

Chapter 21

Future-Oriented LCA

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Abstract LCA is often applied for decision-making that concerns actions reaching near or far into the future. However, traditional life cycle assessment methodology must be adjusted for the prospective and change-oriented purposes, but no standardised way of doing this has emerged yet. In this chapter some challenges are described and some learnings are derived. Many of the future-oriented LCAs published so far perform relatively short-term prediction of simple comparisons. But for more long-term time horizons foresight methods can be of help. Scenarios established by qualified experts about future technological and economic developments are indispensable in future technology assessments. The uncertainties in future-oriented LCAs are to a large extent qualitative and it is important to emphasise that LCA of future technologies will provide a set of answers and not ‘the’ answer.

Learning Objectives

After studying this chapter, the reader should be able to

- Explain the challenges of prospective LCA studies.
- Explain the differences between foresight and LCA.
- Provide an overview of some tools for performing prospective assessments.

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21.1 Introduction: The Need for Future-Oriented LCA

LCAs are often regarded as suitable for decision support also in decision-making that concerns the future, e.g. in technology and product development or strategic decision-making. Surveys on the use of LCA in Nordic countries and in European industry and business show that LCA is frequently used for strategic purposes (e.g. Roos et al. 2016; Frankl and Rubik 2000). Thus, LCA practitioners and researchers apply LCA as a tool in strategy processes and longer term planning. However, the basic economic, environmental and societal/social conditions change with time, and current conditions may therefore not be valid. The environmental interventions of future systems are a product of very complex interactions and dependencies of these basic conditions and thus uncertain. Additionally, scaling issues, i.e. that operational-scale technologies differ from laboratory or pilot scale, adds uncertainties (e.g. Frischknecht et al. 2009; Caduff et al. 2014). Distinctions between retrospective and prospective LCAs, and between state-oriented LCA with an accounting perspective and change-oriented LCA (attributional or consequential) are made (Rebitzer and Ekvall 2004) and traditional life cycle assessment methodology must be adjusted or changed for the prospective and change-oriented purposes. However, no standardised way of doing this has emerged.

As explained in Part II of this book, the core of process-based LCA has traditionally been a detailed analysis of the processes of the entire life cycle of the product. It is assumed that the product is known and fully specified and, in principle, all materials, resource consumptions, discharges and environmental impacts, including all subprocesses, should be assessed. In practice, there is always a limit to how much information is included and a tendency to focus more on some parts and processes than others.

These limitations can become a problem if the LCA is narrowly considered a question of obtaining the results and figures that come from the process. If instead the LCA is considered a process of learning in which the people and organisations involved in the process acquire knowledge about the product and its environmental impacts, the limitations will often appear less severe. One of the important outcomes of an LCA is the knowledge obtained about which parts of the life cycle process are uncertain and of which there exists no precise information. To make proper sense of the results, a detailed understanding of the background of the figures is needed.

Over the years, prospective elements and learning/decision elements have increasingly been introduced into LCA (e.g. Wender et al. 2014). The prospective elements of LCA concern both the production system or functional unit that is the object for the LCA, as well as the general societal conditions surrounding this system. In strategy management literature, the latter is often labelled the system's strategic environment; not to be confused with the system's physical environment which most often is in focus in life cycle assessments. In practice, it is often difficult

to distinguish exactly between the product system and its societal condition. One practical way to distinguish this is that the characteristics of product systems can be affected (selection of materials and their flows) by its manufacturer whereas the societal conditions (such as cost of energy and commodities, availability of materials, cycles in national economies) cannot be affected. Second, future changes are not only affected by possible decisions. Future changes in both the product system and in its surrounding societal conditions are affected by four types of factors: (1) socio-cultural, (2) technological, (3) economic and (4) political/legal factors.

With this in mind we define prospective or future-oriented LCA as a systematic assessment of future events and developments in society, technology, economy and policy that in the long-term could considerably influence the product system (and/or functional unit) and its societal conditions and hereby the environmentally relevant flows.

It is argued that integration of long-term scenarios in LCA is needed for use of LCA in typical strategic planning and public policy planning. A more explicit and systematic handling of uncertain aspects are important dimensions in this and have been addressed, e.g. by Miller and Keoleian (2015).

A working group (WG) was established by the Society for Environmental Toxicology and Chemistry (SETAC) to address the issues of developing systematic scenarios as a basis for studies of future product systems (Weidema et al. 2004). Its report provides rather detailed recommendations for development of scenarios with a particular focus on the needs in LCA. Scenarios include three basic elements “the definition of alternative future circumstances, the path from the present to the future, and the inclusion of uncertainty about the future”. In this chapter, the aim is to provide a broader understanding of the concepts and methods for future-oriented studies as well as linking up to literature on future-oriented LCA. Scenario analysis is therefore just one of the methods included here to address the uncertain future.

