Chapter 15
Life Cycle Costing: An Introduction

Jan-Markus Rödger, Louise Laumann Kjær and Aris Pagoropoulos

Abstract The chapter gives an introduction to life cycle costing (LCC) and how it can be used to support decision-making. It can form the economic pillar in a full life cycle sustainability assessment, but often system delimitations differ depending on the goal and scope of the study. To provide a profound understanding this chapter describes several approaches and terms, fundamental principles and different types of costs. A brief introduction is given to conventional LCC and societal LCC but the main focus is on environmental Life Cycle Costing (eLCC) as the LCC approach that is compatible with environmental Life Cycle Assessment (LCA) in terms of system delimitation. Differences are explained and addressed, and an overview is given of the main cost categories to consider from different user perspectives. As inventory data is often sensitive in financial analyses, a list of relevant databases is provided as well as guidance on how to collect data to overcome this hurdle. In an illustrative case study on window frames, the eLCC theory is applied and demonstrated with each step along the eLCC procedure described in detail. A final section about advanced LCC introduces how to monetarise externalities and how to do discounting.

All authors contributed equally

J.-M. Rödger (✉)
Division for Quantitative Sustainability Assessment,
Department of Management Engineering, Technical University of Denmark,
Kongens Lyngby, Denmark
e-mail: januw@dtu.dk

L.L. Kjær · A. Pagoropoulos
Section of Engineering Design and Product Development,
Department of Mechanical Engineering, Technical University of Denmark,
Kongens Lyngby, Denmark

M.Z. Hauschild et al. (eds.), *Life Cycle Assessment*,
DOI 10.1007/978-3-319-56475-3_15

Learning Objectives
After studying this chapter, the reader should be able to:

- Understand the fundamental principles of Life Cycle Costing.
- Know how to use Life Cycle Costing as a tool to make good decisions from different perspectives—as a product/service developer or someone who buys a product/service.
- Know historical and current application areas.
- Know different variants of Life Cycle Costing approaches and understand their differences e.g. in terms of system boundary approaches.
- Be familiar with the monetarisation of intangible elements, which approaches are available.
- Know how to deal with costs in the future (discounting).

15.1 Introduction

Life Cycle Costing (LCC) can form the economic pillar in a full life cycle sustainability assessment comprising the environmental, economic and social dimension (see Chap. 5). LCC is a versatile technique capable of being applied for a range of purposes and at different stages in the project or asset life cycle to support decision-making. It might be undertaken both as an absolute analysis (e.g. to support the process of budgeting) and as a relative analysis (e.g. in order to compare alternative technologies; Langdon 2007). Three variants of LCC can be distinguished. Conventional LCC, also termed financial LCC, is the original method, and in many ways synonymous with Total Cost of Ownership (TCO). Environmental LCC is aligned with LCA in terms of system boundaries, functional unit, and methodological steps. Lastly, Societal LCC includes monetarisation of other externalities, including both environmental impacts andsocial impacts.

For conventional LCC, standards from various government bodies and industry sectors have been developed, includingISO 15663,IEC 60300-3-3, BS 3843, AS/NZS 4536, ISO 15686. For environmental LCC the work of the scientific working group within SETAC on LCC resulted in the LCC methodology described in (Hunkeler et al. 2008), while societal LCC is still at an early stage of development, and more research work is required.

The three types of LCC will be explained in Sect. 15.2. As the approach that is most aligned with LCA, environmental LCC will be the type of LCC explained in depth and exemplified throughout this chapter. Section 15.3 presents the steps of an environmental LCC and provides some practical information for data gathering. A case study in Sect. 15.4 shows how to apply the approach. Section 15.5 elaborates on some advanced issues in LCC, including how to monetarise externalities and how to deal with discounting in LCC.

15.2 Fundamental Principles and Variants of LCC

LCC can be conducted for different purposes, and the methodological choices will depend on the goal and scope of the study. This section introduces the fundamental principles in LCC, including the different purposes and the influence of the target group. This is followed by a description of different types of cost and terminology, before the three variants of LCC are explained.

15.2.1 Fundamental Principles of LCC

As the name suggests, LCC is a technique that assesses costs over the life cycle of a product or a system. Literature features a multitude of terms synonymous to LCC to describe costing across the life cycle of a product, a system or a project, including Through-Life Costing (TLC), Whole-Life Costing (WLC) and Total Cost of Ownership (TCO). It should be noted that in the absence of any internationally recognised standard to describe these terms in detail, differences between them remain a subjective opinion based upon experience, field of study and economic standpoint (Boussabaine and Kirkham 2008).

Conducting an LCC can have different purposes. It may be used as a planning tool, an optimisation tool, a tool for hotspot identification, as part of a life cycle sustainability assessment of a specific product, or to evaluate investment decisions.

A primary consideration relates to the timing of the analysis, where two main types of LCC can be distinguished. *Ex ante* LCC is a prospective approach based on estimates, and is conducted at the early stages of decision-making. In contrast, *ex post* LCC is a retrospective approach based on actual results, usually conducted at the end of a project or a specific time period.

Another relevant consideration is the target group. The target group might be a single actor in a value chain such as a producer or a user or it might take the whole value chain into perspective. The choice of the target group during the goal and scope definition phase of the LCC has implication on the necessary level of detail.

Consider the life cycle cost of a passenger car (see Fig. 15.1). At first, taking the driver perspective (user in Fig. 15.1) for a passenger car, fuel and insurance costs, as well as taxes and potential maintenance are very relevant information in the operation phase, indicated by different grey shadings in the figure. In contrast, a manufacturer would be interested in a detailed analysis of the operational (OPEX) and capital expenditures (CAPEX) such as logistics, research & development (R&D), marketing and so on. Taking the view of a recycler, they would rather be interested in a detailed description of the constitution of the service fees and those expenditures related to recycling the product. A detailed description of costs to be considered from different perspectives and in the different life cycle stages is given in Sect. 15.3.

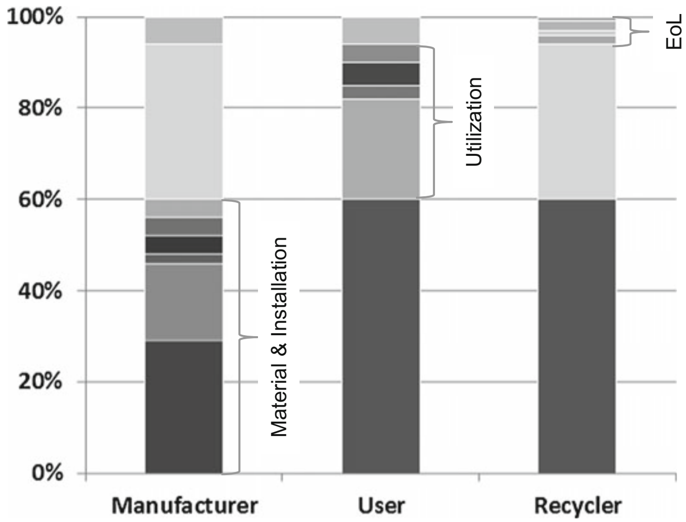

Fig. 15.1 Different level of details for different actors in life cycle costing of a passenger car

15.2.2 Different Types of Costs and Terminology

Costs, Revenues and Value Added

A cost is normally considered as being synonymous with a price of something—it is the monetary value that someone has to pay for something. In an LCC, costs are identified over the life cycle of the product.

