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Life-cycle assessment (LCA) is a tool for improving the knowledge base of decision-making. Decision-making, in turn, is about influencing the future. Therefore, explicit and implicit scenarios are essential for the application of LCA. However, the relationship between scenarios and LCA has not been systematically analysed and explored in the past. This is the reason why the Society of Environmental Toxicology and Chemistry (SETAC) Europe launched the Working Group on Scenario Development in LCA in 1998. This report summarises the findings of nearly 4 years of deliberations and discussions. We sincerely hope that this report can contribute to a better understanding of the role of LCA in decision-making. However, because scenarios are a new frontier for the LCA community, it has to be regarded as a starting point, as a base for further scientific analyses, discussions, and developments.

The editors and authors want to thank the numerous persons within and outside of the working group who have contributed to discussions at meetings or by e-mail. All people actively involved in the working group are listed below. We also want to thank Roland Clift and Greg Norris for agreeing to be reviewers for this document. Their detailed comments helped enormously in shaping the final version of this document. In addition, David Hunkeler provided extensive, invaluable comments for all parts of an advanced draft of the report.

Members of the working group (in alphabetical order) who have actively contributed to the discussions and deliberations within the 4-year working period are listed below:

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Peter Sliwka
Guido W. Sonnemann
Michael Spielmann
Alberto Tintinelli
Bo P. Weidema
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Executive Summary

The Working Group on Scenario Development in Life-Cycle Assessment (LCA) was launched by the Society of Environmental Toxicology and Chemistry (SETAC) Europe in April 1998. It has dealt with the issue of developing systematic scenario approaches as a basis for studies of future product systems and environmental impacts. This report presents the resulting discussions, reviews, and implications of different types of scenario concepts. We also present an overview of different methods for futures studies that can be used in LCA. Certain aspects of modelling, in particular in life-cycle inventory (LCI) analysis, are also elaborated because modelling is an essential part of the development of a scenario. The modelling of impact categories within life-cycle impact assessment (LCIA) was the focus of a separate SETAC Europe working group (e.g., see Udo de Haes et al. 1999).

In the context of LCA, we define a scenario as a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future and, when relevant, a description of a path from the present to the future. Scenarios can be an essential tool for investigating and illustrating the uncertainties in an LCA. They may concern the technosphere, the ecosphere, or the valuesphere (i.e., the sphere of value systems). Each scenario includes a scenario frame, which is typically developed as part of the goal and scope definition. It also includes relevant parts of the technosphere, ecosphere, or valuesphere models that form the backbone of the LCI or LCIA (see 'The scenario concept in life-cycle assessment' in Chapter 2, p 7).

On the broad conceptual level, we distinguish between cornerstone scenarios and what-if scenarios. A set of cornerstone scenarios is a set diverse enough to provide an overall view of the studied field. What-if scenarios are used for comparing 2 or more options in a well-known situation where the practitioner is familiar with the decision problem and can set a defined hypothesis on the basis of existing data. Hence, the choice between cornerstone and what-if scenarios depends on the time frame and complexity of the systems involved as well as on the goal of the study (see 'Two principal approaches to scenario development in life-cycle assessment studies' in Chapter 2, p 11).

The description of the future situation is generated through the use of methods for futures studies. Several different methods are available (see 'Futures Studies of Product Systems' in Chapter 3, p 17):

- extrapolation of historical and current trends into the future;
- dynamic modelling, which involves the identification of the mechanisms that influence the future and the modelling of how these mechanisms will interact;
- participatory methods, which seek the insight and opinions of experts and stakeholders to describe probable, possible or wanted future situations;
- exploratory methods, which seek to illustrate the diversity of possible futures by combining analytic techniques with imaginative techniques;
- normative (or goal-oriented) methods, which begin with stating the desired future and then move backwards in time to identify the necessary steps for reaching this goal; and
- cornerstone scenario methods, which combine aspects of the other methods, especially participatory, dynamic modelling, and exploratory methods, with the aim of creating several distinct cornerstone scenarios.

Scenarios are sometimes defined in a more narrow sense, including only what we call ‘cornerstone scenarios' generated through cornerstone scenario methods. Our definition is much broader, including what-if scenarios and scenarios developed with all of the methods above.

Similar to cornerstone and what-if scenarios, different methods for futures studies may be applicable in different cases, depending on, for example, the time horizon of the study and the complexity of the

---

1 As defined by ISO 14040 the term ‘product' includes both services and material goods.
Table S-1 Suggested methods for futures studies with different time frames and complexity

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Term</th>
<th>Specific, predictable processes</th>
<th>Less predictable processes and more complex systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short and medium</td>
<td>Extrapolation methods</td>
<td>Dynamic modelling and participatory methods</td>
<td></td>
</tr>
<tr>
<td>Long</td>
<td>Dynamic modelling, exploratory and normative methods</td>
<td>Cornerstone scenario methods</td>
<td></td>
</tr>
</tbody>
</table>

system investigated (see Table S-1). The choice may also depend on the influence of the decision-maker. Results from extrapolation may be useful for the background system, that is, for parts of the system investigated where the decision-makers do not have a large influence. For the foreground system, the part of the system that the decision-maker can directly control, exploratory and normative methods are likely to provide more useful information (see ‘Step 3: Choosing futures-studies method’ in Chapter 3, p 20).

The discussion provided here on LCI modelling is an elaboration on the prospective (also called ‘effect-oriented’ or ‘consequential’) methodology. Prospective LCI methodology aims at describing the consequences of changes made within the technological system investigated. It is distinguished from a retrospective (also known as ‘descriptive’, ‘accounting’, ‘attributional’) LCI methodology that aims at describing the environmental properties of a technological system. In a prospective LCI, the system investigated is typically expanded to include the processes that are actually affected by a change in the original system. Many allocation problems can be avoided through such a system expansion. What processes are affected depends on the scenarios and, therefore, on the market mechanisms that can be modelled using concepts of competition, price elasticity, and market constraints. Including these concepts in LCI modelling will have implications for the system boundaries (see ‘Prospective Life-Cycle Inventory Modelling’ in Chapter 3, p 28).

Default scenarios for different parts of the technosphere can be developed based on value systems within socio-cultural viability theory (cultural theory; see ‘Default scenarios and their basis in cultural theory’ in Chapter 2, p 6). We demonstrate how 3 extreme value systems that are relevant for decision-making can be the basis for such default scenarios: the hierarchist, egalitarian, and individualist perspectives. These default scenarios may be used when the development of case-specific scenarios is judged to be either unnecessary or infeasible (see ‘Default Scenarios in Life-Cycle Inventory’ in Chapter 3, p 41).

Scenarios for the ecosphere and valuesphere are primarily used in the 2 LCIA sub-phases, characterisation and weighting across impact categories (see Chapter 4). The results of ecosphere and valuesphere scenarios are the characterisation and weighting factors. The hierarchist, egalitarian, and individualist perspectives can also be used for developing default scenarios for the LCIA (see ‘Default Scenarios in Life-Cycle Impact Assessment’ in Chapter 4, p 47).
Introduction

Traditionally, economic and technological planning was to a large extent based on predictions, which worked reasonably well in the relatively stable 1950s and 1960s. Since World War II, the trends shaping the business environment (such as growing markets, economic growth, or prices of the raw materials and energy) had typically been stable. In the 1970s, this development was broken by dynamic crises. One major change after another emerged in an unprecedented fashion. Wack (1985b) states that since the early 1970s, errors in predictions have become more frequent and also of unprecedented magnitude. As a result, previously successful means of decision-making within the 20th century corporate culture started to become ineffective, and many companies experienced unpleasant surprises in their strategic decision-making. The turbulence of our time has first and foremost affected conditions and expectations for organisations of any kind and made previous business experience almost obsolete as a standard for successful decision-making. Anticipating major shifts in the environment of the organisation has become a crucial challenge in business planning. Because the changes in the surrounding systems are extremely fast and manifold, no single ‘right’ projection can be deduced from past behaviour. Rather, the better approach is to accept unpredictability and uncertainty, try to understand it, and make it part of the reasoning in any planning (for the background and history of scenarios, see Malaska 1983, 1985; Wack 1985b; WBCSD 1998; Glenn 1999).

Unpredictability and uncertainty have thus become highly relevant factors in each and every decision-making situation within today’s business and policy-making. Scenario development is a tool for systematic observation of the environment of, for example, a company, to be better prepared for alternative emerging future circumstances, and also to actively construct one’s own future. Scenarios have been increasingly used in planning processes since the 1970s. The best-known scenario studies are probably the reports of the Club of Rome (Meadows et al. 1972), which have made a significant contribution to the popularity of scenarios and their continued study. These reports served as an example for other organisations in their future planning.

Scenario development seems to be important also in life-cycle assessments (LCAs) because LCA is often regarded as suitable for supporting planning processes or other kinds of deci-
sion-making that concern the future. To address unpredictability, change, and uncertainty in the context of LCA, the Society of Environmental Toxicology and Chemistry (SETAC) Europe launched the Working Group on Scenario Development in LCA in April 1998. The SETAC Europe LCA Committee proposed that the working group should deal with the issue to develop systematic scenarios as a basis for studies of future product1 systems and environmental impacts (SETAC 1997). Subsequently, the task was extended to include allocation, impact assessment, and other parts of actual modelling (SETAC 1998) because modelling is necessary in the development of a scenario in a quantitative LCA.

It should be noted that important parts of this document (particularly in 'Futures Studies of Product Systems' in Chapter 3, p 17) are based on a document by Weidema (2003) prepared as part of the Danish LCA-methodology development and consensus project funded by the Danish Environmental Protection Agency.

1 As defined by ISO 14040 the term product includes both services and material goods.
Framework of Futures Studies Methods

Introduction

It should be noted from the start that future-oriented research is not a science in the strict sense (as, e.g., natural sciences) and does not have controlled experiments (see Table 2-1). Futures research\(^1\) uses information from a large number of sciences. Studying the future does not necessarily simply involve economic projections, sociological analysis, or technological forecasting in a narrow sense. It can include a multidisciplinary examination of change in all major areas of life to find the interacting dynamics that are creating the next age. Performing simple economic projections is also a way to study the future (see 'Scenario development by extrapolation' in Chapter 3, p 20). There is ongoing debate as to the organisation of methods for futures studies (Glenn 1999).

Futures Studies in Other Disciplines

Definition review

The term 'scenario' is widely used in a broad sense in various areas. In particular, in the military, game theory, theatre, software development, and life-cycle assessment (LCA), the term 'scenario' is used to refer to the setting of frame conditions or a description of the system to be modelled. Other terms often found in this context include 'framework', 'outline plan', 'background story', and 'guidelines'. Herman Kahn introduced the term 'scenario' into plan-

\(^1\) Also called 'futures studies' or 'prospective studies'; futurists have not reached consensus on the name or definition of their activity; see more about this in Glenn (1999), and some related definitions in Table 2-1.
Table 2-1 Glossary of terms in future-oriented research

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>A forecast is a probabilistic statement, which does not mean that you believe that the forecasted event will occur (Glenn 1999). For forecasts, a number of possible futures have to be taken into account. Future pictures in the form of a forecast each have a probability (objective or subjective) that is neither 1 nor 0 (Gausemeier et al. 1995).</td>
</tr>
<tr>
<td>Futures research</td>
<td>Use of methods to identify systematically the consequences of political options and to identify alternative futures with policy implications for decision-makers. Futures research is decision-oriented. For example, it seeks to identify current forces that should be understood in order to make more intelligent decisions (Glenn 1999).</td>
</tr>
<tr>
<td>Futures studies</td>
<td>Exploration of what might happen and what we might want to happen. Futures studies is subject- or question-oriented. For example, what are the critical technologies that will have the greatest influence over the next 25 years (Glenn 1999)?</td>
</tr>
<tr>
<td>Prediction</td>
<td>A prediction is a statement that you believe will be true (Glenn 1999).</td>
</tr>
<tr>
<td>Prognosis</td>
<td>A conventional prognosis captures quantitatively the actual situation and calculates the future situation with the help of a formula the future situation (von Reibnitz 1991). A future situation that can be predicted (or rejected), based on scientific experience, with such a high probability that alternative future situations are negligible. The prognosis therefore has a probability of either 1 or 0 (Gausemeier et al. 1995). Prognoses can be reliable only as far as the present circumstances are largely unchanged. Therefore, the time horizon of a prognosis is limited to a maximum of one year into the future (Scholz and Tietje 1996).</td>
</tr>
<tr>
<td>Projection</td>
<td>An estimate of the future possibilities based on historical data (i.e., a surprise-free base-line forecast) (Glenn 1999). The most general form of a future picture. No probability can be assigned to a projection (Gausemeier et al. 1995).</td>
</tr>
<tr>
<td>Prospective studies</td>
<td>The study of the future to develop a strategic attitude of the mind with a long-range view of creating a desirable future (Glenn 1999).</td>
</tr>
</tbody>
</table>

Working group members have presented several definitions of scenarios found in the literature. These definitions include 3 basic elements of scenarios: the definition of alternative future circumstances, the path from the present to the future, and the inclusion of uncertainty about the future:

- Mesarovic and Pestel (1974): 'The consequence of possible decisions, measures and events are called a scenario' (e.g., population growth scenario).
- Hansmann (1983): 'A description of the development of the object of the analysis in alternative framework conditions'.
- Meristö (1991): 'A holistic script about the future, which defines working environment of a company based on different assumptions and describes the paths from present to the future' and 'Possible, but not necessarily probable views of the future'.
- von Reibnitz (1991): 'Scenarios are descriptions of a future situation and the development respectively the description of the way which leads from the present into the future'.
• Vartia (1994): 'Scenarios are used to describe that part of the organisations’ environment for which projections are difficult or even impossible. Scenarios give the possibility to prepare for alternative and uncertain future options without knowing anything about the probability of the possible outcomes. This makes the scenarios different from forecasts. Effective scenarios are distinct, logical and they are different enough from each other so that they are able to describe the central changing factors of the future and place questions on existing assumptions'.

• Gausemeier et al. (1995): 'A description of a complex future situation that occurrence can not be predicted for sure as well as the presentation of the development that could lead from the present to the future'.

• Scholz and Tietje (1996): 'In contrary to prognoses, scenarios do not try to predict the future. Scenarios do more try to ‘throw light on’ thinkable future possibilities'.

• Bartusik and Cabala (1997): ‘One possible picture of future conditions of the object and its environment; above mentioned conditions are described by characteristics of the results of given sequences of events (situations) and factors which disturb the natural run (evolution) of these sequences'.

In summary, it seems that the term 'scenario' has been used in 2 different ways: first, to describe a snapshot in time or the conditions of important variables at some particular time in the future and, second, to describe a future history—that is, the evolution from present conditions to one of several futures (Futures Group 1994a). According to the Futures Group (1994a), at least when scenarios are used in policy analysis, the nature of evolutionary paths is often important because policies can deflect those paths. It should also be noted that the presentation of the development from the present to the future is not equivalent to dynamic modelling; rather, it should be described as reasoning for the probability of a certain scenario giving snap-shots of time explaining the development.

The ‘scenario trumpet’ metaphor in Figure 2-1 illustrates the key issues discussed above. The trumpet includes all possible states of a case. That is, XB, XC, and XD represent different scenarios; XE1 and XE2 represent extreme scenarios.

**Default scenarios and their basis in cultural theory**

Because the number and variety of scenarios for a given study are in principle infinite, it can be of help to define (extreme) default scenarios, which can be used to set the frame or used in cases

![Figure 2-1 The scenario trumpet metaphor (Scholz and Tietje 2001)](Copyright © 2001 by Sage Publications, Inc. Reprinted by permission of Sage Publications, Inc.)
where individual scenarios cannot be developed due to time and resource constraints. Hofstetter (1998) has analysed the problem of modelling subjectivity and variability thoroughly and he proposes to use the socio-cultural viability theory (Thompson et al. 1990), called ‘cultural theory’ for short, to distinguish 5 extreme value systems that are illustrated in Figure 2-2. Thompson et al. (1990) derive these value systems by looking at the strength of the relation people have with their group and the degree to which an individual’s life is circumscribed by externally imposed prescriptions (their ‘grid’). The viable positions of each individual in this group-grid typology and their cultural biases are called ‘ways of life’. The assumption is that these viable combinations have a large influence on the value system of individuals and their groups.

