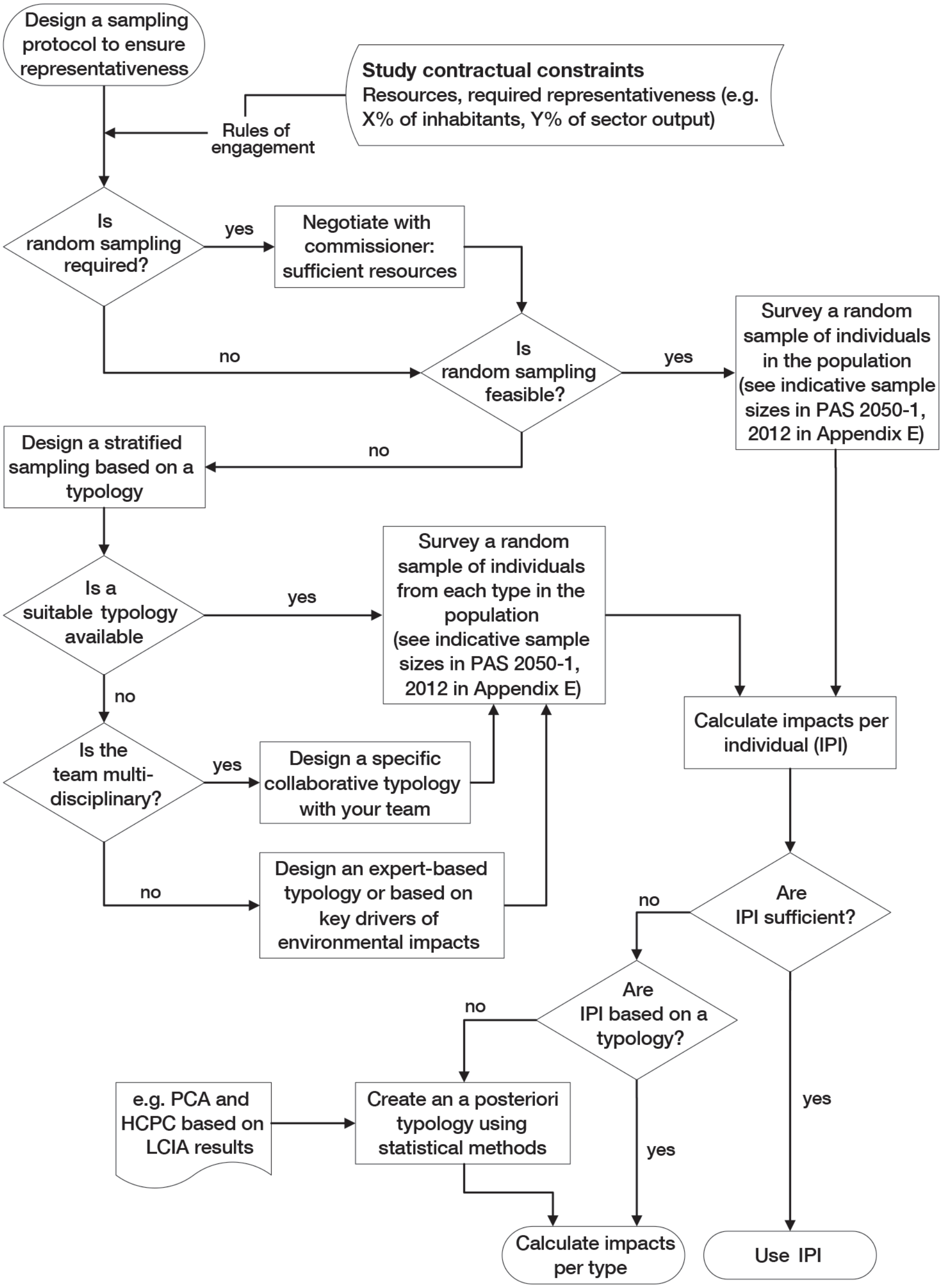


Figure 8.8. Recommendations for designing the sampling protocol.

9

Building life cycle inventories

Once the study is properly designed, all important flows in the studied systems or system types need to be estimated with the most reliable data possible. It is important to distinguish between foreground and background data collection since these two types of data require completely different collection strategies.

Foreground data collection

Key data to collect

In principle, all foreground data (i.e. the data describing the system of interest to the LCA study) should be compiled and modelled into LCI.

In practice, and following the 80/20 Pareto principle, it is much easier to compile the bulk of the data than the remaining few details, some of which may well be key contributors to impacts.

Therefore, over the last three decades of LCA practice, ad minima lists of key inventory items were compiled for most agri-food systems. The main contributors to impacts in the agriculture sector (see Appendix F p. 138), except for land use change in the tropics, are usually the use of fertilizers, the use of pesticides, animal feed and manure management. When performing LCA of aquaculture and fisheries, a number of sector-specific considerations should be included, as described in Appendix F3. The main contributors to impacts in the seafood sector are usually fuel consumption in fisheries and feed provision in aquaculture. When post-harvest stages take place on the farm (e.g. pulping and drying of coffee), a separate section should list the technical processes, quantities of water, energy and inputs used as well as the fate of waste and co-products. Generally speaking, the conversion factors and yields in products of each important process will play a critical role in the eco-efficiency of the studied product. Eco-efficiency can be defined as the ability of a system to deliver a function while minimizing its impacts on the environment. For instance, the feed conversion ratio, which is the number of kilograms of feed needed to produce one kilogram of animal product (meat or milk), should be estimated with a high level of precision and include uncertainty data in the LCA study of animal products.

Figure 9.1 below provides key parameters for an LCI questionnaire by product category.

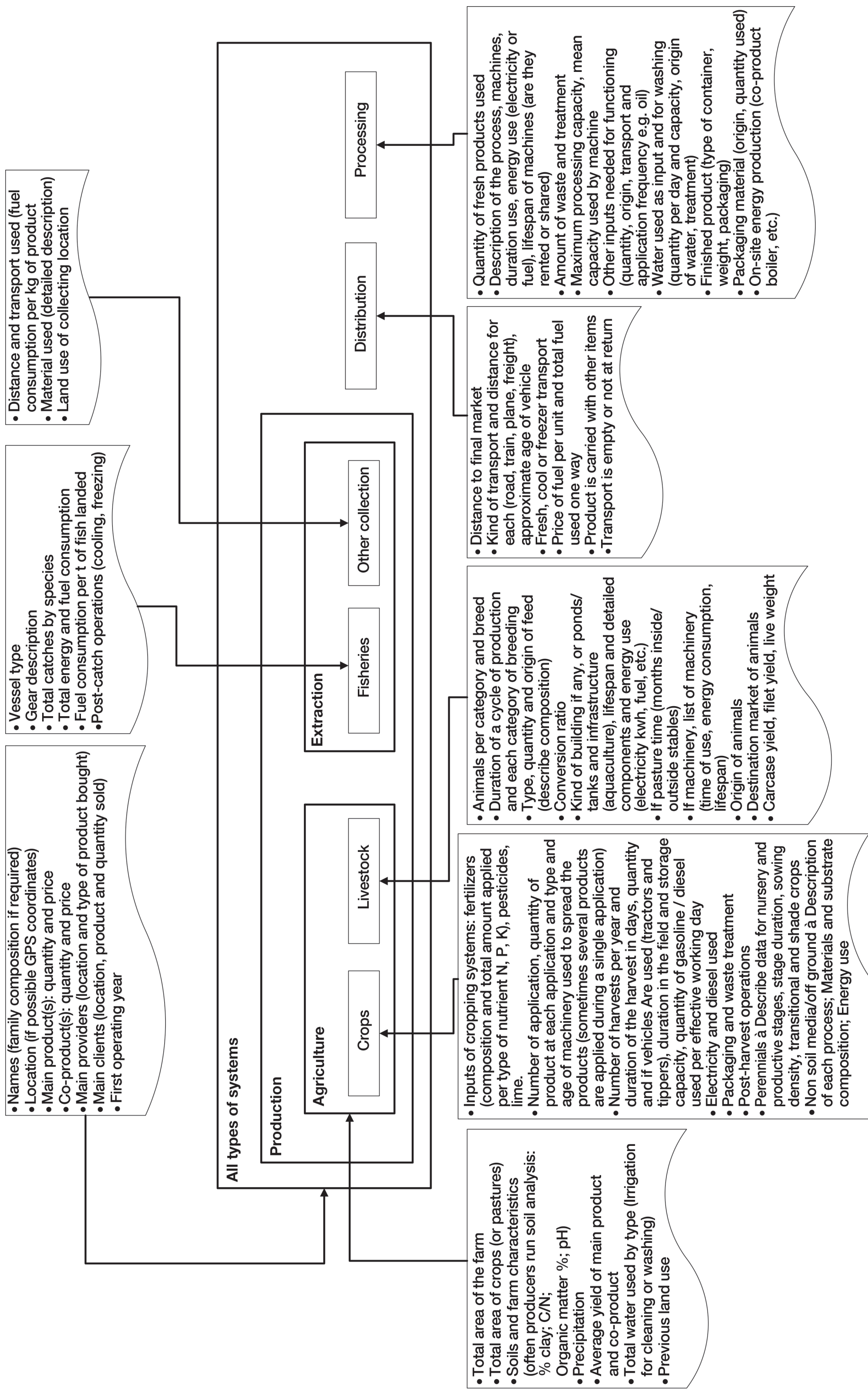


Figure 9.1. Key parameters for an LCI questionnaire depending on product category.

Temporal aspects

Of course, the temporal dimension is a key factor in collecting representative data. All agri-food systems have important variability over time and these variations should ideally be captured in LCI datasets. Agri-food systems are exposed to climate variations and potentially extreme events that continuously and sometimes deeply affect their performances. It is therefore paramount to consider several years in data collection. In areas where extreme events are regular, such as hurricanes on the Atlantic coast of the Caribbean islands and Central America or El Niño/La Niña phenomena (Bertrand *et al.* 2020), their frequencies and impacts should be investigated in greater detail. Likewise, water availability or scarcity are also deeply influenced by seasons, which will be critical when studying seasonal crops or crops with several harvests per year. In the case of perennial crops, it is also paramount to account for the whole perennial cycle, since partial modelling, based on single years for instance, can severely bias the LCA results (Bessou *et al.* 2013; Bessou *et al.* 2016).

Overall, the basic temporal variability should be accounted for by adapting the data collection protocol to each system type: at least three seasons/year for each studied system, at least all phases of perennial crops should be modelled, and each phase should use either a typical year or an average of three to five years. Recommendations for the modelling of perennial crops in LCA are summarized in Bessou *et al.* (2013) and further updated in Basset-Mens *et al.* (2018).

If the studied system is located in a region with regular extreme events, for instance occurring once or twice over three years, this major disturbance should also be modelled in the LCA, either by designing scenarios with and without these extreme events to show a range of situations or by designing an average scenario taking account of the regular destruction of the infrastructure and production in the system performance.

How to design a LCI questionnaire

Questionnaire design is very important. The questionnaire must include information on the means of production and the operations of the farm. Questions may be more open-ended if the interviewers conduct the surveys themselves or closed questions if data collection is delegated. On farms, it is necessary to have the details of the crops in space (area, density of sowing, intermediate crops) and the crop rotations in time (length of the crop cycle, crop before and after and if the same sequence is repeated over time), and non-productive and productive periods must always be differentiated.

Next, the cultivation operations must be detailed, indicating the quantities and types of inputs for each. The data must be collected according to one specific period, generally a productive cycle. This period should be well defined because the quantities will be expressed per area, per unit of product and per unit of time. The questionnaire and the questions on the day of collection should be asked in the units commonly used by the actors. To save time during the interview, the data will be converted afterwards. Ideally, knowledge on the various local common units should be gathered early in the survey timeframe to anticipate potential errors and cross-checking in the field. It might be important, for instance, to verify the volumes of commonly used recipients such as empty tomato cans.