LCC can also include revenues which are considered as negative costs. Hunkeler et al. (2008) argue that there are no fundamental problems involved in adding the revenues in the analysis, as long as it is clear how it is being carried out, although for practical reasons they are frequently left out. Depending on the context, inclusion of revenues may be required in order to effectively support decision-making. Consider an example where a window manufacturer uses LCC to compare the life cycle costs of two windows. The two windows are identical, except that one has an extra decorative feature. In this example, for LCC to be of practical use, it needs to evaluate thetrade-off between the extra costs of the feature versus the expected increase in sales. In cases where LCC covers multiple target groups—e.g. manufacturer and user in the passenger car example from before—adding revenues can be confusing, as the cost for one actor is often the revenue for another. In this case, it is important to clearly distinguish between costs and revenues for each target group. In environmental LCC, where multiple perspectives are common, only the value added for each life cycle stage is accumulated in LCC, in order not avoid double counting. See Sect. 15.3 for a detailed description of value added.

15.2.3 Temporal Distribution

Since in LCC, costs are accumulated over a lifespan, one needs to consider that the monetary flows occur at different times. This complicates the analysis for two reasons.

The first is that prices change due to the market dynamics. Looking at cars for example: all costs associated with a car, viz. steel, labour, fuel, plastics, taxes, are likely to change from year to year. In the long run there is a sustained increase in the general price of goods, which effectively alters the purchasing power of currency—a phenomenon known as inflation. In LCC one would like to compare costs based on a chosen reference year and therefore all costs needs to be adjusted to that year when doing the comparison. This is done by using inflation rates. Equation 15.1 shows how to calculate the price P of a product at time t (in years) assuming an inflation rate r, where $P(0)$ is the price at the reference year ($t = 0$).

$$P(t) = (1 + r)^t P(0) \tag{15.1}$$

The second complicating fact is that people are likely to have a time preference, and often prefer to spend money later rather than now. One solution to take these considerations into account in LCC when comparing future and present costs is discounting. Discounting essentially weights impacts by assigning a lower weight to costs in the future than present costs, and is discussed in greater detail in Sect. 15.4.

15.2.4 Internal Versus External Costs

Costs borne by actors directly involved in the life cycle of the product are termed *internal costs* (sometimes also referred to as ‘private costs’). However, a product or system may involve other costs, borne by other actors indirectly influenced by the product life cycle, e.g. as a result of pollution or othersocial impacts. These are termed *external costs*.

External costs (also termed externalities) are value changes caused by a business transaction, which are not included in its price, or value changes caused as side effects of the economic activity (Dodds and Galtung 1997; Hunkeler et al. 2008). For example, in the construction of a highway close to a residential area, one possible external cost that is not normally included in the life cycle costs of the highway is the value reduction of the houses close to the highway due to the increased noise levels. In conventional LCC, external costs are usually not included. If the external costs are already expressed in some monetary unit, they can be included in the environmental LCC. In societal LCC, externalities can be monetarised and included in the assessment. External costs and monetarisation in general is covered in Sect. 15.5 (Advanced LCC). Table 15.1 gives an overview of the most common terms used in LCC and their definitions.

Table 15.1 Definitions of terms used in LCC

Term	Definition
Price	The amount of money that will purchase a finite quantity, weight, or other measure of a good or service (Sullivan et al. 2006)
Revenue	The income generated from sale of goods or services, or any other use of capital or assets, associated with the main operations of an organisation before any costs or expenses are deducted
Internal cost	Costs borne by actors directly involved in the life cycle of the system under study
External costs	External costs (also termed externalities) are value changes caused by a business transaction, which are not included in its price, or which occur as side effects of economic activity (Dodds and Galtung 1997; Hunkeler et al. 2008)
Value added	Value added is the difference between the sales of products and the purchases of products or materials by a firm, covering its labour costs and capital costs as well as its profits (Hunkeler et al. 2008)
Life cycle costs	The sum of value added over the life cycle of a product or a system (Moreau and Weidema 2015)
Net Present Value (NPV)	NPV is the sum of all the discounted future cash flows that takes into account the time value of money over the entire life time (Park 2011)
Discounting	A method used to convert future costs or benefits to present values using a discount rate (Langdon 2007)
Inflation rate	A measure of the overall change in prices for goods and services over time
Exchange rate	Currency conversion between different currencies

15.2.5 Three Variants of LCC

To understand the differences between the three types of LCC, Fig. 15.2 shows how they relate to the three pillars of sustainability (people, planet, and profit) and which costs they include.

LCC can have various goals, depending on the needs and perspectives of the study commissioners. In an LCC of a private vehicle, the user might not be interested in the end-of-life stage of the car, while society might also include broader impacts, which are not borne by the user or the supply chain such as public health expenditures due to particulate matter emissions. To accommodate for these differences, three variants of LCC have been proposed (Hunkeler et al. 2008): Conventional LCC, Environmental LCC and Societal LCC. The differences between the three variants are summarised in Table 15.2.

Conventional LCC (cLCC)
Conventional LCC (also sometimes called financial LCC) was originally designed for procurement purposes in the U.S. Department of Defence (White and Ostwald 1976; Korpi and Ala-Risku 2008). LCC is mainly applied as a decision-making tool, to support acquisition of capital equipment and long-lasting products with high

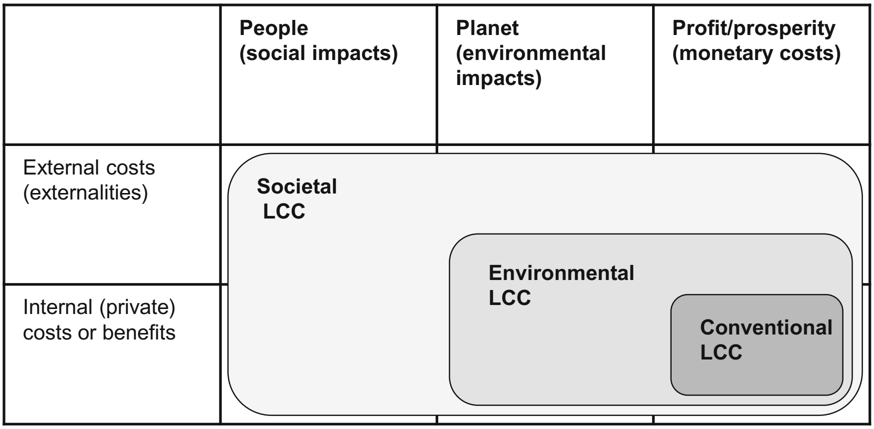

Fig. 15.2 Comparison of the three different types of Life Cycle Costing (Adapted from UNEP 2011 guideline)

investment costs (Hunkeler et al. 2008). Conventional LCC is done from the perspective of a single actor, often the user of a solution. An example would be the procurement of a car, where the driver evaluates different options from an economic viewpoint. In this case, focus is on acquisition costs, taxes, fuel costs and anticipated maintenance costs and might even considerend-of-life costs orrevenues (second-hand value) in the evaluation. Conventional LCC can also be done from the manufacturer point of view, breaking down the life cycle costs with specific focus on the production stages, and—if also borne by the manufacturer—end-of-life costs. In conventional LCC, only internal costs are considered, often ending up with one result for Total Cost of Ownership (TCO), or in cases of hotspot identification with a breakdown of activities, also known as Activity-Based-Costing (ABC). Discounting of the results is recommended. See more about discounting in Sect. 15.5.

