SCORELCA

STUDY N° 2015-07

PRACTICAL RECOMMENDATIONS FOR PROSPECTIVE LCA / REFERENCES AND EXAMPLES IN THE FIELD OF ENERGY

SUMMARY

June 2017

Scientific coordinators:

- **Florent Querini**
ECOSTATIS - 5, rue Royale
69001 LYON

- **Frédérique Bouvart, Emmanuel Hache, Stéphane Tchung-Ming**
IFP Energies nouvelles - 1 et 4 avenue de Bois Préau
92852 Rueil-Malmaison Cedex

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.

- ✓ This work has been supported by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) www.ademe.fr

- ✓ 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.

I. Context and aim of the study

Greenhouse gas emission objectives for Europe towards 2050, strategies development through consequential life cycle assessment (LCA), studies of products and systems that possess a long lifetime (such as buildings or transportation)… All these issues require a prospective vision of energy and material flows. Therefore, life cycle inventories (LCIs) should include long time horizons to support prospective calculations in LCA. Expert institutes are conducting prospective simulations on energies (e.g. potential energy mixes, innovative solutions, etc.) or resources (e.g. potential availability, potential consumptions, means of extraction and associated impacts) at long-term horizons (2030, 2050). Using these studies, other institutes are developing LCIs associated with energies and resources. However, these studies are based on complex methodological choices, not well known and hardly predictable.

In this framework, SCORE LCA wanted to conduct a study in order to:
- Establish a state of the art of existing inventories and analyze these inventories,
- Establish recommendations to use these inventories in LCA,
- Illustrate the study with concrete examples.

II. Overview of the methodology

This section presents in a short manner (summary sheets) the methodology to follow when conducting a prospective LCA. It is, for a practitioner already familiar with the study, a guidebook when he/she conducts a prospective LCA.

0. PROSPECTIVE SCENARIO TYPOLOGY			
	Direction 1 – project objectives *Clarify the question(s) raised in the study and its context.*	**Direction 2 – development process** *Characterize the nature of the data and scenario methods used*	**Direction 3 – Scenario content** *Qualify the content of the scenarios by analyzing its level of integration*
Polarity	**Exploratory scenarios** (What can happen?) **vs. decisional** (How to reach a given target ?)	**Intuitive** (based on qualitative date / judgments from participants) **vs. formal** (based on rational and analytic tools) **approach**	**Complex** (scenarios with intricate causal relations, illustrating alternative development schemes based on a large amount of actors, sectors and large time and spatial scales) **vs. simple** (scenarios with a limited coverage)
Scenario characteristics	**Topic** Is it a societal question? Is the study dealing with a given sector or region? Is the question related to a given group (institutional, private…)? **« Client »** What is the purpose of the study (creative thinking, strategic decision, communication…)? What is the point of view (industrial operator, municipality, public decision-maker…)? What is the considered dissemination process (internal, restricted, public, event-specific…)? Who is implied in the scenario design process? **Point of view** Is it a forecasting (assessing the future from a current starting point, i.e. an exploratory scenario) or a backcasting (identify compatible paths with a pre-defined end-state, i.e. normative scenario) scenario? Is the study about considering a given future year (fixed point / « photograph ») or the trajectory covering a time period **Scales** What is the time scale, with what resolution? What is the spatial scale, with what resolution?	**Nature of the data: quantitative / qualitative respective shares** Qualitative data = based on expert judgments (mental models) Quantitative data = based on the use of quantitative tools and formal models: simulation, forecast, system analysis, etc. Quantification can occur at different stages: to sort, quantify and harmonize the knowledge provided by experts (mixed intuitive/formal approach) or to build long-term trajectories using dedicated tools (models based on economic theory). **Type of model and use** Is there one or several models used to generate the scenarios? If so, which type of models? • Simulation, optimization (on which parameter?) or recursive models? • Top-down (macro-econometric models, computable general equilibrium models, etc.), bottom-up (partial equilibrium model with sectorial coverage to specify) or hybrid (e.g. integrated economy-energy-environment model) models? **Organization and resources** Data collection: participative (e.g. expert group or survey) or centralized (bibliography review carried out by a small number of authors) approach? Resources: large or limited resources? **Orientations / constraints linked with the context of the study** Is there one/several opinion biases influencing data choices (e.g. division by 4 of GHG emissions by 2050, 100% renewable energy scenario, etc.)?	**Time dimension** Trajectory or point in the future? What is the level of details (year, month, day…) of the scenario? For quantitative models: nature of the anticipations of agents? Discount rate? **Spatial dimension** Is the scenario regional, national or multi-national? What is the level of disaggregation? Is the level of details built considering its imbrication in a larger scale? Is this choice adequate given the studied phenomena? **Sectorial dimension** Is the study considering one or several sectors? How are they interconnected? Are the sectors of interest described in a coherent manner regarding their importance in the study? **Nature of the variables and boundary conditions** Are the variables of the scenario part of the same field (e.g. assumptions on technologies) or are they heterogeneous (economy, demography, technology, etc.)? Can we identify structural hypotheses at the limits of the scenario (legal, behavioural…)? **Dynamics and level of deviation** Are the scenarios extrapolating past trends or illustrating disruptive scenarios, with swift changes and bifurcations? **Uncertainties and quantitative models** Is the uncertainty taken into account in the scenarios? Is it exogenous (sensitivity analysis, Monte-Carlo simulations…) or endogenous (stochastic programming, robust programming…)?

1. GOAL AND SCOPE OF THE STUDY

The following steps **must** be followed by the practitioner in order to ensure the transparency required for interpreting the results. If one step is skipped, the practitioner has to precise why he/she did not treat this step so that the interpretation can be conducted knowingly.

1.1 Objectives :

Context of the study? Are the decision-maker / commissioner and the practitioner the same person? Does the commissioner want to limit the scope to one or several trend scenarios or does he want to study scenarios integrating breakthroughs and deviations compared with past trends (if so, they should be identified)?

Is the context of the study affected by an ideological bias (explicit or underlying)? Does the study aim at calculating the way to reach a pre-defined target or is it exploring the field of possibilities? In case of breakthroughs and deviations, what are the drivers (e.g. climate-related / technological / industrial policies, sharp behavioral changes, etc.)?