For animal production, it is important to distinguish the categories of animals, their management (time in the building, diet) and the management of excreta. Figure 9.2 shows recommendations for designing LCI questionnaires. In addition to details on farm operations, it might also be necessary to collect extra data that are input variables for emission models and cannot be found in the literature (e.g. slope, existence of a buffer zone etc.). The list of these particular data will obviously need to be properly prepared before going into the field for the survey.

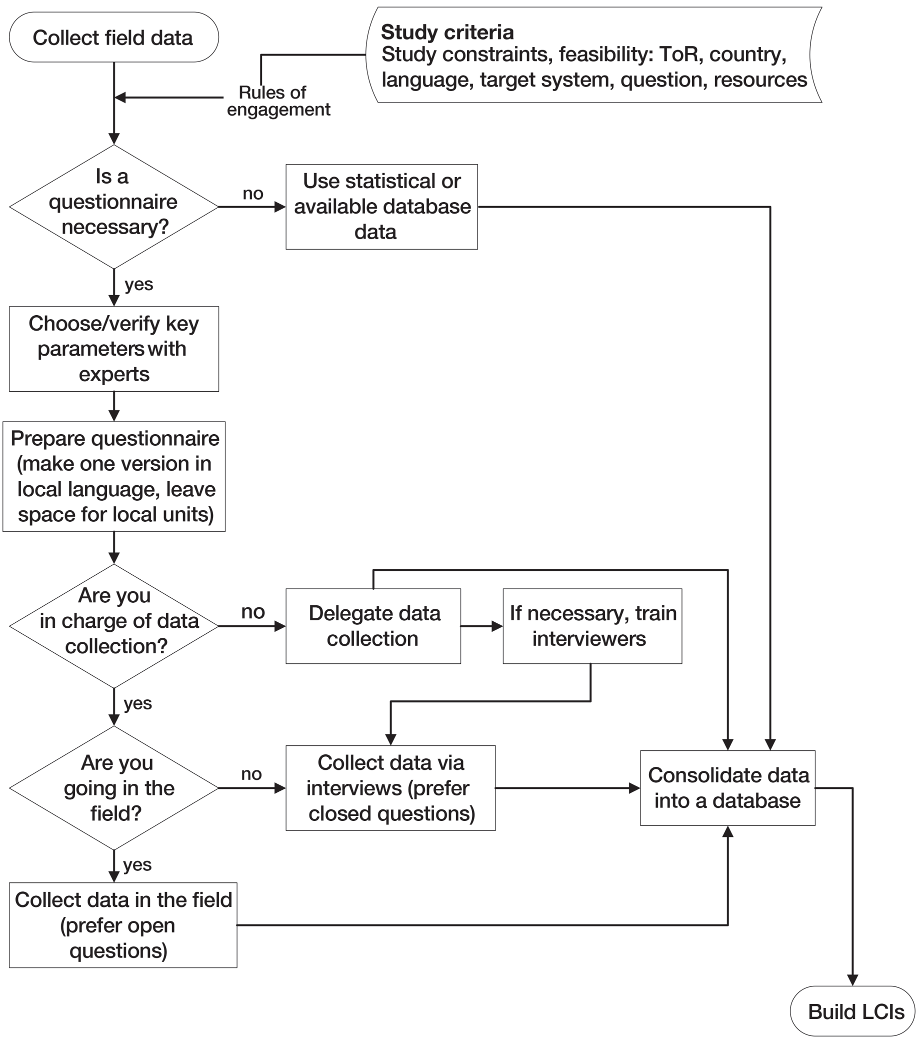


Figure 9.2. Recommendations to design a questionnaire for LCI field data collection.

How to best collect reliable data at field level

In LCA studies for agri-food systems in developing countries, foreground data need to be collected directly in the field. Collecting reliable data at field level requires specific skills and a proper organization. Based on our field experience, we formalized our recommendations of best practices on surveying stakeholders (Figure 9.3).

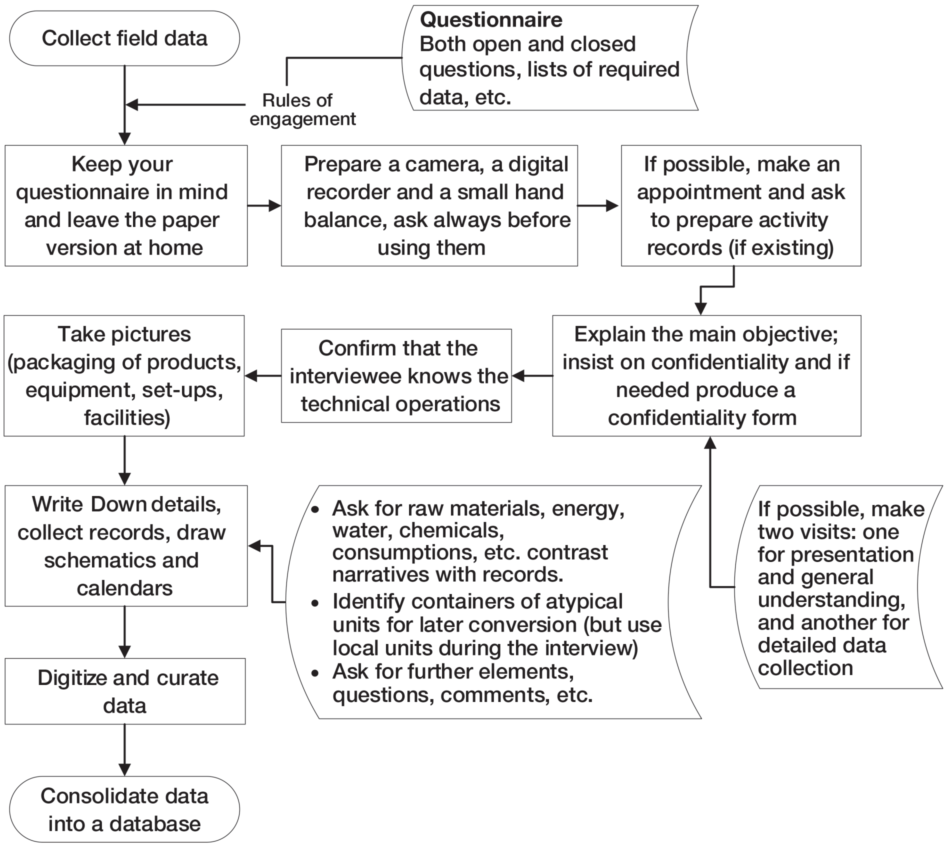


Figure 9.3. Key steps and recommendations to collect reliable data from the field.

Fieldwork has enabled us to see that trust is a fundamental factor in any exchange of information, as much for connecting with actors as for obtaining quality data. When the LCA experts conduct their own data collection, having a paper questionnaire may lead the discussion exclusively to the questions in the established order. Often, the person surveyed stares at the paper, which can limit the discussion. We obtained the best results when the questionnaire was hidden in the expert's pocket and notes were written down in an empty notebook while having coffee, tea or other regional traditional drinks and trying to make the speaker comfortable.

During an LCA study, we ask about every detail of the activity. Put yourself in the person's shoes and imagine a complete stranger coming into your home and asking you questions about everything you do... If you do not understand why and how the data are going to be used, would your answers be reliable?

To facilitate discussions during a field visit, we recommend to start by introducing yourself and talking about the goal of the study, then taking a tour of the place (farm or industry) with, when authorized, a camera, a digital recorder and a small hand balance. However, using recording devices may make some people less comfortable. The practitioners need to be attentive to their actual willingness to be recorded or not since this might affect the content of the discussion. It is also useful to verify the information with different questions, for example asking for plant density per hectare and yield per tree, then asking for yields per hectare. For animal products, the quantity of feed and product must be asked and at another point the concept of the conversion ratio must be discussed. An example of surveys is available in Box 9.1.

Box 9.1. VCA4D study of pineapple and mangoes in Dominican Republic, working in a multidisciplinary team (I. Acosta-Alba, EvaLivo)

During VCA4D studies, there is a mandatory field mission for the whole team (economist, sociologist and environmental expert). During several interviews, the method that best allowed the understanding and collection of data was to start the discussion by presenting the goal of the study, introducing the team and talking about the confidential nature of the data that will be collected (a confidentiality agreement can even be signed). The visit then started and we asked about the history of the activity during the tour. Taking pictures is a good opportunity to ask questions and to observe key details (empty packaging of used products that are not always mentioned, machinery, the brands and types of machinery to obtain the power and consumption described on the engines, etc.).

Field observation makes it possible to note details that the actors do not consider important, such as the plots on which the first non-productive years of mangoes, plantain banana or cassava crops are often planted. For pineapple, the construction of infrastructure linked to cropping (paths, mounds, drainage) is a stage which requires the use of heavy machinery and where 30% of the surface is kept as a nursery for reproduction. While the productive period lasts 18 months, if the establishment of the crop and the nursery are taken into account, the land is rented for a period of three years.

After the first conversation, the interviewee was more comfortable and we asked for a quiet place to sit down and continue with more specific questions. Sitting allows easier taking of notes and better concentration. When farm records exist, they can be consulted at that time. To resume the discussion, if time permits, it is possible to continue by drawing a plan of the farm if there are distant plots. Then, the interviewee can describe technical itineraries by unrolling the work calendar and each technical intervention describing products used and their application each month of the year. Since most of the steps were already described during the visit, the questions can be more concrete. This entry is also helpful in addressing input quantities and costs, as well as key labour issues, especially when operations are manual.

With regard to industrial players, a discussion with the manager or director on the history of the company, followed by a visit led by the production manager and a discussion with the quality and purchasing manager were valuable sources of information. Carrying out the interviews in this way made it possible to combine the information and to validate it by cross-checking the data.

How to best delegate data collection

Data collection is a key step in obtaining reliable data. When it is necessary to delegate data collection for whatever reason (time, cost, large samples), the preparation phase will be longer. Setting up the tool used for data collection (Excel spreadsheet, questionnaire) and training interviewers are time-consuming processes. It is also important to provide enough time for data formalization: translation when surveys are conducted in the language of the country, information systematization and database creation to be sufficiently precise in the questions to avoid errors. Training interviewers in LCA principles by doing at least one survey test with them is a way to ensure better data. It is also key to train interviewers on all the possible sources of uncertainty related to the data and on the need to cross-check and validate data onsite. It is essential that reviewers provide sufficient information on the origin and level of confidence of each piece of data in the questionnaire or Excel spreadsheet used for the survey.

How to validate and complete datasets

As previously discussed, the reliability of the data is the result of multiple actions throughout the data collection process. Here, we propose a summary of these steps that aim to make this dataset as reliable as possible (Figure 9.4). The possible sources of uncertainty attached to field data are numerous. People may wish to please the interviewers, or they may not trust them and not want to give them their actual data. They may not keep formal records of their practices and forget what they did. They may have used what they had at hand to measure the inputs they apply, such as the cap of a bottle for a pesticide and the interviewer will need to estimate the corresponding quantity in international units. As already demonstrated, it is important to validate as much information as possible while still in the field to secure the data. It is advised to ask for invoices for all purchased or paid inputs if the farmer does not know the amount of a given input. Plots should be visited since they will reveal the actual situation of the crop (e.g. crop associations, slope of the land, etc.). Active ingredients and formulas of fertilizers should be checked by looking at the packaging of inputs, while certain containers should be weighed to convert their capacity into international units. Pictures can be taken, after getting explicit agreement from the farmers, to remember. While still in the field or just after (e.g. once back at the hotel), the origin of each figure, the way it was estimated, and its level of confidence must be reported as precisely as possible in the survey file.