Environmental LCC (eLCC)
Unlike the single actor perspective of the conventional LCC, environmental LCC (eLCC) is aligned with the ISO standard 14040 and 14044 on LCA in the sense that it takes the perspective of a functional unit and considers the whole life cycle, including all actors in thevalue chain or life cycle. Unlike the conventional LCC, which is industry driven, environmental LCC was rather developed to support LCA in the sense that it covers the economic dimension, and helps identify hot-spots in terms of both cost and environmental impacts. Besides the internal costs borne by actors in the life cycle, environmental LCC may also include external costs that are expected to be internalised in the near future. In the case of the car, this means that anticipated extra taxes on pollution from fuel combustion might be included in the operational cost. In principle, including external costs from environmental impacts that are quantified in the LCIA results in double counting, since the impacts are

Table 15.2 Comparison of the different variants of life cycle costing

	Conventional LCC	Environmental LCC	Societal LCC
Goal	The assessment of all life cycle costs that are directly covered by the main producer or user in the product life cycle	The assessment of all life cycle costs that are directly covered by all stakeholders connected to the product life cycle	The assessment of all life cycle costs that are covered by anyone in the society
Definition of the life cycle	Economic lifetime, often excluding end-of-life	Complete life cycle	Complete life cycle
Perspectives	Mainly one stakeholder, either manufacturer or user	One or more stakeholders connected to the life cycle	Anyone in the society, often governments
Reference unit	Product or project	Functional unit	functional unit
Types of costs	Internal costs of one stakeholder, focusing mainly on acquisition and ownership costs	Internal costs of stakeholders connected to the life cycle, plus external costs and benefits expected to be internalised such as CO_2 taxes	Internal costs of all actors plus external costs, i.e. impacts that production or consumption have on third parties
Adjustment to inflation	Yes	Yes	Yes
Discounting of results	Consistent, with discount factors ranging between 5 and 10%	No. Discounting the results of the LCC would make the analysis inconsistent with the steady-state assumption of LCA (see Sect. 15.5 on discounting)	Consistent but usually low discount factors (<3%)
Consistent with LCA?	No	Yes, but with a risk of double counting the monetarised environmental impacts	No, due to risk of double counting and inconsistencies with the quasi-dynamic approach in sLCC (see Hunkeler et al. (2008))
Standards	Multiple standards, including ISO 15663, IEC 60300-3-3, BS 3843, AS/NZS 4536, ISO 15686	None, but follows the LCA standards ISO 14040/14044	Currently no standards

accounted for in both analyses. This is not necessarily a problem as long as it transparently shown in the presentation of results and is done consistently for all alternatives being compared (Hunkeler et al. 2008). Like in LCA, the environmental LCC is a steady-state model, and therefore no discounting of the results is usually done. Section 15.3 explains the steps of an eLCC in detail.

Societal LCC (sLCC)

The aim of the societal LCC is to support decision-making on a societal level including governments and public authorities. It includes quantifying the environmental effects in monetary terms. As such, societal LCC (sLCC) includes selected external costs by assigning a monetary value on them. This process is called monetarisation of costs (or impacts). In practice, it is performed by translating the impact results from the LCA into monetary units, e.g. assessing damage costs (see Sect. 15.5 for different monetarisation methods). In this way, the sLCC incorporates the LCA results, and the LCA results should therefore be reported as a subset of the LCC to avoid double counting. An LCC that monetarises all environmental impacts from the LCA is in some cases termed full environmental LCC (Hoogmartens et al. 2014). A sLCC goes one step further and also monetarises social impacts such as: affected social well-being, job quality, etc. In this way, the LCC can be linked to Corporate Social Responsibility (CSR). An sLCC offers the possibility of presenting the result in one single monetary unit, essentially comprising all three pillars of sustainability in a combined Life Cycle Sustainability Assessment (LCSA) aimed at supporting e.g. policy decisions (see Chap. 5). However, this approach of combining all results in a single value is often criticised, mainly because of the uncertainties involved, stemming from both the fact that is difficult to ensure that all relevant external costs are taken into account and from the fact that the external costs are highly uncertain. Discounting is common in sLCC, see more in Sect. 15.5.

As a method for supplementing LCA with economic measures, the eLCC is recommended due to the consistency in the scope of the two analyses. The procedure and methodological considerations are presented in the following section, along with an application example using the case on window frames in Chap. 39 and also known from the other methodology chapters.

15.3 Environmental LCC (Aligned with LCA)

Environmental Life Cycle Costing (eLCC) is the only analysis comparable to the environmental Life Cycle Assessment (LCA) approach. This section gives guidance on how to conduct an eLCC in a consistent way and in parallel to an LCA. It covers three steps:

1. Goal and Scope definition
2. Data collection
3. Interpretation and sensitivity analysis

In general, the overall approach is very similar to the standardised LCA, but there are some important differences, which may both make the analysis easier and more laborious. One advantage is that characterisation or weighting of inventory data can be avoided in eLCC, since the aggregated cost data provide a direct measure of the financial impact and can be aggregated without further processing. On the other hand, the distribution of impacts over time is very important in LCC compared to LCA due to the use of discounting which depends on when the impact or cost occurs. If eLCC results are intended to be used in parallel to LCA, various assumptions must be aligned which will be described in detail below.

15.3.1 Goal and Scope Definition

The goal and scope definition in eLCC is similar to what is needed in LCA and henceISO 14040/44 should be used as a basis (see Chaps. 7 and 8). The goal and scope should be clearly defined but due to the iterative approach, the scope may be revised along the analysis. For instance, eLCC can be used both as a planning tool and as an accounting and reporting tool. Usually it is used for prospective, consequential, and change-oriented assessments to evaluate alternatives, in order to support the product or system design phase, which has utmost influence on prospective costs and emissions along the various life cycle stages.

Functional Unit
For an eLCC, the functional unit shall be defined in a similar manner as for an LCA (see Chap. 8). If the LCC is meant to be conducted in parallel to an LCA, the functional unit needs to be identical.

System Boundaries
System boundaries must be clearly defined and documented like in an LCA (see Chap. 8). If the eLCC is conducted in parallel to an LCA, system boundaries for both must be equivalent and assume the same user perspective. However, eLCC is coarser and it is not always necessary to break down all stages and collect all upstream processes. All real and anticipated money flows should be internalised in a systematic way. The inclusion of external costs in an eLCC is sometimes required while in other situations the system boundaries are negotiable. In general, the inclusion of external costs that are anticipated to be internalised in the decision-relevant future is required.

Cut-Off Criteria
There is an important difference between eLCC and LCA in terms of cut-off criteria. Especially for complex systems with more than a thousand processes, process-based LCA leaves out processes that are assumed to have a negligible contribution thus introducing cut-offs (see Chapt. 8). LCC on the other hand does not suffer from these truncation errors, as costs that occur upstream in the supply chain are assumed to be represented in the price of a product or a service. The cost of purchasing a car for example will include all costs associated with the production of the car, including raw materials, overheads, R&D, marketing, profits for the supply chain and so on. If this is not the case, someone in the supply chain would have to produce at a loss or zero profit, a situation that is clearly unsustainable in the long run.

Although reasonable, the hypothesis that upstream costs are always included in the price is not without exceptions. The price of most commodities is strongly determined by the laws of supply and demand. Market downturns often leave those suppliers with the highest production costs in dire straits, forcing them to either sell at a loss or lay up their assets for a period until the market recovers.

It should be highlighted that an eLCC can be used to inspire the system scoping of an LCA. When considering the life cycle of a product it might be easier for stakeholders to identify all monetary costs over the life cycle rather than environmental impacts and material uses. These costs can be used as a guidance to include all necessary processes (including services) needed to sustain a product or a system over its life cycle in the LCA. Services are often neglected in LCA and including them in the eLCC might inspire to also include them in the LCA. One example could be service and maintenance costs for a car, which is important for the life cycle costs, but might easily be forgotten in the LCA.