21.1.1 Foresight and Future-Oriented LCA

The practical processes to strategically deal with the future development of science, technology, economy and of the society has been studied since the 1940s (Jantsch 1967; Bell 2009). Many of the widely used foresight techniques were developed by American military planners during the Cold War period—aiming to ‘think the unthinkable’ and to prepare for it—and later-on adapted by large corporations to strengthen their intelligence capability. Over time, the conceptual and methodological development of prospective technology assessment (also known as and used interchangeably with the term ‘foresight’) has broadened, and produced a considerable and varied toolbox with ample applications in governmental policy-making and corporate strategizing. Today, it has become an important

practice to deal with uncertainties in technology development and strategically guide decision-making, planning and actions.

Whereas LCA seeks a systematic and comprehensive analysis of environmental impacts over a product's life cycle, technology foresight usually does not focus particularly on environmental aspects of future technologies. On the contrary, technology foresight is often criticised for having a too optimistic and positive view on the future technologies disregarding the environmental impacts and risks that also are connected to the technologies. Furthermore, it is well documented that experts in general are over-optimistic in their assessment of the future potential of the technology in which they have their expertise (Tichy 2004). The principles of life cycle assessment are thus very different from the principles of technology foresight. On many points the two approaches are quite opposite, as shown in Table 21.1. But how can technological foresight then be relevant to LCAs that are usually made for present-time products and systems? The key elements of life cycle assessment are the identification and analysis of all the different processes in the entire life cycle of an industrial product or a technological system, including careful accounting of the materials and energy flows associated with the processes. Technology foresight studies normally address partial elements of the (future) technological systems in the sense of the main technical functionality, while a life cycle assessment gives a more comprehensive picture of the actual technological system in use and its different components. In its traditional form, LCA is a very detailed method, focusing on certainties and the most precise data available, while a foresight study is sketchier, process-oriented and—at least to some extent—trying to deal with the uncertain aspects of future developments.

The next section explains some of the methods applied in foresight studies a bit more in detail.

Table 21.1 Characteristics of the methodological approaches of LCA and technology foresight—in a traditional and archetypical form

Issue	Life cycle assessment	Technology foresight
Concept of time	Present and near future	Future, long-term perspective
Procedural focus	Analysis, assessment, interpretation	Synthesis, reflection, interpretation, elucidation
Data sources	Data, information, records, etc.	Information, opinions, questionnaires, statements, etc.
Analysis object	Products or services with the same functionality	Technical functionality of technologies and systems
Delimitation of analysis	Life cycle perspective, environmental impacts	Many issues and themes
Key results	Objectified results, aiming to provide precise answers	Sketches, scenarios, strategies and uncertainties

Adapted from Rasmussen et al. (2005), see also text

21.2 Prospective Methods

In this section the aim is to provide a broader view of different methods that can be applicable in future-oriented LCAs. Prospective technology analyses (or technology foresight) apply a variety of methods and approaches that have been adapted from standard social-science research methodologies. One group is the quantitative methods such as S-curve analyses, analogies, experience curves, and different sorts of extrapolations of time series. LCA studies most often apply this type of methods when there is need to predict the future and they are mainly applicable for the short-term analyses (see also Table 21.2). Quantitative methods are often difficult to apply in prospective analyses where uncertainty is high, time horizons long and changes in technology or market situation can be large. We are then left with qualitative methods (or judgmental methods) such as literature reviews, expert panels, scenarios, futures workshops and Delphi surveys.

An overview of the use of technology foresight methods in policy making can be found in Popper (2008). An overview of their use in corporate contexts can be found in Daheim and Uers (2008).

Over the last 50 years, systematic methods of analysing expected futures have been developed. Foresight has appeared as a common name designating these methods. The purpose of technology foresight is not prediction of the future or exclusively to identify data about a technology in the long-term future. The purpose is rather to establish a fuller understanding of the possible technology futures and the forces shaping the future developments. The goal is to support current strategic discussion and decision-making as well as possible rather than predicting precisely. Foresight develops a well-informed context for current decisions.

21.2.1 *Diffusion Modelling, S-Curves and Analogies*

Diffusion modelling, S-curves and analogies are all quantitative methods for prospective technology analyses. S-curves or ‘Utterback-curves’ are based on the assumption—or empirical observation—that technologies usually go through a distinct technological maturity life cycle on the market (Utterback 1996). Related models are diffusion models or Fisher-Pry substitution models (Fisher and Pry 1971). The S-curve hypothesis states that the market growth is slow in the early phase (infant or ascent phase). In the next phase market growth rapidly increases (growth phase), and in a third phase (market maturing) growth flattens out or even becomes negative, see Fig. 21.1. Hereafter, new technologies fulfilling the same needs or several needs in a better or cheaper way overtake the market. It is often useful to check scenarios for the future diffusion of the technology with traditional S-curve methodologies. Traditional market forecasts based on extrapolation of historical data in the early phases of a technology’s market presence tend to underestimate the growth rates of the market, whereas the later forecasts

overestimate the growth rate. The reason for this is that the technology has reached a more mature phase resulting in a less steep market growth. Anticipating an analogue technological maturity life cycle can be helpful, but the overall problem is to estimate when the market peak occurs.