The most important characteristics of the 5 extreme archetypes can be summarised in the following:

1) Individualists are free from strong links to group and grid: In this environment all limits are provisional and subject to negotiation. Although they are relatively free of control by others, they are often engaged in controlling others.

2) Egalitarians have a strong link to the group, but a weak link to their grid: In this environment there is no internal role differentiation, relations between group members are often ambiguous, and conflicts can occur easily.

3) Hierarchists have a strong link to group and grid. In this environment people are both controlling others and subject of control by others. This hierarchy creates a high degree of stability in the group.

4) Fatalists have a strong link to the grid but not to a group. These people act separately and are usually controlled by others. They do not make any decisions and are therefore not relevant in the context of scenario development.

5) Autonomists are assumed to be the relatively small group that escapes the manipulative forces of groups and grids.

According to Hofstetter (1998), the value systems in Figure 2-2 have been used by several authors in risk perception studies. Experiences show that this distinction is very valuable in explaining attitudes of people. However, it is important to stress that this theory does not imply that there are only 5 types of people. Almost nobody conforms to the viewpoints of a single group in a consistent way. In addition, it has been shown that people can switch between different attitudes depending on the context. Therefore, the archetypes are extreme positions not likely to be held by anyone, but useful because they delimit the area of possible positions.

It is plausible that the representatives of the 3 extreme archetypes, individualist, egalitarian,
and hierarchist, have distinctly different preferences as to modelling choices (creating the future picture) that have to be made. Hence, they are relevant for decision-making and are employed for the default scenarios (see 'Default Scenarios in Life-Cycle Impact Assessment' in Chapter 4, p 47). The fatalist tends to have no opinion on such preferences because he is guided by what others say. The autonomist cannot be captured in any way because he thinks completely independently. Thus, the fatalist and autonomist views cannot be used for creating default valuesphere scenarios. In this report, default scenarios are proposed as extreme cases if no other scenarios based on more specific information are available. They can be applied to both the life-cycle inventory (LCI) and the life-cycle impact assessment (LCIA) phase.

The benefit of socio-cultural viability theory is that we can predict a wide range of basic attitudes and assumptions for the 3 remaining valuation archetypes. Typical values in the 3 different perspectives are shown in Table 2-2. These 3 perspectives are commonly used for scenario building (e.g., see FROG, GEOpolicy, and Jazz scenarios in WBCSD [1998]).

**Scenarios in Life-Cycle Assessment Studies**

**The scenario concept in life-cycle assessment**

Future environmental interventions and the future development of underlying unit processes are highly uncertain. Environmental interventions are a product of very complex, difficult to understand dynamic systems, driven by forces such as population growth, socio-economic development, and technological processes, among others.

However, this problem is not unique to LCA. A similar problem occurs in the field of climate change modelling. This fact was acknowledged in the recent Intergovernmental Panel on Climate Change (IPCC) Report (Nakicenovic and Swart 2000), stating that prediction of future anthropogenic greenhouse gas (GHG) emissions is impossible. In order to facilitate a sound scientific analysis, alternative GHG emission scenarios have became a major tool for analysing potential

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Table 2-2 Typical attitudes and general assumptions in the 3 different perspectives representing the basis for the default scenarios (adapted from Hofstetter 1998; used with permission from P. Hofstetter, Zurich, CH)

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Egalitarian</th>
<th>Individualist</th>
<th>Hierarchist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural bias</td>
<td>Fundamentalism</td>
<td>Pragmatic materialism</td>
<td>Ritualism and sacrifice</td>
</tr>
<tr>
<td>Ideal of fairness</td>
<td>Equality of result</td>
<td>Equality of opportunity</td>
<td>Equality before the law</td>
</tr>
<tr>
<td>Rationality</td>
<td>Critical</td>
<td>Substantive</td>
<td>Procedural</td>
</tr>
<tr>
<td>Criteria</td>
<td>Argument</td>
<td>Experience</td>
<td>Evidence</td>
</tr>
<tr>
<td>Management style</td>
<td>Preventive</td>
<td>Adaptive</td>
<td>Control</td>
</tr>
<tr>
<td>Intergeneration respon-</td>
<td>Present &lt; future</td>
<td>Present &gt; future</td>
<td>Present = future</td>
</tr>
<tr>
<td>sibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Future generations</td>
<td>Fragile</td>
<td>Self-sufficient</td>
<td>Resilient</td>
</tr>
<tr>
<td>Attitude to nature</td>
<td>Attentive</td>
<td>Laissez-faire</td>
<td>Regulator;y</td>
</tr>
<tr>
<td>Attitude towards human</td>
<td>Construct egalitarian society</td>
<td>Channel rather than change</td>
<td>Restrict behaviour</td>
</tr>
<tr>
<td>Perception of human</td>
<td>Born good</td>
<td>Self-seeking</td>
<td>Sinful</td>
</tr>
<tr>
<td>nature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trust</td>
<td>Participation</td>
<td>Successful individuals</td>
<td>Procedures</td>
</tr>
<tr>
<td>Sovereignty</td>
<td>Collective</td>
<td>Consumer</td>
<td>Institution</td>
</tr>
<tr>
<td>Desired system properties</td>
<td>Sustainability</td>
<td>Exploitability</td>
<td>Controllability</td>
</tr>
</tbody>
</table>
Scenarios in Life-Cycle Assessment

long-range developments of the socio-economic system and corresponding emission sources.

Different LCA groups in Europe use the term 'scenario' to denote different aspects of their studies. Some state that every LCA includes at least one scenario (Braunschweig and Jahn 1998), while others argue that the scenario concept is relevant only when there are at least 2 different, future-oriented scenarios. Some use the concept to denote the alternatives that are studied in a comparative LCA. Others use it only to denote alternative background situations in which the comparison can be made. As a theoretical example, consider a comparative LCA that is carried through to compare 3 different products (see Figure 2-3). The comparison is based on the assumption that the products will be recycled or incinerated after use. Some LCA groups would use the scenario concept to denote the different alternative products that are compared, while others would use it to denote the different waste management options that might be relevant in the future.

On the basis of the definitions of scenarios presented in 'Definition review' (p 3), we suggest the following, rather broad definition of scenario in LCA studies: 'A description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future and, when relevant, a description of a path from the present to the future'. According to this definition, scenarios cover possible future situations, and each scenario may in turn contain one or more product alternatives to be studied within the scope of LCA.

We distinguish between the complete scenario and the frame of the scenario—that is, the general outline or brief description of the scenario. For example, in a study comparing different paper products with the same function, the scenario frame for the end-of-life phase could be 100% incineration; 70% closed-loop recycling and 30% incineration; or 40% closed-loop recycling, 40% open-loop recycling, and 20% landfill with or without prior incineration. These scenarios could reflect the situations of different future developments (more or less incineration and recycling capacity, new regulations, etc.). This scenario frame can also be qualitative. It is developed in the first phase of the LCA, the goal and scope definition.

The complete scenario also includes the models that are developed in the LCI and the scenario frame (see Figure 2-4). These models should, of course, be consistent with the scenario frame. As indicated by our scenario definition, the models are based on assumptions that should be explicitly specified.

Braunschweig and Jahn (1998) state that scenarios in LCA studies may evaluate different elements or parameters of the product system (the term 'product system' relates to the system in reality and not the model of the product system [see Rebiter 1999]) or the surrounding environment. According to Hunt and Johnson (1995), changes in the surrounding environment can include changing circumstances, such as changes in technology, environmental damage becoming tangible, and improved understanding of environmental science. However, Wack (1985a) notes that scenarios can effectively organise a variety of seemingly unrelated economic, technological, competitive, political, and social information and translate it into a framework for judgment. In LCA studies, a distinction between 3 different types of scenario applications can be made accordingly:

• technology scenarios,
• environment scenarios, and
• valuation scenarios.

Technology scenarios can be based on assumptions concerning technological developments,

![Figure 2-3 A life-cycle assessment comparing 3 products based on different assumptions concerning waste management](image-url)
waste management options, and options for electricity production. Environment scenarios can be based on assumptions concerning threshold levels, the development of the background load, etc. Valuation scenarios can be based on assumptions concerning what set of values is relevant for the study in question.

**Methods for futures studies in life-cycle assessment**

The description of the future situation is generated through the use of methods for futures studies. Several different methods are available. Weidema (2003) presents 6 groups of methods:2

1) Extrapolating methods are based on the belief that the future represents a logical extension of the past. ‘Trend analysis, time series, regression, econometrics and simulation modelling are tools of extrapolating methods’ (Futures Group 1994b).

2) Exploratory methods concentrate on structuring possible futures, typically using qualitative descriptions. ‘Morphological analysis, relevance trees, mind mapping and future wheel are representatives of the tools of this category’ (Glenn 1999).

3) Dynamic modelling describes the future by identifying the determining mechanisms of past events or the causal connections among system elements, and how these influence the future. Examples of these tools are analogy analysis, technological sequence analysis, stakeholder analysis, and structural analysis (Vanston 1995).

4) Cornerstone scenario methods arise from the belief that the future is essentially unpredictable. Considering the uncertainties included in the future, dynamic modelling will not lead into one future but rather to many different futures, any of which may be described in the form of a scenario. Scenario methods combine aspects of other tools with the aim of creating several scenarios.

5) Participatory methods find expert and stakeholder opinions and insight about the future more useful than rational methods. Tools used in participatory method include the Delphi technique, scanning, focus groups, charrette, Syncon, and future search conferences (Glenn 1999).

6) Normative methods investigate how we want the future to be and how to obtain this goal. Objectives that may be very discontinuous from the present trends are defined, and then the normative method moves backwards to the present to identify the necessary steps for reaching these objectives (Coates 1994). One normative method is ‘backcasting’. According to Robinson (1982), ‘The major distinguishing characteristic of backcasting analysis is a concern, not with what futures are likely to happen, but with how desirable futures can be attained. It is thus explicitly normative, involving working backwards from the particular desirable future end-point to the present in order to determine the physical feasibility of that future and what policy...

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2 Weidema (2003) presents the methods as forecasting methods but considers this concept synonymous to what we call 'methods for futures studies'.
measures would be required to reach that point'.

Figure 2-5 presents the aforementioned 6 futures-studies methods corresponding to the application areas of LCA according to Weidema (1998a) (compare Figure 2-6). The scenario definition of the working group, given above, does not exclude the use of any of the methods presented in Figure 2-5. All of the methods listed above can contribute to scenario development in LCA studies. The application of the methods is described in 'Futures Studies of Product Systems' in Chapter 3 (p 17).

**Time horizon of scenarios**

For what time period should a scenario be conducted? How far ahead should a study look? There are no universal answers to these questions. The time span of scenarios has to be determined separately in each case and will be determined at least partly by business considerations such as the lifetime of existing plants and the lead time for developing new products or services.

Hunt and Johnson (1995) suggest that environmental scenario development should, as far as possible, cover a time-scale commensurate with that used for business strategy development. According to Meristö (1991), the time horizon of a scenario is typically longer than that of usual strategic planning. In her study about scenario planning in European companies, the time horizon of the scenarios was for most companies between 6 to 15 years, while their usual strategic planning includes a time span of only 3 to 5 years.

Weidema (1993a, 1998a) has presented a typology of LCA application areas in which he distinguishes between 3 categories based on time horizon: the operational, the tactical, and the strategic level. The operational level is characterised by being non-comparative and by the results being used directly on the product itself, the typical example being product declaration. The tactical level typically includes improvements being evaluated by comparison between products. The results are used to influence the surroundings of the product: producers, suppliers, employees, and customers. Typical examples are eco-labeling criteria. The strategic level, instead, includes improvements evaluated in relation to an environmental target, and the results are used to place the product in a larger context.

The time horizon of scenarios should be consistent with the goal of the study. In an LCA of a hydropower plant, it might be relevant to look very far into the future, to the time when the hydropower plant is no longer used. In an LCA of a nuclear power plant, it might be relevant to consider the very long time spans that will pass before the nuclear waste becomes harmless. Factors causing high uncertainty in trying to look too far into the future include rapid, unforeseeable changes in technology, increasing understanding of environmental sciences, which may change our
Two principal approaches to scenario development in life-cycle assessment studies

On the basis of the different definitions of scenarios discussed in 'Definition review' (p 3), 2 basic approaches of scenarios in the context of LCA studies are identified: what-if scenarios and cornerstone scenarios (see also Pesonen 1998).

What-if scenarios

The what-if scenario is the more widely used of the 2 approaches in LCA studies. It is used to compare 2 or more options in a well-known situation where the researcher is familiar with the decision problem and can define a scenario on the basis of existing data or knowledge. These are often studies where some specific changes within the present system are tested and their implications to environmental impacts are studied. The results of a study using what-if scenarios are typically quantitative comparisons of the selected options: for example, alternative A is better than alternative B by x%. This type of research could also be defined as one offering operational information in case of short- or medium-term decision-making situations. According to CHAINET (1998), 'operational information describes small changes of small-scale systems with a short time horizon'. Several authors claim that there should not be more than a few scenarios in a study because otherwise the decision-making will become unmanageable for decision-makers. However, an LCA can include a larger number of what-if scenarios because these typically are not very complex.

Cornerstone scenarios

The cornerstone scenario approach, instead, does not necessarily give quantified results comparing any pre-set alternatives. It offers guidance in the field of study and typically serves as a base for further research. In the cornerstone approach, the researcher chooses several options, which can be very different, in order to get an overall view of the studied field; these alternatives then serve as ‘cornerstones’ of the studied field. The results of the cornerstone scenario approach can point out a potential direction of future development. The cornerstone scenario approach offers a tool for long-term planning, and the nature of this type of study and the information gained from it is more strategic than in the what-if scenario approach. 'Strategic information refers to large and possibly quantitative changes of large-scale systems with long time horizons' (CHAINET 1998). Cornerstone scenarios can offer new ways of seeing the world, which allows the decision-makers to break out of a one-eyed view (i.e., 'out of the box' thinking). Cornerstone scenarios can thus serve as means to re-perceive reality.

Results of a study using the cornerstone scenario approach often serve as a basis for further, more specific research where the scenarios can be defined according to what-if scenarios. Wack (1985a) has also paid attention to the importance of starting with scenarios at a more general level (in his definitions, first-generation scenarios) and then working further towards more specific ones (decision scenarios). He claims that one cannot start with a narrow focus because key issues (or dimensions) will thus be missed: ‘You must wide-angle first to capture the big picture and then zoom in on the details’.

Several similarities between the features of the 2 basic research approaches, quantitative and qualitative research (see e.g., Burns and Bush 1998), and the 2 defined basic methods of scenario development can be stated. Table 2-3 summarises the features of what-if scenarios and cornerstone scenarios defined on the basis of differences between quantitative and qualitative research.

According to the ISO 14040 standard, possible application areas of LCA studies (ISO 1997) include product development and improvement, strategic planning, public policy-making, marketing, and others. We believe that for typical strategic planning and public policy planning research the use of the cornerstone approach is necessary. All the other applications mentioned here may use either what-if scenarios or both types of scenarios.

