

CONSIDERING GEOGRAPHIC ASPECTS IN LCA: BENEFIT AND IMPLEMENTATION

Scientific synthesis

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SCORE LCA is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

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- ✓ The views and recommendations expressed in this publication are those of the authors and do not necessarily reflect, unless otherwise stated, the views of all members of SCORE LCA.
- ✓ The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

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SUMMARY

This report is a scientific review of the project entitled *Considering geographic aspects in LCA: Benefit and implementation* funded by ScoreLCA and conducted by the CIRAIG and IFP Energies nouvelles.

The key concepts and challenges of considering geographic aspects in LCA are presented here. The report includes a synthesis of current standards and recommendations on geographic representativeness in LCA as well as a review of current and upcoming approaches to consider geographic aspects in LCA and their use.

The second part of the study analyzes these approaches according to a series of criteria, specifically pertaining to relevance and operationalization. Based on the analysis and a survey sent out to members of the LCA community, short- and long-term recommendations on the different aspects of integrating the geographic dimension in LCA are set out. They are aimed at various stakeholders (LCA practitioners, LCA database developers, LCIA method developers and LCA researchers). A logic diagram for the practical implementation of inventory regionalization and spatialization recommendations is proposed.

KEYWORDS: LCA, regionalization, spatialization

Acronyms and abbreviations

CF: Characterization factor

DB: Database

EF: Elementary flow

GHG: Greenhouse gas

GIS: Geographic information system

ILCD: International Reference Life Cycle Data System

ISO: International Organization for Standardization

LCA: Life cycle analysis

LCI: Life cycle inventory

LCIA: Life cycle impact assessment

G&S: initial phase of an LCA study where the goal and scope are defined

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Study context

ScoreLCA mandated the CIRAIG and IFP Energies nouvelles to conduct a study on the interest of considering and implementing geographic aspects in life cycle assessment (LCA). ScoreLCA set out the following objectives:

- Conduct a critical analysis of the relevance of considering geographic aspects in LCA and the various related approaches
- Highlight the practical and conceptual challenges of implementing these approaches in LCA
- Define practical recommendations on ways to integrate geographic aspects

Regionalization in LCA

The following box defines certain terms related to geographic aspects in LCA.

- **Geographic coverage:** Area of geographic validity of an inventory or impact method that indicates the area to be represented. For example, the ReCiPe impact methodology is geographically representative of Europe, and TRACI is geographically representative of the United States.
- **Regionalization:** Used to provide a representative overview of the processes and phenomena that are spatially variable in a given region. Inventory regionalization yields an inventory that is more representative of the geographic coverage to be modeled, while impact regionalization calculates regionalized characterization factors (CFs) for each elementary flow (EF) that are representative of a geographic area by taking into account the spatial variability of the parameters and most influential mechanisms for a given impact.
- **Spatialization:** Attributes a geographic location to elementary flows. A geographic location is critical to the use of regionalized CFs. Different types of geographic information may be added and eventually correspond to the native spatial resolution of the impact method.
- **Archetype:** Like impact regionalization, the approach regionalizes the impact and spatializes the inventory, accounting for the most influential parameters and impact mechanisms. The difference between the archetype approach and an exclusively geographic regionalization of the impacts is that the parameters on which the archetype is based may be decoupled from their geographic position and used generically. For example, an archetype based on population density makes it possible to differentiate the impact of fine particle emissions in urban and rural areas. This type of archetype may be used without knowing in which exact city of the world the emission occurred.

The geographic aspects are an integral part of an LCA on many levels. First, the life cycle stages and therefore the elementary flows that constitute the life cycle inventory (LCI) may be geographically scattered owing to the globalization of supply chains. Also, an emission in a given area may have a different impact depending on its location. This impact may be local, regional, continental or global based on the type of emission and the characteristics of the receiving environment.

Considering the geographic aspects in LCA appears to be a promising avenue to increase the representativeness and reliability of the results. Regionalization provides a representative description of processes and phenomena that are spatially variable. Here, variability involves current variations and is distinguished from uncertainties, which refer to a lack of knowledge on reality (Huijbregts 1998). Providing a representative descriptions of spatially variable processes and phenomena should reduce the uncertainty associated with the shortage of information on their spatial location. However, enhancing geographic representativeness can add to the LCA practitioner's workload, specifically in terms of data collection and modeling (Baitz et al. 2012). One of the challenges of integrating regionalization is therefore to find a level of geographic representativeness that is adapted to the study objectives.