21.2.2 *Experience Curve (Learning Curve)*

The concept of experience curves is based on learning curves first introduced by T.P. Wright reporting on a study of cost reductions in airplane production in America in the 1920s and 1930s (Wright 1936). The experience curve in contrast to learning curves applies not only to labour-intensive situations, but also to process-oriented ones. During the 1960s and 1970s experience curves were increasingly used in industrial forecasting and marketing strategy (Fusfeld 1970; Boston Consulting Group 1972). The experience curve describes how cost reductions appear in line with accumulated production. Accumulated production is used as a substitute for accumulated experience in the learning system. The mathematical expression of the experience curve can be written in the following way:

$$C_t = C_0 \cdot Q_t^{-k} \quad t = 1, \dots, T, \quad (21.1)$$

where observations of the unit cost at time t , C_t are calculated as average over the observed variables. C_0 is the cost of the first unit produced. Q_t is the accumulated production at time t , and, finally, k is the learning factor.

In future-oriented LCA learning curves can be used for estimating future efficiencies of new technologies, and it has been shown that the learning factor (k) is fairly stable for each specific technology and is typically between 0.9 and 0.75 (Weidema et al. 2004). It has also been shown that emission coefficients are closely related to the cumulative investment and it is suggested that conservative learning factors (0.85–0.95) can be used as proxies for the physical efficiency improvements in flows (Weidema et al. 2004).

As examples, the performance and efficiency of operational-scale technologies will differ from those of laboratory-scale or pilot-scale equipment in terms of performance and efficiency figures gained with process modelling. Gavankar et al. (2014) suggest that LCAs based on immature data should be interpreted in conjunction with their technology and manufacturing readiness level. This can in practice relate to the learning curves.

21.2.3 *Delphi Studies*

Delphi is characterised by Linstone and Turoff (1975) “as a method for structuring a group communication process so that the process is effective in allowing a group of

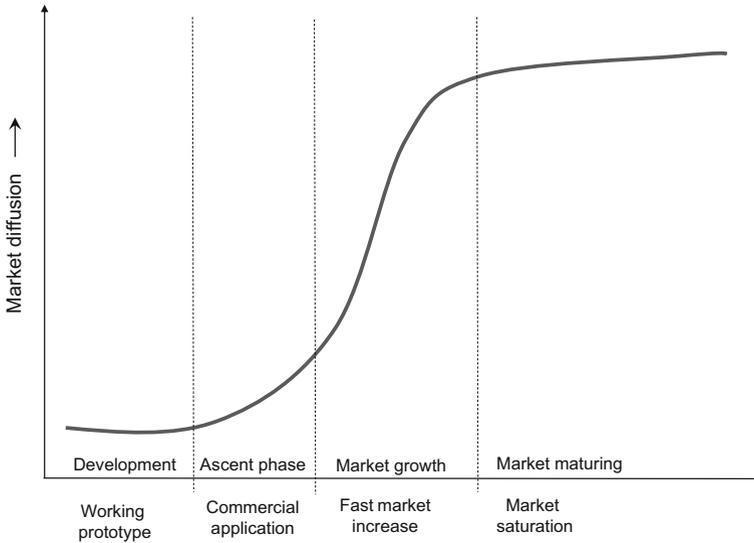


Fig. 21.1 Example of an S-curve

individuals, as a whole, to deal with a complex problem”. In practice, Delphi studies are often based on questionnaires sent to a selected panel of experts. The foresight period may range from few years to 20 or 30 years. A Delphi process includes typically two rounds where the results from each round are communicated to the participants in order to achieve a consensus or reveal divergent (bipolar) viewpoints among the participants. Technology foresight studies based on the Delphi method have been carried out on a national level in Japan since the 1970s. Delphi surveys are often based on the formulation of ‘statements’ about the future societal, technological, economic or political development. An example could be ‘More than 75% of all new wind turbines are without gear-boxes’. Statements can be formulated as a desk-study or using iterative processes at workshops or via questionnaires. The statements are then exposed to a number of questions such as: ‘Period in which the statement will have first occurred’, ‘If realised what will be the impact on the environment?’, etc. Lists of such statements and questions are sent in two rounds to selected experts. When filling in the questionnaire the experts are typically also asked to state their level of expertise on each of the statements. See the example in Table 21.2. For statement 1 some kind of normal distribution can be observed on the period in which the statement will first occur. For statement 4 the results indicate disagreement among the respondents.