Lastly, for minor costs that are not likely to alter the result of the analysis, cut-off criteria need to be applied. For a single life cycle stage (e.g. raw material extraction, production or transport, etc.) a rule of thumb could be that costs that are likely to contribute to less than 1% of the total cost of that stage can be neglected (Hunkeler et al. 2008).

Allocation

Complex systems are subject to allocation to perform an eLCC. In LCA, it is recommended by the ISO 14040 to divide theunit process into sub-processes or to expand the system in order to avoid allocation (see Chap. 8). On the other hand, system expansion is not performed in eLCC. This is due to the fact the eLCC is solely an attributional indicator that can only describe costs, and does not trace the consequences of particular decisions. Special attention is required to ensure a consistent system definition.

The overhead costs are a good example where an allocation method is required. These costs describe all ongoing business expenses, which are not directly linked to production. For those categories, usually costs or revenues are de facto used as allocation keys. For example, in a refinery that refines crudeoil into a number of products, if 40% of the revenue comes from gasoline, then 40% of the overhead costs are allocated to gasoline production.

Inventory

In the inventory analysis, costs should be quantified in one currency (e.g. euro or US dollar) and be based on a common year. For example, if a previous version of a product is compared with the latest version, the costs of both must be aligned in terms of the actual value of the currency at those specific times. If two variants of the same product (e.g. a sedan and a station car) are compared it is necessary to include all relevant costs. Relevant means in particular if costs of the alternatives change (e.g. energy costs, material costs, transportation, etc.). In terms of absolute LCCs (stand-alone) all costs must be taken in account.

Simply adding costs of all actors in the life cycle would not yield any meaningful result. The cost of one actor is the revenue of another, and this process would end up aggregating the same costs multiple times. Instead, what should be considered in an eLCC is the value added at each stage of the life cycle. Value added is the difference between the sales of products and the purchases of products or materials by a firm, covering its labour costs and capital costs as well as its profits.

To get an overview of the hot-spots of the assessed product systems it is recommended to use cost categories on different aggregation levels (see Fig. 15.3). The 1st level consists of three life cycle stages (Manufacturing, Operation and End-of-Life) and external costs. For a manufacturer, the main objective is to analyse every cost in detail during manufacturing, thus the level of detail is higher compared to the other stages in the life cycle. For an operator or user the main focus is on the different costs during the use of the product or service. This affects the data collection strongly. To make the data collection more applicable it should be distinguished between the user perspective and the manufacturer perspective (see Sect. 15.2) thus each life cycle stage has several sub-categories at the second level. For example, if the life cycle costs from a user perspective is to be analysed,

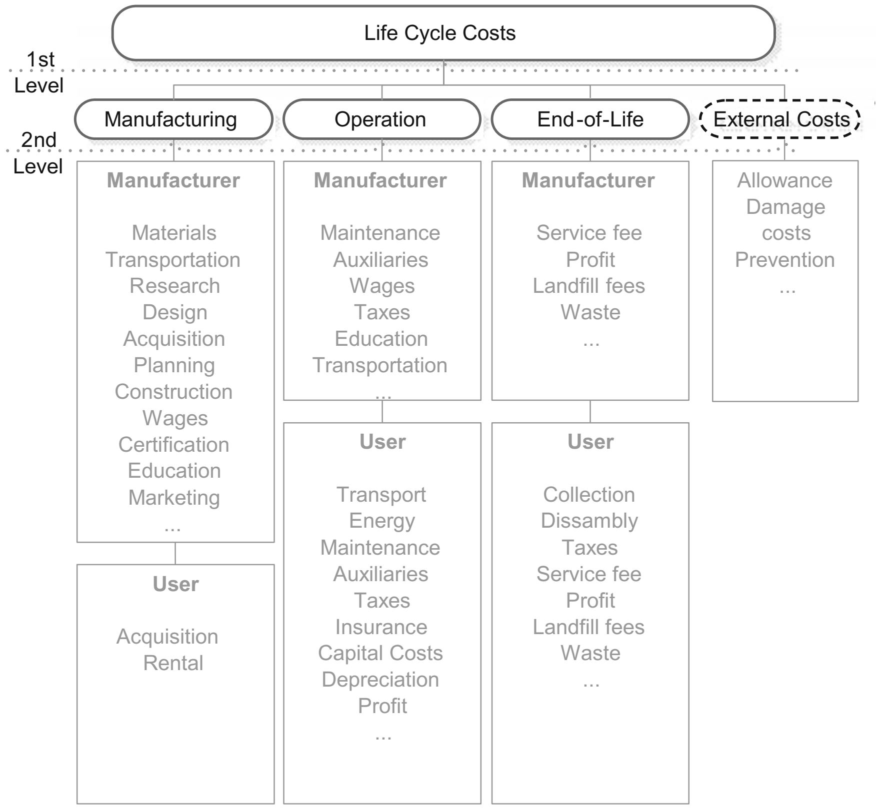

Fig. 15.3 Overview of cost categories distinguish between aggregation levels and between Manufacturer and User perspective

the level of detail for the manufacturing stage is much smaller and the acquisition costs can used as a decent proxy for every cost that occurs upstream. External costs as the fourth stage is another topic within the eLCC and consist mainly of costs for emission allowance (see Sect. 15.5), damage and prevention costs. If external costs are included in the assessment, care must be taken to avoid double counting as described in Sect. 15.2.

15.3.2 Collection of Data for Inventory Analysis

The availability of reliable cost data is crucial in order to perform a realistic life cycle cost analysis. Gathering financial data can be time-consuming and will depend on the collaboration with the involved companies and institutions. The following sections discuss issues in regards to information gathering, particularly for company-based data sources, independent data sources and indirectly derived data.

Company-Based Data Sources

When collecting data internally in a company, there are usually several existing data sources. Accessing them requires the collaboration and involvement of various departments within the company, a task which may be challenging due to unclear responsibilities, lack of resources in the departments and confidentiality issues as well as constraints against an additional economic assessment method.

Typical internal and external data sources in relation to each of the life cycle stages are:

- **Investment and Manufacturing stage**. *Internal*: R&D, Production, and Human Resource Departments
- **Use stage**. *Internal*: R&D, Product Development, accounting systems and Sales (e.g. consumption patterns and sale prices). *External:* Publicly available databases and industry statistics (e.g. fuel prices and taxation costs borne by the user).
- **End-of-life**: *Internal*: R&D or Product Development, who have dealt with the recycling or redistribution of product systems. *External:* EU-directives, international conventions etc.

Independent Data Sources

Financial data can be very sensitive, especially if the results are intended to be published. In these cases most of the data need to be gathered from other independent data sources and references.

Examples of public databases are shown in Table 15.3, giving an overview of different cost categories. These data are published at least annually. However, the scope of each database is different, and it is important to check each data source in terms of comprehensiveness, validity for different regions, currencies and time period to ensure that the data are comparable, while also taking the goal and scope definition into account.