Which typology (a, b or c) does the study belong to?

a.	*b.*	*c.*
LCA of an existing product or a range of existing products at a future time horizon	LCA of a product extrapolated from laboratory scale to commercial deployment	LCA of a whole sector (e.g. transportation, energy) in a prospective context

1.2 Nature of changes

Is the study related to a decision or a change?

Yes Is the change internal or does it go beyond the studied system?		*Yes* Section 1.3
Internal Section 1.3	*Beyond* Consequential LCA (SCORELCA 2012-01)	

1.3 Time horizon

Short-term	*Medium-term*	*Long-term*
The characteristics of the system can be known by extrapolating existing data. Policies affecting the system are also known.		Data are very uncertain and extrapolation is not straightforward. The system might experience technological breakthroughs or radical behavioral changes. Future orientations (economic / industrial / tax / energy policies) are vague or unknown

1.4 Product and range of products

One product	*Range of products*
Technical data mainly	Broader perimeter + economy and policy-related data regarding respective market shares of the different products

1.5 Functional unit (FU)

Validity of the FU over time? If long-term study, "scenarisation" of the FU?

What is the time perspective of the FU?

Photograph at a given time horizon	*Evolution between now and a given time horizon*

1.6 Scope of the study (foreground vs. background)

Definition of the boundaries and first identification of prospective data

Foreground	*Background* Dynamics of the sector	
Time horizon and dynamics of the sector	*< foreground* Leave the perimeter as it is	*> foreground* Move to the foreground

1.7 Choice of environmental impacts for characterisation

The relevance of the following impacts may decrease with the time horizon :

Scarcity	*Economic modelling*	*Damage*:	*Normalisation*
E.g. CML2001 Abiotic Depletion Potential, Water scarcity	E.g. ReCiPe resources, externalities	E.g. endpoint impacts	E.g. European-equivalent

1.8 Validity of allocation methods

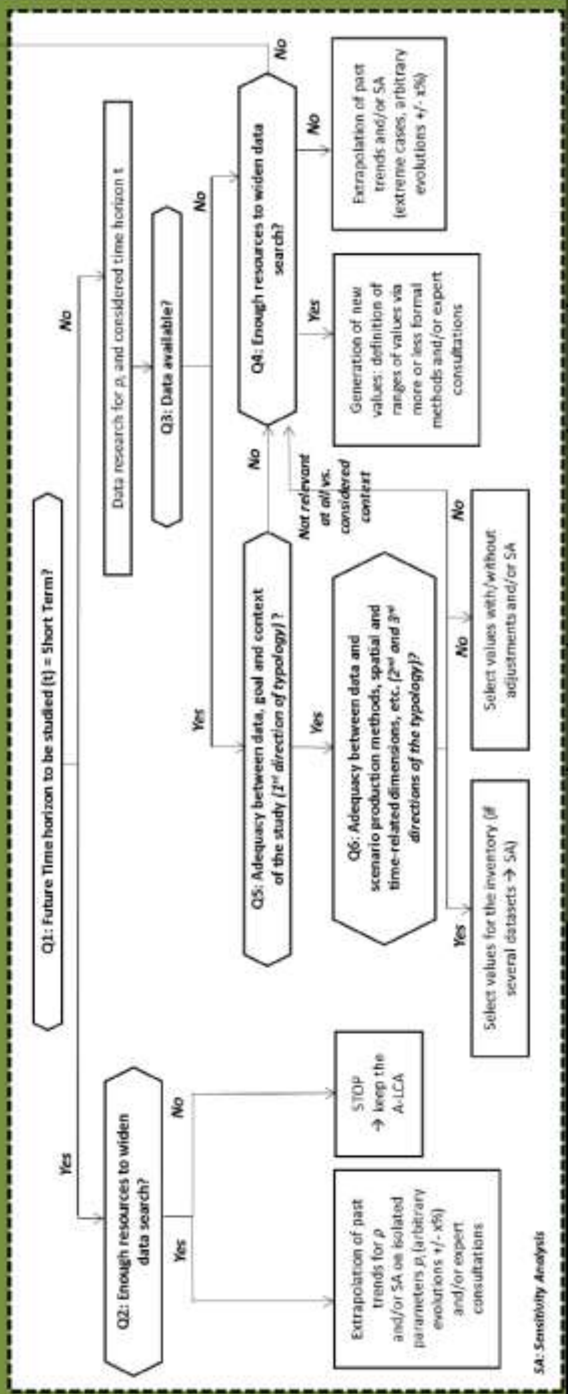
Two specific cases may be problematic in a prospective context:

Co-product treated as a waste at $t_{initial}$ and becoming a product with an economic value at t_{final}.	*Economic allocation only valid at $t_{initial}$*

2. LIFE CYCLE INVENTORY : IDENTIFICATION OF PARAMETERS TO CONSIDER FOR PROSPECTIVE EVALUATION AT THE GIVEN TIME HORIZON	
Two available methods	
Subset S1	*Subset S2*
Conduct a first attributional LCA at $t_{initial}$ and identify the hotspots for every impact characterized. Keep the hotspots corresponding to parameter likely to change at the time horizon considered.	If out-of-trend scenarios are considered, identify breakthroughs and potential deviations to enlarge data search to additional parameters

3. LIFE CYCLE INVENTORY : DECISION TREE

Get and choose data using the following questions:



Q1: Time horizon of the study?	
Short term Q2	*Medium-long term* Q3

Q2: Enough resources to widen data search?	
Not enough Attributional LCA at $t_{initial}$	*enough* 1 .Extrapolation of past trends of parameters 2. Expert consultation 3. Sensitivity analysis on isolated parameters

Q3: Available data for p at considered time horizon?	
No Q4	*Yes* Q5

Q4: Enough resources to widen data search?	
No Extrapolation of past trends, sensitivity analyses, expert consultation. Revision of goal and scope of the study.	*Yes* Formal methods (such as Delphi)

Q5: Adequacy between objectives and context of the study (typology, direction 1)	
Yes Q6	*No* Q4

Q6: Adequacy between data and scenario production methods, spatial and time-related dimensions, etc. (directions 2 and 3 of the typology) ?	
Yes Use the data	*No* Adapt the data. Otherwise, Q4

4. GETTING THE DATA		
4.1 Energy-related data Refer to studies presented in 4.4 before searching for other sources.		
4.2 Mineral and metal-related data Seek information on producer association websites and conduct academic literature research (e.g. using Scopus or Google Scholar). For instance:		
Aluminium The Aluminium Association (www.aluminum.org), European Aluminium (www.european-aluminium.eu/), Association Française de l'Aluminium (http://www.aluminium.fr/industrie/associations/afa), World Aluminium (www.world-aluminium.org), etc.	*Steel* World Steel Association (https://www.worldsteel.org), Steel Manufacturers Association (steelnet.org/), Eurofer (www.eurofer.org/), etc.	*Minerals* National Mining Association (http://nma.org/), International Minerals & Mining Association (http://www.iom3.org/international-mining-minerals-association), International Council on Mining and Metals (https://www.icmm.com/en-gb), etc
4.3 Extrapolation of past data Use institutional websites, such as INSEE, Eurostat, Data.gouv.fr, etc.		