Table 21.2 Example of Delphi statements and affiliated questions related to future environmental impacts of wind turbines

Statement No.	Statements about future wind power technology	Your level of expertise on the field of the statement			Period in which the statement will have first occurred					Impact on wind power's cost competitiveness			Environmental effects due to manufacturing and decommissioning of wind technology						
		Own field of work	Knowledgeable	No knowledge	Before 2005	2006 – 2010	2011 – 2015	2016 – 2020	After 2021	Never	Highly beneficial	Beneficial	Neutral	Harmful	Highly harmful	Highly beneficial	Beneficial	Neutral	Harmful
1	10% of Europe's electricity from wind power	14	28	2		8	28	11	5		15	19	4		7	15	12	3	
2	More than half of all new turbines in Europe are placed offshore	11	29	4		6	10	10	8	6	5	17	8	7	4	11	15	5	
3	40% cost reduction of wind produced electricity relative to 2001	13	24	7	1	10	7	12	3	4	26	5	1		7	9	11	4	
4	Global implementation of Kyoto targets	5	30	9	1	8	9	3	10	5	13	18	2		10	19	12	1	
5	50% increase in EU and European national expenditure on wind power related research	13	21	12	7	8	9		11		7	17	6	3	6	13	9	5	1
6	Other renewable source of energy (other than hydro) becomes fully competitive with wind	7	20	8	1	7	8	9	10	2	3	11	11	6	4	10	15	1	
7	Competitive concept for storage of wind energy (e.g. based on hydrogen)	5	26	15		10	5	9	9		11	14	3		6	9	10	4	

Source Andersen and Bjerregaard (2001)

21.2.4 Scenarios

Scenarios can be defined as stories describing different but plausible futures. They are developed using techniques that systematise the perceptions of alternative futures (Schwartz 1998). Scenarios are basically tools for taking a long-term view in a world of great uncertainty. Up until the 1970s, most future studies aimed at predicting the future using various computer-based forecasting techniques. The rise of scenario analysis in strategic planning activities has largely been ascribed to the inability to provide credible forecasts and the perceived need for introducing tools for imagining, analysing, discussing, suggesting and preparing for sets of equally ‘plausible’ futures and running scenarios is essential when handling prospective assessments.

21.2.5 Technology Roadmaps

Technology roadmapping is a forward-looking approach developed and widely used to support strategic long-term planning within organisations like industrial companies (e.g. Phaal et al. 2004). As the name indicates, road map studies analyse and discuss the road ahead for the development of a specific industrial product or a specific technology. Roadmaps seek to capture the surrounding conditions, threats and opportunities for a particular group of stakeholders in a technology area or in an area of technology application.

Technology roadmaps can take on different forms. Usually, they include a graphical representation of the future developments as a central element. These often appear as multi-layered charts describing connections between different sub elements and different expected trends and developments. The connections between the different developments also indicate how and in what time period different actors are meant to contribute. Figure 21.2 shows an example of such graphical representations of roadmaps. Horizontally, it goes from the past to a future vision and vertically it goes from identification of, e.g. specific skills through development of a technology based on these skills, a product delivered by the technology and to the market for that product. Usually, a graphical representation of the future development and the interplay between different sub-elements is a central element in a roadmapping exercise.

Through describing and discussing the possible road ahead, including the problems and risks that can be expected, the roadmap perspective is built up.

The technology roadmapping approach is increasingly applied in foresight studies, especially in those exercises that are focused upon particular industrial sectors like, e.g. the energy sector. Traditional technology roadmapping describes a specific, partial perspective, e.g. the perspective of an industrial company or interest organisation with a clearly defined goal. The approach is thus explicitly subjective and normative. Within the limitations of the subjective perspective, the approach of technology roadmapping can lead to a comprehensive and multi-faceted understanding of a desirable development path for a technology and of the interplay between different kinds of activities (e.g. market, scientific, or industrial activities), different drivers of change, etc.