Once back at the office, the dataset should be cleaned up and submitted for critical review (CR) by an external technical expert to check orders of magnitude, units, and consistency across data. It is also important to compare it with existing literature references or datasets. This will help identify aberrant values and gaps that can be asked about again or checked back with the surveyed stakeholder either during a second mission or by email or a phone conversation. Remaining data gaps should then be filled based on expert advice and the literature or by proxies. Finally, while creating new processes in the LCA software, the metadata for each piece of data should be reported as precisely as possible, including origin of the data, method of estimation/calculation, representativeness, and reliability. The data quality management system proposed by Weidema and Wesnæs (1996) or another more personal system can be used as long as the overall data quality is properly described.

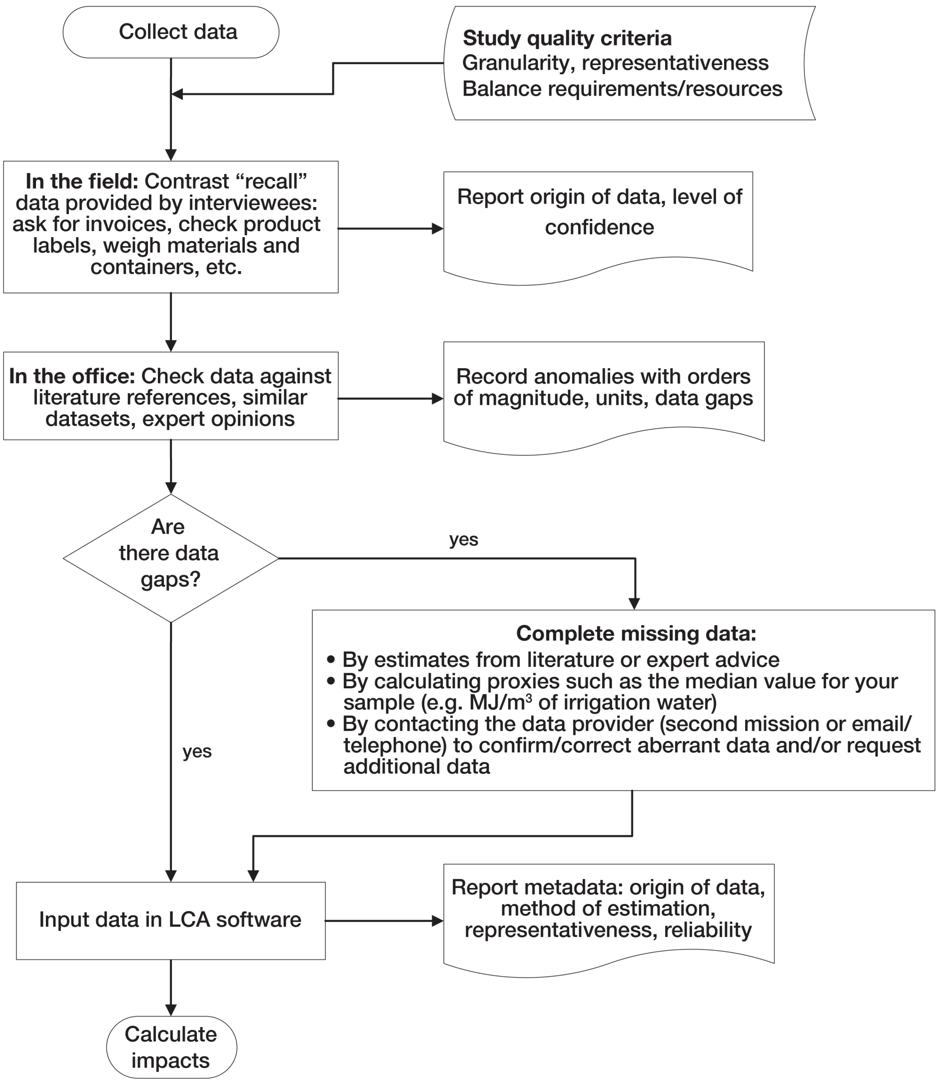


Figure 9.4. Recommendations on data quality management at all steps of the data collection and reporting process.

Horizontal averaging of unit processes data

Averaging data might seem straightforward, but is subject to several decisions that can greatly influence results. One might want to model each sample separately (one LCI dataset per site), but this easily becomes impractical in LCA models. Thus, most datasets need to be averaged to a certain extent, but this raises its own set of challenges. For example, one might be faced with several datasets that represent vastly different scales of production. Production practices might also vary, and one needs to determine if sets of farming practices can be considered as one production practice or if they must be divided into several (e.g. tillage and non-tillage agriculture). Rather than predefined divisions, such as geography or crop, the LCI data should be organized according to what is most relevant for the study. For example, a crop cycle (spring or autumn) might have much larger influence on the LCI data than the region of farming. In other cases, scales of production or farming practices might result in the most relevant criteria. These aspects also relate to typology, which was described in Chapter 8 section "System boundaries, typologies and sampling strategies".

Averaging data among diverse actors can be done on the basis of production volume or representativeness (Henriksson *et al.* 2013). This can be done either in one LCI dataset (e.g. weighting the inputs to the outputs of farms), or with regards to what the study seeks to represent (e.g. based upon production practices). In this context, it is important to reflect upon the goal and scope of the study. As mentioned in Chapter 8 section "System boundaries, typologies and sampling strategies", LCA studies tend to imply broad representation (e.g. soybean production in Brazil), while the primary data often only represents a few farms in one province. For many agricultural commodities it makes better sense to break up the unit processes related to distinct production practices and conform to a title that better represents the actual study area (e.g. tillage and non-tillage soybeans from Mato Grosso).

Direct field emissions

Agri-food systems feature direct emissions associated with practices, which should be estimated by way of models (as it is generally too resource-intensive to measure them) and included in the LCIs. Direct emissions are often among the top contributors to environmental impacts depending on the system type and category. Soilless cropping systems (e.g. algae, vertical farming, hydroponics, etc.) do not present critical risks of emissions to the soil, except in relation with the management of crop and other residues. The most important (in terms of contribution to impacts) direct emissions per major agri-food category are summarized in Table 9.1. In Appendix G (p. 143), a list of free tools to model field emissions for LCI is provided.

Table 9.1. Direct emissions per agri-food and seafood category.

Direct emissions	Cropping systems	Livestock systems	Aquaculture systems *	Fisheries	Comments
Ammonia (NH_3)	+	+	+	N/A	High volatilization under tropical conditions; volatilization is particularly high with organic inputs such as slurry and during composting process.
Nitrate (NO_3)	+	+	+	N/A	Most important and difficult to model, especially under tropical conditions. Very dependent on soil type, drainage and irrigation practices. Livestock systems may emit nitrate associated with grazing.
Nitrogen oxides (NOx)	+	+	+	N/A	NOx emissions are hard to quantify since both NO_2 and NO are concerned and unstable. Still these emissions are important to consider because they contribute to various impact categories. They should not be neglected, especially in the case of slash and burn land preparation.
Nitrous oxide (N_2O)	+	+	+	N/A	N_2O fluxes are not very important in terms of mass, but play a key role in the global warming impact of intensive agricultural systems with high N-fertilizer inputs. N_2O emissions are both direct and indirect; indirect emissions are related to further downstream emissions after leaching, volatilization and re-deposition. N_2O emissions should be also considered in the case of land use change leading to soil carbon loss and related N mineralisation, and in the case of peat cultivation. Only the IPCC guidelines propose a comprehensive framework to account for all emissions of N_2O.
Nitrogen (N, total)	N/A	+	+	N/A	Relevant in livestock systems (manure management) and in aquaculture (from faeces, uneaten feed and mortalities). This elementary flow should be declared only when specific forms of N emissions cannot be discriminated from other emissions.

Direct emissions	Cropping systems	Livestock systems	Aquaculture systems *	Fisheries	Comments
Methane (CH_4)	+	+	+	N/A	Relevant and very important for crops such as paddy rice, cattle, and pond fish systems. CH_4 emissions are particularly critical in the case of peat drainage and oxidation, as well as when fields are flooded. In aquaculture, CH_4 emissions may occur in the context of pond fertilization. Depending on the origin of CH_4, either biogenic or fossil, the impact will be different. In the case of peat oxidation, emissions are equivalent to fossil emissions due to a very long geological storage.
Carbon dioxide (CO_2) from urea/limestone	+	N/A	N/A	N/A	There might be some inconsistency in the ecoinvent database, where CO_2 input in urea production is not accounted for.
CO_2 from LULUC	+	+	-	-	CO_2 related to land use (changes in management practices) or land use change concerns both carbon in biomass and in SOC; CO_2 emissions are due to changes in carbon stocks which are often allocated over a given period of time, without a proper accounting for carbon dynamics. Potentially relevant for fisheries and aquaculture only when using wooden vessels and when performing land clearing for new pond aquaculture systems.
Phosphate (PO_4^{3-})	+	-	+	N/A	Associated with P-fertilizers.
Phosphorus (P, total)	+	+	+	N/A	Relevant in agriculture in conditions of high water erosion (independently of the computation of phosphate emissions associated with fertilization), and in livestock and aquaculture (from faeces, uneaten feed and mortalities). This elementary flow should be declared only when specific forms of P emissions cannot be discriminated from other emissions.
Particulate matter	+	+	-	+	Relevant in intensive agricultural systems due to the use of heavy machinery in the field for harvesting or straw baling.
Pesticides	+	+	-	+	Important in intensive agriculture. May be relevant in fisheries (e.g. antifouling).
Trace contaminants **	+	+	-	+	Important in the context of manure management, organic and mineral fertilization and pesticide/antifouling use.

Direct emissions	Cropping systems	Livestock systems	Aquaculture systems *	Fisheries	Comments
Biomass extracted	N/A	N/A	-	+	In fisheries, biomass extraction produces biotic impacts on both the fish resource (stock) and the ecosystem. It is notably important in fisheries tapping overexploited stocks, and indirectly in aquaculture through aquafeed.
Land area	+	+	N/A	N/A	Land area use may be assessed per se or in connection with soil quality and biodiversity assessment. Soil quality is a major issue in agriculture as it determines the production potential as well as the delivery of many ecosystem services which in turn affect productivity. So far, the international consensus (GLAM 2) is to assess changes in SOC as a proxy for soil quality change as it is an integrated indicator of many processes occurring in the soil. Soil organic fluxes should be used in a consistent way for the various impact categories, namely "soil quality" and "global warming", the latter in case of net emissions. Biodiversity loss due to land use is also important and the approach from Chaudhary *et al.* (2015) is proposed as interim by GLAM
Sea bottom area	N/A	N/A	N/A	+	Sea bottoms may be damaged by bottom trawler fisheries.

Scale: negligible (-), non-negligible (+), not applicable (N/A). *Excluding the provision of feed inputs, which are considered in Cropping systems. **Trace contaminants include trace elements (metallic, metalloid) and organic pollutants. SOC: soil organic carbon; LULUC: land use and land use change; GLAM: Global Guidance for Life Cycle Impact Assessment Indicators and Methods.