Figure 2-6 summarises the use of cornerstone and what-if approaches corresponding to the 2 dimensions of application areas of LCA studies, time and complexity. If the research problem is specific and covers a short to medium time horizon, what-if approaches are typically used. If the time horizon grows and the problem area becomes more complex, cornerstone approaches are more suitable. What-if and cornerstone approaches describe the 2 ends of the continuum from very strictly defined scenarios to complex research settings in the cornerstone approach. Scenarios are, however, not limited just to these 2 ends of
Table 2-3 Features of the basic scenario approaches (Pesonen 1998)

<table>
<thead>
<tr>
<th>What-if scenarios</th>
<th>Cornerstone scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of research is well known; researcher is familiar with the object of the research</td>
<td>Field of research is new, unknown to the researcher</td>
</tr>
<tr>
<td>Research object is simple</td>
<td>Research object is complex</td>
</tr>
<tr>
<td>Well-defined research plan, standardised research</td>
<td>Open research plan, scenarios are developed in the course of the study</td>
</tr>
<tr>
<td>Purpose of the study is to investigate consequences of specific, discrete assumptions and uncertainties, which do not have any long-term implications</td>
<td>Purpose of the research is to increase understanding about the studied object; usually long-term implications are studied</td>
</tr>
<tr>
<td>Comparison of existing systems (process alternatives, product modifications, etc.)</td>
<td>Design and development (of new products, technologies, etc.)</td>
</tr>
<tr>
<td>Operational or tactical information</td>
<td>Strategic information (often serve as a base for further, more specific research with what-if scenarios)</td>
</tr>
</tbody>
</table>

the continuum, but different variations including features of the 2 basic approaches are possible. Stevels (1997) has presented different levels in environmental improvement of products (see also Table 2-4):

- Level 1: Incremental improvement, which will result in improvements as high as 5% to 10%
- Level 2: Complete redesign of existing concepts, which will result in improvements as high as 30% to 50%
- Level 3: Alternative fulfilment of functionality, which may result in improvements as high as 50% to 75%
- Level 4: Change of functionality, which may result in more than 75% (factor 4) improvements

The levels of improvement suggested are a combination of technical, social, and institutional innovation. The higher levels of design require changes in society and require the engagement of multiple stakeholders. The time horizon of different levels is also included in Table 2-4. The optimisation of existing systems concerns decisions with a short time horizon, while the change of product systems and improvements to existing technologies concern decisions over a medium time horizon. Fundamental changes of several technologies or concepts pertain to long-term decisions (see CHAINET 1998).

The different levels of improvement also require different levels of information. Level 1 typically requires operational information, and research in this case would use what-if scenarios. At Level 4, instead, strategic information is required, which makes a cornerstone scenario approach more suitable for this case.

**Relation of scenarios to the conventional phases of life-cycle assessment**

The frames of scenarios are defined through the first phase of LCA, the goal and scope definition, but the details of these scenarios are worked out in the subsequent phases. As indicated in 'The scenario concept in life-cycle assessment' (p 7), we distinguish between technology scenarios, environment scenarios, and valuation scenarios. Intuitively, these are connected to, respectively, the inventory analysis, the characterisation, and the weighting (Sonnemann 1999a). Although, in reality, the connection is slightly more complex, the details of technology scenarios are mainly developed through the modelling in the inventory analysis. The details of environment and valuation scenarios are both developed in the impact assessment. Table 2-5 summarises the dimensions of LCA scenario frames that directly influence the modelling in the inventory analysis and impact assessment.

**Goal and scope definition**

The goal and scope definition phase of an LCA starts with the idea to carry out the study. It includes the thought process during which the goal and scope of the study are elaborated. It also includes the writing of the part of the LCA report
Figure 2-6 Two basic approaches to scenario development in life-cycle assessment research

Table 2-4 Levels of improvement (CHAINET 1998)

<table>
<thead>
<tr>
<th>Level of improvement</th>
<th>Goal</th>
<th>Example</th>
<th>Time horizon</th>
<th>Change of consumer lifestyle</th>
<th>Infra-structure change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Incremental improvements</td>
<td>Current, better, TV</td>
<td>0–2 years</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>Redesign of existing concepts</td>
<td>'Green TV'</td>
<td>0–5 years</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>Alternative fulfilment of functionality</td>
<td>LCD TV</td>
<td>0–10 years</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>4</td>
<td>Sustainability</td>
<td>?</td>
<td>0–30 years</td>
<td>++++</td>
<td>++++</td>
</tr>
</tbody>
</table>

Table 2-5 Influence of life-cycle assessment scenario development on inventory analysis and impact assessment

<table>
<thead>
<tr>
<th>Dimension of LCA scenario development</th>
<th>Direct influence on inventory analysis</th>
<th>Direct influence on impact assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>System boundaries</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Allocation methods</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Space</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Characterisation methods</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Weighting methods</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
in which the goal and scope of the study are presented. The suitable content of the goal and scope part of the LCA report is presented in, for example, ISO 14040 (ISO 1997).

A scenario frame is the general outline or brief description of the scenario. The frames of the scenarios investigated in the LCA often develop in parallel with the goal and scope of the study. They can have several things in common, such as the geographical and temporal boundaries of the study.

When an LCA contains more than one scenario, the different scenarios are generally based on different sets of assumptions (Braunschweig and Jahn 1998). In many case studies, the assumptions behind the scenarios are implicit. However, to facilitate an assessment of the validity of the different scenarios, it is important that these assumptions be explicitly described. The goal and scope part of the LCA report is the natural place for such a description. This is consistent with ISO 14040, which states that the assumptions in the LCA should be described in the scope definition.

Inventory analysis

The inventory analysis is basically the modelling of the relevant technological system. This modelling is part of the scenario development and should, of course, be consistent with the frames for the technology scenarios. This can affect, for example, the choice of data in the inventory analysis.

The inventory analysis can also be affected by environment and/or valuation scenarios. For example, if an environment scenario is based on the assumption that the problem of climate change will be solved in 100 years from now, this should affect the temporal boundaries in the modelling of GHG emissions from landfills. The temporal boundaries might also be affected by the choice of valuation scenarios, and the valuation scenarios can have a decisive effect on the choice of parameters in the inventory analysis (Weiner 1999).

Scenario development often leads to more complex data needs. If the study includes more than one scenario, data must be collected for each scenario. In addition, the data uncertainties can be very large in scenarios that are based on technology that is not yet in use. In such cases, the need for methods for dealing with uncertainties is strong. Furthermore, a procedure for estimating input data for future processes can be required.

The parts of the technological system (flows or processes) that dominate the results of the LCI analysis can be identified through a dominance analysis. It is relevant to consider whether the different technology scenarios influence these parts. If this is not the case, the LCI results do not depend significantly on the choice of scenario. On the other hand, if the choice of scenario has a large effect on the LCI results, the validity and probability of the scenarios should be discussed in the interpretation of the LCI results.

Specific modelling issues in LCI that are relevant for prospective LCA are elaborated in detail in 'Prospective Life-Cycle Inventory Modelling' in Chapter 3 (p 28).

Impact assessment

Environment scenarios and valuation scenarios mainly correspond to 2 different elements of the LCIA: characterisation and weighting (Sonnemann 1999a). An environment scenario is used for calculating the potential environmental effects of the emissions and resource consumption that are caused by the technological system. The frame of an environment scenario can include, but is not restricted to, geographical boundaries (e.g., global, European, or national) and temporal horizons. The environment scenario also includes the model that is used for calculating the environmental effects.

Pollutants will often have environmental impacts long after they have been emitted. These long-term impacts depend on other events in the technological system and in the environment. Hence, the temporal horizons, at least, are affected by assumptions about future events. Comparing the concept of environment scenarios to the scenario definition earlier in this chapter, it can be concluded that the temporal horizon adds the essential future perspective and that the environmental scenario is based on assumptions about future events and the path from the present to this future. The geographical area in which the model is applied is a necessary part of the description to specify the scenario (Sonnemann 1999a).

Weighting factors can be obtained by various approaches. The choice of one specific method can be considered as a choice of one specific valuation scenario. Moreover, the weighting factor itself can depend on environment or technology scenarios about future damages. As an example, the default weighting factors for the depletion of different resources in environmental priority strategies (EPS) in product design depend on technology sce-
scenarios concerning the future extraction of these resources (Steen 1999).

Specific modelling issues in LCIA that are relevant for prospective LCA are elaborated in detail in Chapter 4.

Interpretation
The objective of the interpretation is to determine the significant issues, in accordance with the goal and scope definition. The scenarios have to be checked in completeness, sensitivity and consistency (see ISO 2000b). Moreover, the uncertainty of the results has to be analysed and the quality of data assessed. The procedure is iterative and interactive with other phases of LCA. Finally, in the conclusions, also the strengths and limits of the scenarios have to be considered and reported if the choice of scenario is important for the LCA results (Sonnemann 1999b).

When presenting the results of a multiple scenario study, the issue of uncertainties included in each of the scenarios becomes extremely important. The decision-maker has to be fully aware of the uncertainties underlying each scenario in order to be able to make comparisons between them. Uncertainty in scenario development will be discussed briefly in the next section.

Uncertainty in scenario development in life-cycle assessment
If the outcome of a future event is sure, we speak of certainty. In this case, the probability of the future event is either 1 or 0. Correspondingly, a future event is uncertain if the probability of the event is neither 1 nor 0. Uncertainty is inherent to futures studies because one cannot predict the future. However, one may express a prediction in terms of intervals to which estimates of probability can be assigned. These probabilities will always be subjective, but they may be more or less well documented and more or less based on previous experience (as extrapolations).

Cornerstone scenarios aim at structuring and understanding uncertainty, not by merely criss-crossing variables and producing dozens or hundreds of outcomes, but by creating a few internally consistent pathways into the future (Wack 1985a). Scenarios must help decision-makers to develop their own feel for the nature of the system, the forces at work within it, the uncertainties that underlie the alternative cornerstone scenarios, and the concepts useful for interpreting key data (Wack 1985a). When the results of a multiple scenario study are presented, the issue of uncertainties included in each of the scenarios becomes extremely important. The decision-maker has to be fully aware of the uncertainties in each scenario in order to be able to make comparisons between them.

Uncertainty in LCAs arises because of several different reasons. Huijbregts (1998) distinguishes between 6 sources of uncertainty and variability in LCA: parameter uncertainty, model uncertainty, uncertainty due to choices, spatial variability, temporal variability, and variability between sources and objects. Most of these uncertainties are a problem in every LCA. The probability of a certain future development is dependent on the probabilities of those factors, which have been chosen to describe, reflect, or model the selected scenario.

In studies concerning the future, the parameter uncertainty will most probably be of great importance, as will the model uncertainties. Uncertainties due to spatial and temporal variability are not particular for prospective studies. Maybe the time range is larger, though the problems are the same as in any study. Variability between objects/sources is an issue, which refers to the choice of input data (i.e., site-specific, average, or marginal data). This issue is discussed in detail in Chapter 3.

Huijbregts (1998) has offered some solutions on how to deal with the aforementioned issues of uncertainty within LCAs. The tools available to address different types of uncertainty and variability in LCAs include probabilistic simulation, correlation and regression analysis, additional measurements, scenario modelling, standardisation, expert judgment or peer review, non-linear modelling and multi-media modelling. According to Huijbregts (1998), scenario modelling should be useful especially in cases where there is uncertainty about choices and temporal variability.

Combining several methods is a way to reduce uncertainty, but it may also be a way to ensure that the full range of possibilities is presented, thus, revealing a larger uncertainty than what would be assumed when using only one method.

Compared to this inherent uncertainty, the uncertainties of the specific futures-studies methods may seem less important. However, scenarios do differ in reliability, depending on the methods applied, and uncertainty is also inherent to specific aspects of the methods. An extrapolation, where a curve is fitted to a number of historical values, will have an inherent uncertainty expressed as the ‘goodness of fit’ (correlation coefficient) be-
tween the curve and the historical values, which can then be used to calculate a confidence interval for the predicted values. When an extrapolation or a model combines several variables, the prediction of each variable as well as each relation between variables has its own uncertainty, which have to be cumulated.
Scenarios in Life-Cycle Inventory

In this chapter, the implications of scenario development for the life-cycle inventory (LCI) phase of a life-cycle assessment (LCA) are elaborated. This concerns how methods for futures studies can be applied to the product system investigated (see 'Future Studies of Product Systems', below), specific modelling issues to be addressed ('Prospective Life-Cycle Inventory Modelling', p 28), as well as the use of default scenarios ('Default Scenarios in Life-Cycle Inventory', p 41).

Futures Studies of Product Systems

Step 1: Identifying relevant parts of the product systems

It is not equally important to investigate the future of all parts of a product system, and there may even be entire LCAs in which scenario development is not necessary. The following factors may affect the scope of futures studies in an LCA:

- the general speed of development of the relevant markets, technologies, and exchanges (elementary flows according to ISO 14040);
- environmental significance of these developments for the conclusions of the LCA;
- expectations about radical, or atypical, developments;
- the time horizon of the study relative to the expected development; and
- the position of the specific process in the life cycle of the product.

Speed of development

Futures studies are relevant for the part of the product system in which changes in markets and technology are expected to be large. Markets generally develop more slowly as they mature. With time, the product becomes more well-defined (the obligatory product properties tending to become more encompassing), and the market boundaries and production
constraints less volatile (tending to be determined more by natural geography, such as climate and natural transport barriers, than by administrative differences). Likewise, the production costs and technologies develop more slowly as the ultimate physical constraints of each material, process, or technology are approached. There have been several attempts at classifying different industrial sectors according to their speed of development, though none of them are fully satisfactory. An example is given in Table 3-1. The size of most process exchanges decrease over time, following the general efficiency development in the corresponding technology, but for exchanges that are in focus because of their economic value or their known environmental effects, the speed of development may be above average (e.g., the phasing out of chlorofluorocarbons [CFCs]).

Environmental significance of developments

Futures studies are also more relevant for the part of the product system where changes in markets and technology have a large impact on the conclusions of the study. These parts can be identified through an LCA on the current product system. Dannemand Andersen and Bjerregaard (2001) used earlier LCAs on offshore wind farms to identify the most significant environmental aspects. These results were used as a basis for a future-oriented LCA aiming at analysing the environmental effects of wind turbines in a long-term perspective.

Table 3-1

<table>
<thead>
<tr>
<th>Traditional sectors</th>
<th>Mixed sectors</th>
<th>Dynamic sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;10 years</td>
<td>5–10 years</td>
<td>1–5 years</td>
</tr>
<tr>
<td>Building materials</td>
<td>Basic and intermediate chemicals</td>
<td>Aeronautics</td>
</tr>
<tr>
<td>Foodstuff</td>
<td>Machinery</td>
<td>Artificial and synthetic fibres</td>
</tr>
<tr>
<td>Inorganic chemicals</td>
<td>Motor vehicles</td>
<td>Electronics</td>
</tr>
<tr>
<td>Iron metallurgy</td>
<td>Rubber</td>
<td>Frozen and freeze-dried foods</td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>Electrochemicals</td>
<td>Pharmaceutical</td>
</tr>
<tr>
<td>Paper</td>
<td></td>
<td>Plastics</td>
</tr>
<tr>
<td>Petroleum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textiles, clothing, footwear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Position in the life cycle

The time horizon may be different in different parts of the product system. In the future-oriented LCA on wind turbines, the time horizon for the manufacturing of wind turbines was 2020 to 2030. The time horizon for the dismantling was a further 20 years into the future (Dannemand Andersen and Bjerregaard 2001). Even when the time horizon of part of the study is far longer than 5 years, not all processes in the life cycle may be affected sufficiently far into the future that future studies become relevant (see Figure 3-1 for an illustration of this situation).

Step 2: Determining the necessary precision

As any other aspect of LCA, scenarios may be made in varying degrees of precision. Covering the most important processes in the studied life cycles, a scenario may include (in order of increasing detail)

- the general direction of the development, in terms of technology and exchanges;
- the relative speed of development of the relevant processes;
- the situation at specific points in time, corresponding to the time horizon of the study; and
- the specific technology and its exchanges at such specific points in time.

If the general direction of development confirms or enhances the current situation, this qualitative information may be adequate as an addition to a life-cycle study based on current or historical data. For example, to conclude that an alternative energy source that currently competes with fossil fuels will continue to be competitive, it is adequate to have the general knowledge that costs of fossil fuel resources will be slowly increasing in the long term (as reserves are depleted) and that costs of the alternative energy source will continue to fall (following an ordinary learning curve).

The relative speed of development of different processes must be taken into account if the direction of development does not in itself provide a clear indication and if the speed of development is not uniform for all the involved processes. This information, which is still qualitative, may sometimes be adequate basis for a conclusion. For example, when the price of all fossil fuels is expected to increase in the long run, it is necessary to know the relative speed of price developments for coal, oil, and natural gas, in order to determine which fossil fuel will be the most competitive in the future.

Combining knowledge on the direction and speed of development with more quantitative information allows scenarios of the market situation and the technologies involved at specific points in time. For example, information on the current costs of coal and wind power and the actual speed of cost developments for these 2 technologies (e.g., expressed in average percentage change in raw material costs and efficiency per year and/or as a coefficient of a learning curve) may allow one to predict whether wind power or coal power is likely to be the most competitive at a specific point in time.