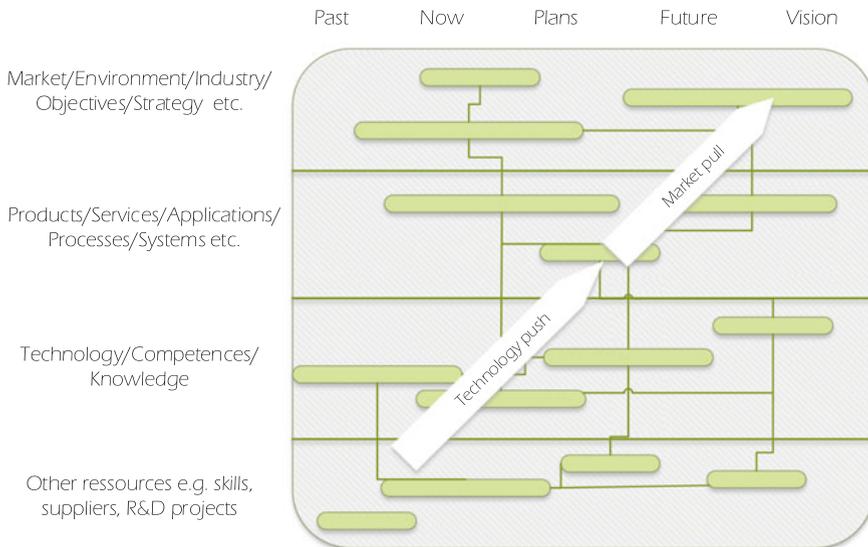


Fig. 21.2 Example of the architecture of a technology roadmap project. After Phaal et al. (2004)

21.3 Key Concepts in Future-Oriented LCA

21.3.1 *Dealing with the Future*

Future orientation is often categorised into short-term (1–5 years), medium-term (3–15 years), long-term (more than 20 years), and very long-term (more than 50 or 100 years). Several types of approaches to the future can be distinguished depending on the purpose of the study.

- *Predictive approaches*, which answer the question “What will happen?” are meant to be defined for simple objects and short-term studies. Predictive studies are forecasts (the likely scenario) and what-if (conditioned to some specific events). Predictive approaches aim at describing the most likely futures and generally involve forecasting current trends into the future creating ‘surprise-free’ or ‘business as usual’ like images of the future.
- *Explorative approaches*, which answer the question “What can happen?” aim at describing a number of plausible futures, which may be possible, desirable/feared and/or realisable, and start out from present trends leading to equally likely futures. They are external (related to exogenous conditions) and strategic (conditioned to some actions completed in a certain way). Cornerstone scenarios are also defined as explorative scenarios and are meant for complex objects (e.g. energy systems) and long-term time horizons.
- *Anticipative or normative approaches*, which answer the question “How can a specific target be reached?” are created on the basis of desirable or feared visions of the future. Anticipative approaches involve working backwards from a future state to find possible pathways to that particular future. This methodology is often termed ‘back-casting’.

In practice, scenarios in future-oriented LCAs are often based on a mix of prediction, exploration and anticipation.

The SETAC WG on scenarios in LCA defined all methods for dealing with the future in future-oriented LCA and divided them into six groups of methods: extrapolation methods, exploratory methods, dynamic modelling, cornerstone scenarios, participatory methods and normative methods, and put them into an LCA application setting as illustrated in Fig. 21.3. When choosing and applying a future-oriented method (e.g. a scenario approach) it is important to keep in mind that the time horizon must be consistent with the goal of the study (Weidema et al. 2004).

An important distinction is made between ‘what-if’ scenarios and ‘cornerstone’ scenarios. ‘What-if’ scenarios are used to compare two or more well-known situations. They are the most widely used and frequently applied in the sensitivity analysis as discussed in Chaps. 11 and 12. ‘Cornerstone’ scenarios are more uncertain and do not necessarily provide quantitative results. They point out a potential direction of future development and have a more long-term perspective. Future-oriented technology assessment in most cases deals with cornerstone

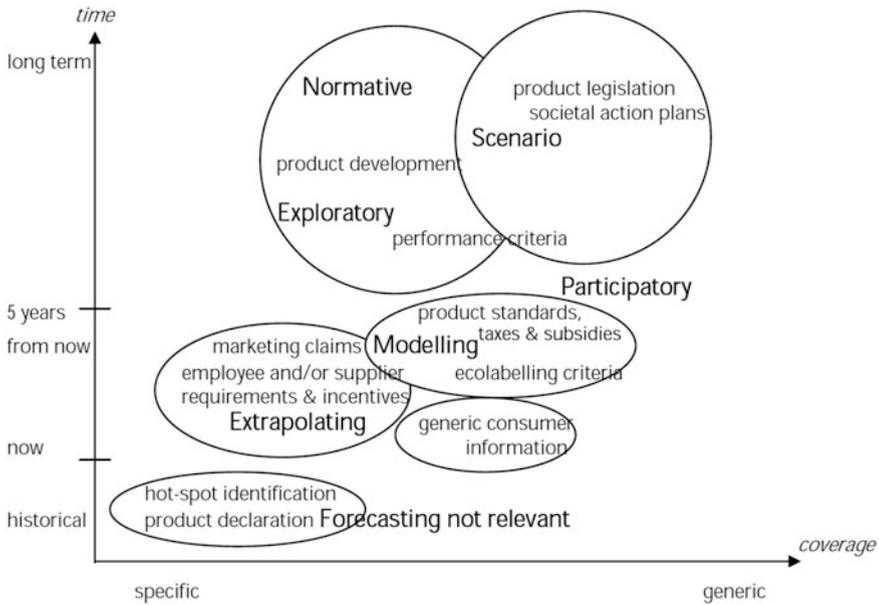


Fig. 21.3 Relevance of different future-oriented approaches in relation to applications of LCA (Weidema 2003)