It is possible to consider geographic aspects in LCA at:

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- The inventory level (regionalizing the inventory to ensure the better geographic representativeness of the studied systems and the spatialization of the elementary flows)
- The impact assessment level to better account for the spatial variability of the receiving environments in order to characterize the impact (impact regionalization)

Several practical challenges and issues arise when seeking to better integrate geographic aspects in LCA. The study therefore also aims to answer these questions:

- How should the inventory data be regionalized? What should the level of detail be?
- How should the elementary flows be spatialized? What should the level of detail be?
- How should the characterization factors be regionalized? What should the level of detail be?
- How should the different resolution scales between the inventory and characterization factors be handled when calculating the impacts?
- How should the results be interpreted?
- Which tools does each user (LCA practitioner, database developer, impact method developer, etc.) require?

Study methodology

The study involves four phases:

- Phase 1: Synthesis of current standards and recommendations on geographic representativeness requirements in LCA
- Phase 2: Literature review of current and upcoming approaches that consider geographic aspects and their use
- Phase 3: Analysis of possible approaches to consider geographic aspects in LCA and their integration and application in LCA
- Phase 4: List of practical recommendations to select an approach to consider geographic aspects based on the context and proposals to better account for geographic aspects in LCA

The first two study phases are part of the analysis: the overview of LCA standards and guidelines and the scientific corpus.

The synthesis of the standards and guidelines is based on 15 documents (ISO standards, legislative texts such as the EU directives, LCA guidelines and guidance). In total, 111 recommendations pertaining to geographic representativeness were identified. Most (90%) are equally focussed on the life cycle inventory and life cycle impact assessment stages.

The review of the literature on regionalization approaches and their use led to the selection of 28 references (articles, theses and reports) on regionalization that discussed LCA case studies, methodological development, LCI databases (ecoinvent v3), impact methods (including LIME and IMPACT World+) and LCA tools and software (SimaPro, Gabi and especially OpenLCA and Brightway). Based on these references, 36 approaches to integrate geographic aspects in LCA were determined. The approaches vary significantly since they may be applied to different methodological aspects and seek to respond to very different and very specific issues. Ta presents an overview of these approaches, which were categorized according to:

- Objective: inventory regionalization, inventory spatialization, impact regionalization, integration of regionalization during impact calculation
- Application in LCI databases and LCA software

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Table 1 – Approaches categorized according to the methodological aspects they address in LCA

Methodological aspect	Type of approach and number of references	
ACV		
Sensitivity analysis		1
	Sensitivity analysis for regionalized LCA	1
Conceptual approach		1
	Conceptual integration of GIS in LCA	1
Regionalized LCA calculation		2
	Regionalized LCA calculation method	1
	Modification of LCA matrix computation	1
Software implementation		3
	Regionalized LCA calculation	1
	GIS integration	1
	Visualization of the locations of the processes that generate impacts	1
LCI		
Regionalization		6
	Regionalized inventory description	2
	Using GIS to determine least impactful growing areas	1
	Use of a parameterized LCA model	1
	Method to select processes to be regionalized	2
Spatialization		2
	Determination of water categories	1
	Description of geographic location processes that integrate location uncertainty	1
Regionalization and spatialization		6
	Approach to define the required level of LCI regionalization and spatialization	1
	Determination of land use LCI using GIS	4
	Process disaggregation	1
DB – spatialization		2
	Use of a geographic descriptor for each process	1
	Determination of the best approach to spatialize DB inventory flows	1
DB – data quality		1
	Pedigree matrix to assess the level of geographic representativeness	1
DB – regionalization		1
	Process descriptions per country	1
Software implementation		1
	Textual process localisation	1
LCIA		
Classification		1
	Determination of the relevance of calculating the local or regional impact of a fixed or mobile emission source	1
Spatial differentiation		4
	Creation of regionalized CFs by adapting USEtox to local characteristics	1
	Creation of regionalized CFs by evaluating biodiversity in the study area	1
	Creation of regionalized impact CFs by using freshwater incidence on human health	1
	Determination of a relevant native scale for regionalized CFs	1
Impact methodology		1
	Area-specific regionalized impact methodology	1
Software implementation		2
	Textual localisation of CFs	1
	Parameterization of regionalized impact methods	1
Interpretation		
Impact localisation		1
	Visualisation of impact localisation	1
Integrative LCA tool		
Use of GIS		1
	Tool that integrates LCA and GIS	1