4.4 Etudes dans le domaine de l'énergie

	Actors	Countries	Use of Model	Scenarios			
				Geographic coverage	Sector Coverage	Time Horizon	Trajectories ?
ADEME *Visions énergétiques 2030 - 2050 de l'ADEME*	Public	France	No	France	Energy sector, supply and demand	2050	No
ADEME *Mix électrique 100% ENR ?*	Public	France	Yes	France + countries at the border	Production, storage, consumption and electricity trade	2050	No
BP *BP Energy Outlook*	Private	UK	?	World	Energy sector, supply and demand	2035	Yes
ExxonMobil *The outlook for Energy : A View to 2040*	Private	US	?	World	Energy sector, supply and demand	2040	Yes
RTE *Bilan prévisionnel de l'équilibre offre-demande d'électricité en France*	Private	France	Yes	Western Europe 12 countries	Production, storage, consumption and electricity trade	2030	No
Agence Nationale de la Coordination de la Recherche pour l'Energie *Scénarios de l'ANCRE pour la transition énergétique*	Academic and research center	France	No	France	Energy sector, supply and demand	2050	Yes
Enerdata *Global Energy Scenarios to 2040 / Understanding our energy futur*	Private	France	Yes	World	Energy sector, supply and demand	2040	Yes
AIE *World Energy Outlook*	International Institution	International	Yes	World	Energy sector, supply and demand	2040	Yes
Commission Européenne *EU energy, transport and GHG emissions trends to 2050 / Reference scenario 2013*	Academic and research centers	Europe	Yes	Europe 28 countries	Energy sector, supply and demand	2050	Yes
AIE *Energy Technology Perspectives 2015 - Mobilising Innovation to Accelerate Climate Action*	International Institution	International	Yes	World	Energy sector, supply and demand	2050	Yes
World Energy Council *World Energy Scenarios Composing energy futures to 2050*	Public & Private	International	Yes	World	Energy sector, supply and demand	2050	Yes
Energy Modelling Forum *Publications relatives aux exercices de l'EMF*	Academic and research center	International	Yes	Variable	Variable, global or energy sector	2050+	Yes

<table>
<tr><th colspan="4">5. INTERPRETATION</th></tr>
<tr><td colspan="4">5.1 Data consolidation and scenario building
This step is recommended, particularly when using a large amount a data.

Several data sources can be used during the previous steps. Ensure in this step that data are not contradictory, e.g. optimistic expert reports vs. study using conservative assumptions.

In case several data are available for one or several parameters, build scenarios based on consistent values for these parameters. The scenario formative method (cf. section 2.2.2.1 of main report) can also be used to ensure this.</td></tr>
<tr><td colspan="4">5.2 Critical analysis</td></tr>
<tr><td>Clearly explicit the hypotheses in order to take into account the limitations of the study during the interpretation of the results.</td><td>Compare result contributions between $t_{initial}$ and t_{final}. Be vigilant when high disparities are observed.</td><td>Analyze results while taking into account the potential obsolescence of environmental characterization models.</td><td>Use external data to assess the relevance of data used in the study: e.g. assumptions on growth, oil prices, etc.</td></tr>
</table>

III. Foresight for energy and resources: history and overview of methods

History generally records the creation, in 1946, of the RAND Corporation and it then becoming an independent think tank as the starting point of modern "foresight" or "prospective" or "futures" assessment. However, it would appear that we need to go a lot further back into history to find the sources of this forecasting or forward-looking discipline. With the first utopias (Plato's Republic , Thomas More's Utopia , François de Rabelais' Thelema , and Francis Bacon'sNew Atlantis), some authors down through history have developed constructions of the world that are built on philosophical, moral, sociological, or political thinking. Economists, and economic theory more generally, have also contributed plenty to constructing the discipline. Admittedly, the concept of "foresight", "futures", or "prospective" assessment did not appear in the major works of economic thought of the 18th and 19th Centuries, but the concerns of certain economists (Malthus, Jevons, and Marx, the formulations of their hypotheses and the conclusions they came to outline the reflexes of prospective assessment methodology, in particular as regards natural resources and their depletion, possibly to exhaustion.

Admittedly the industrial revolution made it possible to lay down the markers for the issues constituting the core of the activity of foresight or prospective assessment (consumption trajectories, depletion of resources, technical-economic approach), in particular carried by considerations related to the trajectories of raw materials demand. However, it did not make it possible to provide an overall structure for a scientific discipline relating to foresight or prospective assessment. The industrial revolution process took nearly one century to spread throughout Europe, and such a piecemeal development was not conducive to taking into account an overall set of issues and/or a common geography. And so we had to wait until after the Second World War and a common movement for reconstruction, and for satisfying planning needs and/or strategic and sector-based needs (in particular military ones) to see modern foresight and prospective assessment become structured scientifically at international level. The Second World War marked a disruptive change for the discipline of foresight or prospective assessment. Firstly, a methodological disruptive change, since the post-war period corresponded to a certain form of rationalization of the activity. Secondly, a geographical disruptive change, since two centers of foresight gradually imposed themselves, one in the United States (Rand Corporation, and Hudson Institute), and the other in France (Centre d'Etudes Prospectives, and Futuribles International).