scenarios and focus of the remainder of this chapter will be on approaches in this category, since these are less developed in the LCA literature.

21.3.2 Dealing with Time Horizons

Time horizons in a future-oriented LCA is a central issue. Choice of time horizon depends on the focus area and the goal of the LCA. For example, foresight for areas that are difficult to change, such as roads and energy supply infrastructure, needs to have a different time horizon than foresight for areas that change quickly, such as information and communication technology. In practice, future-oriented LCA studies often look towards the future in the long-term or medium-term, but set up possibilities for action and recommendations in the short-term.

21.3.3 Dealing with Uncertainty

In this context the term uncertainty does not refer to statistical uncertainty or uncertainty on measurements or data values of given parameters, but uncertainty in

a more qualitative sense. It is uncertainty about what the characteristics of the technology are, how widespread the technology is going to be used, and other open questions and issues that are yet unknown. Therefore, uncertainty in future-oriented LCA studies will necessarily need to be addressed in a qualitative manner, at least in part of the analysis, and cannot be reduced to stochastic, systemic or methodological uncertainties only.

Traditionally, many scientific areas aim at identifying and describing certainties and neglect or underestimate the uncertain aspects and risks connected to the field and to the new knowledge produced. In connection with technology development and techno-scientific activities, this has been called the tradition of objectification or purification (Latour 1993). For example, questions of how the technology will be produced, which use-context it implies, which support technologies, infrastructures and support systems it requires, etc. can be hidden or ignored. Moreover, analyses within the history of science and technology and within the sociology of knowledge, show that a considerable amount of new uncertainties and risks are generated in connection with development of new technology and new knowledge (e.g. Beck 1992).

As a response to this, new forms of analytical practices that focus more explicitly on the uncertainties have been developed (e.g. Harremoës 2003). When dealing with sustainability and environmental aspects of new knowledge and technologies, the way uncertainties and risks are addressed by the different knowledge communities becomes of completely central importance (Funtowicz et al. 1999; Hisschemöller et al. 2001; EEA 2001; Lemons 1995).

An illustration of the traditional focus on certainties is a figure with a circle. Inside the circle is the known. Outside the circle is the unknown, called ‘no-know’ in Fig. 21.4. In between is a large, fuzzy area of partially known but uncertain issues. The fully known area is in fact very small and therefore, dealing with technology development and transition processes to new technological systems is identical to working with the uncertain issues. To be capable of analysis and assessment of the uncertainties is of central importance for the development of new technology areas since they include ‘positive’ opportunities as well as ‘negative’ effects and risks of the new developments.

Two main types of uncertainty are usually pointed out in the uncertainty literature: Epistemic uncertainty (lack of knowledge) and variability uncertainty (ontological uncertainty—due to inherent variability and indeterminacy). See Chap. 11 for further details on both. In connection with decision support through analysis and modelling, a distinction between three levels of uncertainty in between fully determined and total ignorance and indeterminacy have been pointed out (Walker et al. 2003):

1. Statistical uncertainty;
2. Scenario uncertainty;
3. Recognised ignorance.

Scenario uncertainty refers to assessment of possible, plausible futures and the making of—to some degree unverifiable—assumptions in connection with this.

Fig. 21.4 Understanding of 'known' and unknown ('no-know') (Harremöes 2003)



The uncertainties of future-oriented LCA activities belong to a large extent to level 2 and 3, rather than level 1.

From a technology foresight perspective, the differences between technology foresight and LCA can in practice be used productively in the design of strategic, future-oriented studies with sensitivity to environmental aspects (Rasmussen et al. 2005). For example, a combination of technology foresight and LCA were employed in a project in the wind energy area, making it possible to keep a strategic environmental perspective throughout the project (Andersen et al. 2007). From the technology foresight methods, trends mapping, a Delphi questionnaire, scenarios and a number of different expert panels were employed. In the first phase, a full present-time LCA was carried out. A later step in the process was a simplified LCA 'scanning' of selected aspects of the future wind power technology. Figure 21.5 shows the different phases of the project.