In addition to the normative analysis and literature review, a survey was sent out to members of the international LCA community. The survey (23 questions) focused on current practices and perceptions on inventory regionalization and spatialization in LCA and was shared on the *LCA discussion list*¹ and via word of mouth. A total of 42 respondents took part in the survey. They averaged 7.5 years' experience in LCA. One-third were LCA consultants and analysts, one-third were academics and the remaining respondents were consultants in various fields (chemistry, bio-products, energy, etc.). The

¹ An LCA discussion forum led by PRe Consultants
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survey provided information on a series of practices and perceptions, significantly increasing the relevance of the critical analysis and clearly highlighting the needs of the LCA community.

Based on the results of the literature review, the project team's expertise and the survey responses from members of the LCA community, a critical analysis of the approaches was carried out in an effort to determine their strengths and weaknesses, their level of development and their short- and long-term applicability. The following criteria were selected to assess each approach:

- Theoretical limitations and biases: aspects not covered, strong hypotheses
- Practical limitations: availability of appropriate data and tools, skills to be developed
- Relevance of the approach: contribution and interest of the approach in terms of issues and the representativeness and reliability of LCA results
- Level of development: turnkey method, additional methodological development needs, current level of practice
- Level of operationalization: ease of application by the practitioner, coherence with other approaches, data collection efforts required, ease of integration in current tools, need to develop specific tools, need to call upon expertise in other fields

Practical recommendations to consider geographic aspects in LCA

In this report, the critical analysis of the different approaches is presented as a detailed grid. The analysis made it possible to set out recommendations on integrating geographic aspects LCA, as described in Table 1. They are categorized according to a highly operational approach:

- By type of question raised when the issue of the geographic aspects is discussed
- By type of recipients/users (LCA practitioners, LCA database developers, LCIA method developers, LCA researchers)
- By time horizon (recommendations applicable in the short-term using current tools and recommendations for longer-term developments)

Table 1 – Recommendations for the short- and medium-term integration of regionalization in LCA