Various models are available to estimate direct emissions from agriculture, featuring varying levels of complexity, accuracy and data requirements. Recently, some of the main model sets used in agricultural LCA – ecoinvent (Nemecek and Schnetzer 2012), World Food LCA database (Nemecek *et al.* 2015) and AGRIBALYSE (Koch and Salou 2016), which are all described in Appendix B (p. 122) – were sometimes limited regarding their suitability to model nitrogen emissions in contrasting agricultural situations (Avadí *et al.* 2022). Regarding the suitability and choice of a model, several criteria must be taken into account with regard to both model performances and the data availability to run the model. There are also challenges in ensuring overall consistency, whether among the different models applied for various emissions or with regard to other considered processes that are often modelled with ecoinvent. The decision tree proposed in Figure 9.5 only applies to nitrogen compounds but could be adapted to other compounds should more models be available. It is meant to aid the decision-making process and emphasize where to find further resources. Additionally, in Table 9.2 we present several model recommendations for various field emissions.

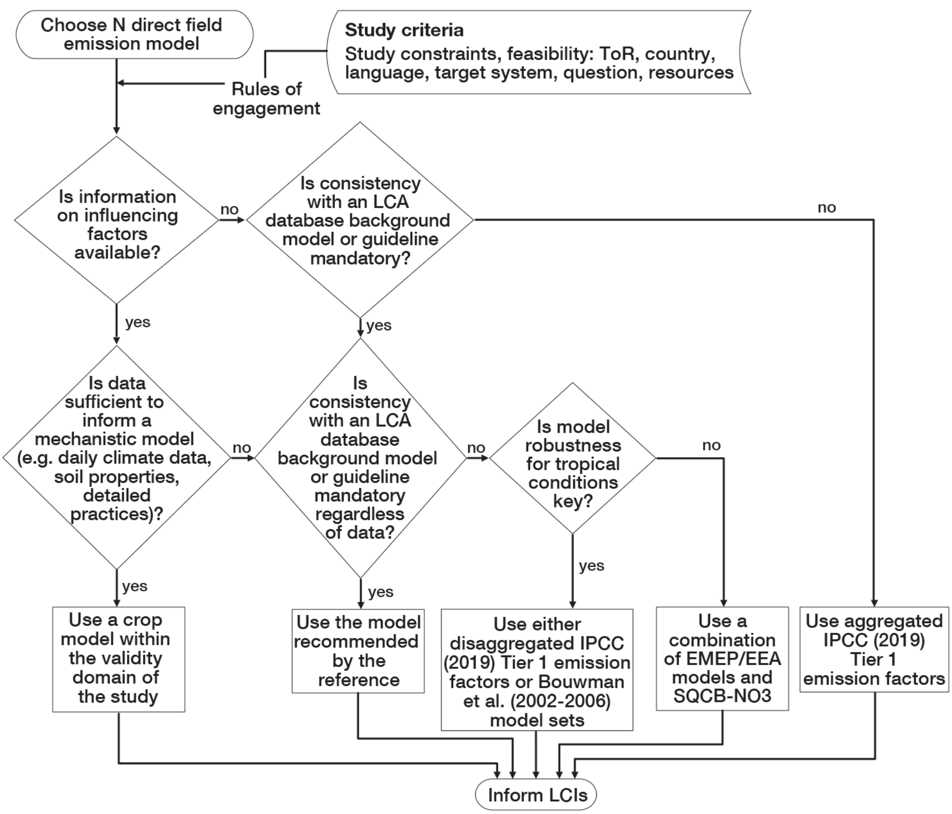


Figure 9.5. Decision tree to guide the model choices for nitrogen (N) field emissions (see also Table 9.2).

Table 9.2. Recommended models for agricultural direct emissions.

Direct emission	Recommended models	Second-choice models (under resource limitations)	Comments
Ammonia (NH_3)	Bouwman and colleagues[d] EMEP/EEA (various versions[b])	AGRAMMON model[c] IPCC 2019-Tier 1 (Hergoualc'h *et al.* 2019)	Both models are empirical simple ones, yet EMEP/EEA includes emission factors for more organic fertilizers than AGRAMMON (which is used by ecoinvent). Bouwman and colleagues modelling work, either as exponential model or emission factors used in IPCC would be more suitable for tropical conditions.
Nitrate (NO_3)[a]	SQCB-NO3 (Faist Emmenegger *et al.* 2009)	IPCC 2019-Tier 1 (Hergoualc'h *et al.* 2019)	SQCB-NO3 ensures compatibility with ecoinvent. It is extremely sensitive to precipitation and irrigation, and as it consists of a linear regression, negative values may occur. It is not more robust than the IPCC empirical factor but makes it possible to consider some agricultural parameters (although it is not adapted to perennial cropping systems for instance)
Nitrogen oxides (NOx)	EMEP/EEA	Bouwman and colleagues, made available via the webtool https://gnoc.jrc.ec.europa.eu/[d]	EMEP/EEA includes emission factors for organic and mineral fertilizers. Bouwman and colleagues provide an exponential model that can be run if data is available or derived into emission factors extracted from the article.
Nitrous oxide (N_2O)	IPCC 2019-Tier 1 (Hergoualc'h *et al.* 2019)	Bouwman and colleagues, made available via the webtool https://gnoc.jrc.ec.europa.eu/[d]	Empirical simple models for agriculture and manure management, respectively. IPCC 2019 is mostly derived from Bouwman and colleagues modelling work; disaggregated emission factors make it possible for some emissions to account for wet/dry climate and the type of fertilizers. Referring directly to the original Bouwman and colleagues models require some more data but make it possible to be slightly more precise in terms of pedoclimatic conditions and practices.
Methane (CH_4)	For peat oxidation and paddy rice cultivation: IPCC 2019-Tier 1 For enteric fermentation: IPCC 2019-Tier 1	For peat oxidation and paddy rice cultivation: IPCC 2019-Tier 2 For peat oxidation: Hooijer *et al.* 2010	Empirical simple models for enteric fermentation, manure management and rice, with a gradient of complexity from Tier 1 to Tier 2 For peat oxidation, the Hooijer *et al.* model makes it possible to account for the influence of water table management on the oxidation rate, which is critical to assess the impact of drainage practices.
Carbon dioxide (CO_2) from urea/limestone	IPCC 2019 (Hergoualc'h *et al.* 2019)	No alternative	Simple stoichiometric model that ensures mass balance. Consistency with background production processes for urea and limestone must be checked.

Carbon dioxide (CO_2) from LULUC	IPCC 2019-Tier 1 (Ogle *et al.* 2019)	IPCC 2019-Tier 2 (Ogle *et al.* 2019) RothC (Coleman and Jenkinson 2014)	CO_2 emissions from LULUC concern both carbon losses from biomass and from SOC, for which all default factors are provided in IPCC. On the contrary when applying SOC models that do only focus on soil, it is important not to forget adding carbon loss due to biomass. IPCC-Tier 2 approach relies on a simplified CENTURY model version. It requires to inform a lot of parameters, for which many default factors are provided, and extensive climate data. RothC is a semi-empirical model widely used to simulate SOC dynamics. It can be helpful to model land use change but requires monthly input data. In cases of LUC through slash-and-burn, it is important to also consider other emissions than just CO_2 also based on IPCC recommendations.
Phosphorus (P)	SALCA-P (Prasuhn 2006; Nemecek and Schnetzer 2012) informed by RUSLE2 erosion model (Foster 2005)	No alternative	Empirical simple model, but globally applicable and with minimal detail needed. Ensures compatibility with ecoinvent and AGRIBALYSE.
Trace elements	SALCA-SM (Freiermuth 2006; Nemecek and Schnetzer 2012) informed by RUSLE2 erosion model	No alternative	Empirical simple model, but globally applicable and with minimal detail needed. Ensures compatibility with ecoinvent and AGRIBALYSE.
Pesticides[e]	PestLCI Consensus webtool (primary distribution) (https://pestlciweb.man.dtu.dk/)	Default emission fractions for a panel of pesticide application situations (OLCA-Pest project) [e] + (Gentil-Sergent *et al.* (2021) for tropical conditions	Two possible levels of complexity depending on the purpose and resource of LCA study
Water	Aquacrop model (http://www.fao.org/aquacrop/en/)	Cropwat Model (http://www.fao.org/land-water/databases-and-software/cropwat/en/)	Both Aquacrop and Cropwat models require input data but Aquacrop permits a finer discrimination of practices especially irrigation mode. Under important resource constraints, using the water consumed as declared by the farmer might be the only feasible option though

LULUC: Land use and land use change

[a] The recent Indigo-N v.3 model (Bockstaller *et al.* 2021) includes an original formalism based on drainage periods and N balances (for NO_3) and combines EMEP/EEA and IPCC models with correction factors for all gaseous N emissions. In principle, it would be better adapted to contrasted agricultural situations, especially those prevalent in developing contexts, with marginally larger data requirements. [b] All versions of the EMEP/EEA air pollutant emission inventory guidebook (latest one of 2019) are available from https://www.eea.europa.eu/themes/air/air-pollution-sources-1/emep-eea-air-pollutant-emission-inventory-guidebook [c] The latest version of the AGRAMMON model and related reports is available from https://agrammon.ch/en/ [d] All relevant Bouwman and colleagues references are listed in Appendix B. [e] The forthcoming OLCA-Pest project (http://www.sustainability.man.dtu.dk/english/research/qsa/research/research-projects/olca-pest) aims to operationalize and harmonize the emission quantification and impact characterization of pesticides in LCA. SOC: soil organic carbon.

Notes: See details for N models in Appendix B. Uncertainties should be quantified when using any of the models. Second-choice models should be used when resource limitations prevent the use of the recommended models.

Background data collection

More often than not, parts of the inventory will have to be obtained from background databases such as ecoinvent, ILCD, World Food LCA Database or other commercial LCI databases. These background data typically include "background" processes representing the provision of energy, packaging, infrastructure and other industrial inventory items.

A unit process dataset contains at least:
- one reference product (which is the main output flow);
- metadata containing description and documentation of the dataset, including a description of sources and the modelling approach to create the dataset;
- a list of all relevant intermediate exchanges, "from" and "to" the technosphere, often referred to as "processes" by practitioners;
- a list of all relevant elementary exchanges, "from" and "to" the environment.

Especially under resource constraints, practitioners may be in the situation where they will not be able to model key inventory items that would normally belong to the foreground, such as the production of on-farm organic fertilizers or industrial feeds. In those cases, database processes would be necessary, but for full disclosure (as some of these items may be key system elements, with a large weight in the whole system's impacts) practitioners should always list all assumptions made and proxies used in the form of an explicit table listing the data sources used in the inventory. The following list offers some hints on how to perform background data collection and chose proxies:
- If grid electricity for the specific country or location of interest is not available from ecoinvent or another suitable commercial database, the national energy or electricity mix is usually obtainable from government reports (as listed, for instance, in http://iea.org). The practitioner can then construct a tailored grid electricity process, such as by combining different types of energy generation available in the databases in the proportions representative of the national energy mix.
- This approach can be replicated with regard to the use of water resources, in particular to establish a localized mix of the different origins of the water used, whether renewable or fossil.
- A similar approach may be applied to construct processes representing industrial products, such as packaging and other metal, glass, fibre, wood or plastic products (e.g. fishing gear, greenhouses, etc.).
- The use of agricultural machinery for certain agricultural operations is available in AGRIBALYSE, on a per hour basis.
- Various types of agricultural, industrial and agro-industrial infrastructure are available in ecoinvent, AGRIBALYSE and other databases. Infrastructure includes buildings, key industrial equipment such as boilers and pumps, fishing gear, aquaculture infrastructure, fishing vessels, etc.
- Pesticides and chemicals in general should be modelled in terms of their active substances, some of which are available in ecoinvent. When a specific substance

is not available, at least the substance group, as defined in PubChem (https://pubchem.ncbi.nlm.nih.gov/), would be available. Please note though that only some pesticides are readily characterized by the most common toxicological impact methodologies.