On the other hand, the need to forecast future product systems in prospective LCA can also draw a lot upon the principles of foresight, e.g. in the attempt to build scenarios. Some suggestions for the inclusion of forecasting methods are provided by Weidema et al. (2004) in a systematic form as presented in Table 21.3 and in Fig. 21.3.

There has been a number of studies applying prospective LCA in practice with some of them aiming more at the methodological aspects, in particular for assessing emerging technologies (Wender et al. 2014; Frischknecht et al. 2009). When performing LCA for emerging technology cases, practitioners have responded with a number of strategies to be prospective, including:

- Developing structured scenarios within LCA models (Pesonen et al. 2000; Hospido et al. 2010)
- Statistical time-resolved data (Zimmermann et al. 2015)
- Thermodynamic process modelling (Grubb and Bakshi 2011)

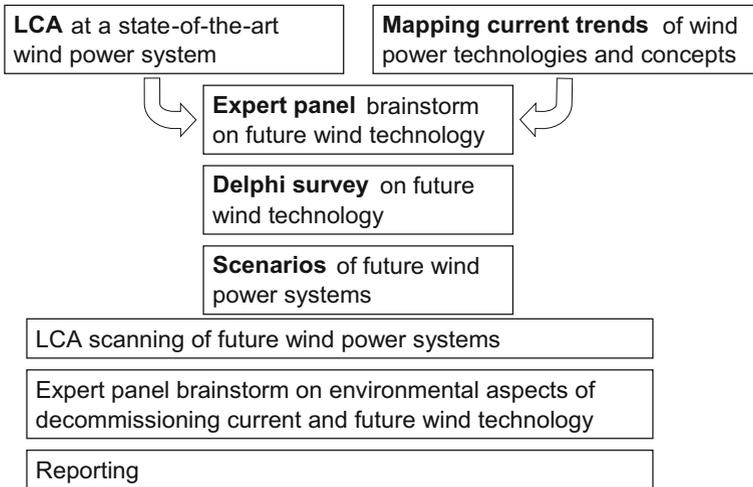


Fig. 21.5 Example of methodological design of a technology foresight-LCA project in the wind energy area. Modified from Andersen et al. (2007)

Table 21.3 Suggested forecasting methods for studies with different time frames and complexity

Term	Complexity	
	Specific and predictable	Less predictable and more complex
Short (1–5 years)–medium (3–20 years)	Extrapolation methods	Dynamic modelling and participatory methods
Long (>20 years)	Dynamic modelling, exploratory and normative methods	Cornerstone scenarios methods

Reproduced from Weidema et al. (2004)

- Consideration of experience curves from analogous industries to identify potential future improvements in efficiency (Wender and Seager 2014)
- Dimensional analysis to explore scaling effects (Caduff et al. 2014; Gavankar et al. 2014)
- Exploring market-driven impacts through consequential LCA (Weidema 2003), and
- Uncertainty bounding analyses to provide upper and lower limits to environmental impact (Eckelmann et al. 2012).

These advances allow the development of life cycle inventories descriptive of future technological developments and accounting for parameter and scenario uncertainty in exploring how the life cycle inventory may change with future developments and alternative process configurations (Wender et al. 2014). However, many of the advances do not address the complex long-term forecasting (Table 21.3).

21.4 Concluding Remarks

LCA is to a large extent being applied to support decisions that extend into the future. There are a number of challenges related to such future-oriented LCAs to which foresight methods may provide important inputs even though both methods are very different. LCAs aim to provide quantitative results, but much of our knowledge of the future is only qualitative. Therefore, LCA of future technologies will provide a set of answers and not 'the' answer. In addition to the steps already taken in any LCA, which to a large extent relate to different extrapolation methods, future-oriented LCA need to establish scenarios and to relate to uncertainties that are not just stochastic but rather linked to scenario uncertainty and recognised ignorance. Scenarios should be established through the help of qualified experts about future technological and economic developments, which are indispensable in future technology assessments. Different types of scenarios are relevant to different situations, e.g. what-if scenarios are relevant in comparison of well-known situations in the short-term and in specific cases, whereas cornerstone scenarios aim to point out a potential direction in the future development with a long-term perspective.

A number of prospective or foresight methods, from extrapolation to technology roadmaps, were presented which all can play a role when performing future-oriented LCA. However, providing more specific guidance in performing future-oriented LCA is difficult due to different requirements and conditions for each specific case in terms of, e.g. time horizon and complexity. Nonetheless, a set of questions about the future technology development in a given field is a helpful tool developed to systematically address the different kinds of driving forces shaping the future technology development in this field. The questions help getting, at first, an overview of the driving forces and barriers and, later, maintaining this overview in the further discussion of the driving forces. The set of questions is presented in Appendix.