Question	Short-term recommendations	Long-term recommendations
Preliminary questions		
Is the implementation of an inventory regionalization or spatialization process necessary?	<u>For practitioners:</u> In the study objectives and scope, define needs in terms of study quality (acceptable level of uncertainty). This may be qualitative. An acceptable level of uncertainty must be discussed with the study recipient or sponsor. Then, the spatial uncertainty of the preliminary results must be assessed, at least qualitatively, based on expert knowledge. The level of uncertainty must be compared to the acceptable level of uncertainty in order to determine whether the practitioner must implement the process or not. There should be special focus on studies pertaining to a decision that could have significant or debatable impacts (implementation of public policies, sensitive issues), studies disclosed to the public, international supply chain studies (e.g. for the textile or building sector) and consequential LCAs.	<u>For research:</u> Suggest a more systematic operational method to assess the interest of regionalization for a given area.
How to prioritize the effort between inventory regionalization and spatialization?	<u>For practitioners:</u> No current method prioritizes effort. Inventory regionalization and spatialization must therefore be carried out in parallel whenever relevant to the study results. However, inventory regionalization at the start of the study minimizes the efforts required during spatialization since certain spatial information may have already been collected.	<u>For research:</u> Suggest a more systematic operational method to prioritize efforts between inventory regionalization and spatialization. Regionalization experience is required to support and validate the method.
Inventory regionalization		
How to regionalize the inventory?	<u>For practitioners:</u> The quality of the geographic representativeness of the data and the description of the product system (contextualization) must be enhanced in order to regionalize the inventory. Contextualization must be carried out as a priority if the main uncertainty for a flow stems from the choice of economic process or the elementary flow that represents it. Regionalization will therefore be less time consuming than anticipated from the onset.	<u>For DB developers:</u> Set out regionalized datasets that are representative of all regions of the world, including emerging countries when they are important to the global market considered in the study. Regionalization will there be less time consuming for practitioners.
How to evaluate the quality of the geographic representativeness of the data?	<u>For practitioners:</u> Despite certain theoretical biases, the pedigree matrix remains the most operational method to assess the quality of the geographic representativeness of data. The spatial uncertainty associated with the most impactful economic and elementary flows (the matrix qualifies flow values and not the choice of processes) of the processes can therefore be evaluated to give priority to inventory regionalization over lesser quality data.	<u>For DB developers:</u> Continue the efforts to associate a pedigree matrix to each economic flow. <u>For pedigree matrix developers:</u> Provide conversion factor sets as uncertainty for each type of process.
Where should efforts be focused?	<u>For practitioners:</u> Whenever accessible, the most detailed data should be used, regardless of the processes. The most relevant and operational approach to select the processes that should be regionalized is a damage-level contribution analysis for each process. The spatial uncertainty of the most impactful processes must then be assessed to ensure that only the most contributing processes with the greatest spatial uncertainty are selected. Evaluating spatial uncertainty is only possible using the pedigree matrix or expert knowledge. There should be special focus on energy production and consumption, transport, agriculture-related, land use and waste management processes, since they may be affected by significant geographic variability from one region to the next.	<u>For practitioners:</u> Select the processes to be regionalized by considering their influence on the results and their spatial uncertainty. <u>For LCA software developers:</u> Set out software that can compute LCA calculations in a probabilistic manner so as to be able to carry out contribution analyses that account for data uncertainty. The approach developed by Heijungs (1996) would then directly be operational.
How should efforts be prioritized?	<u>For practitioners:</u> The inventory regionalization effort (concretely, the number of processes to be regionalized) must reflect the study quality requirements set out by the study recipient or sponsor, the means available to carry out the study and data availability. The ILCD recommends that priority be given to the regionalization of foreground data. As reported by many survey respondents, electric grid mix regionalization is relatively simple and often yields significant benefits.	<u>For LCA research:</u> Develop a method to give priority to more systematic inventory regionalization efforts based on the study objectives, decision-making context, studied sector and available means.
What should the level of detail be?	<u>For practitioners:</u> Theoretically, the level of detail required to regionalize the inventory depends on the type of processes and the effort that practitioners want to invest. From the practical perspective, the practitioners must therefore analyze each process individually and determine the level of detail required based on expert knowledge and available data. The ILCD recommends regionalizing data based on economic market limits.	<u>For research:</u> Develop guidelines that provide a relevant level of regionalization for each process type.
Inventory spatialization		
How can spatialization be carried out?	<u>For the practitioner:</u> Flow spatialization essentially depends on the target level of detail (which is a function of the study means and objectives and the needs of the impact that is assessed) and the practitioner's level of expertise. A practitioner with GIS experience may rely on spatialization if the study requires a high level of spatial detail (description of elementary flows at the geographic coordinate, complex systems scale). For less fine spatialization, upstream inventory regionalization also spatializes the elementary flows by using the geographic scope of the processes by either using an adapted LCA tool or adding geographic information by hand. However, this step can be time consuming and may be limited by access to data. The least time-consuming recommendation for practitioners is to use characterization factors that have already been aggregated by LCIA methodology developers and for which the practitioner has the information (continent, country). <u>For LCIA methodology developers:</u> Set out aggregated CFs by clearly specifying the aggregation proxies and provide the spatial uncertainty of the CFs. <u>For LCA software developers:</u> Suggest LCA software to facilitate flow spatialization by, for example, making it possible to automatically apply the geographic scope of a process to its elementary flows.	
What type of spatial information should be used?	<u>For the practitioner:</u> The type of spatial information that must be provided to spatialized elementary flows depends on the studied impact and the level of aggregation of the CF. The practitioner must therefore consider the impact methodology. <u>For LCIA methodology developers:</u> The type of information that must be provided for native resolutions must be selected based on its relevance to the representation of the geographic variability of the CFs for a given impact. Developers must also consider the geographic information that is accessible to practitioners to develop regionalized CFs. For example, national CF aggregation can be more practical for a practitioner who does not know the biome of land use for a given crop and country or the drainage basin from which a country takes its water.	<u>For LCA software developers:</u> Set out software that can simply and coherently support different types of spatial information.

