SCORE LCA

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THE USE OF MONETARY VALUATION OF ENVIRONMENTAL IMPACTS IN LIFE CYCLE ASSESSMENT: STATE OF THE ART, STRENGTHS AND WEAKNESSES

FINAL REPORT

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"The use of monetary valuation of environmental impacts in life cycle assessment: state of the art, strengths and weaknesses"

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

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1 SUMMARY

Monetary valuation, or monetarisation, is the practice of converting measures of social and biophysical impacts into monetary units so that they can be compared against each other and against the costs and benefits already expressed in monetary units. The fundamental question that monetarisation seeks to answer is how to valuate (impacts on) non-market goods (i.e. goods for which no market, and hence no price, exists, such as a clean atmosphere).

Monetary valuation is not a new idea. Since 1936, monetary valuation has been a common and essential practice in Cost Benefit Analysis (CBA) of public and private projects with economic, environmental and social impacts. Monetary valuation allows for the overall assessment of a project, when the total monetarised and discounted environmental, economic and social impacts are aggregated into a single score (Net Present Value, NPV). If NPV>0 the project is worth carrying out. Alternative projects can, hence, be compared and the one with the highest NPV is deemed superior to all others.

Monetary valuation methods have been developed within the utilitarian paradigm of welfare economics inherent to both neoclassical and ecological economics. Welfare economics is the study of economic efficiency, i.e. how to maximise social wellbeing. When this wellbeing is maximised among equal and autonomous agents in and across generations, the goal of welfare economics becomes identical to the goal of sustainable development.

Some LCIA methods already include aspects of monetary valuation, notably LIME, EPS, EcoIndicator and Stepwise.

The main objectives of the study have been:

- To review systematically, analyse critically, and evaluate the existing methods available for converting (LCA) results quantified in physical units into monetary units and assess the applicability of the different methods in LCA;
- To assess the use and barriers associated to the use of monetary valuation by the LCA community;
- To provide recommendations for the use of monetary valuation in the context of LCA.

The study includes a literature review and benchmarking of both monetary valuation methods and their applications in LCA, as well as a web-based survey of the extent of use and opinions on monetary valuation methods among LCA practitioners.

The literature review identified a lack of uniformity in both classification and nomenclature and a general absence of consistent definitions of the different methods for monetary valuation. The study therefore includes a new classification with definitions of monetary valuation methods.

The benchmarking encompasses 8 monetary valuation methods and 12 applications for LCA. Each method and application is benchmarked according to 6 criteria:

- Scientific foundation
- Documentation
- Completeness
- Uncertainty
- Complexity

- LCA relevance & compatibility

with in total 50 sub-criteria, specifically developed for this purpose. Each sub-criterion is scored on a scale from 1 to 5 for compliance. Each score has been documented and justified with a text description.

Each method is described in terms of its application areas and the strengths and weaknesses of each method. Based on the evaluation of these features, LCA impact categories for which the method is recommendable are identified.

In general, conjoint analysis is identified as the most appropriate method for the majority of LCA impact categories, when directly observable market prices are not available. The budget constraint method can be used to minimise the uncertainty on the monetary value of a human life year and thereby for anchoring the values obtained by the conjoint analysis. The hedonic pricing method is recommended for impact categories where the impacts are directly observable and only use values are involved, such as the nuisance from odour, noise, traffic, or living in a crime-prone neighbourhood, and job-related nuisances such as psychological and ergonomic stress. All other monetary valuation methods are not recommended for LCA, except in very specific situations.

In practical LCA applications, conjoint analysis has unfortunately only been scarcely used in LCIA methods, pointing to the need for more studies to confirm the practical usability of conjoint analysis for monetary valuation in LCA. In contrast, there are many LCA applications of the abatement cost method, which is not recommended by our assessment, mainly because it does not provide valuation of damages.

The web-based surveys among LCA practitioners show a large interest in and support for monetarisation in LCA, but also a smaller group of respondents with legitimate objections to monetarisation. However, the majority of objections do not fundamentally reject monetary valuation, but rather criticize bad practice in its application. Also, stakeholder involvement and acceptance is stressed as important.

The different points of criticism identified in the surveys are addressed in the "Good practice recommendations" from the study. A decision tree is suggested, which takes into account both the scientific and procedural aspects identified as important in the surveys and in the literature review.