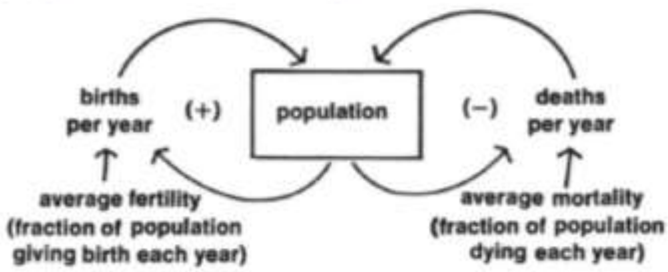
From the methodological point of view, the period from 1945 to 1960 corresponded to a form of rationalization and of development of a scientific discipline "for the construction of futures" that was based on scientific development methods. This rationalization took place in three ways: (i) through the prevalence of technological scenarios; (ii) through the construction of alternative scenarios in most studies; and (iii) the professionalization of the discipline. American foresight or prospective assessment, funded to a large extent by the military-industrial complex, thus started to structure various methodologies inherent to these changes: game theory, modeling, impact matrices, and the Delphi method. In parallel, two major changes reinforced those practices: the development and deployment of new technologies such as the nuclear bomb and the massive use of pesticides, and a certain propensity to forecast demographic doom and disaster.

The second centre of development of prospective or foresight assessment was located in France, where two "families" of prospective assessment specialists (Gaston Berger, Bertrand and Hélène de Jouvenel) put in place their own organizations and their own periodicals. French prospective assessment is focused more on issues of long-term national planning, and, unlike technological foresight assessment, the French, and more generally European discipline has a vision that is more humanistic, utopian, and breaking with the past.

Whereas environmental concerns emerged as of 1945 in the United States, in particular due to debates on nuclear armament and power, and on the use of pesticides, it was not until the late 1950s and early 1960s that alarmist lines of speech about these issues were heard in Europe. And as of the late 1960s, the concern for depletion of natural resources had become generalized in the international economic and societal debate, witness the Stockholm Conference in 1972, and the founding of the Club of Rome, a genuine catalyst in international awareness of environmental issues. Published in 1972, the report by the Club of Rome, The Limits to Growth, using a simulation model developed by the Massachusetts Institute of Technology (M.I.T), pointed, for the first time, to the risk of a global shortage of raw materials, based on long-term scenarios. The authors of the report did not give any precise projections for the various raw materials, but were alarmed at the possible collapse of the production and consumption model observed since the post-war years.

The model used in the report The Limits to Growth is structured around stocks variables (capital investment, population, natural resources, land, effective capital investment ratio, and pollution) and flows variables (variation in material living standard, per capita food production, and per capita investment). A basic principle of systems dynamics is to introduce "feedback" loops between the various variables of the system, it being possible for such feedback effects to be positive, negative, or stabilizing.

Figure 1 : Example of a population feedback loop



Source: Meadows et al. (1972)

The 1990s saw the emergence of a form of fragmentation of the discipline of foresight or prospective assessment, marked by project-oriented and less all-encompassing foresight. Even after several decades of structuring, prospective or foresight assessment still sorely lacked standardization. The English terminology is not standardized, and what is called "prospective" in French may be termed Futures Studies, Futures Research, Foresight, Futurology, Futuring…. The origin of this lack of common vocabulary lies in particular in the multiplicity of educational backgrounds of the people involved in prospective assessment work: economists, engineers, mathematicians, physicists, sociologists, designers, etc.

Ancient times: intellectual thinking	Magic prediction, soothsaying, prophecy Utopia
1945-1960: Rationalization, and setting up of methodological frameworks	Prevalence of technological prospective assessment in the United States Planning-oriented and normative prospective assessment in France Systematic construction of alternative scenarios Professionalization, founding of establishments in France and in the United States Dissemination of research findings, and writing of works
1970-1980: international structuring and industrialization of the discipline	Globalization of the issues and of the activity of prospective assessment: environment, and energy Generalization of normative prospective assessment Development of strategic prospective assessment in companies and marked involvement of companies in that activity Managerial prospects for foresight or prospective assessment

1990-2000: fragmentation of the discipline and unipolar world	Predominance of forecasting and prediction Rise of critical studies Fragmentation into various disciplinary fields, reduction of multi-disciplinarity Marginalization of the discipline
2000-: reunification into a multipolar and unstable world	Return to the concerns of the 1970s: energy and environment Globalization of the constraints and need for policies that evoke futures Strategic prospective assessment and creativity in companies Integration of R&D, strategy, and marketing

Table 1 : Phases in structuring the discipline

The historical details mentioned above illustrate how numerous authors have always wanted to define and study possible futures. Supplementary to this analysis, another review of the literature was conducted to identify and explain the various practices, approaches, and tools used in foresight or prospective assessment.
Beyond the confusion surrounding the terminology as pointed out above (we should remember that there is no clear, precise, and shared definition of the concepts of foresight or prospective assessment, or of scenarios), the second detailed study of the bibliography revealed a wide diversity of methods associated with foresight or prospective assessment, and a multitude of ways of presenting them.
However, there is a certain consensus on the general philosophy governing such exercises. Foresight or prospective assessment is seen as a fundamentally cross-cutting discipline that aims to define and to study possible futures in order to enlighten decisions and actions. Practitioners agree that the object of the exercise is "not to predict the emergence of future events, but rather to highlight the major forces that can steer the future in different directions". A distinction can be made between two sets of forces that contribute to shaping the future of socioeconomic systems:

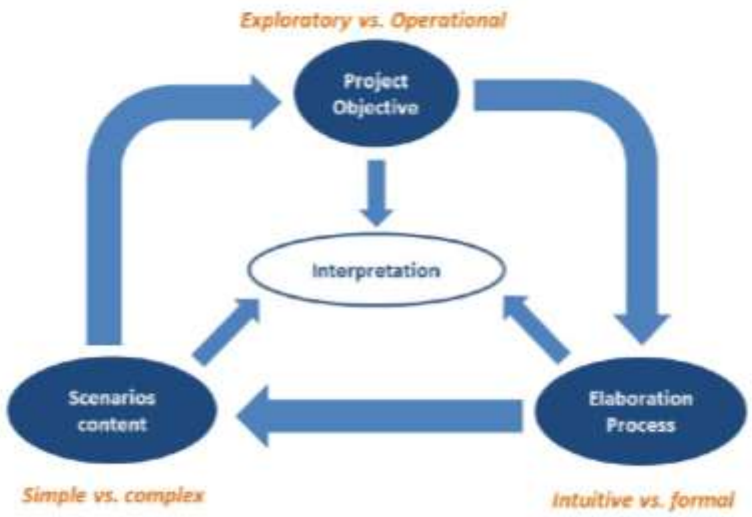
- the forces for change: "drivers" corresponding to technical changes (new technologies, progress, etc.), economic changes (prices, policies, etc.), and social changes (in lifestyles, behaviors, etc.) that contribute to shifting the system away from its initial state;
- and the forces for inertia: "restraining" forces of the technical type (limited technical progress, high costs, etc.), or of the economic, political, or structural types (bureaucracy, vested interests, etc.) that pull the system back towards its initial state.