Question	Short-term recommendations	Long-term recommendations
How can geographic information be added?	<u>For practitioners:</u> The means to add spatial information to spatialize and then adequately characterize the elementary flows depend on the type of software. SimaPro or GaBi may be used for studies that require little flow spatialization or spatialization at a relatively aggregated level. Otherwise, significant effort may be required. For studies that require the spatialization of many flows or spatialization at higher resolution, OpenLCA or Brightway should be used.	
What should efforts focus on?	<u>For practitioners:</u> Selecting the impacts for which the elementary flows must be spatialized should be based on a contribution analysis of midpoint impacts for endpoint impacts. Only impacts with geographic variability must be selected. For IMPACT World+, the regionalized issue categories are: land use, biodiversity, water use impacts, terrestrial acidification, aquatic acidification (freshwater), aquatic eutrophication, marine eutrophication, carcinogenic effects (short and long term), non-carcinogenic effects (short and long term) and respiratory effects (inorganic). Once the impacts are selected, the elementary flows to be spatialized must be selected through contribution analyses based on elementary flows. Elementary flow/process sets must be determined. In other words, it is not necessary to spatialize all of the elementary flows with the same name but only those for the most contributing processes.	<u>For practitioners:</u> Select the elementary flows that must be spatialized by systematically considering their influence on the results and spatial uncertainty. <u>For LCA software developers:</u> Set out software that can compute LCA calculations in a probabilistic manner to carry out contribution analyses that account for data-related uncertainty.
How should efforts be prioritized?	<u>For practitioners:</u> The inventory spatialization effort (concretely, the number of elementary flows to be spatialized) must reflect the study quality requirements set out by the study recipient or sponsor, the means available to carry out the study and data availability.	<u>For LCA research:</u> Develop a more systematic method to assign the priority based on the study objectives, decision-making context, studied sector and available means.
What should the level of detail be?	<u>For the practitioner:</u> The level of detail is driven by the objectives of the LCA and a compromise between time spent and gains in terms of relevance. It is not possible to recommend a specific level of detail. The choice is part of an iterative approach.	<u>For LCA research:</u> Propose a systematic methodology able to identify the level of detail the most suited to the study objectives, decision-making context, studied sector and available means.
Regionalized impact calculation		
How can regionalized impacts be calculated?	<u>For practitioners:</u> SimaPro and GaBi may be used to calculate regionalized LCA. In order to facilitate the work of the practitioner, DB and LCIA method developers must predefine the different spatialization scales of the elementary flows. <u>For LCIA method developers:</u> Predefine spatialized elementary flows in SimaPro and GaBi. <u>For DB developers:</u> Integrate spatialized elementary flows in datasets.	<u>For practitioners:</u> Perform regionalized LCA calculations by accounting for the uncertainty of elementary flow localisation. Aggregated CF-related uncertainty currently accounts for the localisation uncertainty, which is not easily modified by the practitioner. <u>For software developers:</u> Set out simple software for all practitioners to manage localisation uncertainty and resolution differences between the inventory and automatically spatialize process-related emissions during regionalization.
Impact regionalization		
Which impact methodology should be used?	<u>For practitioners:</u> Always select the impact methodology with the most relevant geographic coverage in light of study objectives and opt for regionalized impact methodologies whenever possible. The use of regionalized CFs at the native scale should only occur in response to a specific need in light of the additional spatialization effort that is required. It is best to prefer continent- and country-level aggregated CFs whenever possible. <u>For LCIA method developers:</u> Set out CFs that are aggregated at relevant levels in light of the information that an LCA practitioner could gather. Provide detailed documentation of the impact methodologies, specifically indicating the aggregation proxies that are used. Highlight the area of validity of the CFs that are developed in order to limit irrelevant uses.	<u>For practitioners:</u> Integrate the uncertainty associated with the CFs when calculating results uncertainty. <u>For LCIA method developers:</u> Systematically set out CFs and their related uncertainty; make it possible to parameterize the CFs to best adapt them to the context of the study when required by the practitioner. <u>For LCA software developers:</u> Set out software to calculate uncertainty that integrates CF uncertainty and parameterization.
Interpretation		
How should the impacts be visualized?	<u>For practitioners:</u> If the study does not require specific information on impact localisation, an interpretation of impacts aggregated at the global level remains relevant so as not to increase the practitioner's workload. However, the use of software such as OpenLCA, which makes it possible to visualize impact origins on a map, can provide a new dimension to the interpretation, increase relevance and provide new opportunities, specifically with regards to strategic implementation choices or more targeted actions.	<u>For LCIA method and LCA software developers:</u> Set out software to visualize the original and final locations of the impacts on a map.
How should sensitivity analyses be carried out?	<u>For practitioners:</u> The use of expert knowledge remains the most operational approach to determine the impacts and processes on which sensitivity analyses should be carried out.	<u>For research and software developers:</u> Set out a simplified tool to easily carry out sensitivity analyses for regionalized LCA.