The surveys reveal a need for education and information to correct some misunderstandings about what monetarisation is and does:

- How monetary valuation is distinct from other economic tools, such as Life Cycle Costing, Material Flow Cost Accounting, Ecoefficiency, etc., and how these tools relate to each other.
- How abatement cost methods are different from monetary valuation methods seeking to assess utility losses, and clarifying their application fields and relations to Life Cycle Inventory.
- The relative merits of monetary valuation in relation to other methods to weight or compare different impacts.
- The monetary valuation methods available, their applicability and recommendations on their use. Some modern and new approaches to monetarisation (Conjoint analysis and the budget constraint) are still not well-known among practitioners.

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- The good practice and limitations of monetary valuation.

2 GLOSSARY

Abatement cost methods
Cost estimation methods where the change in availability of a good is assessed in terms of the potential costs of the marginal counter-balancing change (replacement) or marginal measure that prevents the change. Most often the abatement cost is determined at a specified (policy-determined) target level. Includes conceptually analogous methods using terms such as mitigation, avoidance, reduction, control, restoration, or replacement costs. Not to be confused with the averting cost method, where it is the actual preventive or offsetting expenses that are measured, thus expressing a willingness to pay.

Benefit
Value obtained from productive activity. Divided in revenue (income) and external benefits (positive externalities), the sum of which is the Social benefit.

CF (see characterisation factor)

Characterisation factor (GB) or **Characterization factor** (US)
Factor derived from a characterization model. Applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator.

CV (see Contingent valuation)

Contingent valuation (CV)
A stated preference valuation method where the marginal value of a good is identified from the stated willingness to pay or accept compensation for a specified change in the availability of the good.

Cost
Value spent in order to produce or obtain a good. Divided in Private cost (see Life Cycle Costing) or external cost (see Damage cost), the sum of which is the Social cost.

DALY (see Disability-Adjusted Life Year)

Damage cost
Negative externality. Cost arising from economic activities of one actor which impact on another without this cost being part of the price of the good or service supplied by the first actor.

Disability-Adjusted Life Year (DALY)
Unit of measurement for health impacts, expressed in loss of person-years weighted by the severity (the health state) on a scale from 0 to 1, where 1 is a state of full health. See also Quality-Adjusted Life Year.

Distance-To-Target method (DTT method)
An LCIA weighting method that weight impacts by the ratio of the current level of each impact and a target level for the same impact.

DTT method (see Distance-To-Target method)

Eco-efficiency
The ratio between the value added of an activity or product and its environmental impacts. When applied to a product, it is the ratio of LCC/LCA results. The concept may be applied to any physical measure of environmental impact, and may then be used to identify hotspots in a product system with high environmental impacts relative to the value added (low eco-efficiency). While relevant as a tool to increase value added, it is less relevant to support overall cost reductions, since it simply provides an incentive to increase internal costs and reduce external costs. This becomes obvious when expressing environmental costs (and benefits) in monetary units: the relevant measure to minimise is not internal/external costs but internal+external costs, i.e. total costs. Thus, when it is possible to express environmental costs (and benefits) in monetary units, eco-efficiency simply measures the level of internalisation of costs, and loses its relevance as a tool to compare systems.

Environment
Surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation (ISO 14001). Often divided in the social environment (humans), biophysical environment (nature) and economic environment (resources).

Externality
The unaccounted costs and benefits arising from economic activities of one actor which impact on another. Externalities can arise not only from activities, but also by a failure to act (typically for example, a government failure to ensure a regulated market). Externalities can be divided into positive (external benefits) when they constitute a gain of human wellbeing and negative (external costs) when they constitute a loss of human wellbeing. If an optimal resource allocation is to be reached, externalities must be internalised (e.g., the value of a loss of welfare should be paid by the agent causing the externality by an amount equal to the damage cost).

Good
A product that provides utility. In economics, the term "good" is often used to cover both tangible goods and intangible goods (services), i.e. in parallel to what in LCA is termed "product".

Internalisation
Adjustment of prices to reflect social costs & benefits, e.g. through adjustment of insurances, subsidies, taxes on emissions and production costs of external benefits.

LCA (see Life Cycle Assessment)

LCC (see Life Cycle Costing)

LCI (see Life Cycle Inventory analysis)

LCIA (see Life Cycle Impact Assessment)

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LCI result (see Life Cycle Inventory analysis result)

LCSA (see Life Cycle Sustainability Assessment)

Life Cycle Assessment (LCA)
Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040). Note that according to the ISO definition of environment (see this), LCA includes social, biophysical and economic impacts.