• Animal feeds and especially aquafeeds are particularly difficult to model, because most commercial producers do not disclose the exact formulation of their products nor the origin of raw materials. One should ideally seek to include feed producers as part of the primary data collection. When this is not an option, educated guesses based for instance on import/export data (available, among other resources, via TradeMap, https://www.trademap.org/) would be necessary to determine the likely source of feed ingredients. Literature, technical reports and dedicated websites (https://feedtables.com/; https://www.feedipedia.org/content/feed-databases) can be used to reconstruct the feed formulations based on the declared nutrient contents, if the few feeds available in ecoinvent, AGRIBALYSE and other databases are not suitable as direct proxies.

• Transport – expressed in terms of tonne-kilometre (tkm) – is modelled in databases following for instance freight capacity, EURO standards and assuming good road conditions. As in developing contexts transportation means very often do not comply with international standards, and an important proportion of roads are not in mint condition (e.g. Bove *et al.* 2018), transport of goods should be carefully modelled and proxies used should be considered as underestimations.

• If key inventories are missing and if the practitioner want to quickly find out if they are available in certain commercial, free or paid databases, the openLCA Nexus platform can be used to do a search (https://nexus.openlca.org/).

Quality management and critical review (CR)

If the framework of the LCA project or the expertise allows it (in particular if this has been planned and anticipated in the DMP), all or part of the product datasets may be distributed, according to different modalities, via supply agreements, licence agreements or open data. In any case, this prospect of future dataset release adds requirements in terms of metadata management when building LCIs.

When the results of the LCA study are intended for public communication, a CR must be implemented. In this case, before starting the study, confidentiality agreements giving access to data for the CR procedure should be drawn up in addition to a budget and time allocation if the reviewer is an external expert, which seems preferable. The CR elements are also useful at the end to check if all steps of the study were reasonably fulfilled. According to technical specification ISO/TS 14071 (2016), the main objective of the CR procedure is to ensure that the LCA is consistent with the ISO standards (principles of ISO 14040:2006 framework and with the directives and requirements of ISO 14044:2006 standard). The ISO/TS 14071: 2016 was updated in 2019. The final report shall cover all the elements of the CR. An interesting document (dated but still relevant) which details CR steps is the review by Weidema (1997), which was partially adapted in this section.

The steps of a CR are: identification of the expert leading the CR (including a self-declaration of independence and skills), description of support given for CR, an appraisal on conformity of LCA with ISO standards, including scientific and technical validity and transparency and consistency of the study. Finally, the CR might include suggestions for improving the methodology and finally the limitations identified in relation to the objectives of the study. Table 9.3 summarizes main elements for the appraisal on conformity of LCA with ISO standards, including scientific and technical validity and transparency and consistency.

Table 9.3. Main elements for the appraisal on conformity of LCA with ISO standards including scientific and technical validity, transparency and consistency.

Consistency with these international standards: Main points in goal and scope	**Data used are appropriate and reasonable in relation to the objectives of the study**
• Functions of the studied product systems • FU • Systems to be studied • System boundaries and criteria used in establishing system boundaries and the justification of these criteria • Allocation procedures	• Reference unit in relation to which the environmental exchanges are calculated • Geographical representativeness • Applied technology/the technological level • Period during which data has been collected • Source of the data, how data have been collected and how representative they are, and the significance of possible exclusions and assumptions • Assumptions used on the source of fuels and electricity mix shall be clearly stated and justified • Validation procedure used • CR of the inventory analysis • Check calculations
Scientific and technical validity of methods used to perform LCA	**Results and interpretation**
• Transparency in characterization and CFs • Weighting methods and operations • Documentation and sources referencing the relevance of the selected methods	• System comparability assessment • Interpretation of the results according to the objective and scope of the study; interpretation must include data • Quality assessment of data and sensitivity analysis

10

Performing impact assessment

In this part of the guide, we propose decision keys for the choice of the most appropriate LCIA methods, an overview of recommended LCIA method sets, a brief analysis of their validity for developing contexts, overall uncertainty and operationality, and finally, a specific focus on important impact categories for agri-food LCA, often showing non-consensual approaches.

Overview of available and recommended sets of LCIA methods

LCIA method development is an ongoing endeavour, from the very beginnings in the early 1990s to the most recently released models in 2019-20, as depicted in Figure 10.1. More recent models have increasingly focused on spatialization of impact assessment.

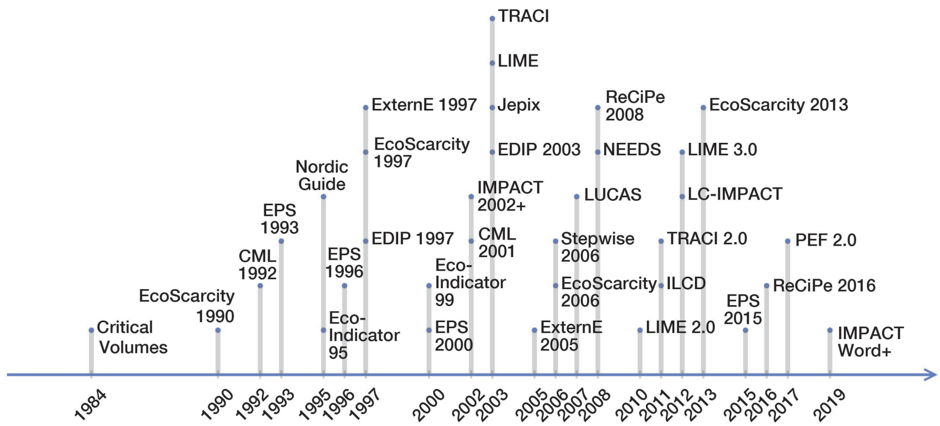


Figure 10.1. Timeline[7] of LCIA method development. Source: https://github.com/BenPortner/lca-methods-timeline

7. The EF method 3.0 published for use during the EF transition phase, was published in november 2019, and available in SimaPro from June 2020.

A multi-parameter and complex choice

The choice of an LCIA method or an overall LCIA method set depends on multiple parameters and is complex for LCA practitioners. This choice will include both scientific considerations, compliance with the commissioner's expectations and needs and resource constraints for the study (including, for instance, the availability of LCIA methods in LCA software).

From a scientific point of view, all important environmental impacts should be covered for the studied system while several of them do not benefit from consensual and operational methods yet (see specific focus in section "Impact categories" and Appendix H p. 144). The chosen method should ideally rely on the state-of-the-art knowledge and model, be valid in the studied context, not have large uncertainties, but also be operational (e.g. available in LCA software). In many cases, it should also allow acceptable comparisons with existing references to help benchmark and interpret the results for decision-makers. From a commissioner standpoint, it might be expected to obtain a simple and aggregated overview of the results to simplify the interpretation of the results and the decision-making process. Finally, depending on the resources allocated to a project or study, it might simply be impossible to explore refined solutions for modelling LCIA impacts. In Figure 10.2, we propose some decision keys to choose an LCIA method set taking account of the study constraints.

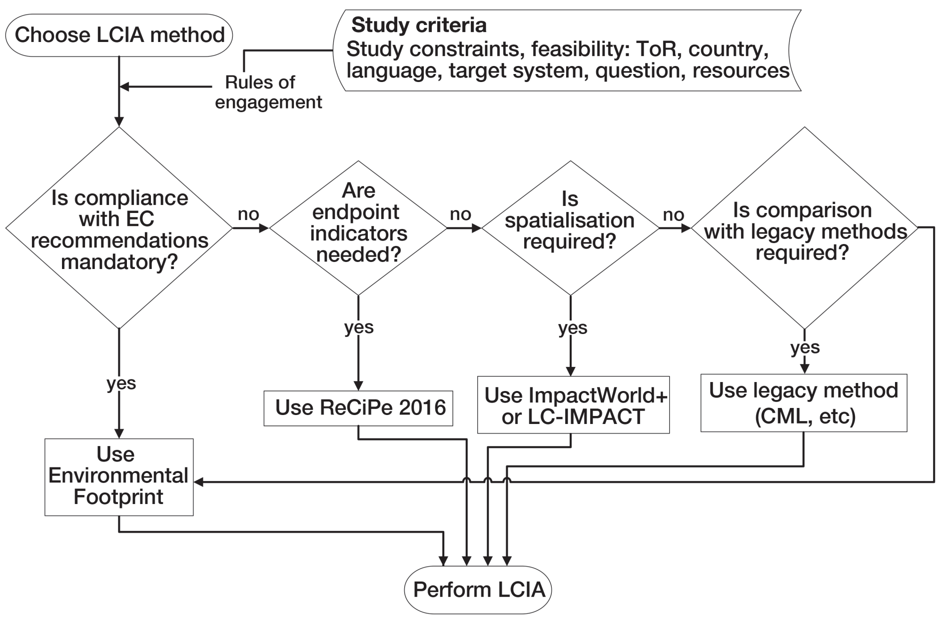


Figure 10.2. Which LCIA method set should be chosen (and why)?

An important and complex "offer"

Developing LCIA models constitutes an old but still topical challenge within the LCA scientific community that gave rise to an intense and still highly active scientific production. Several authorities at both international and European levels are involved in critically analysing this immense corpus of scientific production, coordinating consensus-building efforts and making recommendations for LCA practitioners. The main institutions coordinating the provision of guidance on LCIA are the Institute for Environment and Sustainability in the EC-JRC, in cooperation with the Environment DG and UN Environment.

As mentioned in Chapter 3, the JRC first developed the ILCD handbook series of recommendations covering all aspects for conducting an LCA (EC-JRC 2011) (https://eplca.jrc.ec.europa.eu/). The LCIA guides provide requirements for assessing the emissions and resource consumption associated with a product in terms of impacts on the environment, human health, and resource depletion. In 2013, the European Commission established the PEF and OEF, or more generally EF framework to contribute to "Building the Single Market for Green Products Facilitating Better information on the environmental performance of products and organisations COM/2013/0196". The common methods to measure and communicate the life cycle environmental performances for PEF and OEF, have been defined in a specific EU recommendation (2013/179/EU) to fulfil the requirements of the EF scheme. Compared to the ILCD scheme (EC-JRC 2011), in the EF scheme some LCIA methods have been completely changed, while others have been fine-tuned or unchanged. The EF scheme only recommends methods at midpoint level while ILCD also recommended endpoint methods. The EF framework is currently in its third version: EF 3.0.

Table 10.1 presents an overview of LCIA methods recommended for some key impact categories for agri-food LCA studies in the LCIA method sets from the Life Cycle Initiative (UNEP 2016, 2019) and EF 3.0 (Zampori and Pant 2019), as well as the methods used in ReCiPe 2016 (Huijbregts *et al.* 2016), IMPACT World+ (Bulle *et al.* 2019) and LC-IMPACT (Verones *et al.* 2020). IMPACT World+ (http://www.impactworldplus.org/en/), an update of IMPACT 2002+, LUCAS and EDIP, is a recently released LCIA method set offering an updated midpoint-damage framework, spatially-resolved impact categories and a subdivision between short-term and long-term damages for long-term impact categories. LC-IMPACT (https://www.lc-impact.eu/) is a newly proposed method providing CFs at the damage (endpoint) level for 11 impact categories, seven of which include spatial differentiation (no midpoints are included). The goal of this method was to consolidate the latest modelling developments scattered in the scientific literature. Appendix I (p. 176) presents the full lists of LCIA methods recommended by EF 3.0.

Table 10.1. Methods, indicators and references behind recommended LCIA method sets for some of the most important impact categories for agri-food LCA studies.