If necessary, the relevant technologies may then be further quantified, also in terms of exchanges, by combining specific technical information with

| Materials and production: Forecasting not relevant if only current processes are affected |
| Electricity consumption: Forecasting relevant for the electricity production, ideally as a function of time |

Disposal: Forecasting relevant because disposal takes place far into the future

Figure 3-1 The environmental impacts (arbitrary values) of an electricity-consuming product as a function of the lifetime, showing the parts of the life cycle for which futures studies are relevant.
Scenarios in Life-Cycle Assessment

general scenarios on technical efficiency and emission control.

**Step 3: Choosing futures-studies method**

Several methods can be used for futures studies. For our purpose, the methods can be classified under the 6 headings that are outlined in Chapter 2 (‘Methods for futures studies in LCA’, p 9).

What method for futures studies is applicable in a specific situation does not depend on the required precision. Instead, it depends, at least to some extent, on the time horizon of the scenario and the predictability and complexity of the system or subsystem for which the scenario is developed. Weidema (2003) describes the relevance of the methods as presented in Table 3-2.

The divisions in Table 3-2 should be regarded as one suggestion only. Even given this suggestion, the distinction between the different situations and relevant methods is not sharp, in practice, and more than one method may be relevant in a specific situation. Often, different methods can be combined to give a more reliable picture of the future (see ‘Combining different methods for futures studies’, p 27).

The choice between methods for futures studies may also depend on how strongly the decision-maker can influence the part of the system for which the scenario is developed. Results from extrapolation may be useful for the background system, that is, for parts of the system investigated where the decision-makers do not have a large influence (Frischknecht 1998). For the foreground system, the part of the system that the decision-maker can directly control, exploratory and normative methods are likely to provide more useful information.

**Step 4a: Scenario development by extrapolation**

Extrapolation is the simple, linear or non-linear prolongation into the future of historical relations. Figure 3-2 shows a simple linear extrapolation of a time series of aluminium recycling rates. The recycling rates are extrapolated by dividing the secondary production of a metal with the primary production. Because recycling rates are influenced by many different conditions, both technical and political, this may be an example of an area where simple extrapolations may not be valid beyond a few years.

In the future-oriented LCA on wind turbines, it was considered possible to extrapolate several aspects decades into the future with some accuracy. These aspects included the size in MW per turbine, the quantity of materials, and the relation between cost and market volume (Borup and Dannemand Andersen 2002).

While all time series of data may be extrapolated, it is usually not meaningful to do this without further information and assumptions. Therefore, to improve the reliability the following recommendations can be given:

- The extrapolation should preferably be based on the determining factor for the expected development and the trend for this.
- The time series of data should be sufficiently long. Weidema (2003) states that the data on which an extrapolation are based should normally go at least 5 years back, preferably 10 years. However, when radical changes have taken place, which have

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Term</th>
<th>Specific processes$^a$</th>
<th>Less predictable processes and more complex systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Long</td>
<td>Dynamic modelling, exploratory and normative methods</td>
<td>Cornerstone (scenario) methods</td>
</tr>
<tr>
<td></td>
<td>Short and medium</td>
<td>Extrapolation methods</td>
<td>Dynamic modelling and participatory methods</td>
</tr>
</tbody>
</table>

$^a$ Specific processes are those which no radical or untypical developments are expected or in which such developments are under the control of the decision-maker
altered or radically influenced the determining factors, it does not make sense to include data from periods previous to those changes.

- Any constraints on the extrapolation should be considered (e.g., physical or political boundaries for the development of the extrapolated factor). When the extrapolated development approaches a constraint, the extrapolation will no longer be a good approximation. Instead, dynamic modelling can be a more adequate method (see 'Step 4b: Scenario development by dynamic modelling', p 23).

Some general conclusions from empirical observations may be applied. One is that the introduction of a new technology tends to follow an S-curve, so that the initial penetration is slow but with a logarithmic increase, followed by a linear growth, again followed by a logarithmic decrease in cumulative penetration until the market is saturated.

Another empirical observation is that the production costs per unit produced tend to decrease with increased experience from the production. This development is described by so-called learning or experience curves, a logarithmic curve typically described by a learning factor, which is the cost reduction achieved when the cumulative production is doubled. Learning and experience curves for the production of power plants have recently gained more widespread use in energy models (Mattsson 1997; Mattsson and Wene 1997; IEA 2000; Pehnt 2001). The learning factor, which tends to be fairly stable for each specific technology (see Figure 3-3) is typically between 0.9 and 0.75, meaning that the specific production cost is 10% to 25% less each time the cumulative production has doubled. More innovative technologies tend to have the lowest learning factors (largest cost reductions) compared to more established technologies (cf. also Figure 3-3), also implying that the learning factor does change when seen over very long time horizons.

The learning curves for cost reductions mainly reflect savings in manpower, though physical efficiency improvements also play a role. Karvonen (2000) shows a good correlation between gross emissions and cumulative investment in the Finnish pulp and paper industry, and Pento and Karvonen (2000) show that emission coefficients are even more closely related to cumulative investments. Claeson (2000) finds that the learning factor is 0.94 for energy losses from a specific technology for electricity production from natural gas. Conservative learning factors (i.e., 0.85 to 0.95) may therefore be used as proxies for the physical flows in a life-cycle study when the physical efficiency improvements in these flows are not known from other sources.

One should perhaps add that learning curves in the strict sense refer to industrial process costs and the increased efficiency of labour only and consider different aspects such as engineering improvements, servicing technicians’ progress, job familiarisation, development of the parts supply system or manufacturing methods. Learning curves have sometimes been expanded to a technological progress function considering progress in technological developments of products (see
Fusfeld 1973). In fact, experience curves instead of learning curves consider not only learning, but innovation and scale (Lloyd 1979). The transfer of learning curves to a technology is not a foregone conclusion because, very often, learning curves were applied on a company level in business management, and because the parameter is cost, not efficiency, environmental impact, and so on. But learning curves have proven as empirically powerful.

Sources of time series may be
- technical literature and technical experts on the process in question,
- statistics of industrial associations, and
- general statistical publications.

An extrapolation is not necessarily quantitative but can be, for example, a text description of the consequences of extending the prevailing trends into the future. This is illustrated by the example in Textbox 3-1.

Limitations of extrapolation
Because extrapolation is based on historical data alone and does not include combined effects of several developments, it can be used only for medium- or short-term predictions for smaller, specific areas, where no radical or untypical developments are expected. The limits between short, medium, and long term cannot be precisely defined and may differ from application to application because the applicability of extrapolation depends on the dynamics of the system investigated, the precision required in the study, and perhaps most importantly, what other options are available. In cases when an extrapolation gives only a crude indication, it might still not be feasible to obtain more reliable or relevant information through another method. In spite of its limitations, an extrapolation is a better prediction of the future than an assumption of status quo. Thus, even when there is no time or resources to involve technical experts, it may be justified that a non-expert makes a simple extrapolation as a first approximation.

**Step 4b: Scenario development by dynamic modelling**
Dynamic modelling is the analysis of the interactions of several cause–effect mechanisms over time, depending on their relative strengths and probabilities of occurrence. This method is based on an identification of relevant mechanisms, their probabilities of occurrence, and their interactions.
3: Scenarios in life-cycle inventory

Textbox 3-1 Qualitative extrapolation regarding the European electricity market

Current trends of harmonisation and liberalisation of the market will continue. The transmission capacity will continue to be expanded according to the market demand. The result is that current boundaries between electricity markets in Europe will cease to exist, so that geographically there will be only one single European market. The current situation, in which the building of nuclear and hydro power plants in Europe is politically constrained, will continue to prevail. Emission quotas will continue to be in effect, or even tightened.

In this way, otherwise surprise-free scenarios are adjusted to accommodate the expected interactions of determining mechanisms.

Many of the publicly available scenarios for more complex systems (concerning, e.g., electricity production, disposal, collection of waste), as provided by governmental bodies or industry organisations, are based on modelling. Models can be divided in bottom-up engineering-economic models (such as EC 1995a; Mattsson 1997; Mattsson and Wene 1997; Stein and Wagner 1999; Gielen and Moriguchi 2001; Kram et al. 2001), and top-down macroeconomic and general equilibrium models such as those used by IEA (2000).

Jochem (1999) delivers a critique of engineering-economic models compared to top-down models and concludes, 'Top-down [modelling] communities have far too little knowledge imbedded with regard to technological change, saturation in high income economies, and structural change. Engineering-economic modellers, on the other side, have little to say on the influence of rebound effects or income effects, which may be very important in specific target groups (e.g., private households)'. Jochem recommends a better integration of the communities of engineering-economic and top-down modellers. The Bichel Committee (1999) presents an interesting combination of technical analysis, farm-level economic analysis, and use of a general equilibrium model in a study on phasing out of pesticide use.

Complex models, as the ones mentioned above, cannot be explained in few words, and we therefore give only a few examples of more domain-specific models and applications (see example in Textbox 3-2).

Another example, adapted from De Beer (2000), demonstrates a very simple, qualitative form of dynamic modelling, with only a few variables (see Textbox 3-3).

Limitations of dynamic modelling
Because dynamic modelling includes the combined effects of several developments and is not based on historical data alone, it can more readily be used for futures studies with a longer time horizon. Still, depending on the number of variables and the degree of uncertainty included in dynamic modelling, it may result in oversimplification of the future. In studies that deal with less predictable processes and more complex systems where the driving forces can work in many directions, dynamic modelling can benefit from being supplemented by participatory methods (see 'Step 4c: Participatory scenario development', p 24). For futures studies with a longer time horizon, it is reasonable to apply several, diverse cornerstone scenarios (see 'Step 4e: Cornerstone scenario development', p 26).

Dynamic modelling will typically require the involvement of technical experts for the identification of relevant mechanisms, their interactions, and their probabilities of occurrence. It may thus be too sophisticated for the kind of situations described under extrapolation (medium- or short-term predictions for smaller, specific areas, where no radical or untypical developments are expected).

Step 4c: Participatory scenario development
Participatory scenario development uses the insight and opinions of experts and stakeholders to derive statements on the possibility and/or probability of future events and mechanisms and their interaction. The insight and opinions of experts and stakeholders are derived from

- scanning of published information,
- questionnaire polling,
- one-to-one interviews, and/or
- panels, in which different opinions are confronted.

Scanning of published information is the most neutral of the methods, but its scope is limited to the issues on which published information is available, and it does not allow interaction between the source and the inquirer. Questionnaire polling has the advantage of involving a larger and possibly representative group of people.
Textbox 3-2 Dynamic modelling of the energy use and emissions from transport

The energy consumption for transport per kg good may change over time, depending on changes in
- modal choice (ship, rail, truck, airplane),
- transport distances,
- vehicle sizes,
- capacity usage,
- traffic conditions,
- combustion efficiency, and
- education and maintenance.

Changes in emissions depend on all of the above plus changes in fuel composition and emission control. The interdependence of the different variables can be expressed in the form of equations, and a time series can be determined for the determining variables. This constitutes a model. Several such models of transport systems exist, e.g., as a result of the EU COST 319 action (Hickman 1999; Joumard 1999).

Textbox 3-3 Qualitative dynamic modelling of steel casting technologies

Potential technologies for steel casting (identified through participatory methods, see 'Step 4c: Participatory scenario development', p 24) are scored in a matrix according to their current stage of development and their degree of technical innovation compared to the currently applied technology.

<table>
<thead>
<tr>
<th>Stage of development</th>
<th>Degree of technical change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
</tr>
<tr>
<td>Commercial</td>
<td>Thin slab casting</td>
</tr>
<tr>
<td>Demonstration</td>
<td>Thin slab casting with liquid core reduction</td>
</tr>
<tr>
<td>Experimental</td>
<td>–</td>
</tr>
<tr>
<td>Applied research</td>
<td>–</td>
</tr>
</tbody>
</table>

Supplemented by a consideration of costs and benefits (strip casting having the largest potential for energy savings), this dynamic modelling leads to placing the most probable future technologies (thin slab casting and strip cast) on a time series.

One-to-one interviews provide more flexibility in soliciting arguments for the answers given, in searching for biases and contradictions, and in following unexpected lines of inquiry arising from the interview situation. Panel methods, in which the opinions of the participants are confronted, may be used both with an exploratory orientation to stimulate creativity and divergence and, more commonly, with a consensus-orientation to reach some degree of consensus among the panellists.

The future-oriented LCA on wind turbines included 3 participatory elements (Dannemand Andersen and Bjerregaard 2001; Borup and Dannemand Andersen 2002). A brainstorming was carried through to identify factors that are important to the future market and technology of wind power. The brainstorm involved a panel of 10 experts in relevant areas. The beliefs and insights on these factors investigated through a questionnaire that was distributed to attendants at an international wind energy conference. At the end of the study, a workshop was held to discuss options for the dismantling and recycling of wind turbines. When selecting sources or participants for polling, interviews, or panels, varying weight may be placed on involvement of
a representative group (typically the overall concern in questionnaire polling),
• different stakeholders (important when aiming at consensus), and
• sources of interesting and extreme positions (important when the focus is more exploratory).

All participatory methods have an element of subjectivity, which may be countered in different ways:
• The selection of sources or participants may be biased, excluding certain stakeholders or extreme positions. This may be countered by letting the selection be done by one or more 'neutral' third parties. The exclusion of participants due to a lack of resources or access to specific forms of communication (e.g., access to electronic mail or telephone services) should be avoided.
• The wording of questionnaires or the presentation of issues to interviewees or panel-lists can pre-determine the results. This may be countered by starting with more open questions, pre-testing the questions on a critical panel, and including specific test questions that address the same issue from a different angle. Participants should not be forced to answer questions that they do not feel qualified to answer.
• A human tendency to stay within traditional patterns of thought may be countered by specific mental techniques to stimulate new thoughts among participants.
• There is a tendency for participants to answer questions in the way that they expect the interviewer desires. Ensuring anonymity of participants may enhance their willingness to give controversial or extreme answers to questions. When working with panels, this may be further stimulated by group facilitation techniques such as simulations and games.
• Information on how others have answered the same questions, and possibly also their arguments for such answers, may stimulate revised answers or counter-arguments, especially when anonymity is ensured. (Such repeated questioning with feedback and anonymity has become known as the 'Delphi technique'.)

Future studies resulting from participatory techniques are quite often available in published form.

Limitations of participatory methods
Participatory methods are especially relevant when controversial or complex aspects of a life-cycle study are dealt with. Several opinions may be heard, including more extreme positions, which may be disregarded by more analytical methods such as dynamic modelling. When stakeholders are involved, participatory methods may furthermore increase the probability of acceptance of the results from a LCA and thus speed up the subsequent implementation. However, because of their subjective elements, participatory methods may still be seen as unacceptable both by those who feel unable to influence the result and by those who see the participatory process as endangering to their established power.

Also, participatory methods are quite time consuming and difficult to apply, and will therefore typically be too sophisticated for the kind of situations described under extrapolation (medium- or short-term predictions for smaller, specific areas, where no radical or untypical developments are expected).

Step 4d: Exploratory and normative scenario development
For processes upon which the decision-maker has a large degree of (potential) influence, and especially in the context of product development, it may be more interesting to examine how the future could be (using exploratory methods) or how it should be (using normative methods) than how it is likely to be (using analytical methods, such as extrapolations or dynamic modelling).

Exploratory methods concentrate on structuring possible futures, typically using qualitative descriptions. Exploratory methods combine analytic techniques that branch into broader topics or develop smaller subtopics or consequences and imaginative techniques aimed at filling all gaps in the analytical structure. In this way, the full field of possibilities is identified and structured, providing a multitude of combinations and permutations as a starting point for, for example, product development. This large number of possibilities may afterwards be reduced according to economic, technical, and strategic criteria, summarised as, for example, breakthrough potential and importance to the decision-maker.