Practical implementation of recommendations in the short term

A decision-support diagram for the regionalization and spatialization of the LCA inventory was set out to ensure the practical implementation of the recommendations by practitioners in the short term (Figure 1). It was developed for use with available tools that enable contribution analysis (e.g. Simapro LCA software). The full report includes a tutorial for this diagram, applied to the case study of manufacturing two plastic in France (conventional polyethylene terephthalate (PET) and biobased polylactide plastic (PLA, from corn)) and their comparison for human health and ecosystem quality impacts. The diagram defines a logical series of steps that may be carried out using common tools such as LCA software, inventory databases and impact assessment methods. The approach described here is considering an LCA assessing endpoint damages but it may be used in the case of midpoint impact categories as well.

The aim of the diagram is to provide tangible support for LCA practitioners seeking to prioritize their regionalization and spatialization efforts (i.e. select relevant processes, impacts and elementary flows). The process is iterative. Certain steps in the diagram depend on the goal and scope of the study and available means and data (green stars) to, for example, determine the number of processes that the practitioner will regionalize as part of the first iteration. There are three phases:

- **Preliminary phase:** This phase aims to identify needs in terms of reducing spatial uncertainty. As a reminder, the main objective of inventory regionalization and spatialization is to reduce spatial uncertainty in order to increase the relevance of the results. Tools to quantitatively assess spatial uncertainty are not yet available. However, a qualitative analysis of the risk of geographic variability within a system and of the studied impacts could be undertaken by the practitioner (e.g. based on expert knowledge). The first question in the diagram is therefore based on the notion of an acceptable level of uncertainty, which refers to the level of uncertainty that the decision-maker (to whom the study is addressed) will accept in the decision-making process. It is the result of a dialogue with the study recipient. Also, while it may not be possible to quantify the level today, the recipient may agree (or disagree) with the limits of the study and therefore require (or not) a more extensive study. It is therefore important that the practitioner be aware and transparent with regards to the limits of the study in terms of regionalization and spatialization.
- **Regionalization phase:** Inventory regionalization is carried out first. Indeed, several of the geographic data collected in this phase may be useful afterwards to spatialize the inventory. This phase is based on the identification of the most contributing processes for which the risk of geographic variability is high. Contribution analyses are suggested at the endpoint level in order to alleviate the practitioner's workload but they may also be carried out at the midpoint level. This phase must therefore be conducted for each indicator that is considered. The regionalization of the selected processes is based on the geographic representativeness of both the nature of the process and the amount required with respect to the modeled region. Actions on the nature of the processes and the associated amount must be carried out in parallel.
- **Spatialization phase:** The spatialization of the inventory is based on the identification of the most contributing impacts for which the risk of spatial variability is the highest. The elementary flow/process sets that most contribute to the selected impacts may then be spatialized. Once regionalization and spatialization have been carried out, the diagram must be iterated in order to verify whether the resulting level of uncertainty is acceptable (or not) based on the study objectives.