	Life Cycle Initiative (GLAM)	EF 3.0	ReCiPe 2016	IMPACT World+	LC-IMPACT
Water scarcity/stress					
Midpoints	AWaRe (Boulay *et al.* 2018)	AWaRe	m^3 consumed/ m^3 extracted	AWaRe	N/A
Human health	(Motoshita *et al.* 2014)		(Pfister *et al.* 2009)	(Boulay *et al.* 2011)	(Pfister *et al.* 2009)
Ecosystem quality	N/A		(Pfister *et al.* 2009; Hanafiah *et al.* 2011)	Terrestrial: (van Zelm *et al.* 2011), Freshwater: (Hanafiah *et al.* 2011), Thermal pollution: (Verones *et al.* 2010)	(Verones *et al.* 2017)
Eutrophication					
Midpoints	Freshwater: (Helmes *et al.* 2012) Marine: (Cosme *et al.* 2017)	Freshwater and marine: Struijs' Chapter 6 in RECIPE 2008 (Goedkoop *et al.* 2009)	Freshwater: (Helmes *et al.* 2012) Marine: N/A	Freshwater: (Helmes *et al.* 2012) Marine: (Roy *et al.* 2012)	N/A
Ecosystem quality	Freshwater: (Azevedo *et al.* 2013a, b) Marine: (Cosme *et al.* 2017)		Freshwater: (Azevedo *et al.* 2013a, b) Marine: N/A	Freshwater: (Tirado-Seco 2005; Helmes *et al.* 2012) Marine: (Roy *et al.* 2012)	(Helmes *et al.* 2012; Azevedo *et al.* 2013b; Scherer and Pfister 2015)
Toxicity and ecotoxicity	Generic scientific recommendations (USEtox recommended)	USEtox 2.1. (Rosenbaum *et al.* 2008)	USES-LCA 2.0 (Van Zelm *et al.* 2009)	Parameterized version of USEtox for continents	USEtox 2.1. + (Rosenbaum *et al.* 2015b; Fantke and Jolliet 2016)
Biodiversity due to LULUC	(Chaudhary *et al.* 2015)*	N/A	(de Baan *et al.* 2013; Elshout *et al.* 2014); combination of absolute species loss at the local, regional, and global scale, using species·yr	(Curran *et al.* 2011; de Baan *et al.* 2013)	(Verones *et al.* 2019, 2020); PDF (global scale)
Soil quality	SOC deficit potential (Brandão and Milà i Canals 2013) + erosion (RUSLE) (Foster 2005)	Soil quality index based on LANCA (Beck *et al.* 2010; Bos *et al.* 2016)	N/A	N/A	N/A

*We recommend Chaudhary and Brooks (2018) instead, which is an update and extension of Chaudhary *et al.* (2015). SOC: soil organic carbon; GLAM: Global Guidance for Life Cycle Impact Assessment Indicators and Methods; PDF: potentially disappeared fraction.

What is the validity of state-of-the-art LCIA methods for developing contexts?

Methods for global impact categories, such as climate change, are generally valid at the global scale. For impact categories dependent on local or regional conditions, the spatialization of CFs is key for applying LCA in tropical conditions and has received considerable attention in recent decades. This is the case for the AWaRe water scarcity indicator, which is fully spatialized. However, the use of spatialized CFs is complicated for LCA practitioners due to their absence from the most common LCA software. Furthermore, certain impact categories such as ecotoxicity reflect mostly the sensitivity of ecosystems and organisms in temperate conditions while the sensitivity of tropical organisms to various toxic compounds has very seldom been tested and is not reflected in available CFs (Gentil *et al.*, 2019). Although the increasing spatialization of LCIA models constitutes an important step forward for applying LCA in tropical conditions, there is room for improvement in this regard to better account for the sensitivity of tropical organisms.

What is the uncertainty attached to LCIA models and indicators?

In the LCIA phase, uncertainty is due to the choice and characteristics of underlying models and the list of substances for which CFs are computed (Alyaseri and Zhou 2019; Cherubini *et al.*, 2018). Model uncertainty, due to "the structure of and the mathematical relationships defining the models themselves (including models for deriving emissions and CFs used in impact assessment models)" (Bamber *et al.* 2020), cannot be reduced by LCA practitioners, but it should be understood. For instance, (eco)toxicity impact categories feature much higher uncertainty (expressed in terms of the order of magnitude of error in CFs) than impact categories such as climate change or eutrophication. This is due to the understanding and choice of modelling approaches used to represent the underlying environmental mechanisms. Practitioners should keep in mind that (model, parameter) uncertainty may vary with the position of an indicator in the causality chain linking emissions to damage indicators through midpoints. For a holistic consideration of uncertainty it is useful to compare the results of midpoints and endpoints, and if the conclusions change, a more thorough analysis should be made (Rosenbaum *et al.*, 2018).

Certain authors have been able to include the uncertainty attached to LCIA models in uncertainty analyses of LCA results, such as illustrated for instance in Henriksson *et al.* (2015a) for climate change and in Henriksson *et al.* (2015b) for freshwater aquatic ecotoxicity. However, including the uncertainty due to LCIA models into the more commonly performed data uncertainty analysis to provide comparisons among alternative systems with an associated level of confidence remain complex for LCA practitioners.

All impact categories for which no consensus models exist (e.g. impacts on biodiversity) are particularly prone to important differences across model results. In principle, when a specific impact category features a large contribution to endpoints, it should be contrasted across methods, and the differences explained to the study commissioner.

How operational is the use of LCIA models for LCA practitioners?

The operationality of LCIA models is contrasted among impact categories, from the global warming potential (GWP) impact that has been available in the first releases of the LCA software and is regularly updated, to recent and spatialized LCIA models such as biodiversity loss due to land use and land use change (LULUC) and which are still completely absent from LCA software. As mentioned earlier, spatialized LCIA models could be of great relevance for LCA studies in developing countries but they are generally not supported by most common LCA software such as SimaPro. Spatialized CFs are available in the literature and should be downloaded and used in other tools such as Excel and GIS sofware, which makes their integration more complicated for LCA practitioners. Finally, there might often be some difference of versions between the LCIA models implemented in LCA software and those proposed by their authors (e.g. USEtox versions), which requires some careful checking.

Impact categories

Appendix H (p. 144) explains and illustrates the meaning of each impact category (e.g. global warming or climate change impact, soil quality impact, human toxicity and ecotoxicity, biodiversity due to LULUC, and water scarcity footprint), presents a digest of the state of the art on available methods, uncertainty aspects, and validity domains; proposes decision trees to help select among methods, describes operational aspects (included in LCA software), and provides general recommendations/warnings on the links between inventory flows and impact assessment in relation to software used.

11

Interpreting the results for each stakeholder category

LCA is a decision support tool and each stakeholder needs to understand and trust the results to be able to make sound decisions. In this part of the guide, we formalize our recommendations on the best ways to secure, compare, present and share LCA results for decision-makers.

Accounting for uncertainty in LCA studies

Overview of all potential sources of uncertainty

LCA results cumulate several sources of uncertainty that are often not estimated or made visible for decision-makers who would need to know how confident they can be on the values presented in an LCA study. As explained by Heijungs (2021): "After all, knowing the probability of making the wrong decision may affect the decision you make". Making large uncertainties visible around LCA result values can be disturbing but pretending they do not exist is also an extreme exaggeration of their precision. The challenge then is to be able to account for main uncertainties and reach a reasonable estimate of their robustness and degree of confidence.

Many authors formalized the various sources and types of uncertainty attached to LCA results (Huijbregts 1998a, b; ISO 2006b; Igos and Benetto 2015). Uncertainty can be attached to the parameters (input data), the choice and value judgement, and the models used. All of these components of the LCA calculation can be affected by all three sources of uncertainty, which can be summarized as reported by SCORE LCA (Igos and Benetto 2015; Igos 2018):

- First, systematic uncertainty (uncertainty) corresponds to imprecision linked to the experimenter, the measuring instrument or the method of estimation used (e.g. surveys). It corresponds to the error associated with the estimated value that is the difference between the measured value and the "true value" of the quantity that we are trying to measure.

• Second, stochastic uncertainty (variability) comes from the estimation of the mean of a naturally variable parameter based on a sampling procedure.
• Third, epistemic uncertainty (unrepresentativeness) arises directly from a lack of knowledge about the data, models or rules describing a complex system.

Variability cannot be reduced but it can be better characterized. That is what is aimed by designing relevant typologies and appropriate sampling protocols over time, space and technology. Uncertainty can be reduced or eliminated with more or better data and knowledge. Depending on the origin of the uncertainty, one might prefer to talk about variance, dispersion, scatter or spread.

To test the separate influence of some methodological choices on results, such as choice of allocation factor, or different impact assessment methodologies, sensitivity analyses can be useful. Sensitivity analyses can help estimate how critical the uncertainty related to those choices may be, but they cannot quantify the propagation of the full uncertainty associated with all choices combined. Other uncertainty sources may be treated with a quantitative uncertainty analysis, such as by using Monte Carlo (MC) simulations.

In Table 11.1 we summarize some of the best-known sources of uncertainty related to LCA results. Many of these relate to previous sections of these guidelines. That said, we also acknowledge that there often are many unquantifiable and unknown sources of uncertainty in LCA. Moreover, many software programs have limitations with regards to accounting for all of these different sources, still enabling a set of distributions, using different uncertainty parameters (e.g. min-max, arithmetic standard deviations, or geometric standard deviations), and offering different ways of propagating results.

Table 11.1. Best known sources of uncertainty related to LCA results.

Source	**Example of source of variance**	**Possible parameters**
Sampling framework	Biased samples	Hard to account for
FU	Moisture content, edible yields	Best estimates
Field emission models	Parameter uncertainty	Model-specific or literature estimates
Fate of run-off	Unknown fate of N and P	Literature estimates
Economic inputs	Non-existent or inaccurate record-keeping	Variances calculated from sample
Food waste and loss	Fraction spoiled or lost	Best estimates
CFs	Uncertain models or variable input data (e.g. toxicity data)	Impact assessment method-specific variances or sample of input data
Unrepresentativeness	Old data, proxy data, etc.	Pedigree approach

Variance related to CFs varies from ±50% for GWPs to orders of magnitude for toxicological potentials. These dispersions are, however, applicable to all types of LCA, and not unique to LCA in the context of developing or emerging economies. Thus, these guidelines will mostly focus on the dispersions related to LCI data.

Detailed issues to deal with uncertainty within agri-food LCA in developing and emerging economies

For agri-food LCA in developing and emerging economies, the collection of primary data in the field is generally the best (or only) option to perform an inventory of the studied system. However, record-keeping on quite diversified agri-food systems might be poor or non-existent in such contexts, which means that collected data may have a high uncertainty and larger samples are needed to capture the performance of a sector. As already detailed in Chapter 8 (section "System boundaries, typologies and sampling strategies") and Chapter 9 (section "Foreground data collection"), this emphasizes the importance of the different data collection stages, including the sampling framework, horizontal averaging of data, and sources of overall dispersion.

Conversely, in more industrialized countries, producers generally keep better records on their production processes and have more homogenous production practices, but they are also less willing to share due to corporate confidentiality. Much LCI data in industrialized contexts therefore only represent one or a few data points. This is also a reason why data quality ratings (DQRs) have become an accepted practice to quantify dispersions for these processes. The DQR is a scoring system for qualifying data in LCA studies that was first developed by Weidema and Wesnæs (1996) and has been further developed and used by all LCA database. This data quality-checking system is summarized in Chapter 11 (section "Best practice to account for uncertainty").