Normative (or goal-oriented) futures studies investigate how we want the future to be and how to obtain this goal. In contrast to, for example, dynamic modelling, which investigates possibilities and probabilities and generally moves forward
into the future in terms of forces at play, normative methods state objectives that may be substantially discontinuous with the trends at play, then move backwards to the present to identify the necessary steps for reaching the objectives. Besides this particularity, any of the other methods for futures studies may be applied also in normative scenario development. This approach is at the heart of organisational planning. It allows an organisation to orchestrate and target its resources to achieve a goal. The statement of the goal itself must be realistic and take into account present and future resources and contexts. A crucial part of a normative scenario is the detailed analysis, which reveals the specific steps that must be taken at specific times.

Exploratory and normative scenario development require a detailed knowledge of the involved organisation and technical field. It must therefore be performed in close co-operation with knowledgeable people in the organisation. The involvement of the decision-makers is essential in the criteria-setting stage of exploratory studies and the goal-setting stage of normative studies.

Limitations of exploratory and normative methods

Normative, and to some extent exploratory, scenario development is relevant only for processes upon which the decision-maker has a large degree of (potential) influence, so that the necessary steps can be taken to reach the selected goal. It may be tempting to place unrealistic confidence in the potential influence of the decision-maker, and to place too little emphasis upon outside influences. Exploratory methods may yield an overabundance of possibilities, which makes it difficult to identify which of the possibilities are the most relevant.

Step 4e: Cornerstone scenario development

For long-term scenarios in complex situations where many interdependent forces are at play, it is unlikely that a specific scenario can be identified as the single ‘most likely’ description of the future. Instead, cornerstone scenario methods aim at presenting a broad range of plausible outcomes (scenarios), which can serve as a basis for robust conclusions that are viable over the wide range of possible futures.

The term ‘scenario’ comes from the dramatic arts, where a scenario refers to an outline of the plot. A cornerstone scenario is an integrated, coherent, and consistent narrative description of a plausible future situation, often including a description of the development from the present to the future to focus attention on causal processes and decision points (see ‘Cornerstone scenarios’ in Chapter 2, p 11).

As stated above, scenario methods combine aspects of the other tools. The future-oriented LCA on wind turbines included cornerstone scenarios based on the results of extrapolation and participatory methods (Borup and Dannemand Andersen 2002). Often cornerstone scenarios are based on dynamic modelling, displaying the conditions of important variables over time, thereby giving a quantitative underpinning of the narrative description. The nature of evolutionary paths is especially relevant when scenarios are used directly in decision-making, because decisions can deflect those paths. However, a scenario does not have to be based on a model, but can be a simple description of a situation.

A set of cornerstone scenarios usually contains at least one scenario that represents a surprise-free continuation of the present forces at play. Other scenarios are typically based on assumptions regarding significant changes in one or more of the particularly important cause-effect mechanisms (typically technological, political, economical, or sociological mechanisms). By using self-consistent sets or combinations of changes on more than one factor, then even in a many-factored setting, 3 to 6 scenarios are sufficient to capture the range of future possibilities.

Cornerstone scenario methods are widespread, and many good examples have been published (see, e.g., UN 1990; Gallopin et al. 1997; Glenn and Gordon 1998; WBCSD 1998). General scenarios for use in LCAs may be derived from such published sources (e.g., the model-based energy scenarios of the EU [EC 1996]). A scenario methodology for use in product design, with both participatory and normative elements, is described by Manzini and Jégou (2000) (see also Partidário and Vergragt 2000).

Limitations of cornerstone scenario methods

Because cornerstone scenario development combines the features of participatory methods, dynamic modelling, and exploratory methods, it is a cumbersome tool. It may be unnecessarily sophisticated for medium- or short-term time horizons and for more specific, uncomplicated situations.
Step 5: Consistency check

Different methods for futures studies may be appropriate for different parts of the product systems. This is not in itself an inconsistency, as long as the choice of method is justified and the assumptions used in the different methods are not inconsistent. To check consistency, it is necessary to verify that assumptions and results are used in a consistent manner within each scenario in the product systems and also that they are used in a consistent manner in different parts of the product systems.

Combining different methods for futures studies

Applying more than one method for futures studies can be a way of validating the assumptions and/or outcome of each individually applied method. In particular:

- For an extrapolation, the outcome of dynamic modelling may be used to validate the relationship between different trends used, and the identification of which trends are determining and directly related to time.
- An extrapolation or a dynamic model may be validated by participatory methods (e.g., asking experts), which may also provide reasons that the extrapolation or model should be adjusted, for example, due to expected legislation, economical changes, or other initiatives that might affect the extrapolated trend or the modelled relations.
- Results of participatory methods are often more normative (what the future should be) than analytic (what the future is likely to be). Dynamic modelling may give a more analytical perspective on a result from participatory methods.

The outcome of one method may be used as input in other methods, for example:

- As an input to dynamic modelling, an extrapolation may be used as one of more basic mechanisms or equations in a model, and participatory methods may provide information on causal relations and probabilities of events and mechanisms, and interaction between mechanisms.
- In extrapolation and dynamic modelling, the insights from exploratory methods may be used to ensure that all important aspects have been taken into account.
- In participatory and cornerstone scenario methods, an extrapolation can be used as a surprise-free base-line scenario (‘suppose things keep going as they have in the past’) to be modified.
- In participatory methods, the results of practically all other methods for futures studies may be used when designing topics and questions, or directly for the participants as background information for questions or as a common input to which they can relate.
- Normative scenario development may apply both the methods and the results of any of the other methods for futures studies. In particular, dynamic modelling techniques may be useful during the ‘backtracking’ step, though even extrapolations can be applied ‘in reverse’.
- In cornerstone scenario methods, results from dynamic modelling, participatory and normative methods may be used as (part of) one or more scenarios.

Prospective Life-Cycle Inventory Modelling

A model system is a system in which the relevant entities of the original system are reflected and where the relations between these entities are similar to those in the original system (Klir 1991). The life cycle that we draw on a piece of paper and the life cycle that we create in the computer in order to calculate the environmental inputs and outputs are both models of the original, real-world life cycle. The life-cycle model developed in a scenario-based LCI should be an appropriate description of the relevant parts of the future technological system.

In this section, a prospective LCI methodology is presented. It has previously been outlined by, for example, Tillman (1998). This methodology is often known under different names, such as ‘change-oriented’, ‘effect-oriented’ (Ekvall 1999), or ‘consequential’ (Weidema 2003). The principles and applicability of the prospective LCI methodology are described in ‘Applicability of the prospective methodology’ (p 28). The subsequent sections deal with different methodological problems in the LCI. For each methodological problem, we have tried to formulate an ideal methodological option and simplified options that can be of practical use. In the next few sec-
tions, system boundaries are discussed, and some of the following questions are raised: 1) what parts of the life cycle investigated should be included in a prospective LCI, 2) where should the system boundaries be expanded to include parts of other life cycles, and 3) what parts of other life cycles should be included in the expanded system? When it has been decided what parts of the life cycles are to be included in the system investigated, the next step is to decide what technologies should be modelled for each unit process in the system investigated. ‘Identification of the competing product’ (p 38) concerns the question of what product should be supplied by unit processes in the expanded system. ‘Identification of the marginal technology’ (p 39) presents a procedure for the identification of the marginal technology for the parts of the system that are only marginally affected by changes in the life cycle investigated. ‘Technology development’ (p 40), finally, touches briefly upon the problem of future technology development. This area is more fully covered in ‘Futures Studies of Product Systems’ (p 17).

**Applicability of the prospective methodology**

The prospective LCI methodology described herein aims at describing the consequences of changes. It is distinguished by several authors from a retrospective LCI methodology (or descriptive, accounting, attributional, etc.), which aims at describing the environmental properties of a system (Heintz and Baisnée 1992; Weidema 1993a; Baumann 1996, 1998; Frischknecht 1997; Heijungs 1997; Cowell 1998; Hofstetter 1998; Ekvall 1999; Tillman 2000).

The word ‘prospective’ implies that the LCI is future oriented. It is sometimes argued that retrospective LCIs concern existing systems, and prospective LCIs concern future systems. This is the reason why we describe prospective LCI methodology in the context of scenario development. As stated in Chapter 2, scenarios are descriptions of possible future systems.

However, the connection between the prospective or retrospective LCI and directions in time is not simple. A prospective LCI can be carried through to model the future consequences of present or future changes. But it can also be used in a historic context, to model the consequences of changes made in the past. Similarly, a retrospective LCI can be carried through to describe the environmental properties of an existing system but can also aim at describing the environmental properties of a possible future system. Hence, it is not quite correct to state that prospective LCI methodology is always, and only, applicable for studying future systems. It is more correct to state that a prospective LCI methodology is applicable to produce information on the consequences of actions. Such information is relevant to an audience that believes that each action should be assessed on the basis of its consequences (Ekvall et al. 2003). In normative moral philosophy, this view is called ‘teleological situation ethics’.

**Allocation for multifunction processes**

The allocation problems are fairly well known. They have been extensively discussed in, for example, the former SETAC Europe Working Group on Inventory Enhancement and in ISO. Although a compromise has been reached (ISO 1998), it has been criticised for its failure to take sufficient account of the fact that different approaches to the allocation problem are relevant to different situations (e.g., Ekvall and Tillman 1997; Baumann 1998). It also fails to deal explicitly with all aspects of the methodological problems involved. Hence, there may be a need to refine the methodology, both through adjustments of the description in the ISO standard and by means of the formulation of additional recommendations.

The discussion and recommendations presented here are valid for prospective LCI methodology (i.e., for modelling the consequences of possible actions). They are based, to a large extent, on previous publications by Weidema (2001) and Ekvall and Finnveden (2001). We distinguish between allocation for multifunction processes and allocation for open-loop recycling, because different methodological descriptions apply to these 2 cases (Ekvall 1999).

Figure 3-4 illustrates a simple, theoretical multifunction process with 2 products. Only product A is used in the life cycle investigated; it provides an internally used function, product B provides an external function (i.e., a function that is used in another system).

When the allocation problem is not significant (e.g., because possible actions have little effect on the demand for product A in the system investigated), the most easily applicable allocation approach can be used. Otherwise, the adequate approach to the allocation problem depends on how the process reacts to a change in the use of product A in the life cycle investigated. We distinguish between 3 different, theoretical types...
of multifunction processes that call for different, prospective approaches to the allocation problem:

1) products A and B are produced independently.
2) Production of product B depends on the demand for product A.
3) Production of product A depends on the demand for product B.

In the first case, possible actions can have a significant effect on the production of product A but little effect on the production of product B because both products are independently produced. Our methodological recommendation is to divide the multifunction process into single-functional subprocesses (if any, see Figure 3-5), allocate based on physical, causal relationships within the multifunction process (as described in ISO 1998), or apply an approximation of these approaches.

**Justification:** in this case, the quantity produced of product A may change but the quantity produced of product B is not significantly affected. Both subdivision and physical allocation approaches model the effects on the environmental burdens from a multifunction process where the quantity produced of one product is changed while the quantity produced of other products remains the same.

In the second case, possible actions can have a significant effect on the production of both products because the production volume of both products is decided by the demand for product A. If there is a demand for the function provided by product B, it is likely to replace another product. As an example, consider a hypothetical LCA of a diamond product. The residues from diamond mining (product B in Figure 3-6) are used in road construction. An increased use of diamonds results in an increased quantity of residues being available for road construction. This means that other road construction materials can be replaced. If part of product B goes to waste prior to the action, a change in the demand for product A is likely to affect the waste management of product B.

Our methodological recommendation in the second case is to include all environmental burdens from the multifunction process in the system investigated. In addition, it should include the unit processes (if any) that would be affected by a change in the production of product B in the multifunction process, including the possible waste management of product B or the production of competing products (product C in Figure 3-7). The prospective LCI model should also include any significant differences in the environmental burdens of the use and waste management of product B, compared to the use and waste management of product C.

**Justification:** the object of the prospective LCI is to include that which is affected by a change in the use of product A in the life cycle under study. The multifunction process is affected, because, in this case, it depends on the demand for product
A. Hence, the multifunction process should be included in the system. The production of product C could also be affected, as discussed above. If so, it should be included in the system investigated. The same applies to any significant differences in the use and waste management phases of other life cycles that result from the change from product C to product B in other life cycles.

The third case is when possible actions have little effect on the production of both products because the production volume of both products is determined by the demand for product B. In this case, an increased use of product A in the system investigated will not affect the multifunction process. Instead, 3 things might happen. An increased volume of other products might be produced that fulfill the same function as product A (product C in Figure 3-7). If product A has more than one potential use, a reduced quantity of product A might be available for other purposes. This, in turn, could result in the increased production of products that fulfill this alternative purpose (product D in Figure 3-7). On the other hand, if part of product A goes to waste prior to the action, the increased use of product A means that less waste is generated.

As an example, consider a hypothetical LCA of a road. Part of the residues (product A in Figure 3-6 and Figure 3-7) from a mining operation is used in the construction of this road. The remainder of the residues is deposited in a landfill. The use of the residues in the road construction is unlikely to affect the mining operation. Instead, the effect of the decision to use these residues is that less residues end up in the landfill.

As a second example, consider a hypothetical LCA of a table produced from particleboard that is manufactured from sawdust from a sawmill. The sawdust (product A) contributes little to the total revenues of the sawmill. The sawdust that is not used for particleboard production is sold at a lower price as fuel. It is reasonable to assume that the sawmill processes are not affected by the demand from the particleboard producer. Instead, the effect of an increased production of particleboard is likely to be that less sawdust is sold as fuel, and that other fuels (product D) will be used instead.

Our recommendation for the third case is to exclude the multifunction system from the system under investigation. Instead, the system investigated should include any significant reduction in waste management or alternative uses of product A. Furthermore, the system should include the production of products C and D if these are affected by the use of product A. In the road construction example, the system should exclude the mining operation but include the avoided land-filling of mining residues. In the particleboard example, the system investigated should exclude...
the sawmill, but include the avoided use of sawdust as fuel, as well as the production and use of the fuel that is required to replace the sawdust.

**Justification:** Again, the object of the prospective LCI is to include that which is affected by a change in the use of product A in the life cycle investigated. The multifunction process is not affected, because, in this case, it only depends on the demand for product B. Hence, the multifunction process should be excluded from the system. The production of products C and D might be affected, as discussed above. If so, they should be included in the system investigated. The same goes for the waste management of product A, if any.
Note that the 3 cases presented above are theoretical constructs. The behaviour of real multifunction processes often is a combination of the different cases. Products from a multifunction process can rarely be expected to be completely independent of each other (Ekvall and Finnveden 2001), and a multifunction process can rarely be expected to depend on the revenues from only one of the products. The considerations above do not refer to such total independence but to the dependencies involved when producing and using a small amount of either more or less of product A. For such marginal changes, the above considerations give a reasonable reflection of real dependencies.

The ideal option for dealing with the allocation problem caused by multifunction processes is to include all unit processes to the extent that they are affected by a change in the use of product A in the life cycle investigated. A consequence of the previous paragraph is that this often means applying a combination of the approaches described above. Such a procedure is rarely feasible. Hence, simplifications are necessary.

One line of simplification is to apply only one of the above approaches for each multifunction process. This requires that, for each multifunction process, one of the cases above be chosen as the best approximation of the behaviour of the real multifunction process.

Another line of simplification is to use the easiest allocation approach for most of the multifunction processes in the system investigated and only apply the more advanced approaches to the allocation problems that have the largest potential effect on the conclusions of the LCA. This requires that the most significant allocation problems in the system be identified.

There may be large uncertainties concerning what unit processes are affected and to what extent by the use of product A. When the uncertainties are large and the effects may be significant for the conclusions of the LCA, different what-if scenarios should be developed based on various assumptions regarding the effects on the different unit processes. Such scenarios can be called ‘sub-scenarios’, and they should, of course, be consistent with the main scenario that is described through the prospective LCI model.

**Allocation for open-loop recycling**

Open-loop recycling is the recycling of material from one product system into another (ISO 1998). The allocation problem occurs when material is recycled from the system investigated as well as when material is recycled into it. The LCI international standard allows several different approaches to the allocation problem, although it states that the approach used for outflows of recycled material should be consistent with the approach used for inflows of recycled material (ISO 1998).