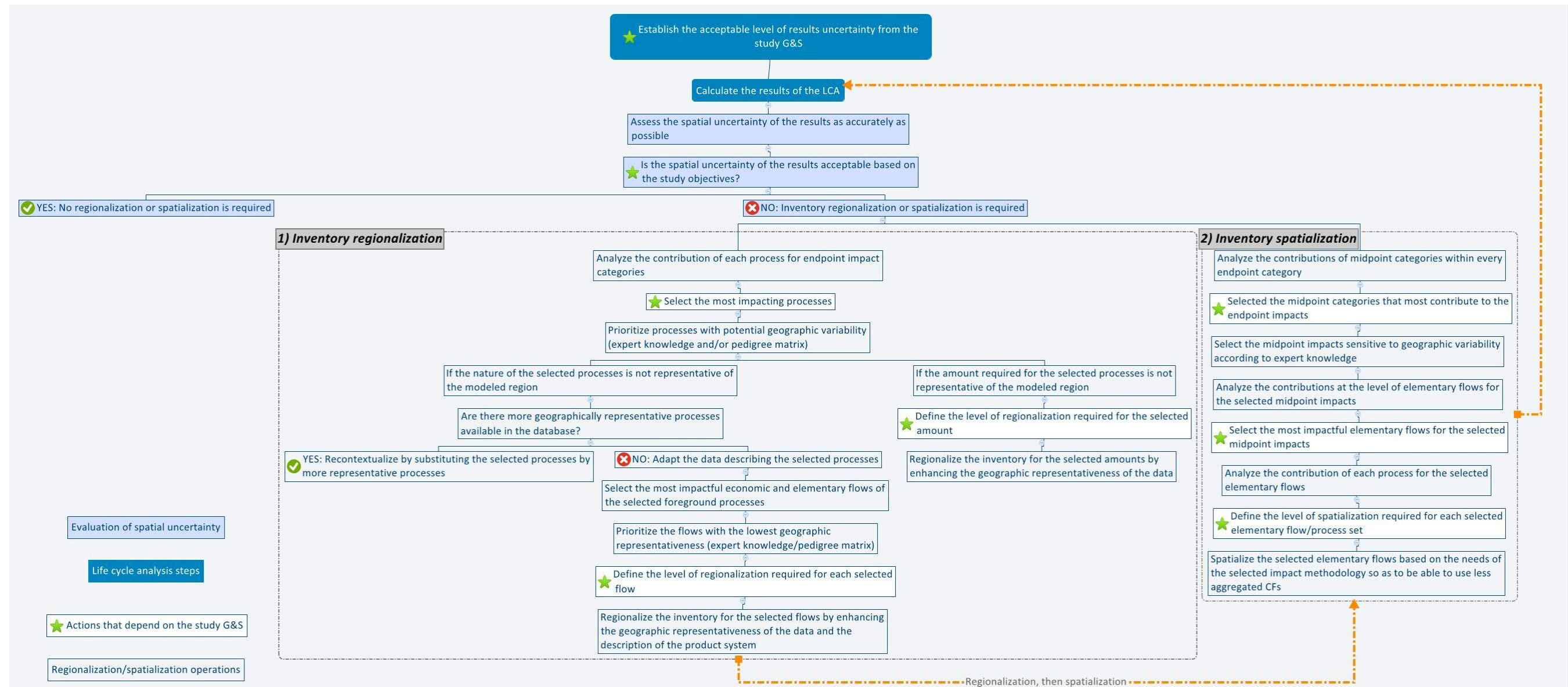


Figure 1 – Logic diagram for the realistic implementation of inventory regionalization and spatialization in LCA by practitioners (Abbreviations: G&S: Goal and scope initial phase of an LCA; CF: characterization factor)

Conclusions and perspectives

This report made it possible to carry out a critical review on the relevance of considering geographic aspects in LCA and the various related approaches. The requirements and recommendations based on the state of the art are linked to the practical and conceptual obstacles to the implementation of these approaches in order to determine practical recommendations on the various ways to integrate this dimension. Recommendations are set out for the short and long terms and for targeted LCA stakeholders. A diagram to support decision-making was designed for the practical implementation of these recommendations by LCA analysts and practitioners. The aim is to optimize the regionalization efforts carried out by LCA practitioners (i.e. being able to reduce the spatial uncertainty of the LCA without considerably increasing the effort required).

The study was also an opportunity to determine the ways in which the geographic aspects impact the LCA. Several case studies are used throughout the report to illustrate these interventions. The various approaches relating to the geographic aspects were categorized, and an analytical framework was established. Parallels were drawn with the practical concerns voiced by practitioners in order to set out recommendations to provide day-to-day support and help them to more efficiently manage the efforts invested. A detailed case study was developed to illustrate the use of the diagram (bio-based vs. fossil-based plastic production).

Long-term recommendations are focused on systematic developments that will inevitably be driven by the experience to be gained in regionalization, which, for the moment, is in its earliest stage (with few stakeholders). The number of experts will certainly rise owing to the practical implementation and integration of the first developments (tools, software and databases fully adapted to spatialization and regionalization). The experience of the operationalization of regionalization will also increase and should expand the practice. This expansion will also lead to enhanced knowledge of the factors that influence regionalization in each impact category, thus making it possible to better structure long-term developments.

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