Table 15.3 Public database for life cycle cost data

Type	Scope	Name	Link
Crude oil	Sectors, monthly, country	International Energy Agency	www.iea.org/statistics/topics/priceandtaxes
Plastics	Global, weekly	The Plastic Exchange	www.theplasticsexchange.com
Marine fuel oils	Sector, daily, global	Ship and Bunker´s	www.shipandbunker.com/prices
Chemicals	Sector, daily, global	ICIS, Part of RELX Group	www.Icis.com/chemicals
Metals	Sector, daily, global	London Metal Exchanges	www.lme.com
Commodities	Sector, yearly, global	United Nations	www.comtrade.un.org/data
Inflation	Sector, country, monthly	World Bank	www.data.worldbank.org
Wages	Sector, country, yearly	International Labour Organization	www.ilo.org
Currency exchange rates	Yearly, monthly	World Bank	www.data.worldbank.org
Power, gas, coal, oil	Daily	European Stock Exchange	www.eex.com/en

CES EduPack (Granta Material Inspiration 2016) is a leading commercial database that comprises several material and process information. There is a specific Eco Design and Sustainable Development tool, which can analyse the product and design decisions in regards to costs. Another secondary data source for prices is economic input–output tables combined with mass flow analysis on industry sector level. If information on material amount is available (e.g. from the LCA) information on how much a sector pays for the amount can be extracted from comparing monetary supply–use tables and physical supply–use tables. See Chap. 14 for more details on input output tables and their application in LCA.

Indirectly Derived Data

If all these above mentioned data sources are not able to provide the necessary cost data, a cost estimation technique needs to be applied. Cost estimation techniques associate the cost of a product or activity to the available information at the time of the analysis (e.g. the cost of a window frame in regards to its size and bill of materials). The following techniques can be used to estimate costs:

- Surveys and interviews
- Expert opinions
- Cost estimation techniques (qualitative or quantitative).

Both surveys and interviews as well as expert opinions can provide useful cost estimates. While these methods are time-consuming, they can provide estimates in cases where data is either not available or hard to predict. Advanced survey methods such as the Delphi method (see Chap. 21) can help combine multiple expert opinions, with multiple rounds of questionnaires helping the group to converge towards a single number.

Cost estimation techniques can be broadly classified into qualitative and quantitative. *Qualitative techniques* identify similarities between products and are more appropriate to implement when time is limited. One example is case-based reasoning (Huang et al. 2012), which compares previous cases and finds the most suitable to adjust to the new case. An example would be the preliminary determination of the cost of a construction project based on similar construction projects that occurred in the past. *Quantitative techniques* on the other hand are more accurate as they take different product or resource parameters during a whole product life cycle into account (Niazi et al. 2006). The parametric approach for example assesses the characteristics of a product and determines mathematical relationships to describe its cost. It should be pointed out that in practice cost estimation is not necessarily linear, as twice the input does not necessarily produce twice the output. Reasons can include the associated economies (or diseconomies) of scale, the existence of large overheads and exponential relations between inputs. Use of advanced cost models such as simulation models or neural networks can take into account non linearity of costs and the dynamic behaviour of systems.

15.3.3 Interpretation and Sensitivity Analysis

Sensitivity analysis inLCC is very similar to LCA, and is covered in detail in Chap. 11. However, there are some differences. The main difference relates to the fact that—unlike environmental impacts and emissions—commodity prices are much more volatile due to the market mechanisms of supply and demand and the fact that commodities are traded in thestock exchange. Prices are very sensitive to cyclical effects such as financial circles, seasonality etc. Therefore in LCC, the timing of costs is very important, and costs with high price variability such as fuel costs should be subject to sensitivity checks.

15.4 Step-by-Step Application of LCC

In the following section, a case study of an environmental LCC is shown, elaborating the different steps to be conducted to identify the whole costs of a product. This procedure is explained by using the case study discussed in previous chapters (see Chap. 39 for a detailed description). The new window is expected by the company Nor-win to gain a market share of 20–30%. The new window differs from existing windows with respect toheat insulation properties, due to the combination of wood and a composite that is comprised of polyamide and glassfibre. Thus, the new window is expected to have a lower overall environmental impact compared to earlier products from the company. However, a quantitative, life cycle costing has not been conducted yet to identify the full economic profile for the manufacturer and customer. The analysis is based on the aforementioned steps of

- Goal and Scope definition
- Data collection for inventory analysis
- Interpretation and Sensitivity Analysis.

As the goal and scope and the inventory analysis are similar to the described LCA cases, this section mainly focuses on how to gather life cycle costing data and the interpretation of the results. Nonetheless a short summary introduces the goal and scope of the study.

15.4.1 Goal and Scope

The study aims to perform a stand-alone eLCC as guidance for the ongoing design of the new window. Economic hot-spots for the window will be identified. The manufacturer wishes to position itself as a proactive company in terms of sustainability, which entails life cycle costing as well. The target audiences are: (1) design departments at the manufacturer and (2) customers to provide transparency about their new product. The function that is analysed here provides the properties described in the LCA for a minimum of 20 years. The analysis includes all life cycle stages from manufacturing to operation and EoL. However, the level of detail differs compared to the LCA as the data for raw material extraction, primary and secondary material production and other upstream processes are reflected in the final material costs. No cut-off criteria were applied because all needed cost data could be found for the time span of 20 years.

15.4.2 Inventory Analysis

Based on the inventory analysis from the LCA, a list of the materials and production related energy consumption was extracted. But the view on production had to be expanded to cover all costs (CAPEX, and OPEX, indirect costs and immaterial costs).

Usually materials are traded hence these costs were found on specific market platforms or at thestock exchange (see Sect. 15.3). The market evaluation, the design and ramp-up of the production entail additional financial efforts and are covered by the R&D costs. Additionally entailed costs (e.g. labour, infrastructure, prototype production) were allocated by dividing the total costs with the total expected production volume. Usually the cost centre is broken down in very high detail to identify potential cut-downs to improve the return of investment. To improve this rate, the OPEX-related costs are very important as well as they reflect the direct product related costs (e.g. raw material, energy, labour, service and maintenance). The labour costs for assembling the window are dependent on the employer and the production site; therefore official wage levels from several statistical websites were used. The so-called overhead costs include production related costs, e.g. heating and ventilation as well as for lighting. Indirect costs entail site permits, regulatory requirements and prospective liabilities. Those were excluded in the case study. Another cost driver is the immaterial costs (e.g. marketing and competition). An essential part for a company is to promote their products on the market. These additional costs were allocated by dividing the total costs with the total expected production volume. Some products or services need additional certification to increase their market value or achieve competitive edge. These costs were allocated by dividing the total costs with the total expected production volume. Another offer for the customer can be transportation from the manufacturing site to the door sill. All these costs are shown for one window in Table 15.4. The main cost driver is the window pane with about three quarter of the total costs. The labour is second most important driver with about 15% of the overall manufacturing costs. All others are relatively small.