The key challenge with foresight or prospective assessment consists in appraising the combined effects of these sets. These component forces are firstly difficult to ascertain individually – the further away the future, the more the effects of them are uncertain – and secondly increasingly complex in their interactions. This growing complexity and the unpredictability of the systems lie at the heart of the approach and justify the need for foresight or prospective assessment, and the associated efforts to structure the methodologies.

For the needs of the study, certain definitions of foresight or prospective assessment of scenarios have been proposed for clarification purposes. The distinction between prospective assessment and scenarios still poses a problem: for some, scenarios correspond to a prospective assessment or foresight technique, while for others, the two concepts coincide or overlap in part. For Mutombo et al. (2007), for example, foresight or prospective assessment covers all of the techniques and processes for constructing scenarios, but it is not limited to them alone. In the remainder of the study, it was chosen to concentrate on the concept of scenarios because it occupies a central place for energy, and is often used when talking about the long term.
In order to provide a framework for understanding and comparing the results of prospective or foresight exercises, a scenarios typology was developed on the basis of the most consensual details of the literature – essentially taken from van Notten et al. (2003), Börjeson et al. (2006) and Mai et al. (2013). This typology constitutes a medium making it possible to develop a critical analysis with a view to subsequent use of the available data, e.g. in the course of a prospective Life Cycle Assessment (LCA).
We should remember that there is no one unequivocal presentation of scenario typologies. Compared with others, the approach selected offers the following advantages: i) being broad enough to address a large number of studies; ii) explaining the place occupied by methodology in the scenario-writing process; iii) being sufficiently pragmatic and operational to give practical entrance keys; and iv) being relatively analogous to the LCA practice, in particular in the sense of the ISO standards.

Overall, this typology can be broken down into three main directions that cover the main stages in the development of the scenarios: defining the objectives, followed by the process of constructing the scenarios, and finally by producing their content (Figure 2). This dynamic vision of the process translates the strong influence of the definition of the objectives of the study (direction 1) on the choices of methods and of input data (direction 2) that themselves influence the content of the scenarios (direction 3). The process may also be circular if the study is a recurrent one, or indeed if the results of the analysis lead to looking again at the question asked. Each of the directions has a "polarity" and includes a non-exhaustive list of structural elements corresponding to characteristics of scenarios. We should note that most of these characteristics do not suggest a binary categorization but rather elements of qualitative and thus partly subjective assessment.

Figure 2 : Structure of the typology of prospective scenarios



Source: IFPEN from Van Notten et al. (2003)

This typology offers a relatively fine analytical framework enabling a practitioner to be aware of the choices of data and methods to which they adhere implicitly by using the results of a prospective study. On this basis the practitioner can then defend their choices when establishing a prospective Life Cycle Inventory (LCI) by selecting the study(ies) enabling them to satisfy as well as possible a criterion of overall consistency (consistency of the studies between themselves and consistency of the frameworks under which the studies were conducted with the study context specific to the LCA). The main implications associated with each direction are as follows:

- Direction 1: The objectives and context specific to the study (identities of the commissioners and practitioners of the study, in particular) are important items to take into account for selecting prospective or foresight data (e.g. energy mix). Exploratory studies can, due to their ambitions, generate thinking, and produce "extreme" scenarios. Their plausibility may be limited, which does not necessarily adversely affect the utility of the exercise because the significance of the message lies in its qualitative lessons. Conversely, the more decisional scenarios generally have a more "operational" dimension.
- Direction 2: The method(s) used to generate the scenarios are structuring items in interpretation of them and thus in potential use of them in another context. The raw or gross values derived from the scenarios do not have any positive intrinsic value – they are essentially incorrect. It is therefore generally difficult to discriminate between the results on such bases. Conversely, the design process is a component item of the "anticipatory framework" of the scenario, to which we adhere by using the associated results. We should note that when sensitivity studies are necessary, it can be advantageous to rely on work that has more pronounced quantitative bases. Such work generally offers higher internal consistency.
- Direction 3: The analysis conducted about the third direction should make it possible to better ascertain the "use value" (i.e. the value for the user), of the scenarios used for integrating prospective or foresight data into the LCI. Generally, comparison of the differences between the scenarios contains more information than the scenarios in absolute terms. In the same way as a

decision-maker seeking to identify the comparative value of the scenarios that are submitted to them, a person in charge of a study must – prior to extraction – estimate the potential variation of the data of interest by i) identifying the possibilities with multiple scenarios; ii) using, as far as possible, sensitivity analysis; iii) adapting the tools used to suit the questions asked; iv) using alternative methods, in particular non-quantitative methods, for broadening the field with experts views…

In order to illustrate use of the scenarios typology, about a dozen reference prospective studies were analyzed using this framework. This also made it possible to highlight firstly the diversity of approaches, and secondly the relative lack of transparency of certain pieces of research work: it is often difficult to clearly identify and get all of the desired information on the study context, the methods and tools used to produce the scenarios, or indeed on the nature of the input data.