Given the generally larger variances in data describing practices in developing and emerging economies, distributions defined by primary data should always be prioritized over DQRs. While empirically derived DQRs have been useful in establishing variances for existent datasets, such as the ecoinvent LCI database (Ciroth *et al.* 2016), they are generally derived from datasets describing unit processes for a few specific sectors in quite industrialized countries with potentially little dispersion. It is, for instance, not uncommon for uncertainty ranges around LCI results to span an order of magnitude (Henriksson *et al.* 2018) (Table 11.2). Moreover, DQRs originate from the pedigree concept of post-normal sciences and therefore tend to quantify uncertainties not covered by traditional statistics (Van Der Sluijs *et al.* 2005; Henriksson *et al.* 2013), such as temporal correlation and completeness. DQRs should therefore be seen as complements, rather than substitutes, for traditional uncertainty parameters.

Table 11.2. Examples of different sources of overall dispersions in processes in developing and emerging economies, defined by the protocol for horizontal averaging by Henriksson *et al.* (2013).

Unit processes	Type	Flow	Inherent uncertainty, CV	Spread, CV	Unrepresentativeness, CV	Overall
Giant river prawn Khulna, unit process data	Primary	Electricity use	Assumed: 0.05	0.935	0.0283	0.937
Giant river prawn Khulna, unit process data	Primary	NH_3, to air	1.73		0.0623	1.73
Soybean farming, Brazil	Secondary	N fertilizers	Assumed: 0.05	1.02	0.0398	1.02
Soybean farming, Brazil	Secondary, IPCC emission model	N_2O, to air	0.63		0.0283	0.63
Groundnuts (peanuts), China	Secondary	P fertilizers	Assumed: 0.05	0.519	0.0283	0.552

CV: coefficient of variation.

Beyond the uncertainty related to the dataset used to characterize a process unit, the structuring of the process tree also affects how variances and uncertainties must be handled. This variance exists at almost every node of the unit process dataset and is hard to aggregate in a meaningful way.

While we generally get our first impression on how unit process datasets should be structured from ecoinvent, the condensed unit process structure of ecoinvent is a product of avoiding cumbersome matrix calculations. For example, ecoinvent tends to include transportation as part of a unit process. In reality, transportation processes are better modelled as separate unit processes (Figure 11.1), which enables more flexibility, easier analysis of results, and more descriptive uncertainty parameters. Another example concerns the inclusion of food loss and waste, it may happen at most nodes along the value chain and can be more easily parameterized if the processes are not too aggregated. Similarly, it could be argued that the DQR should be implemented at each node in the unit processes dataset.

Moreover, covariances often exist among different parameters, such as nitrogen fertilizers and field emissions of N_2O (Groen and Heijungs 2017). Implementing distributions or using circular flows (e.g. electricity used by power plants) can also result in inverted operators, where outputs turn into inputs. This is more common for processes with large variances.

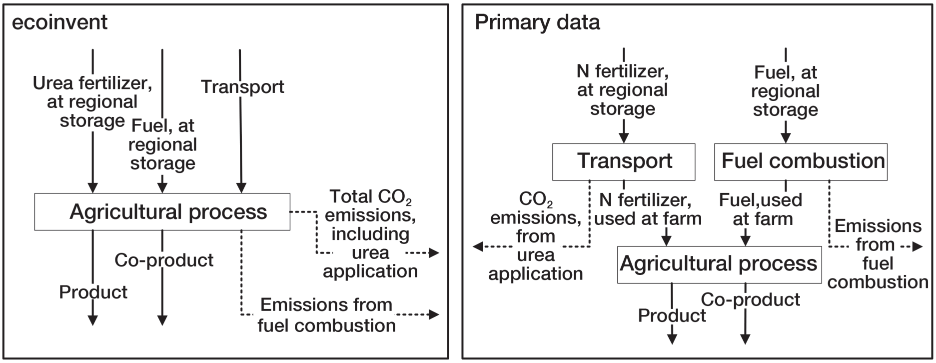


Figure 11.1. Unit processes dataset structure in ecoinvent database and as proposed in these guidelines.

Best practice to account for uncertainty

Depending on the LCA situation and constraints, various approaches are feasible to help feel reasonably confident with the conclusions of the LCA study. Some authors differentiated between non-comparative and comparative LCA studies in relation to the issue of managing uncertainty, arguing that non-comparative LCA studies can simply rely on more qualitative approaches while comparative LCA studies require a quantitative uncertainty analysis.

Qualitative approaches

For all LCA studies, qualitative approaches should be default options for dealing with uncertainty. They can consist of checking the validity of data for the goal and scope of the study and carrying out sensitivity analyses on key parameters.

Data quality checking

In LCA, data quality is key because it defines how well the data will fit with the LCA goal and scope. If the dataset is unsuitable, the LCA results may not provide any useful information on what the actual system impacts are. Distinction between primary and secondary data, typology for agricultural LCA, effort towards better field emission modelling, etc. all converge towards improving data quality to reduce uncertainty on the results. The closer the data is to the real system, the better the data quality.

There are two main ways to determine how close a dataset is to reality. First, statistical indicators can be calculated using mathematical means, but this requires a lot of information on the data distributions for both the sample and the whole population. Second, data quality can be approximated based on expert knowledge according to critical criteria in line with the LCA goal and scope. Given the difficulty in obtaining sufficient datasets in order to run statistical tests, data quality is mostly determined by qualitative means and uncertainty analysis is carried out based on estimated distributions of variables. Based on the pedigree matrix (Weidema and Wesnæs 1996), data quality scores can even be used to derive hypothetical distributions and kill two birds with one stone. However, such a transformation embeds an added layer of uncertainty.

The baseline qualitative approach of data quality relies on several criteria that are mostly common to the various approaches used in ecoinvent, PEF, etc. In the original LCA pedigree matrix, there were five quality criteria: (i) reliability; (ii) completeness; (iii) temporal correlation; (iv) geographical correlation; and (v) technological correlation (Weidema and Wesnæs 1996). In ecoinvent databases, which all include this pedigree matrix, a sixth criterion, "sample size", was added and retrieved depending on the version (no longer included in the version v.3.0). "Correlation" is understood as an adequacy between the data collected and the data needed to represent the studied system. In PEF, "representativeness" is used instead of "correlation" and reliability and completeness are embedded in a global "precision" criterion. Scores from one to five are defined by experts for each criterion, one being the highest quality score, five being the default value when no information on the data quality is available. The information needed to define the scores has remained both consistent and constant across ecoinvent versions (e.g., temporal thresholds have not changed): three, six, 10 and 15 years (Weidema and Wesnæs 1996; Ciroth *et al.* 2016). This qualitative information can be used in two non-exclusive ways: it can be aggregated in order to provide a qualitative assessment of the dataset, hence providing weighted perspectives on the potential outreach of LCA results (cf. qualitative diagnosis); or it can be translated into distribution laws providing mathematical translation of the information precision into value dispersions to be used in uncertainty analyses (cf. uncertainty approximation).

However, as mentioned earlier, for LCA studies in developing and emerging contexts, the use of data quality indicators to define distributions for foreground data does not seem appropriate.

The most detailed guidance on the use of the qualitative assessment of data in LCA is provided in the latest version of the European PEFCR Guidance (EC 2018) and is fully described in Appendix J (p. 178).

Sensitivity analyses

In addition to checking the validity of data for the goal and scope of the LCA study, it should always be possible to test the sensitivity of the results to important parameters and choices one by one. As recommended by the ISO norm: "… the interpretation shall include an assessment and sensitivity check of the significant inputs, outputs and methodological choices in order to understand the uncertainty of the results". A sensitivity analysis contributes to the robustness of LCA results and aids interpretation. Typically, the practitioner will test the sensitivity of the final results to the one-at-a-time variation of key parameters which are known to have a considerable contribution on impacts. We propose a list of key parameters per great agri-food category (Table 11.3) to support the selection of key variables.

Table 11.3. Key parameters for sensitivity analyses depending on product system.

Parameter	Crop systems	Livestock systems	Aquaculture systems	Fisheries	Agri-food processing	Distribution
Energy use (may be expressed as fuel use intensity)	-	+ (e.g. if mechanized)	+ (e.g. recirculating systems)	+	+	+
Feed consumption (may be expressed as feed conversion ratio)	N/A	+	+	N/A	N/A	N/A
Water consumption	+	+	+	N/A	+ (e.g. in water-scarce areas)	N/A
Fertilizer consumption	+	N/A	-	N/A	N/A	N/A
Pesticide consumption	+	-	-	N/A	- (e.g. except for cases described in [a])	N/A

[a] It is not unusual for pesticides to be used as preservation treatment for certain artisanal processed products, such as smoked fish (Adeyeye and Oyewole 2016). Scale: negligible (-), non-negligible (+), not applicable (N/A).

Quantitative approaches

Quantitative uncertainty analyses are especially relevant for comparative LCA studies and are possible by using propagation methods. The most common propagation methods are MC sampling, Latin hypercube sampling, analytical uncertainty propagation and fuzzy interval arithmetic (Groen *et al.* 2014). Each of these have different strengths and weaknesses which should be considered, but MC sampling remains the most frequently used propagation method. While modern software can make use of the graphic processing unit and compute large sets of MC results in a short period of time, many LCA software still rely upon the central processing unit which results in longer computation times. This becomes cumbersome if one wants to run large sets of iterations for large unit process datasets. Thus, since there are no rules for a "sufficient number of iterations" (Heijungs 2019), the final decision often comes down to an arbitrary number. While the sample mean normally starts to conform around 100 MC iterations, it comes down to the unit process dataset, so we recommend 1000 iterations (Groen *et al.* 2014). This said, it is important to highlight that resampled results only constitute arbitrary sample sizes and should therefore be approached carefully with confirmatory statistics (Heijungs 2019).

In practical terms, running MC simulation includes three steps:

1. The first step is to transform discrete input variables into stochastic variables by defining a probability distribution for them. In the LCA community, lognormal distributions are preferred, as negative results will not be generated during the

propagation. It is important when using alternative distributions to make sure that the central value corresponds to the software algorithms. For example, most software expects the arithmetic mean as the central value for lognormally distributed data, as the point-value otherwise would deviate. Moreover, when normal distributions are extremely platykurtic (e.g. standard deviations > means), it is preferable to either limit the range of values used to build the normal distribution, or use triangular distributions, which guarantee that no incorrectly negative values would be possible.

2. Then, a random sampling of values among all input variables is performed (e.g. 1000 times), and for each set of values a result is calculated, progressively drawing the probability distribution of the result itself.

3. Finally, in the case of a comparison between systems A and B, null hypothesis significance testing can be done to check the significance of the difference. A more relevant test could be to test the probability that the difference between A and B exceeds a given threshold, such as 20%, which will give a clearer appraisal of the importance of the difference between A and B.

For background data, probability functions can be based on DQR conversion while for foreground data, they should be based on statistical data from the primary data collected in the field. In some LCA software, there is a dedicated function to conduct uncertainty analyses, such as in the SimaPro software (v9.1.1.1).

Figure 11.2 summarizes some practical recommendations for conducting MC simulations.