Quite often, the effect of recycling material from the investigated system is that another material is replaced. The effect of recycling material into the system might be that landfill or waste incineration is reduced or that less recycled material is used in other product systems (see Figure 3-8). In both cases, the ideal prospective LCI methodology is to expand the system under study to include the unit processes that are actually affected by an increase or reduction in the flow to or from the life cycle investigated. In this aspect, open-loop recycling is similar to multifunction processes where the production of the external function depends on the demand for the internally used function (case 2 in ‘Allocation for multifunction processes’, p 29).

In practice, it can be difficult to identify what unit processes are actually affected by a change in the recycling flows. Recycled material from the system investigated can replace material of the same type (i.e., virgin material or recycled material from other systems). It can also replace completely different types of material or no material at all (Ekvall and Finnveden 2001). Recycling of material into the system investigated might affect different waste management processes. It also might affect several other systems in which the recycled material could have been used, replacing another and unknown material. Again, simplifications are required to make the methodology operational.

The first line of simplifications is to assume that the recycled material competes only with virgin or recycled material of the same type. This simplification has a major effect on the LCI results only if the recycled material competes significantly with completely different types of material or with no material at all.

With this simplification, we still need to establish to what extent recycled material from the system investigated replaces virgin material and to what extent it replaces recycled material from other systems. We also need to study to what extent the use of recycled material in our system results in reduced waste management and to what extent it results in a reduction in the use of recycled material in other systems. The static conceptual model in Figure 3-9 can be used for this investigation.
Figure 3-8 Open-loop recycling to and from the product system investigated and the activities that may be indirectly affected by a change in the quantities recycled.

Figure 3-9 A conceptual model of open-loop recycling through a market for recovered material (Ekvall 2000).
In this model, Y, X, D, and S are material flows to and from the market for recycled material, and P is the price of the recovered material.

If the amount of recycled material from (or to) the product life cycle investigated is changed by ΔX (or ΔY), the effects on other life cycles can be calculated from the price elasticity of supply and demand on the market for recycled material. If X and Y are small compared to D and S, the price elasticity of supply (η_s) and demand (η_d) respectively is

\[ η_s = \frac{ΔS}{ΔP/P} \]

\[ η_d = \frac{ΔD}{ΔP/P} \]

The effects of a change ΔX can be calculated as follows (Ekvall 2000):

\[ ΔD_X = \frac{ΔX}{η_d - η_s} \]

\[ ΔS_X = \frac{ΔX}{η_d - η_s} \]

The equalities are only approximate because D and S are not necessarily exactly equal. The effects of a change ΔY can be similarly calculated:

\[ ΔD_Y = \frac{ΔY}{η_d - η_s} \]

\[ ΔS_Y = \frac{ΔY}{η_d - η_s} \]

The elasticity approach can also be applied for the situation of multifunction processes in the previous section when price elasticities are available.

This elasticity approach requires that the relevant price elasticity values be identified. Values for price elasticity are generally identified through the use of time series and econometric models. The price elasticity strongly depends on the time horizon of the study. In general, the price elasticity is larger in a long-term perspective than in a short-term perspective because in the long-term perspective, decision-makers are able to adapt to changes in the price when making investments. The price elasticity also depends on, for example, the collection schemes and the legislation in place at that time and in that location. This means that the price elasticity should ideally be identified for each individual case of open-loop recycling. Unfortunately, this is not likely to be feasible. Instead, further simplifications are necessary.

For this second line of simplifications, several alternatives exist:

1) use default values for the price elasticity (e.g., the values that are presented by Palmer et al. [1997] and summarised by Ekvall [2000]),

2) assume that the demand and supply are equally elastic (η_d = η_s),

3) assume that the demand or the supply is completely inelastic (η_d or η_s is zero), or

4) develop various what-if scenarios based on different choices among the above approaches.

The main danger in using default values lies in a sense of false security. The actual elasticity in a particular recycling case can differ a great deal from the default values. For the price elasticity of the supply of old newsprint, the literature includes estimates ranging from 0.06 to 1.70 (Palmer et al. 1997). The extremely large span between the estimates may be due to errors in individual estimates, but it is also caused to some extent by case-specific factors such as the time horizon of the study and the time and place where the material was collected for recycling.

As an alternative to using default values, it can be assumed that supply and demand are equally elastic. The consequence of such an assumption is that 50% of the recovered material from the life cycle investigated in the LCI replaces recovered material from other life cycles, and the remaining 50% is a net increase of total recycling. With this alternative approach, the LCI model takes into account the fact that recycled material from the system investigated can replace virgin as well as recycled material from other systems.

The third option is to decide whether the supply or the demand is the most inelastic and set this elasticity to zero. In an LCI model based on this approach, recovered material from the system investigated replaces only virgin material or only material recovered from other systems. This approach might be easier to apply than the approaches above because it renders the LCI model less complicated. This simplification will prob-
ably not significantly affect the LCI results if the difference between the actual price elasticity of supply and demand is large.

There is apparently a large uncertainty in the price elasticity of supply and demand. When this uncertainty appears significant for the conclusions of the LCA, different what-if scenarios should be developed based on various assumptions related to price elasticity. These sub-scenarios should, of course, be consistent with the main scenario that is described through the prospective LCI model.

In many cases, open-loop recycling has a negligible effect on the LCI results. This is likely to be the case when, for example, the flows of recycled material are small compared to the flows of similar materials within the life cycle investigated. When the recycling has no significant influence on the results, the effects on activities outside the life cycle can be excluded from the study. A final line of simplification is to apply this simple cut-off approach to most of the flows of recycled material, and apply the more advanced approaches to only the most important flows.

**Alternative use of constrained production factors**

A constrained production factor is here defined as a resource over which there is competition and where the production volume is constrained. Such resources include renewable as well as nonrenewable resources. They include natural resources but also manmade resources and products of which the quantity produced is constrained by, for example, legislation or physical restrictions.

An increased use of constrained production factors in the life cycle investigated does not affect the production or extraction of the resource. Instead, it means that less is available for other parts of the technological system. This, in turn, may result in an increased production of other products that fulfil the same purpose. The situation resembles the multifunction process where the production of the inherently used product depends on the demand for externally used products (case 3 in 'Allocation for multifunction processes', p 29). The ideal, prospective LCI methodology is to exclude the production of the resource from the analysis, as long as it is unaffected by a change in the life cycle investigated. Instead, the system investigated should be expanded to include the alternative use of the constrained production factors and the production of the competing products (see Figure 3-10). The use and waste management in other life cycles should ideally also be included if they are affected by a change from the constrained production factors to alternative products.

Note that the production of constrained production factors does not necessarily take place in multifunction processes. In other words, this is a case where prospective LCI methodology calls for system expansion even though there may be no allocation problem.

As an example, consider the forest industry. Several LCAs have been performed in order to

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**Figure 3-10** Production or extraction of a constrained production factor and the activities that can be affected by a change in the use of this resource in the life cycle investigated
compare paper recycling with energy recovery through waste paper incineration (Finnveden and Ekvall 1997). In many cases, the results indicate that the incineration option is preferable because the energy from the paper may reduce the demand for fossil fuels. In simple terms, the overall effect of waste paper incineration may be that renewable energy in the form of pulpwood is transformed to paper and then used to replace fossil fuels.

It is not necessary to produce paper from the wood before it is used to replace fossil fuels. The recycling option results in a reduced demand for pulpwood. Because pulpwood is a renewable resource, this reduction in resource demand is often assumed to be of little or no environmental significance (Steen and Ryding 1992; Steen 1996; Hauschild and Wenzel 1998). However, in a sustainable future, forest areas and wood are likely to be renewable but constrained production factors because arable land area will be required to produce food and energy as well as material. A reduced demand for pulpwood means, from a sustainable perspective, that more land will be available for energy production. Hence, in a sustainable future, the effect of saving pulpwood could mean the production of more renewable fuel.

The alternative use of woodland as a source for energy has been included in a case study made to compare recycling and incineration of newsprint and corrugated board (Baumann et al. 1993). The alternative use of wood was shown to be a key issue in this comparison (Ekvall 1996).

As a second example, consider hydropower. In some electricity markets, it is possible to buy electricity generated by a particular production technology. It may be possible to purchase, for example, wind power or hydropower. When an electricity contract specifies the production technology, the electricity supplier is responsible for supplying the corresponding amount of electricity from this production technology to the grid. Kåberger and Karlsson (1998) argue that, in this case, data from the specified technology should be used in the LCA rather than average or marginal data for the geographical area. As an example, if the electricity contract of a Nordic aluminium producer specifies hydropower, data on hydropower production should be used in the LCA, rather than data on average or marginal electricity production in the Nordic countries.

However, hydropower is a constrained (renewable or manmade) production factor in the Nordic countries. An increase in the use of hydropower for aluminium production is not likely to result in an increase in total hydropower production in these countries. Instead, less hydropower will be available for other processes. This means that the demand for the marginal electricity production technology is increased. Ekvall et al. (1998) argue that the long-term marginal technology for electricity production in the Nordic countries may be new plants based on coal or natural gas or existing Swedish nuclear power. The alternative use of the hydropower is obviously likely to be important for the LCA results of an aluminium product. The identification of marginal technologies is further discussed in 'Identification of the marginal technology' (p 39).

The examples above are not exhaustive. Oil and coal with low sulfur content is a constrained production factor. If a low-sulfur fuel is used in the life cycle investigated, fuels with higher sulfur content are likely to be used in other systems. Sawdust was previously regarded as a waste flow. Now it can be considered a constrained production factor: if not used for the production of particleboard, it can be used for fuel production (see 'Allocation for multifunction processes', p 29). There are probably many other such examples.

It is clear from that the alternative use of constrained production factors can have important, indirect effects. If these effects are included in the LCA, they may significantly alter the conclusions of the study. If they are not included, the conclusions may result in a sub-optimisation of the system (e.g., incineration with energy recovery of waste paper instead of recycling of paper combined with energy production in the forest).

General market effects

A traditional LCA is based on the implicit assumption that an increased use of a product in the life cycle investigated will result in a corresponding increase in the production of that product. The discussion above illustrates that this is neither the case for certain products from multifunction processes (see case 3 in 'Allocation for multifunction processes', p 29) nor for products for which the quantity produced is constrained ('Alternative use of constrained production factors', p 35).

In fact, it is reasonable to expect that the assumption is invalid for products in general. Referring to the example of the particleboard table in 'Allocation for multifunction processes' (p 29), it is
not certain that the production of particleboard is affected by decisions to purchase the table. The production of the table may even be unaffected. Instead, the effect of decisions to buy the table might be that less particleboard or fewer tables of this type are available for other purchasers. The indirect effects of buying the table may be that particleboard is replaced by other materials in other products and/or that the production and distribution of other types of tables are increased (Figure 3-11). This indicates that economic analyses of the table market, the table manufacturer, the markets for particle board and competing materials, the producer of the particle board, and so on are required to accurately estimate the environmental consequences of buying the table.

This conclusion can easily be generalised for other products. Increased use of a product in the life cycle investigated is likely to contribute to an increase in the price of the product. This, in turn, is likely to result in a reduced use of the product in other life cycles. The effects of a change depend on how sensitive production and demand are to changes in price. This sensitivity can be quantified in terms of price elasticity (see 'Allocation for open-loop recycling', p 32).

With a radical application of the aim to describe the consequences of changes, it is probably not sufficient, and perhaps not even relevant, to trace the materials in the product investigated back to the cradle, that is, to the extraction or generation of natural resources. The decision to buy the product does not necessarily mean that the amount extracted of these natural resources is increased. In general terms, the consequences of an action propagate not necessarily through the life cycle, but through the overall economic and technological systems in a chain of cause–effect relationships, resembling somewhat the ripples caused by a stone thrown in a lake. The natural starting point of a radically effect-oriented environmental assessment of a specific action is then the point where the action is carried out, that is, the point where the stone hits the water.

If the LCI or LCA is carried through to generate knowledge and ideas for future decisions, the natural starting point is the activities where the intended audience can take action. These activities are denoted as the foreground system by, for example, Tillman (1998).

It is reasonable to expect that the uncertainties in the economic analysis will be large. As indicated,
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this reflects the fact that the actual consequences of an action are often uncertain; however, it can be assumed that the large uncertainties make it impossible or pointless to estimate the consequences far down the cause-effect chains. This implies that the boundaries of the system investigated should ideally be defined at the point where the consequences are so small, or the uncertainties so large, that further expansion of the boundaries will yield no information that is significant for any realistic decision.

A radically effect-oriented LCI, as the one illustrated in Figure 3-11, requires data or assumptions regarding the price elasticity of supply and demand for different products. This indicates that LCI requires co-operation between economists and engineers (Weidema 1993b). Because price elasticity estimates can be difficult to obtain, simplifications are also required to make the method applicable (see 'Allocation for open-loop recycling', p 32). The most obvious simplification is to reduce the size of the system investigated: to restrict the study to the activities where the environmental impacts are expected to be affected the most by the action, regardless of whether these activities are located within or outside the life cycle of the product investigated.

Identification of the competing product

Product substitution means that one product, including materials and services, is replaced by another. As indicated in the previous sections, it is essential to know what products are likely to be substituted by, for example, the co-products or recycled material that leaves the life cycle when allocation is avoided by means of system extension. The following procedure (based on Weidema et al. 1999) can assist in the identification of competing products:

The first step in this procedure is to describe the externally used product (e.g., product B in Figure 3-6) in terms of its properties. These properties may be divided into 3 groups depending on their importance to the customer. Obligatory properties, which a competing product must have in order to be considered as an alternative, include the main functionality. They can also include, for example, additional services, aesthetic properties, image, technical quality, reasonable total cost, and specific environmental properties. In addition, the product may have positioning properties (i.e., properties that improve the market position of the product when compared to products with similar obligatory properties).

The second step of the procedure is the identification of the market segments that are affected by the externally used product. Different market segments can be geographically separated, due to climate, regulations, consumer culture, etc. Within a certain geographical area, similar products with slight differences in the obligatory properties may serve different needs and, hence, affect different customer segments. Weidema et al. (1999) also mention market segmentation in terms of the temporal aspects of the products. This includes peak time electricity and rush hour telecommunications.

The third and final step is to identify the competing products in the market segment affected. Several competing products may, of course, exist in each market segment. The LCI model should ideally include all competing products that are significantly affected by a change in the production of the externally used product. The elasticity approach in 'Allocation for open-loop recycling' (p 32) describes how the affected products can be included in the case of open-loop recycling (see also 'Identification of the marginal technology', p 39, which describes the identification of the technologies that are affected by a marginal change in the demand or supply on the market segment).

The performance of a detailed analysis of all product substitutions in the expanded LCI model, as outlined in this section, is unlikely to be feasible. The most obvious line of simplifications is to restrict the detailed analysis to the product substitutions that are expected to be the most important to the conclusions of the LCA.

Identification of the marginal technology

A specific product might be produced by means of different technologies. Electricity, for example, can be produced with technologies with quite diverse environmental properties. A prospective LCI aims at describing the consequences of changes. This means that the input data used for modelling the production of a specific product should reflect the relevant properties of the technologies that would be affected by a change in the life cycle investigated. If the effect of a decision on the total production volume of a product is small enough to be approximated as infinitesimal, it is termed a 'marginal effect'. The technology affected by such marginal changes is called the 'marginal technology'.

The 5-step procedure presented below (Weidema et al. 1999) can assist in identifying marginal tech-
nologies. It essentially aims at answering 2 questions:

1) What is the situation in which the studied change in demand occurs?
2) Given this situation, what specific technology is affected by the change?

The procedure is composed of 5 steps. The first 3 steps aim at describing the situation in which the change occurs. The last 2 steps aim at identifying the specific technology affected.

1) What are the relevant time aspects?
Economists distinguish between short-term and long-term effects of a change. Short-term effects include only those caused by a change in the use of existing production capacity. The capacity itself is assumed to be constant in the short-term perspective. When long-term effects are investigated, the production capacity is assumed to adapt to the change, and the usage of this capacity is assumed to be constant.

In reality, any change can be expected to have a combination of short- and long-term effects. In addition, short-term as well as long-term effects can be fairly complex in a dynamic system. For example, the short-term effects of an increased electricity demand are likely to concern technologies for production of a mixture of peak-hour and base-load electricity. The long-term effects can include consequences for investments in a mixture of technologies (Mattsson et al. 2001). Hence, the actual marginal effects can be too complex to model accurately.