Table 2 : Polarity and structural elements of the 3 directions of the proposed scenarios typology

	Direction 1 – project objectives *Clarify the question(s) raised in the study and its context.*	Direction 2 – development process *Characterize the nature of the data and scenario methods used*	Direction 3 – Scenario content *Qualify the content of the scenarios by analyzing its level of integration*
Polarity	**Exploratory scenarios** (What can happen?) **vs. decisional** (How to reach a given target ?)	**Intuitive** (based on qualitative date / judgments from participants) **vs. formal** (based on rational and analytic tools) **approach**	**Complex** (scenarios with intricate causal relations, illustrating alternative development schemes based on a large amount of actors, sectors and large time and spatial scales) **vs. simple** (scenarios with a limited coverage)
Scenario characteristics	**Topic** Is it a societal question? Is the study dealing with a given sector or region? Is the question related to a given group (institutional, private…)? **« Client »** What is the purpose of the study (creative thinking, strategic decision, communication…)? What is the point of view (industrial operator, municipality, public decision-maker…)? What is the considered dissemination process (internal, restricted, public, event-specific…)? Who is implied in the scenario design process? **Point of view** Is it a forecasting (assessing the future from a current starting point, i.e. an exploratory scenario) or a backcasting (identify compatible paths with a pre-defined end-state, i.e. normative scenario) scenario? Is the study about considering a given future year (fixed point / « photograph ») or the trajectory covering a time period **Scales** What is the time scale, with what resolution? What is the spatial scale, with what resolution?	**Nature of the data: quantitative / qualitative respective shares** Qualitative data = based on expert judgments (mental models) Quantitative data = based on the use of quantitative tools and formal models: simulation, forecast, system analysis, etc. Quantification can occur at different stages: to sort, quantify and harmonize the knowledge provided by experts (mixed intuitive/formal approach) or to build long-term trajectories using dedicated tools (models based on economic theory). **Type of model and use** Is there one or several models used to generate the scenarios? If so, which type of models? • Simulation, optimization (on which parameter?) or recursive models? • Top-down (macro-econometric models, computable general equilibrium models, etc.), bottom-up (partial equilibrium model with sectorial coverage to specify) or hybrid (e.g. integrated economy-energy-environment model) models? **Organization and resources** Data collection: participative (e.g. expert group or survey) or centralized (bibliography review carried out by a small number of authors) approach? Resources: large or limited resources? **Orientations / constraints linked with the context of the study** Is there one/several opinion biases influencing data choices (e.g. division by 4 of GHG emissions by 2050, 100% renewable energy scenario, etc.)?	**Time dimension** Trajectory or point in the future? What is the level of details (year, month, day…) of the scenario? For quantitative models: nature of the anticipations of agents? Discount rate? **Spatial dimension** Is the scenario regional, national or multi-national? What is the level of disaggregation? Is the level of details built considering its imbrication in a larger scale? Is this choice adequate given the studied phenomena? **Sectorial dimension** Is the study considering one or several sectors? How are they interconnected? Are the sectors of interest described in a coherent manner regarding their importance in the study? **Nature of the variables and boundary conditions** Are the variables of the scenario part of the same field (e.g. assumptions on technologies) or are they heterogeneous (economy, demography, technology, etc.)? Can we identify structural hypotheses at the limits of the scenario (legal, behavioural…)? **Dynamics and level of deviation** Are the scenarios extrapolating past trends or illustrating disruptive scenarios, with swift changes and bifurcations? **Uncertainties and quantitative models** Is the uncertainty taken into account in the scenarios? Is it exogenous (sensitivity analysis, Monte-Carlo simulations…) or endogenous (stochastic programming, robust programming…)?

IV. Prospective LCA and typologies

Generally, prospective studies are based on a variation of the technical/economical parameters of foreground processes (i.e. belonging directly to the scope of the study), while background data are fixed. For instance, while the yield of photovoltaic panels increase between tinital and tfinal in several studies, electricity, fuels and raw materials data are modeled using fixed life cycle inventories.

Only Fukushima et al. (2002) have proposed an approach allowing the dynamic variation of inventories across time thanks to their LCML algorithm. Nonetheless, because of its complexity and the impossibility to implement it in commercial LCA software, their method has not been further used.

The different LCA studied are presented on a map, available on:
https://drive.google.com/open?id=1-z9XbmJfzAnNk4YSoSuu2ye-PV4&usp=sharing

Based on a literature review (existing prospective LCAs) and on the results of an online survey which has been conducted specifically for this SCORELCA study[1]; several prospective LCA typologies have been proposed.

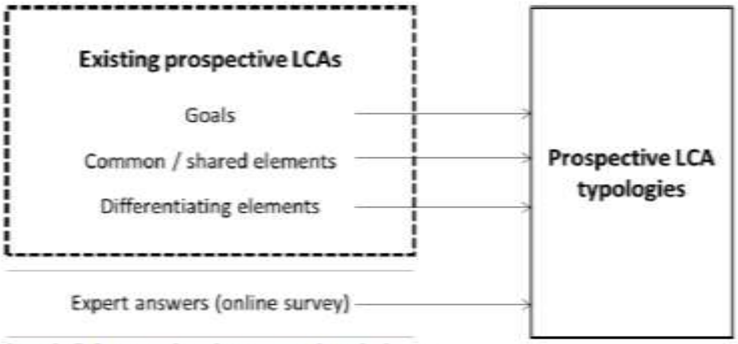


Figure 3 – Prospective LCA typologies: methodology

The following elements have been considered in the typology definition:

- Objectives :

(a) LCA of a product or a range of product at a long-term horizon,

(b) LCA of a product extrapolated from laboratory to commercial deployment,

(c) LCA of a whole sector (e.g. transportation, energy) associated with prospective scenarios.

- Time horizons:

(a) 2020,

(b) 2050,

(c) 2030,

(d) Others

- Methodologies :

(a) Existing scenarios,

(b) Literature and expert views,

(c) Modeling

- Time:

(a) « photograph » of a given situation in the future,

[1] Online survey conducted in May-June 2016. Both experts from the LCA and prospective fields have been questioned. Answers from 68 respondents were analyzed (55 LCA practitioners and 13 experts in the field of prospective system analysis).

(b) Evolution during a given period of time.

Moreover, the analysis of answers to the online survey highlights the following aspects:

- Lack of transparency of available data and studies,
- Lack of skill to use the models and analyze the available studies,
- Confusion between consequential and prospective LCA.

V. Methodology

The aim of this methodology is not to prescribe, along the practitioner questions and needs, one or several datasets from the literature, since the latter is so broad that it is impossible to inventory all values and references. The actual aim is to help the practitioner specifying its needs and understanding, characterizing and comparing the available data in order to develop a critical analysis and, in fine, argue his/her choice of prospective data in life cycle inventory. Considering the inherent complexity of studying future socioeconomic systems (multi problem-dimension-scale systems), their non-predictability, the growing number of scenarios on energy and resources, the diversity of underlying methods and the disparity of results, a priori reducing the number of literature references by recommending a limited number of prospective datasets does not make much sense. Selecting a subset of scenarios can only be done case by case, regarding the question of the study, its context and its objectives. Therefore, the following methodology is a practical framework aiming at supporting an LCA practitioner analyzing and sorting the available data.