The operation costs are dominated by several drivers (see Table 15.5). Value added taxes (VAT), which are highly dependent on the market (e.g. Denmark 25%, Germany 19%), were added based on the price (costs plus profit for the manufacturer). A relatively low profit margin of 10% was assumed here. As some

Table 15.4 Calculation of the manufacturing costs of polyamide/glassfibre window

Manufacturing costs	Inventory value	Costs [€] per unit	Calculated costs [€]	Worst case [€]	Best case [€]
Materials					
Window frame (kg)	14.36	1.63	23.47	26.53	19.55
Window pane (kg)	61.46	5.90	362.39	435.05	289.95
Window packaging (kg)	1.20	0.75	0.90	1.08	0.72
Production					
Assembly (Electricity) (MJ)	165.00	0.02	3.69	4.05	3.33
R&D (h)	0.01	36.74	0.37	0.39	0.35
Marketing (h)	2.00	0.30	0.60	0.63	0.57
Certification (–)	1.00		0.00	0.00	0.00
Overhead (–)	1.00	2.00	2.00	2.10	1.90
Transportation (tkm)	52.83	0.16	8.23	9.88	6.59
Labour (h)	2.05	36.74	75.33	79.09	71.56
Total manufacturing costs			476.98	558.80	394.51

Table 15.5 Calculation of the operational costs of polyamide/glassfibre window

Operation costs	Inventory value	Costs [€] per unit	Costs [€]	Worst case [€]	Best case [€]
Acquisition costs					
Profit (%)	10	4.77	47.70	50.08	45.31
Taxes (VAT) (%)	25	5.25	131.17	152.22	109.96
Interests (%)	5	6.56	32.79	34.43	31.15
Transportation (tkm)	8	0.19	1.46	1.54	1.39
Installation (h)	4	36.74	146.96	154.31	139.61
Use (MJ)	12,400	0.03	334.76	351.50	267.81
Total operation costs			694.85	744.08	595.24

Table 15.6 Calculation of the EoL costs of polyamide/glassfibre window

EoL costs	Inventory value	Costs [€] per unit	Costs [€]	Worst case [€]	Best case [€]
Window frame (kg)	14.30	0.67	9.63	11.56	7.70
Window pane (kg)	61.40	0.11	7.02	8.43	5.62
Window packaging (kg)	1.20	15.35	18.43	22.11	14.74
Transportation (tkm)	3.89	0.28	1.10	1.32	0.88
Total EoL-costs			36.18	43.41	28.94

customers need a loan to purchase the window, interests were assumed here as well with an effective rate of 5% over one year. Usually the customer has to pay for the delivery of the windows as well, thus the transport performance from the inventory was used and multiplied with the specific costs (e.g. national statistical databases). The windows have to be installed as well and those costs entail the working hours as well as the travelling time of the craftsmen and are dependent on the country as well. However, the largest cost driver is the operation. The assumed 20 years, multiplied with the specific price for district heating including inflation adjustment rate (see Sect. 15.3), led to the result that almost half of the expenses are due to theheat losses.

The End-of-Life stage of a product is always uncertain and future costs must be predicted (see Table 15.6). Theaverage inflation rate of the previous years (e.g. 10 years) was assumed as a good estimate. Taking the actual market costs (e.g. from recycling plants) and adjusting them with the inflation rate (e.g. from national statistical offices) over time (e.g. 20 years) led to a valid estimate. Based on the information from the life cycle inventory, the window will be mainly incinerated and recycled. Those costs were available at incineration plants and recycling stations. Adjusting those with an average annual inflation rate of 2% the prospective costs are roughly 48% higher than those in 2015.

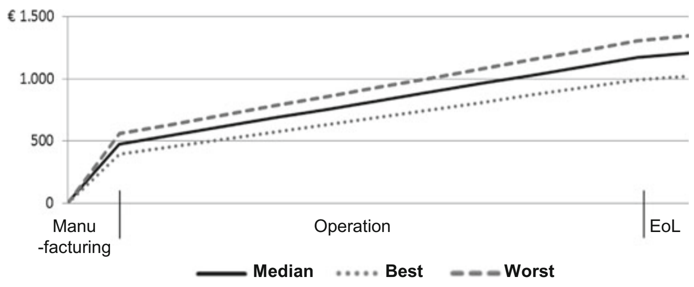

Fig. 15.4 LCC-results including best and worst case assumptions presented over its life cycle

It can be concluded, that the manufacturing and operation stages are most dominant for the new window (Fig. 15.4). Although the costs are based on real market prices, official national and international databases and realistic inflation rates were assumed, an LCC always includes uncertainties. Therefore in each cost centre a specific deviation was assumed and described in the tables above as worst and best case. Based on the assumptions it can be concluded that the life cycle costs have a range of about +11 and −16% compared with the median price of 1.208 € over the entire time span of 20 years.

15.5 Advanced LCC

This section covers some more advanced concepts in regards to LCC and monetarisation in life cycle assessments.

15.5.1 How to Monetarise?

A general problem with some goods and services is that they cannot be traded and it is therefore difficult to determine an objective price for them. Such cases of goods or services without a market can be grouped in the external costs category. Examples of external costs that may call for quantification in anLCC are: the societal cost of respiratory diseases due to air pollution from internal combustion engines, the societal benefits in regional biodiversity from an improved waste treatment plant or the individual benefits of reduced commuting time by using a private vehicle instead of public transport. In the absence of a market price for these values, it is necessary to use monetary valuation to determine their economic value.

15.5.2 Monetarisation of External Costs

Monetary valuation is important in both eLCC and sLCC. As mentioned before, eLCC expands the scope of the cLCC by including cash flows that are expected to be internalised, such as costs for waste disposal and emission taxes. sLCC goes even further, by adopting a societal perspective that includes both all internal costs and selected external costs, as defined in the goal and scope definition.

While monetarisation of external costs can be useful in LCC, especially for socio-economic assessments, it can also be valuable in relation to LCA, as it allows comparisons across impact categories, if the monetarisation is done onmidpoint impact category level. Several methods have been proposed for monetarising externalities, and an overview is given in Fig. 15.5, while Table 15.7 gives a short description of the different approaches.

Most methods try to determine the individuals'Willingness To Pay (WTP) for a particular benefit (or inversely, their willingness to accept a payment in return for a particular loss or disbenefit). An alternative principle determines the external costs in a more direct way by equating them to the costs that would have to be paid in order to avoid or counter balance the change. In order to determine the individuals' Willingness to Pay, different approaches exist, and within each approach multiple methods can be used—each with its own pros and cons. For a more detailed description, see (Boardman et al. 2010).

Table 15.8 shows examples of values for monetarisinggreenhouse gas emissions obtained with three different methods from Table 15.7 and illustrates how the result may be very different depending on the methodology used. The table shows the uncertainties involved in monetarised impacts and how it is important to understand the methodologies behind the analysis. Showing a financial value can easily be perceived as something very definite, with a risk of oversimplifying what are in fact complex issues. While actual market-based costs are factual, monetarised impacts always depend on perceptions and value judgements, which make the underlying assumptions critical for supporting interpretation and presentation of results of an LCC that includes external costs. Methodological choices should always reflect the goal and scope of the study, taking the target audience and the decision-making context into account.

15.5.3 Discounting

There are multiple reasons why costs that occur at different points in time are not directly comparable. From the perspective of behavioural economics, people have a time preference, and prefer to postpone payments as much as possible. A firm in the private sector will prefer to pay suppliers later, and in the meantime invest in expanding its own activities. To solve this problem, it is possible to give a higher weight to imminent costs andrevenues, and a lower weight to future payments.