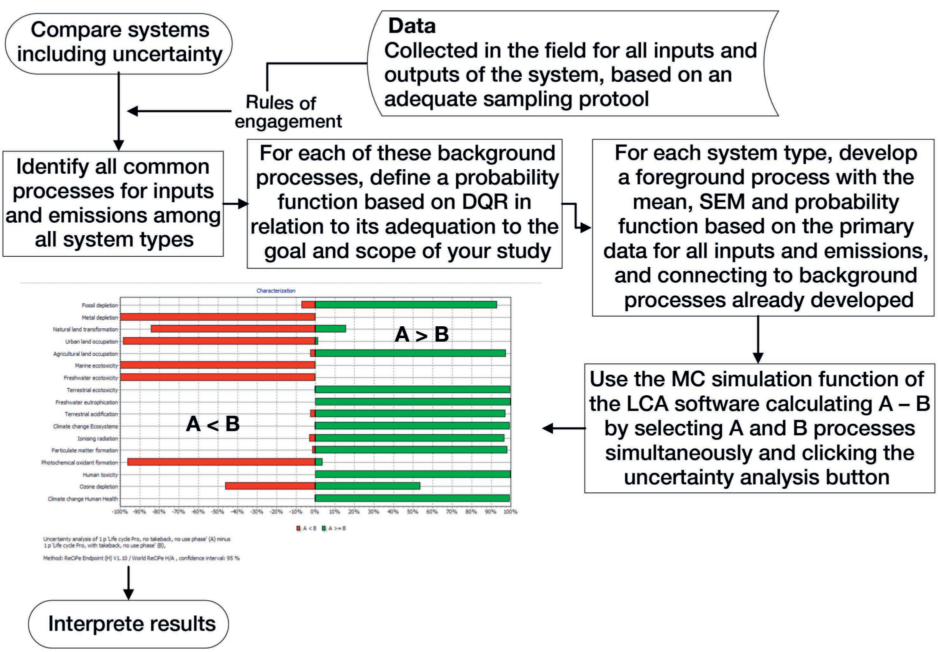


Figure 11.2. Practical recommendations for conducting MC simulations with the SimaPro software. SEM: Standard error of the mean. For complementary instructions please refer to the SimaPro tutorial (Goedkoop *et al.* 2016).

Generally, the objective is to compare the mean impacts between two system types. In this situation, the confidence interval should be defined using the standard error of the mean (SEM) of input data. If the objective is to compare the two populations, the confidence interval should be defined using the standard deviation (SD) of input data. If the SD is used for defining probability distributions, the result will be the probability that impact for A is greater than the impact for B. If the SEM is used, it will be the probability that the mean impact for A is greater than the mean impact for B.

Comparing results with previous studies

Despite being discouraged by several authors and guidelines from doing so, LCA practitioners often compare their results with those from previous studies. Occasionally, they use clever strategies allowing them to recomputing third party results to have a common FU or to use the same LCIA Method, (e.g. Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010). Recent meta-analyses on LCA studies for food products have been published on the basis of a solid methodology for harmonizing the assumptions and methods used among all reviewed studies (Poore and Nemecek 2018). Such rigorous reviews provide public stakeholders and consumers with key references on the environmental impacts of foods and can support adaptation of behaviours, as well as allow other scientific disciplines to integrate environmental information on products or services in a fairly accurate way.

However, as part of a given comparative LCA study under resource constraints, such comparison should be performed and interpreted with caution, because of the potential underlying differences in goals and scopes, assumptions, data sources and design decisions among studies. A priori, only the orders of magnitude of results from different studies should be compared as well as unambiguous rankings between scenarios when scenarios have been compared. When gross differences are found, they should be investigated to identify the causes: either an error or a valid explainable difference. In all cases, the versions of the databases used for the inventory must be strictly the same, as well as the impact assessment methods, in order to have relevant comparisons. When performing said comparisons, particular attention should be paid to aligning system boundaries, cut-off criteria, allocation strategies, background data sources, LCIA methods, and especially FUs. Sometimes previous studies are not sufficiently documented to attempt a recalculation based on a common and recent LCIA method, which would be ideal. At least common FUs should be used, which can often be accomplished by simple conversions (e.g. for crops, mass units to area units when yields are known). For livestock and seafood, comparisons may also be based on product yields, such as tonne of fat- and protein-corrected milk, tonne of live weight, etc. Intermediate indicators such as feed conversion ratios for fed livestock/aquaculture systems sharing common characteristics (e.g. technology, size, intensity) may also be used to compare systems.

The fairest way to make this type of comparison is therefore often to have access to the complete LCI (if possible in unit version, with the individual processes), so as to be able to update old or obsolete underlying processes to their latest updated version. This will also enable impact calculations to be launched using the same LCIA method, which is strictly identical for all the scenarios being compared.

In addition, this recalculation will also make it possible to modify the process tree or process groupings in order to highlight relevant contribution analyses, whatever the scenarios studied.

Sharing and communicating results to support decisions

The results of an LCA study should be communicated to the different types of stakeholders in an appropriate way (Figure 11.3).

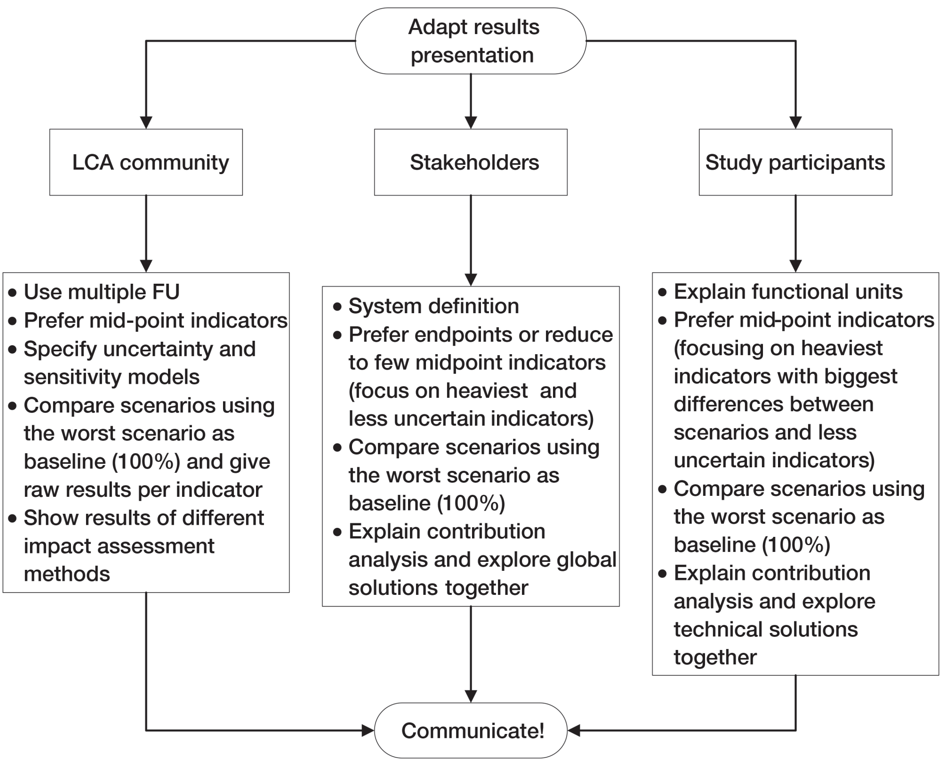


Figure 11.3. Adapting presentation of results to target audience.

LCA calculation results are multi-criteria and therefore by nature numerous at the midpoint level; it is nevertheless in this form that the scientific community shares its results to advance knowledge on environmental impacts. While mid-point tables and graphs are well understood by practitioners, this is generally not the case for non-practitioners. Particularly, for decision-makers and the general public, it is often more effective in the short term to produce simpler forms of specific results that are more intelligible for their level of knowledge than disaggregated midpoints. In the medium or long term, however, it is more relevant to increase the LCA literacy of interlocutors, notably through training.

The first level of simplification of the scientific results consists in using the endpoint results (damage on the three areas of protection: human health, ecosystems and resource scarcity), if the impact method allows it, which is not always the case. The most simplified level of results is to use the single score version, which aggregates all impacts into a single indicator.

The following is a list of tips for additional information to provide when presenting the results:

- If aggregated results such as the endpoint or single score have been used, make sure to always communicate the midpoint version in the appendix of the document as well. This is the standard version for communicating results in the scientific community.
- Provide simple and clear explanations of the sources of uncertainty in the results, as well as the key assumptions that have an impact. Confidence intervals should also be communicated.
- Provide the best available visualization options for decision-makers (see Appendix K p. 181 for options), and if possible the most response-oriented, in order to make the transfers and compromises between scenarios tangible if they exist.

Even at a midpoint level, identifying the best scenario from an environmental point of view is often complex because of the large number of environmental indicators to consider. To simplify comparisons of certain scenarios and to try to reach a simpler choice or communication of the results according to the audience, we propose using a procedure for analysing the results: a protocol to support the decision-making process, which is a structured and systematic procedure to eliminate minor indicators and focus on main differences, including their confidence intervals, based on the quantitative results obtained (Figure 11.4). Note that in a comparative LCA carried out according to ISO 14040/44, this procedure could not replace an in-depth analysis of impact indicators.

The proposed procedure is detailed in Guérin-Schneider *et al.* (2018) and consists in removing from the comparison certain categories of impacts based on simple, quantitative criteria derived from the calculated results. It is quite possible that the scenarios studied cannot be separated even at the end of the procedure. The decision must then be based on other criteria (social, economic, financial, technical, etc.).

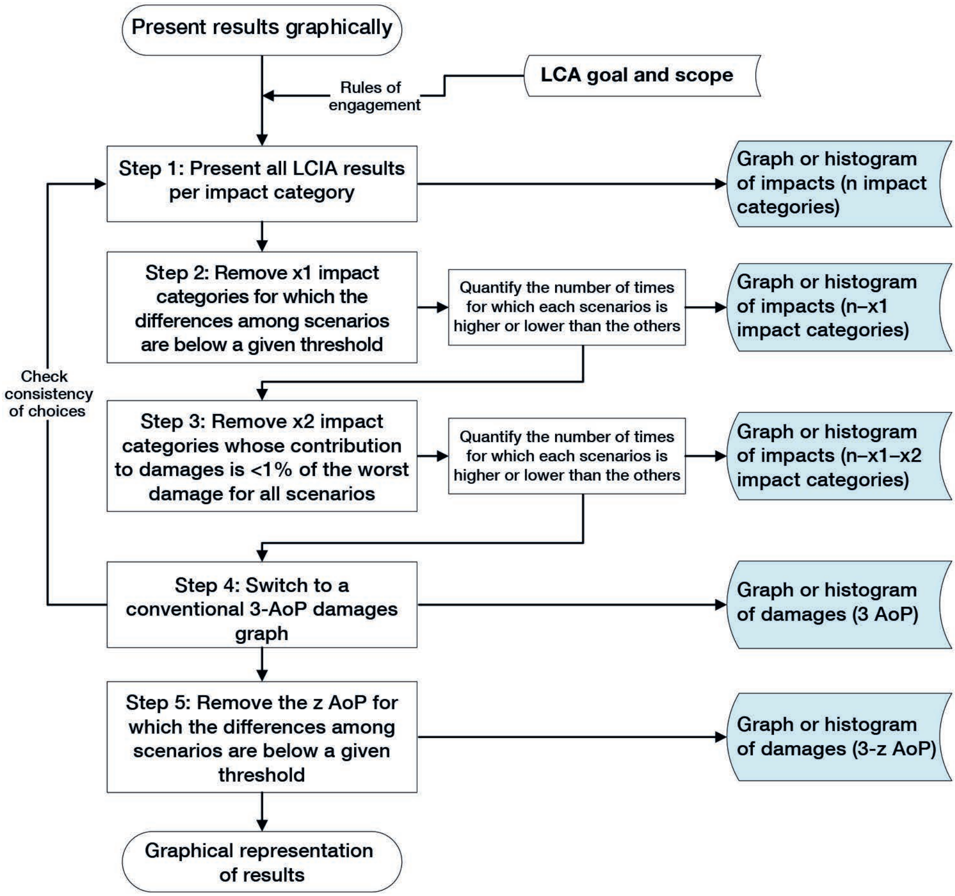


Figure 11.4. Protocol to support the decision-making process based on LCA results (adapted from Guérin-Schneider *et al.* 2018). Comparison of several scenarios (>2).