The proposed approach is a set of questions, followed by a decision tree. It is based on the following elements:

- ISO 14040-44 standards for the structure. The method follows 3 steps: 1. Definition of goal and scope of the study; 2. Life cycle inventory; 3. Interpretation. Not all elements of ISO 14040-44 are included but only those for which a special attention should be paid in a prospective context.
- Prospective scenarios and LCA typologies,
- The survey on LCA and prospective studies practitioners.

Each step of the methodology is, as possible, illustrated by concrete cases excepted from the two didactic case studies presented during the intermediary meeting. These two case studies are the following:

- LCA of a B-segment electric vehicle sold in France in 2030, business as usual hypothesis,
- LCA of the passenger car fleet in Europe between 2016 and 2050.

Goal and scope of the study

GOALS

Similarly to conventional LCA, the aim and the context of study must be clearly defined during this step.
Which typology does the study belong to?

(a) LCA of a product or a range of product at a long-term horizon, e.g. LCA of the vehicles produced by a car manufacturer in 2030.

(b) LCA of a product extrapolated from laboratory to commercial deployment, e.g. LCA of a new battery technology developed in a laboratory

(c) LCA of a whole sector (e.g. transportation, energy) ssociated with prospective scenarios, e.g. LCA of passenger mobility in France in 2050.

What is the context of the study? Are the decision maker / commissioner and the practitioner the same person? Does the commissioner want to restrain the scope to one or several trend scenarios or does he/she want to study scenarios integrating deviations and breakthroughs?
Is the context of the study marked with an explicit or underlying ideological bias? Does the study aim at reaching a predefined objective or is it exploring the realm of possibility? In case of deviations and

breakthroughs, what are the drivers generating them (e.g. policies related to climate, technology or industry, swift behavioral changes, etc.)?

This step must be defined in the most transparent manner since it conditions the validity and the interpretation of the final results.

NATURE OF CHANGES

Is the LCA studying a decision or a change? If so, is the change internal or does it extend outside the boundaries of the system studied?
When the change extends outside the system studied, the LCA is not only prospective but requires using methods specific to consequential LCA.

TIME HORIZON OF THE STUDY

This step specifies the time horizon of the study. Three categories are proposed: short, medium and long term. These three levels are defined by their degree of visibility and uncertainty related to the studied sector:

- Short term: the characteristics of the system can easily be known, by extrapolating the existing data. The policies impacting the system are known.
- Long term: data are very uncertain and extrapolation is not straightforward. The system may experience technological breakthrough or swift behavioral changes. Future orientations (economic / industrial / tax / energy- policies) are vague or unknown.
- Medium term: between short and long term.

Belonging to a given horizon depends on:

- The characteristics of the sector: equipment and infrastructure lifetime (buildings: several decades, car: 15 years, electric network infrastructure: undefined, nuclear power plant: 60 years, phone: 1 to 3 years, etc.), demand dynamics (stable for cars, growing for electronic equipment, etc.), technological progress (slow for electricity, fast for electronics), dependency to policies and standards.
- The level of certitude linked with policy visibility.

PRODUCT AND SYSTEMS OF PRODUCT

This step allows specifying the nature and the volume of data to collect. Indeed, in the eventuality only one product/service is studied, the prospective data to collect will mainly be technical. In the case of a system of products, i.e. when studying a range of product with different characteristics but addressing the same needs, the perimeter will be broader and will include economic data, as well as policies and every other data related to the shares of the different products.

FUNCTIONAL UNIT

This step allows checking if the functional unit (FU) is valid over time. Indeed, the use of a product may change, particularly in a long-term study. For a long-term study, it may be useful to define a specific FU for different scenarios.
Moreover, the FU must specify if the LCA is a photograph at a given time horizon or if it studies an evolution between now and given time horizon (trajectory).

SCOPE OF THE STUDY / FOREGROUND AND BACKGROUND

The perimeter of the study allows sorting data between foreground (for which the practitioner has to look for) and background (for which the practitioner usually uses external databases such as ecoinvent or GaBi). In a prospective approach, the practitioner also has to take into account the steps / processes that may vary over time and for which prospective data are necessary. These data are linked with the time horizon and the dynamics of the sector. Thus, prospective data are necessary when the dynamic of the system implies changes at the considered time horizon.
Moreover, prospective data can also be necessary when the dynamics of background systems are faster than the main system.

CHOICE OF ENVIRONMENTAL CHARACTERIZATION IMPACTS

The choice of environmental impacts can be linked with the prospective aspects of the study. Indeed, some impact indicators can be less relevant depending on the time horizon, in particular:

- Impacts based on scarcity: CML2001 Abiotic Depletion Potential, Water scarcity,
- Impact based on economic modeling : ReCiPe resources, externalities,
- Impacts based on damages : endpoint-level methods,
- Normalized impacts: European equivalent.

VALIDITY OF ALLOCATION METHODS

The methods and allocation factors can be less relevant over time. Two situations can occur:

- Co-product treated as waste at $t_{initial}$ and becoming a product with an economic value at the considered time horizon.
- Economic allocations only valid at $t_{initial}$

Life cycle inventory (LCI)

The proposed methodology to conduct the LCI step follows a decision tree containing 3 steps and 6 questions.

STEP 1 : IDENTIFICATION OF PARAMETERS TO CONSIDER FOR PROSPECTIVE EVALUATION AT THE GIVEN TIME HORIZON

Two methods are proposed to identify the parameters:

- Conduct an attributional LCA at $t_{initial}$ and identify the hotspots for every impact retained. If these hotspots are linked with parameters likely to vary at the considered time horizon, group them in a subset E1 of sensitive parameters p to vary.
- If out-of-trend scenarios are studied, identify the potential breakthroughs and deviations and enlarge the data search to additional parameters (not already included in E1).