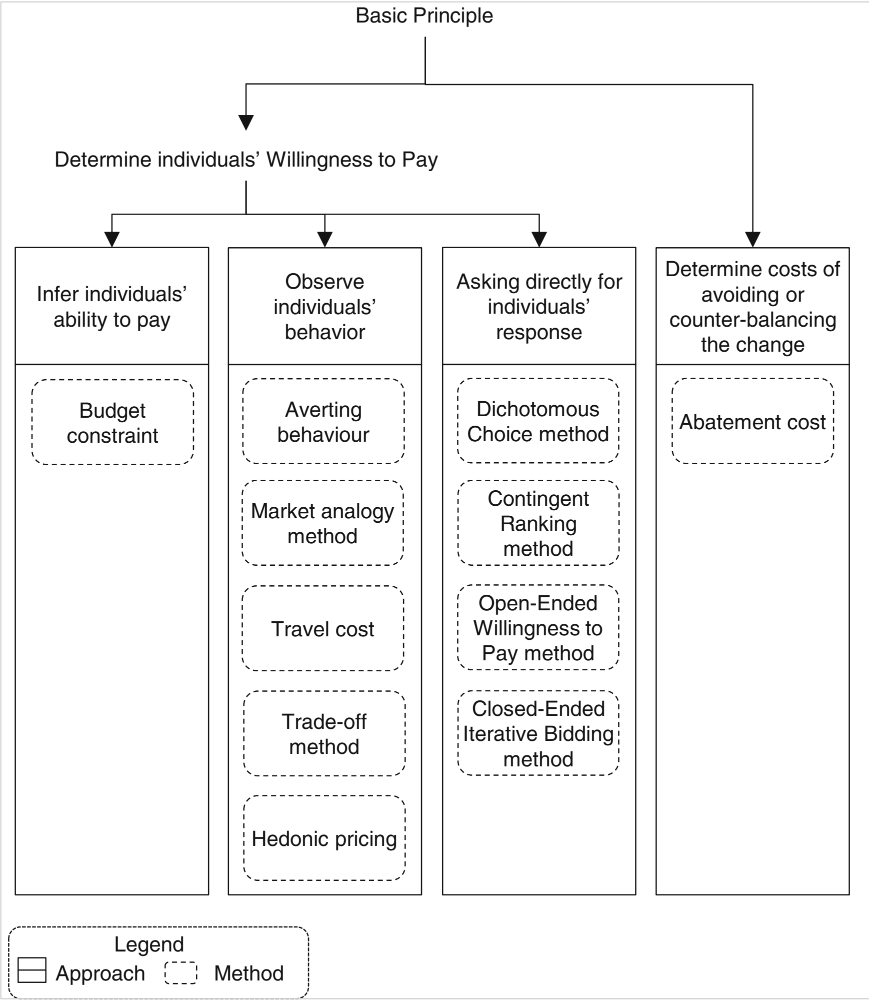

Fig. 15.5 Determining costs—approaches and methods. Based on (Boardman et al. 2010)

The way to determine those weights is through discounting. The weight $w(t)$ for payments occurring at time t is called the discount factor. The discount factor depends on the discount rate r, which is the rate by which the discount factor $w(t)$ decreases over time assuming a first order decrease. The discount factor is calculated as follows:

$$w(t) = \frac{1}{(1+r)^t} \tag{15.2}$$

Table 15.7 Determining costs—approaches' description (Sources: Pizzol et al. 2014; Boardman et al. 2010)

Approach	Description	Possible application area (examples)	Main weakness	Methods
Determine costs of avoiding or counter-balancing the change	The value of the external cost equals the cost of measures needed to mitigate it	Evaluate the cost of greenhouse gas emissions by assessing the costs for carbon sequestration	Does not value utility losses, and hence does not express individuals' attitudes, but rather external targets	Abatement cost
Asking directly for individuals' response	The goal is to elicit people's willingness to pay for changes in quantities or qualities of goods	Ask a number of individuals how much they are willing to pay for the preservation of a national park	Results are highly sensitive to potential sources of error in the survey, as for example the size and the representativeness of the sample of the respondents, and the wording of the questions	Contingent ranking method, Dichotomous choice method, Close-ended iterative bidding, Open-ended willingness to pay method
Observe individuals' behaviour	For cases where there may not be a market for the good or service of interest, its value may be reflected indirectly in the substitute market for a related good	Evaluate the benefit of newer catalysts in cars by evaluating its impact on healthcare costs for respiratory diseases	This approach assumes that people make decisions under full information, a situation that is not satisfied in practice	Market analogy method, Averting behaviour, Trade-off method, Travel cost, Hedonic pricing
Infer individuals' ability to pay	Determine willingness to pay for an additional Quality-Adjusted Life Year.	Evaluate the cost of a statistical life	The approach is only applicable specifically to the value of human well-being	Budget constraint

The sum of all the discounted costs and revenues is theNet Present Value (*NPV*) and is equal to:

$$\mathrm{NPV} = \sum \frac{P(t)}{(1+r)^t} = \frac{P(0)}{(1+r)^0} + \frac{P(1)}{(1+r)^1} + \frac{P(2)}{(1+r)^2} + \frac{P(3)}{(1+r)^3} + \cdots \frac{P(t_{\max})}{(1+r)^{t_{\max}}} \tag{15.3}$$

Table 15.8 Comparison of different approaches for monetarisation of greenhouse gasses in CO_2-eq

Example	Cost per tonne CO_2-eq (€)	Reference	Method
Emission trading scheme (ETS) system	8	(European Commission and Directorate-General Climate Action—B: European & International Carbon Markets 2010)	Market price
Carbon offset program	24	Carbon Offset Program Retrieved August, 2015, from http://www.myclimate.org	Abatement cost
LCIA method (Stepwise2006 v.1.2)	83 €	Weidema (2009)	Budget constraint

where $P(t)$ denotes the cash flows at time t, which is the time of the cash flow. Figure 15.6 shows a simplified flow chart for deciding on the correct discount rate, together with a most probable value. In cases where there is no single correct discount rate, the effect of different discount rates should be investigated through sensitivity analysis, in particular for studies with a long time duration.

The appropriate discount rate depends on the type of cost that is being discounted. For internal costs it is closely related to the cost of borrowing. For private companies a conservative discount factor might be anywhere between 5 and 15%, depending on the required return on investment (Hunkeler et al. 2008). After the financial crisis in 2008 and the worldwide public debt problem, a lower discount factor is more likely for private companies. In the public sector, national ministries of finance generally specify the discount rates to be used in the economic analysis of publicly funded projects. These typically fall into the range of 3–5% (Langdon 2007). In terms ofsocial impacts, British economist Frank P. Ramsey proposed a model in which society would attempt to maximise a social welfare function (Boardman et al. 2010). In that case, the discount rate would reflect on one hand impatience and on the other hand society's preference for smoothing consumption flows over time. Ramsey's formula for society's marginal rate of time preference gives:

$$r = d + g \cdot e \tag{15.4}$$

where r equals the pure rate of time preference (d), plus a term multiplying the long-run rate of growth in per capita consumption (g), by a constant (e). Ramsey's formula usually produces values in the range between 0.5 and 1.2% (Boardman et al. 2010). Finally for environmental impacts, the discount factor depends on the time horizon of the impacts under study. Toxicity from heavy metals can have a