In this case, an obvious line of simplification is to adapt the distinction made by economists between a short-term and a long-term perspective and to include in the model either the short-term or the long-term marginal effects. What effects should be included depends on the time perspective of the study as a whole, but, in most cases, we expect that the long-term effects will be the most relevant to the model.

A second line of simplifications is to ignore the dynamics of the system. This means that the system is modelled as a static system before and after the implementation of any changes in the life cycle investigated.

2) Are specific processes or overall markets affected?
If a decision will only affect a specific process, then the technology of this process is per definition the marginal technology. If the decision influences a market, it is necessary to identify the marginal technology of this market. The identification of the relevant market segment is described in 'Identification of the competing product' (p 38). The subsequent steps describe the identification of the marginal technology in this market.

3) What is the trend in the market?
If a market is affected, the next step is to determine whether or not the overall demand on the relevant market segment is decreasing at a rate that is higher than the replacement rate of existing production capacity. If so, the long-term marginal technology is the technology that is most likely to be phased out. If the demand is increasing or decreasing at a slower rate, the long-term marginal technology is likely to be the technology chosen when new production capacity is installed.

4) What technologies are unconstrained?
If a technology is constrained to its existing production capacity or to a fixed rate of change in terms of capacity, its capacity cannot be affected by any decisions based on the LCA results. Hence, it can never be the long-term marginal technology. If it is constrained to its existing production volume or to a fixed rate of change in production (see 'Alternative use of constrained production factors', p 35, and case 3 in 'Allocation for multifunction processes', p 29), it cannot even be the short-term marginal technology. There may be many reasons for a technology to be constrained in its ability to adjust its production capacity or its production volume:

- natural constraints (e.g., the amount of water available in a specific region; see 'Alternative use of constrained production factors', p 35),
- political constraints (e.g., emission limits, quotas, ban on specific technologies; see 'Alternative use of constrained production factors', p 35), and
- market constraints for co-products (e.g., co-generated heat, animal products; cf. case 3 in "Allocation for multifunction processes", p 29).

In some cases, these constraints can be affected by changes in the life cycle investigated. For example, a change in the electricity demand may influence the political constraints on nuclear power in Sweden and Germany (Ekvall et al. 1998) or on coal power in Denmark. Ideally, the effects of changes on these constraints should be taken into
account in a prospective LCA. In reality, such effects are probably too difficult to model. Hence, an obvious line of simplification is to treat the constraints as fixed entities when the model is developed. This means that any effects on the constraints are disregarded.

5) What technology is actually affected?

Among the unconstrained technologies on the relevant market segment, we may point out the ones that will actually be affected. This is either the technology that is most likely to be phased out or the technology that is most likely to be installed. These preferences are typically determined by the production cost per unit. The technology to be phased out is likely to be the technology with the highest short-term costs. The technology to be installed is likely to be the unconstrained technology with the lowest long-term costs.

In some cases, several technologies can compete at the same cost. In this case, the marginal effects are likely to concern a mix of technologies, even when the model includes only short-term or long-term marginal effects and the dynamics of the system are disregarded. The most accurate LCI model is obtained if each affected technology is included in the LCI model in proportion to the price elasticity of supply for this technology. A simplified method is to include in the model only the technology that is the most sensitive to changes in demand on the market.

Technology development

It is a historic fact that many technologies have been significantly refined over the years. As a consequence, the energy demand and emissions per functional unit have often been radically reduced. This indicates that it is not reasonable to assume that the environmental properties of the technologies in a future system are accurately described through the use of data that represent current technologies.

At the same time, it can be hazardous to take future technological advances into account in an environmental assessment of future systems. The type and magnitude of future environmental improvements are uncertain. The uncertainty can be dealt with through the development of different scenarios based on various assumptions regarding technology development. This reduces the risk that future environmental improvements are taken for granted. Several possible procedures for such scenario developments are available. They are presented in ‘Futures Studies of Product Systems’ (p 17).

Default Scenarios in Life-Cycle Inventory Analysis

Overview

When there are no resources to produce case-specific cornerstone scenarios, default scenarios may be applied instead. Three scenarios are described below, representing 3 extreme perspectives, whose theoretical foundation is provided by the socio-cultural viability theory (Thompson et al. 1990 and Hofstetter 1998): the individualist, the hierarchist, and the egalitarian archetypes (see also ‘Default scenarios and their basis in cultural theory’ in Chapter 2, p 6).

For system delimitation, the important difference between the 3 perspectives concerns the degree of market regulation and the acceptability of environmentally induced change.

The individualist perspective calls for solutions based on free market economy, implying few regulations on competition and a general growth in production, which seeks to take environment into account through innovation and integration into the market mechanisms.

The hierarchist perspective calls for solutions based on globally coordinated regulation and controlled growth that takes into account environmental externalities in the decision-making.

The egalitarian perspective calls for solutions based on local regulation that radically change patterns of production and consumption to a sustainable level.

The consequence for system delimitation in LCA is summarised in Table 3-3, and an example of how this influences the choice of electricity scenarios in Europe is provided in the following section.

Example: Three electricity scenarios for Europe

As an example of how the 3 perspectives influence the system delimitation, we look at the supply of additional European electricity.

In the individualist scenario, an additional demand for electricity will be supplied from the free market, which will be a growing, deregulated European market, where the transmission capacity...
Table 3-3 The consequence of the 3 default cultural perspectives on the assumptions used in life-cycle inventory (LCI) system delimitation (see also Table 2-2)

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Egalitarian</th>
<th>Individualist</th>
<th>Hierarchist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ties between companies</td>
<td>Many</td>
<td>Few</td>
<td>Forced</td>
</tr>
<tr>
<td>Market segmentation</td>
<td>High willingness to substitute very different products</td>
<td>Low willingness to substitute very different products</td>
<td>Substitution may be forced when necessary</td>
</tr>
<tr>
<td>Geographical markets</td>
<td>Localised markets</td>
<td>Global exchange only restricted by transport costs and availability</td>
<td>Regulated markets</td>
</tr>
<tr>
<td>Market trend</td>
<td>Stagnating to decreasing</td>
<td>Growing</td>
<td>Controlled growth</td>
</tr>
<tr>
<td>Production constraints</td>
<td>Strict quotas apply</td>
<td>Only for co-products with a low value relative to the remaining co-products from the same process</td>
<td>Quotas apply</td>
</tr>
<tr>
<td>Important factors for decisions on capital investment</td>
<td>Production costs play a minor role for decisions</td>
<td>Competitiveness, mainly determined by labour costs and skills required</td>
<td>Externalities included in decisions</td>
</tr>
<tr>
<td>Technology development</td>
<td>Fast to medium, depending on economic interests</td>
<td>Regulated speed and direction, varying between different areas</td>
<td>Generally slow, but room for innovation without economic return</td>
</tr>
</tbody>
</table>

has been expanded to allow all producers to compete on equal terms. In this scenario, the highly competitive fossil fuels will continue to be the main source of additional power. Emission quotas do not play any significant role in restricting the use of coal, but the high capital requirements of coal-based technology may allow gas-based technology to gain a considerable market share. Innovation will mainly be driven by an interest in decreasing production costs through more efficient combustion (e.g., through fuel cells).

In the hierarchist scenario, the market is regulated to include environmental externalities in the decision-making, which strives for an optimal balance between societal costs and benefits. This implies the use of tradable emission permits or emission taxes. An additional demand for electricity will be supplied by that power plant which in the given situation has the lowest production costs, taking into account the environmental externalities as translated through taxes and permits. This will place wind power very favourably, as long as acceptable solutions can be found to its localisation. The resulting electricity scenario is a mix of wind power with local biomass and regional natural gas as stabilising technologies.

In the egalitarian scenario, the electricity demand will be stagnating due to a mix of increased efficiency and savings in consumption. Transmission capacity will be limited, as each region relies on its own production capacity. Nuclear power and fossil fuels have been phased out, leaving the electricity to be supplied by combustion of biomass and waste, hydro-, wind and solar sources. A certain loss of supply stability will be accepted. Because production costs play only a minor role for decision-making, a change in demand for electricity will affect the local supplier with the least environmentally benign technology, which in most cases will be the plants based on bio-mass combustion, although hydropower facilities may also be affected in mountain regions.
Scenarios in Life-Cycle Impact Assessment

Scenarios in Ecosphere and Valuesphere within Life-Cycle Impact Assessment Methods

Overview

Within the life-cycle impact assessment (LCIA), according to the ISO standard 14042 (ISO 2000a), scenarios in ecosphere and valuesphere (definitions see Hofstetter [1998]), are used in the 2 phases, characterisation and weighting across impact categories. The results of these scenarios are the basis for modelling to obtain the characterisation and weighting factors. In this chapter, the scenarios on which these factors depend are highlighted. As stated in Chapter 2 ("Relation of scenarios to the conventional phases of life-cycle assessment", p 12) characterisation is primarily related to environmental scenarios (i.e., scenarios in the ecosphere), while weighting across impact categories is related to valuation scenarios from the valuesphere.

Referring to the definition of scenario in Chapter 2 ("The scenario concept in life-cycle assessment", p 7), the choice of the spatial context (i.e., global, European, or national) in which the model is applied is a necessary part of the description of the future situation. The essential future perspective is relevant in LCIA because much of the environmental impacts will occur in the future, even if the pollutant is emitted today. Hence, it is natural that the models contain assumptions about future events and the path from the present to this future. In many case studies, these assumptions are not explicitly reported. For this reason, it is important to raise the life-cycle assessment (LCA) practitioners' awareness of the existence of such implicit assumptions and to motivate them to state them explicitly.

Spatial and temporal boundaries are somehow the basis of the modelling, apart from natural laws. The models of the ecosphere include large uncertainties, as described in general by Hui-
Scenarios within LCIA can use either the cornerstone scenario approach or the what-if-scenario, as defined in Chapter 2 ("Two principal approaches to scenario development in life-cycle assessment studies", p 11). The cornerstone approach is relevant because the research object is complex and not all the casual relationships between environmental interventions and the impact indicators are known. Cornerstone scenarios in LCIA provide strategic information and serve as a base for further research with so-called what-if-scenarios.

The basis for the decision which scenarios are chosen should be defined in the Goal and Scope Definition of the LCA study, as stated in the ISO standard 14041. Within this first step of every LCA, a clear argumentation (from the valuesphere) should be given for the further development of scenarios in the characterisation and weighting across impact categories.

**Procedure for the determination of relevant issues related to scenario development in life-cycle impact assessment methods**

In this section, how scenario development can be integrated into the LCIA methods (as described, for instance, by Udo de Haes 1996; Udo de Haes et al. 1999) can be checked on the relevant issues related to scenario development is outlined. The objective is to identify the scenarios used in the modelling of the ecosphere or valuesphere (environmental and valuation scenarios). By identifying them the LCA practitioner’s awareness of the existence of such sources of uncertainty is improved, and the LCIA modeller is motivated to state them explicitly.

The following 6-step procedure is proposed:

1) Determining the level of sophistication necessary for the respective application.

Not all applications require the same level of sophistication in the LCIA methods. For instance, environmental endpoint indicators (on the damage level) provide more relevant information than midpoint indicators (expressed as potentials) but have a higher inherent uncertainty. Transport processes in LCAs are a good example where a high level of sophistication in the environmental modelling influences significantly the outcome of the study (Nigge 2000). In respect to the valuesphere, the LCA practitioner has for instance to decide if a default method for weighting is used (e.g., the hierarchist version of the Eco-indicator 99 methodology) (Goedkoop and Spriensma 1999), or if the decision-making process in the specific application requires a detailed decision analysis according to the stakeholders’ values.

2) Choosing an LCIA method on characterisation or on weighting across impact categories.

Several LCIA methods have been developed, each with its own assumptions resulting in advantages and disadvantages for different applications. The LCA practitioner chooses usually one or several methods for the LCIA phase of an LCA study.

3) Determining the parts of the ecosphere or valuesphere that are modelled.

LCIA methods contain parts of the ecosphere or valuesphere that are modelled. These parts have to be determined. An example is the modelling of the fate and exposure behaviour of a pollutant.

4) Determining the value choices and the associated assumptions about future (environmental) conditions.

Scenarios are defined in this work as a description of a possible future situation relevant for specific LCA applications, based on specific assumptions regarding the future. Therefore, it is particularly important for the determination of relevant issues related to scenario development in LCIA methods to identify value choices and the associated assumptions about future conditions, both for the environmental situation and the value system.

5) Relating these conditions with the determined models to identify the scenario of each model.

The characterisation of the scenario is performed by relating these conditions with the determined models. To illustrate this procedure in the following sections ("Examples for environmental scenarios", p 45, and "Examples for valuation scenarios", p 46), several examples of identified scenarios in LCIA methods are presented.

6) Consistency check considering the identified level of sophistication.

The identified scenario has to be consistent, in particular with the determined level of
sophistication. Therefore, validation is necessary.

**Scenarios for the Characterisation Step**

**Overview of environmental scenarios**

Characterisation is related to environmental scenarios (i.e., scenarios in the ecosphere). Characterisation factors are obtained by modelling the casual relationships between environmental interventions and the effects.

First, the indicator to measure the relevant impact has to be chosen and validated. In general, a linear relationship is assumed, but because this implies huge errors for certain impacts, a working point has to be defined, particularly depending on the background concentration of a pollutant. For a given working point, there are 2 possible ways for modelling: average and marginal (Udo de Haes et al. 1999).

The modelling of the future impacts needs a time horizon. There are 4 possibilities to introduce a time frame. The first 2 options are based on the idea that LCIA should integrate over time without any discounting, because of the equality principle of sustainability. The last 2 options attach a lower weight to events in the far future. This can be done because future impacts are less certain and can perhaps be avoided or just because we value the present more than the past or the future.

The possibilities are as follows:

- Integration over time without discounting. This implies that all impacts, irrespective of the moment at which they occur, are equally included.
- Approximation of infinite time by the choice of a period, for example, 300 years. Here the assumption is that most of the impacts will have taken place and that the difference with infinite time can be neglected, an assumption which has to be verified.
- Cut-off by choosing a 20-, 50-, 100-, or 500-year period.
- Integration over time with a continuous discounting of for instance 1% or 3% per year (or even 5% to 10% as is usual in economic analysis). Taking into account the individual point of view, this corresponds to the uncertainty of future events, and the preference for the present is often accounted for in economic analysis. It differs therefore from the indefinite time horizon in the equality principle of sustainability.

As a baseline for best available practice, it is proposed that characterisation factors will be calculated for infinite time without discounting. This can also be approached by a given (long) period of time. In addition, it is advantageous to investigate whether a shorter period will yield considerably different results. Thus, best practice will then be expressed in a double result, which enables decision-makers to attach different weights to events in the near and the far future (Finnveden 1998).

A double result means 2 scenarios, one for the near future and the other for the far future. Moreover, continuous discounting could be introduced.

Another important input for the modelling is spatial information. Spatial differentiation may be performed because of differences in fate and exposure mechanisms, differences in sensitivity for effects, or the difference between background levels determining the working point in the dose–effect curve (Udo de Haes et al. 1999). Also, the spatial conditions may change in the future, and they may change in one region more than in another; for instance, the tropical environment is currently changing more rapidly than the European one due to the deforestation.

Three options are possible: global, spatially differentiated, and site-specific impact modelling. The same type of impact models can be used but with different spatial information. The consideration of spatial aspects in the impact assessment phase requires spatial information in the inventory.

As it has been shown, there are several choices to make in the modelling of the environment. Each alternative could be modelled separately as a proper scenario, but for this purpose a huge quantity of data would be necessary. This is the main reason why the required level of sophistication for the respective application has to be defined.

**Examples for environmental scenarios**

In the literature on the current impact category factors, different cases of scenarios can be found. Two examples follow:

1) Time horizons in global warming
   (Houghton et al. 1996):
   In the modelling underlying the global
warming potential (GWP), assumptions are made, as for instance with regard to future economic growth and use of fossil fuel. Then in the characterisation, 3 time horizons (20, 100, and 500 years) are used that are not to be confused with the abovementioned cut-offs. The scenarios show quite different results for the 3 time frames.