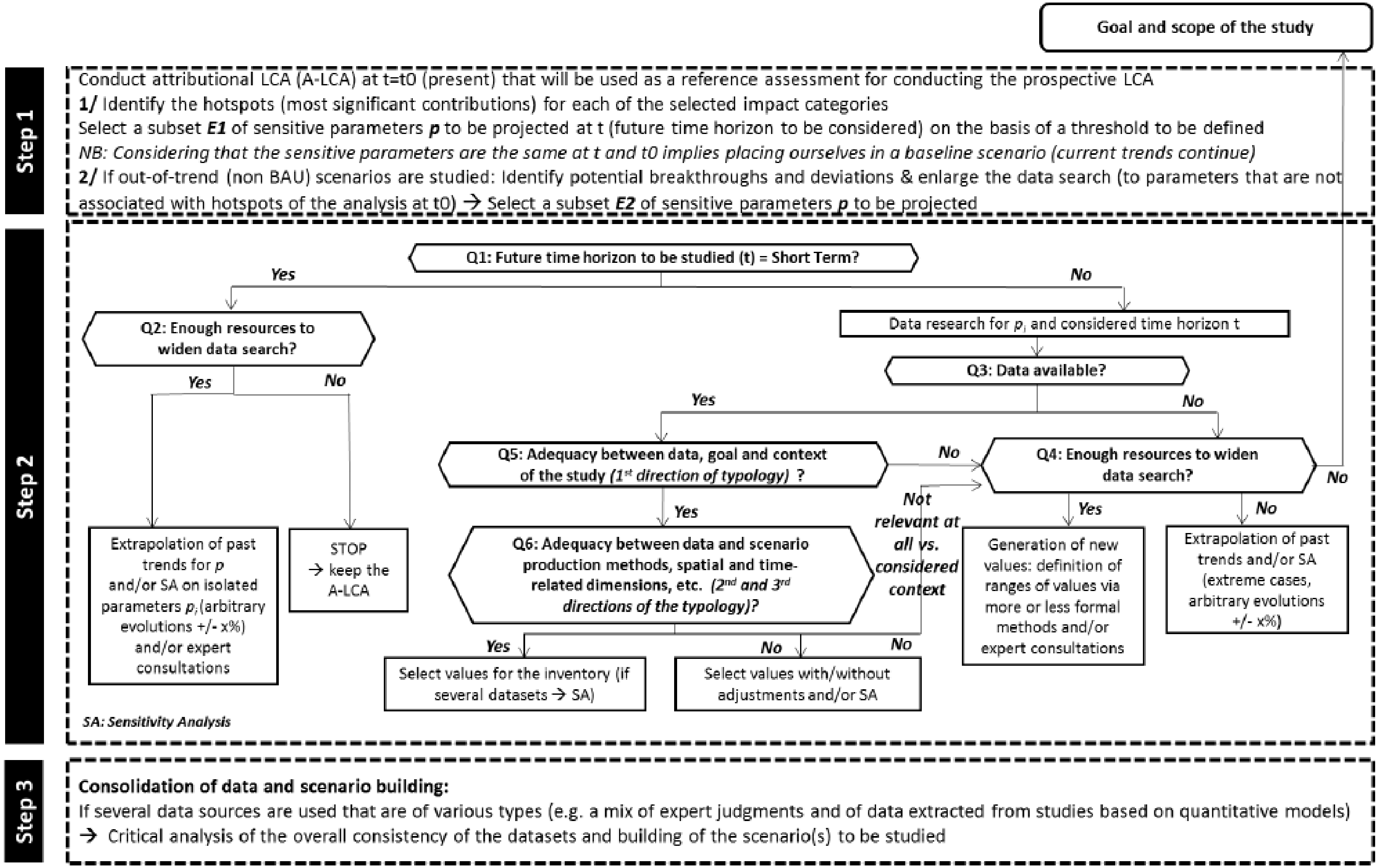


Figure 4 - Decisional tree for conducting the prospective LCI

Q1: TIME HORIZON OF THE STUDY

Depending on the time horizon of the study, the practitioner will move to question Q2 (short term) or question Q3 (medium – long term).

Q2: ENOUGH RESOURCES TO WIDEN DATA SEARCH

If resources are insufficient, we recommend conducting only an attributional at $t_{initial}$, while still having a critical analysis of the results obtained. In case the practitioner has enough time, three approaches can be considered and combined:

- Extrapolations of past trends on p,
- Sensitivity analyses on isolated parameters p_i, taking into account arbitrary evolutions (+/- x%),
- Expert consultation.

Q3: ENOUGH DATA FOR PI AT THE TIME HORIZON CONSIDERED

If data are not available ->Q4

If data are available -> Q5

Q4: ENOUGH RESOURCES TO WIDEN DATA SEARCH

If the resources dedicated to the study do not allow conducting the data search, two alternatives are proposed:

- Extrapolation of past trends, sensitivity analyses and expert consultation, in a similar manner as in Q2,
- Revision of the goal and scope of the study if the data cannot be estimated.

If the resources dedicated to the study are sufficient, the data can be generated using formal methods (such as the Delphi method) and/or using more intuitive methods (expert opinion).

Q5: ADEQUACY BETWEEN DATA, GOAL AND CONTEXT OF THE STUDY

This question is linked with the first direction of the prospective scenario typology: are the underlying hypotheses related to the data used corresponding to the objectives and the context of the study? If so, the practitioner can move to question Q6. If not, the practitioner has to move back to question Q4.

Q6: ADEQUACY BETWEEN DATA AND SCENARIO PRODUCTION METHODS, SPATIAL AND TIME-RELATED DIMENSIONS

This question is linked with the second and the third directions of the prospective scenario typology. If several datasets are adapted, the practitioner can use them directly or eventually design different scenarios / sensitivity analyses. In case they do not correspond, it is either possible to adapt them to the context by modifying them or to move back to question Q4.

Data consolidation, consistency and interpretation

DATA CONSOLIDATION AND SCENARIO BUILDING

Several data sources may have been used during the previous steps. It is necessary in this step to ensure that there are not in conflict, e.g. optimistic expert opinions with a study using conservative hypotheses.
In case several data are available for one or all parameters, it is useful to build scenario based on consistent association of these parameters. The scenario formative analysis can be used for that purpose.

CRITICAL ANALYSIS

Combined with the interpretation of a « conventional » LCA, interpreting a prospective LCA implies the following cautions:

- Clearly explicit the hypotheses in order to take into account the limitations of the study while interpreting the results (transparency),
- Compare the contribution of the results between $t_{initial}$ and t_{final}. Large disparities must alert since they may due to errors / imprecisions in the hypotheses and data used,
- Analyze the results, taking into account the potential obsolescence of some environmental indicators,
- Use external data to assess the relevance of the selected data: e.g. hypotheses on growth, oil prices, etc.