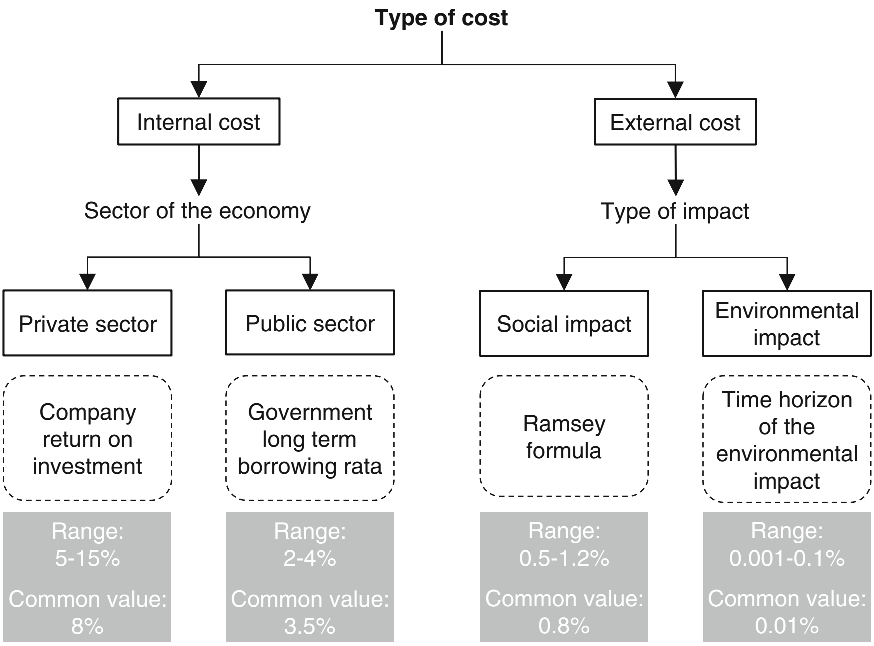

Fig. 15.6 Decision tree for choosing the correct discount factor

long time horizon, as heavy metals are often toxic to humans andecosystems and can remain available in the environment for thousands of years after emission. With that in mind, a discount factor of just 0.0001% that halves the importance of effects every 700,000 years might seem appropriate. On the other hand, toxicity from organic pesticides can have a much shorter time horizon. Diuron for example is a common pesticide with a half-life of approximately 2000 days, so by the same logic a much higher discount rate is appropriate. From the above example, it becomes clear that each environmental impact will require a different discount factor.

Table 15.9 shows the calculation of the NPV of the fuel costs for the average driver in the US, driving 24 miles a day to and from work, by means of a fuel efficient car of 25 miles/gallon with 240 working days per year between 1996 and 2002, where 1996 is used as the reference year. Figure 15.7 shows the discounted fuel costs and discount factors for a range of discount rates. The cost of fuel is shown as the baseline (discounting at 0%). Notice that in case of a high discount factor, fuel costs occurring earlier in time are significantly more important than future costs.

Table 15.9 Calculation of net present value for a discount factor equal to 5%, by applying Eqs. 15.2 and 15.3

Year	1996	1997	1998	1999	2000	2001	2002
Time (t)	0	1	2	6	4	5	6
Discount factor (r)	1	0.95	0.91	0.86	0.82	0.78	0.75
Gasoline price (USD/gallon)	1.20	1.30	1.00	0.97	1.50	1.49	1.25
Fuel cost (USD) [P(t)]	300	325	250	243	375	373	313
Present value (USD 1996)	300 * 1	325 * 0.95	250 * 0.91	243 * 0.86	375 * 0.82	373 * 0.78	313 * 0.75
Net present value (USD 1996)	1879						

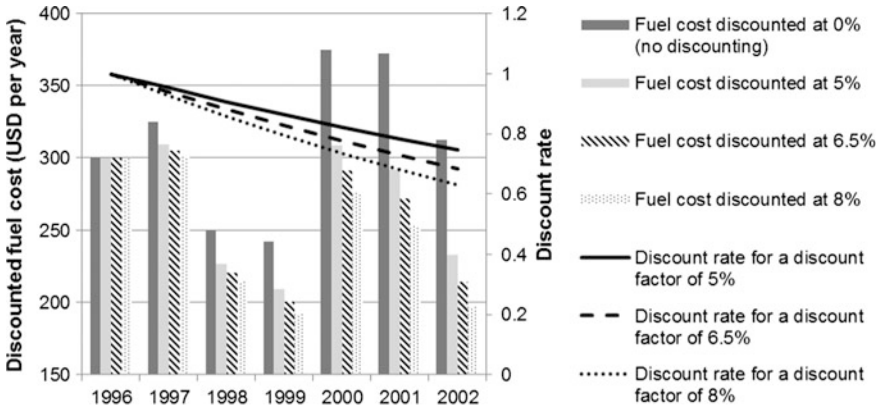

Fig. 15.7 Discounted fuel costs and discount factors for a range of discount rates for the average US driver

References

Boardman, A., Greenberg, D., Vining, A., Weimer, D.: Cost-Benefit Analysis, 4th edn. Prentice Hall, New Jersey (2010)

Boussabaine, A., Kirkham, R.: Whole Life-Cycle Costing: Risk and Risk Responses. Wiley, Hoboken (2008)

Dodds, K., Galtung, J.: Peace by peaceful means: peace and conflict. Int. Aff. R. Inst. Int. Aff., Development and Civilization (1997). doi:10.2307/2623565

European Commission, Directorate-General Climate Action—B: European and International Carbon Markets: Guidance on Interpretation of Annex I of the EU ETS Directive (excl. aviation activities), p. 26 (2010)

Granta Material Inspiration: CES EduPack. Granta Design, Cambridge (2016)

Hoogmartens, R., Van Passel, S., Van Acker, K., Dubois, M.: Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environ. Impact Assess. Rev. **48**, 27–33 (2014). doi:10.1016/j.eiar.2014.05.001

Huang, X.X., Newnes, L.B., Parry, G.C.: The adaptation of product cost estimation techniques to estimate the cost of service. Int. J. Comput. Integr. Manuf. **25**, 417–431 (2012). doi:10.1080/0951192X.2011.596281

Hunkeler, D.D., Lichtenvort, K., Rebitzer, G., Ciroth, A.: Environmental life cycle costing. CRC Press, Pensacola (2008)

Korpi, E., Ala-Risku, T.: Life cycle costing: a review of published case studies. Manag. Audit. J. **23**, 240–261 (2008). doi:10.1108/02686900810857703

Langdon, D.: Life Cycle Costing (LCC) as a contribution to sustainable construction: A common methodology, Final Report. European Commission, Brussels (2007)

Moreau, V., Weidema, B.P.: The computational structure of environmental life cycle costing. Int. J. Life Cycle Assess. **20**, 1359–1363 (2015). doi:10.1007/s11367-015-0952-1

Niazi, A., Dai, J.S., Balabani, S., Seneviratne, L.: Product cost estimation: technique classification and methodology review. J. Manuf. Sci. Eng. **128**, 563 (2006). doi:10.1115/1.2137750

Park, C.S.: Contemporary Engineering Economics. Pearson Prentice Hall, New Jersey (2011)

Pizzol, M., Weidema, B., Brandão, M., Osset, P.: Monetary valuation in life cycle assessment: a review. J. Clean. Prod. **86**, 170–179 (2014). doi:10.1016/j.jclepro.2014.08.007

Sullivan, W.G., Wicks, E.M., Luxhoj, J.T.: Engineering Economy. Pearson Education, New Jersey (2006)

UNEP: Towards a Life Cycle Sustainability Assessment: Making Informed Choices on Products. United Nations Environment Programme, Nairobi (2011)

Weidema, B.P.: Using the budget constraint to monetarise impact assessment results. Ecol. Econ. **68**, 1591–1598 (2009). doi:10.1016/j.ecolecon.2008.01.019

White, G., Ostwald, P.F.: Life cycle costing. Manag. Account. **57**(7), 39–42 (1976)

Author Biographies

Jan-Markus Rödger Involved in LCA/LCC and LCM activities in various industries since 2010. Main activities are the application of science based assessment tools in actual product and production development processes. Interested in the integration of life cycle thinking in the manufacturing environment.

Louise Laumann Kjær Has been working with sustainability assessments and LCA within both the private and public sector as a consultant and researcher since 2009. Special interests include Environmental Input/Output LCA, the relationship between economic and environmental impacts of products and services, and assessing the sustainability of innovative business models such as circular business models and product/service-systems.

Aris Pagoropoulos Researcher of economic and environmental impacts of products and services, with a focus on the shipping and manufacturing industries. Main interests include LCC, data analysis and Environmental Input/Output LCA.