2) The emissions from solid waste treatment over time (Finnveden et al. 1995):
The emissions over time differ significantly depending on the treatment technology. While in the incineration the pollutants are emitted in one moment, emissions from landfill may prevail for a very long time. The emissions from landfill have to be modelled because there are no possibilities to measure future emissions. A choice concerning which time perspective is of interest has to be made. Scenarios with the abovementioned cut-offs of 20, 50, and 100 years could be compared. The emissions would be very different.

Scenarios for the Weighting Across Impact Categories

Overview of valuation scenarios
Weighting across impact categories is related to valuation scenarios from the valuesphere. Weighting factors can be obtained by various approaches: authorised goals or standards (distance to target approach), proxy approach, authoritative panel (societal approach), technology abatement approach, and monetisation (Lindeijer 1996). The choice of one specific method can be considered as a choice of one specific valuation scenario. However, the decision is made in the present, and there may be unforeseen changes in the values of future generations. This aspect signifies an additional uncertainty and can only be considered by the development of quite diverse value scenarios.

Examples for valuation scenarios
The dependence of the weighting factor itself on scenarios is shown here for cases of air emissions, for the ExternE methodology (EC 1995b), and for resource depletion issues.

The Eco-indicator 95 method (Goedkoop 1995) belongs to the distance to target approach. The weighting factor, which includes the valuation of the respective effects, is determined on the bases of target values. The target values are taken primarily from an extensive scenario study carried out by the Rijksinstituut Voor Volksgezondheid En Milieu (RIVM) for the Globe Europe organisation. The report describes the damage caused by each effect on a European scale. In the case of the greenhouse effect, for example, the change is evaluated based on a scenario that under current policies the temperature increase will rise to 0.3 °C per decade, from 0.2 °C per decade at the moment. In the case of ozone layer depletion, it is considered that the use of the respective substance is to be phased out by 2015. On the basis of the scenarios, the impact categories are weighted against each other.

The ExternE methodology (EC 1995b) has been developed within a project on the externalities of electric energy. Environmental impacts are expressed in terms of indicators (e.g., years of life lost [YLL]) and by economic valuation in European currency units (ECUs). In this project, a continuous discounting rate of 0%, 3%, and 10% is applied, corresponding to different valuation scenarios of the future and the path from present to future. The results of this project are used to create the Uniform World Model of Spadaro and Rabl (1998). This model is proposed to estimate simple impact indices of real damages in LCIA. The uniform world corresponds to a scenario created in particular for the European situation, and the results depend strongly on the choice of the discounting rate.

Finally, the input-related impact categories (e.g., the ones that consider resources) have their own typical scenarios. They are typically based on assumptions about the resource supply and demand of mankind in the future. This can include assumptions on technological skills on extraction in the far future. In other words, the valuation scenario can include technology scenarios. One example is the sustainable process method to deal with resource depletion in the environmental priority strategies (EPS) methodology presented by Steen and Ryding (1992). They assume that, by extracting a resource now, future generations will need a massive amount of energy to continue extracting the resource. The use of resources is given a weight according to the energy requirements and emissions that would result from extraction in the far future, using present technological skills. Steen and Ryding (1992) do not take into account technological development, nor that by that time it might be much more attractive to substitute that type of resource with another.
In a more recent EPS version, Steen (1999) discusses these issues but concludes that it is still reasonable to give resources use a weight according to the direct costs, resource requirements, and emissions that would result from extraction in a sustainable far future. However, some account is made for technological development. For example, Steen assumes that the extraction in the sustainable future will be based on renewable energy sources.

**Default Scenarios in Life-Cycle Impact Assessment**

**Introduction to default scenarios in life-cycle impact assessment**

An example for the consequent application of the same value definitions described in the goal and scope phase of an LCA to all scenarios within the inventory and impact assessment step is proposed by the concept of default scenarios. This concept is based on 3 perspectives whose theoretical foundation is provided by 3 extreme archetypes of socio-cultural viability theory (Thompson et al. 1990; Hofstetter 1998): the individualist, the hierarchist, and the egalitarian archetypes (see also 'Default scenarios and their basis in cultural theory' in Chapter 2, p 6).

The environmental and valuation scenarios can be related to the aforementioned default scenarios. The important difference among the 3 perspectives concerns the consideration of the time horizon.

An infinite time horizon without discounting or a very long period of time corresponds to the egalitarian perspective, considering that every generation has the same importance. On the contrary, the short time horizon corresponds to the individualist perspective, considering that every generation has the same importance. Somewhere in the middle of these 2 perspectives, the hierarchist perspective is situated. In this case, because the hierarchist does not favour the present over the future, because in his view there is no scientific reason to choose a time horizon, the hierarchist also chooses the long-term perspective. However, he might opt also for a discounting, taking into account that further technical development will improve the solutions for future generations.

The consequence of the application of the socio-cultural viability theory to scenarios in LCIA is summarised in Table 4-1, and in the following section, examples from literature are provided that are in line with the default scenario concept. The crucial points for LCIA are the assumptions on the time horizon and the spatial differentiation, the resources and the energy future, as well as the risk perception and the scope of knowledge.

**Examples for default scenarios in life-cycle impact assessment**

Two examples for default scenarios in the ecosystem are taken from the Eco-indicator 99 methodology (Goedkoop and Spriensma 1999):

1) Surplus energy for minerals and fossil fuels (Müller-Wenk 1998; Goedkoop and Spriensma 1999):

   There is an important use of scenarios for defining the 'energy future'. These scenarios differ a lot depending on the cultural perspective. According to the individualist perspective, fossil fuel resources are not a problem, advocating a business as usual attitude. Furthermore, an individualistic argument is that, based on experience (especially after the so-called oil crisis), fossil oil depletion is not really an issue. Finally, because the long time perspective is not relevant from this perspective, problems that might occur in the future are not given much weight. In the case of mineral resources, we assume that the individualistic perspective would acknowledge that resource concentrations decrease steadily, but it would not be considered a problem. In contrast to this point of view, for the egalitarian and hierarchist perspectives, both mineral and fossil resources are considered to be a serious problem. However, the egalitarian and hierarchist perspectives differ in the 'view of needs and resources'. The egalitarian view is that resources cannot be managed, while needs can. From this perspective, it is logical to assume that different resources can substitute each other because they are not really interested in the differences between resources, and to implement a need-reducing strategy for fossil fuels as a group rather than investigating the use of separate fossil fuels. The hierarchist view is that needs cannot be managed, though resources can. From this perspective, it is important to look carefully at the differences between the resources in order to develop management strategies.
Table 4-1 The consequence of the 3 default cultural perspectives on the assumptions used in life-cycle impact assessment modelling (Hofstetter 1998)

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Egalitarian</th>
<th>Individualist</th>
<th>Hierarchist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception of time</td>
<td>Long term dominates over short term</td>
<td>Short term dominates over long term</td>
<td>Balanced distinction between short and long term</td>
</tr>
<tr>
<td>Discounting</td>
<td>Zero</td>
<td>High</td>
<td>Technical standard</td>
</tr>
<tr>
<td>Temporal survival dilemma</td>
<td>Future</td>
<td>Present</td>
<td>Present versus future outcomes</td>
</tr>
<tr>
<td>Spatial survival dilemma</td>
<td>Global</td>
<td>Local</td>
<td>Local versus global outcomes</td>
</tr>
<tr>
<td>View of resources</td>
<td>Depleting</td>
<td>Abundant</td>
<td>Scarce</td>
</tr>
<tr>
<td>Attitude towards resources</td>
<td>Need reducing strategy</td>
<td>Manage needs and resources</td>
<td>Increase resources</td>
</tr>
<tr>
<td>Perception of needs and resources</td>
<td>Can manage needs, but not resources</td>
<td>Can manage needs and resources</td>
<td>Can manage resources, but not needs</td>
</tr>
<tr>
<td>Energy future</td>
<td>Low growth (radical change now)</td>
<td>Business as usual</td>
<td>Middle of the road (technical mix)</td>
</tr>
<tr>
<td>Attitude towards risk</td>
<td>Risk-averse</td>
<td>Risk-seeking</td>
<td>Risk-accepting</td>
</tr>
<tr>
<td>Risk handling style</td>
<td>Rejection and deflection</td>
<td>Acceptance and deflection</td>
<td>Rejection and absorption</td>
</tr>
<tr>
<td>Benefit–risk dilemma</td>
<td>Risks</td>
<td>Benefits</td>
<td>Benefits versus risks</td>
</tr>
<tr>
<td>Scope of knowledge</td>
<td>Imperfect but holistic</td>
<td>Sufficient and timely</td>
<td>Almost complete and organised</td>
</tr>
</tbody>
</table>

2) Modelling the ecosphere by the structured aggregation procedure (Hofstetter 1998; Goedkoop and Spriensma 1999):
This general concept was developed by Hofstetter (1998). A concrete application is for instance in the fate analysis for metals, where a choice in the length of the time horizon is necessary. In the long-term perspective, it may take thousands of years for some metals before the steady-state concentration is reached. In the egalitarian point of view, future generations are equally important, so the long-term perspective is used. The hierarchist perspective does not favour the present over the future because there is no scientific reason to choose a time horizon. Based on this view, it is also natural to choose the long-term perspective. The short-term perspective is adequate from the individualist perspective because, with this view, only the near future is relevant.

In the same way, for scenarios in the valuesphere, examples for the application of the 3 default scenarios can be found in the literature:
- The Eco-indicator 99 (Goedkoop and Spriensma 1999) offers in the valuesphere directly the choice among the 3 different aforementioned cultural perspectives. Hence, they correspond to the 3 default scenarios and describe the way the weighting across the impact categories is carried out. This can be demonstrated by the example of the indicator disability-adjusted life years (DALY) (Murray and Lopez 1996) for the assessment of damages for human health. This indicator concept allows combining the impact subcategories ‘mortality’ and ‘morbidity’ and is used for the aggregation of the impact categories ‘climate change’, ‘stratospheric ozone depletion’, and ‘human toxicity’ in the Eco-indicator 99 methodology. Within this approach, an age weighting can be taken into account.
By age-weighting, a scenario is created on how to evaluate the life years for the path from the present to the future. The aspect of age weighting has been looked at from the concept of cultural theory by Hofstetter (1998). The individualist perspective assigns greater importance to being healthy at younger years and considers the human capital approach to be important. Contrary to this position, the egalitarian view rejects the generalisation that children and other adults are generally of lesser importance to society than those in the prime of their life. The hierarchist perspective believes that the group is the important entity. In addition, they tend to obey the law. The law postulates in general the equality of human beings. This discussion shows that age weighting is relevant in the individualist perspective only.

- The discount rates used in the above-mentioned ExternE methodology (EC 1995b) can be interpreted in the following way: 0% discount rate corresponds to the egalitarian perspective; damage in the far future is as important as in the near future. The 3% discount rate can be interpreted as the hierarchist perspective, considering the opinion of an economic scientist. Finally, a discount rate of 10% describes the individualist point of view. A person with this perspective prefers to have what he can in the present, and only the very near future is of interest when considering possible damages.
Conclusions

The scenario concept is used in different ways and has different meanings in different life-cycle assessment (LCA) groups in Europe. As stated in Chapter 2, we agreed to define scenario broadly to be a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future, and, when relevant, also including the presentation of the development from the present to the future. A scenario may concern the technosphere or, to be more specific, the product system. Other scenarios may concern the environmental systems (the ecosphere) or systems of human values (the valuesphere). Each scenario includes a scenario frame, which is typically developed as part of the goal and scope definition. It also includes relevant parts of the models of the technosphere, ecosphere, or valuesphere that result from the life-cycle inventory analysis (LCI) or life-cycle impact assessment (LCIA).

An LCA can include a hierarchy of scenarios within scenarios that concerns different parts of the technosphere, ecosphere, or valuesphere. As an example, the choice of a specific weighting method can be considered as a choice of one specific valuation scenario. The weighting factors themselves can be based on environment or technology scenarios about future damages. The environmental priorities strategy (EPS) default weighting factors for the depletion of different resources, for example, are based on technology scenarios concerning the future extraction of these resources (Steen 1999). The Eco-indicator 95 weighting factor for global warming is based on an environment scenario concerning how fast the temperature will increase.

We found it useful to distinguish between cornerstone scenarios and what-if scenarios. In the first case, the LCA practitioner chooses several options, which can be very different, in order to get an overall view of the studied field. What-if scenarios are used for comparing 2 or more options in a well-known situation where the practitioner is familiar with the decision problem and can define a hypothesis on the basis of existing data. Hence, the choice between cornerstone and what-if scenarios depends on the time frame and the complexity of the systems involved as well as on the goal of the study.

Several different methods for generating descriptions of future situations are elaborated in Chapter 3 (‘Futures Studies of Product Systems’, p 17). These are applicable in different cases,
depending on the time horizon of the study and the complexity of the system investigated. The choice of forecasting methods may also depend on the influence of the decision-maker. Results from extrapolation may be useful for decision-makers who do not have a large influence on the system investigated. When the decision-maker can control the system, exploratory and normative methods may provide more useful information (see Table 5-1).

Prospective LCI methodology aims at describing the consequences of changes made within the product system. This means that the LCI model should include the processes that are actually affected by a change in the product system. What processes are affected depend on market mechanisms that can be modelled using concepts of competition, price elasticity, and market constraints. A close cooperation between LCA practitioners and economists is probably required to accurately model these mechanisms. This, in turn, is likely to have important implications for the system boundaries and the LCI results.

Default scenarios for different parts of the technosphere, ecosphere, and valuesphere can be developed based on at least 3 of the value systems within cultural theory: the hierarchist, egalitarian, and individualist perspectives. These default scenarios may be useful when the development of case-specific scenarios is not feasible. They may also be useful when case specific scenarios are estimated not to give any additional information that is significant to the purpose of the LCA.

Table 5-1 Suggested forecasting methods for studies with different time frames, complexity, and level of control

<table>
<thead>
<tr>
<th>Term</th>
<th>Specific and predictable</th>
<th>Less predictable and more complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-medium</td>
<td>Extrapolation methods</td>
<td>Dynamic modelling and participatory methods</td>
</tr>
<tr>
<td>Long</td>
<td>Dynamic modelling, exploratory and normative methods</td>
<td>Cornerstone (scenario) methods</td>
</tr>
</tbody>
</table>


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<table>
<thead>
<tr>
<th><strong>C</strong></th>
<th><strong>L</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC</td>
<td>chlorofluorocarbon</td>
</tr>
<tr>
<td>D</td>
<td>disability-adjusted life years</td>
</tr>
<tr>
<td>DALY</td>
<td>Design for Environment</td>
</tr>
<tr>
<td>DfE</td>
<td>Division of Technology Industry and Economics (UNEP)</td>
</tr>
<tr>
<td>DTIE</td>
<td>European Commission</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>ECU</td>
<td>European currency unit</td>
</tr>
<tr>
<td>EPS</td>
<td>environmental priorities strategy</td>
</tr>
<tr>
<td>ETHZ</td>
<td>Swiss Federal Institute of Technology–Zürich</td>
</tr>
<tr>
<td><strong>G</strong></td>
<td><strong>S</strong></td>
</tr>
<tr>
<td>GWP</td>
<td>global warming potential</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td><strong>W</strong></td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>IZM</td>
<td>Fraunhofer Institut fur Zuverlaessigkeit und Mikrointegration (Germany)</td>
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A Professional Society for Environmental Scientists and Engineers and Related Disciplines Concerned with Environmental Quality

The Society of Environmental Toxicology and Chemistry (SETAC), with offices currently in North America and Europe, is a nonprofit, professional society established to provide a forum for individuals and institutions engaged in the study of environmental problems, management and regulation of natural resources, education, research and development, and manufacturing and distribution.

Specific goals of the society are:

- Promote research, education, and training in the environmental sciences.
- Promote the systematic application of all relevant scientific disciplines to the evaluation of chemical hazards.
- Participate in the scientific interpretation of issues concerned with hazard assessment and risk analysis.
- Support the development of ecologically acceptable practices and principles.
- Provide a forum (meetings and publications) for communication among professionals in government, business, academia, and other segments of society involved in the use, protection, and management of our environment.

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