Appendix: Questions

The questions are formulated as standard questions which can be specified further in the work in the different technology areas according to the needs. The questions ensure that different types of development mechanisms can be addressed in a systematic manner. It is not expected that answers can be found to all questions in all cases. There will probably be questions which cannot be answered or where only vague guesses can be suggested. One's first answers to the set of questions can be taken up again later in the analysis process, whereby some of the answers and the understanding of the development dynamics can be refined.

The set of questions below is an example of questions that can be used for illuminating future developments in an area (the area in the example is energy

technology). The questions can either be used in a questionnaire survey, for dialogue with individual experts or for reflection internally among the LCA analysts. It is structured in three sections:

- Basics—what technology are we talking about.
- Drivers for technology change.
- Changes resulting from the drivers.

Both ‘positive’ and ‘negative’ drivers (barriers) are meant to be included. The types of driving forces addressed are:

- Technical and technological issues.
- Science and knowledge developments.
- Energy systems—infrastructures.
- Use of the technology—e.g. what role in the electricity systems?
- Where, on which markets, is the technology used—how wide spread is the use?
- Regional and geographical aspects.
- Industrial production of the technology.
- Innovation networks and innovation communities of the technology.
- Public regulation and public support.
- Societal and political concerns.
- Environmental challenges and possible risks.

Each question can be asked for (a) the near future; (b) the midterm future and (c) the long-term future.

1. Basics (in brief)

- 1.1 What technology is addressed?
- 1.2 What different basic technology concepts are available or seen as possible alternatives in the future? By technology concepts we mean for example, thin-film PV, silicon PV, etc.
- 1.3 What are the main elements (sub-technologies) of these technology concepts? e.g. tower, blades, foundation, net connection, etc. of off-shore wind farms, etc.

2. Drivers for technology change

By ‘drivers’ is both meant ‘positive’ and ‘negative’ (limiting) factors influencing the development of the technology.

- 2.1 For each main element: What are the relevant developments in techniques and technological knowledge connected to this component?
- 2.2 For each main element: What relevant influences from generic techno-scientific areas as material research, nanotechnology, biotechnology, biochemistry and information and communication technology can be identified as drivers for change? For example, functional surfaces, biochemical processes, corrosion knowledge, material techniques, sensor technology, microbiologic processes, etc.

- 2.3 What are the relevant developments in integration of the technology in the energy systems and infrastructures? For example, integration technologies, institutional and organisational arrangements, development of fuel supply chains, regulatory procedures, etc.
- 2.4 What are the relevant developments in the use of the technology: what role will it have in electricity systems? For example, central/decentral production; general purpose or specific purpose, niche markets, etc.
- 2.5 What are the relevant developments in dissemination of the technology—how widespread will the use be; on what specific markets?
- 2.6 What regional/national/geographical aspects can be identified as drivers for technology change? For example, specific conditions in some regional electricity systems, climatic aspects, etc.
- 2.7 What relevant developments in industrial production of the technology can be identified as drivers for technology change?
- 2.8 What relevant developments in the knowledge community and the network of innovators of the technology can be identified as drivers for technological change? For example, developments in the ‘industrial sector’ of the technology, industrial innovators/manufacturers, research programmes, other support institutions, etc.
- 2.9 What public regulation and public support can be identified as drivers for technology change? For example, market support, development programmes, etc.
- 2.10 What public, societal and political concerns can be identified as drivers for technology change? e.g. security of supply, employment, safety issues, emission restrictions, etc.
- 2.11 What developments in environmental challenges and risks can be identified and become drivers for technology change?

3. Resulting changes from the drivers

This section concludes from section 2, sketching the picture of the technology in the short-term future, medium-term future and long-term future and pointing out relevant LCI issues.

- 3.1 Taken into account the questions in section 2—What main development path can be identified for the technology?
- 3.2 Taken into account the questions in section 2—What relevant alternative/extreme development paths can be identified?
- 3.3 Direct changes: Technology change.
Picture of the future technology: What will, in brief, be the characteristics of the technology, its design, costs, use and life cycle?
 - Total design and selection of technology concept (also covering material use).
 - Design and the main sub-technologies/main parts.
 - Production processes.

- Installation, e.g. system/support structure, foundation, site preparation, power conditioning equipment, land requirement and storage requirement.
- Operating and maintenance.
- Dismantling and waste handling.

3.4 Expected impacts on LCI issues

How will these changes lead to changes in LCI issues (material/resource consumptions, environmental impacts, etc.)

- Total design and selection of technology concept (also covering material use)
- Design and the main sub-technologies/main parts
- Production processes
- Installation, e.g. system/support structure, foundation, site preparation, power conditioning equipment, land requirement and storage requirement.
- Operating and maintenance
- Dismantling and waste handling

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