Life Cycle Costing (LCC)
An assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle, with complementary inclusion of externalities that are anticipated to be internalised in the decision-relevant future (Hunkeler et al. 2008). Thus, LCC covers the *internal* (private) costs, as opposed to the *external* costs (and benefits) covered by a monetarised LCA result. The LCC covers the value added in each unit process of the life cycle, and the cumulated LCC result is equal to the price of the product (the sum of the value added in the life cycle) when including any costs occurring during use and disposal. When abatement of an impact is included in the LCC, i.e. when the abatement is expected to occur within the decision-relevant future, it is important that the abated emissions are not also included in the LCA to avoid double-counting in relation to decision-making.

Life Cycle Impact Assessment (LCIA)
Phase of *life cycle assessment* aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO 14040)

Life Cycle Inventory analysis (LCI)
Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life Cycle Inventory analysis result (LCI result)
Outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment

Life Cycle Sustainability Assessment (LCSA)
A complete assessment of all costs and benefits, internal and external, related to a product system. Divided in an LCC (covering the internalised costs) and an LCA (covering the externalities, monetarised or not). Any externalities "anticipated to be internalised in the decision-relevant future" that are included in the LCC (see the definition of this) should not also included in the LCA, in order to avoid double-counting.

Material Flow Cost Accounting (MFCA)
Material Flow Cost Accounting, standardised in ISO 14051, is a management tool that accounts for the internal, private costs of a system (which may be a product system). If the system is a product system, MFCA can be seen as a LCC embedded in a Plan-Do-Check-Act management cycle.

MCDA (see Multi-Criteria Decision Analysis)

MFCA (see Material Flow Cost Accounting)

Monetary valuation
The practice of converting measures of social and biophysical impacts into monetary units so that they can be compared against each other and against the costs and benefits already expressed in monetary units (Boardman et al. 2006)

Monetarisation (GB) or **Monetarization** (US)
Synonym for monetary valuation.

Monetisation (GB) or **Monetization** (US)
The process of converting or establishing something into legal tender (see e.g. Merriam-Webster Dictionary 2013). It usually refers to the coining of currency or the printing of banknotes by central banks. Sometimes mistakenly used as synonym for monetary valuation.

Multi-Criteria Decision Analysis
A method for analysing and structuring complex decision-making problems, explicitly considering multiple decision criteria.

Net present value
The sum of costs and benefits over time, with future costs and benefits discounted to their current value.

Non-market good
Good that is not bought or sold directly. Therefore, a *non-market good* does not have an observable monetary value.

Private cost
Costs paid by an actor in order to produce or obtain a good (internal cost, as opposed to external cost). See also Life Cycle Costing.

Value of Statistical Life (VSL)
Willingness to pay value for a marginal change in the probability of death. In a simple approach without discounting, VSL can be converted to the value of a life year by dividing by the number of life years expected to be lived without the premature death.

VSL (see Value of Statistical Life)

Quality-Adjusted Life Year (QALY)
Unit of measurement for wellbeing, expressed in person-years weighted by the severity (the degree of wellbeing) on a scale from 0 to 1, where 1 is a state of full wellbeing. Differs from Disability-Adjusted Life Years in having a positive sign (i.e. wellbeing loss is measured as a reduction in QALY) and in also considering other aspects of wellbeing than health.

QALY (see Quality-Adjusted Life Year)

Social benefit
The sum of revenue (income) and external benefits (positive externalities) of an economic activity.

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Social cost
The sum of private costs (internal costs) and damage costs (external costs) of an economic activity.

Sustainable development
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Value of Life Year (VOLY)
Willingness to pay value for a marginal improvement in life expectancy.

VOLY (see Value of Life Year)

Welfare economics
The study of economic efficiency, i.e. how to maximise social wellbeing. When this wellbeing is maximised among equal and autonomous agents in and across generations, the goal of welfare economics becomes identical to the goal of sustainable development.

Willingness to pay
A measure of the utility of a good. The value that an individual would be willing to pay, sacrifice, or exchange in order to obtain a good

Willingness-To-Pay method
Monetary valuation method seeking to assess utility or changes in utility (as opposed to Abatement cost methods, that are assessing potential costs of marginal abatement activities).

WTP (see Willingness to pay)

3 INTRODUCTION

Monetary valuation, or monetarisation, is the practice of converting measures of social and biophysical impacts into monetary units so that they can be compared against each other and against the costs and benefits already expressed in monetary units (Boardman et al. 2006). The fundamental question that monetarisation seeks to answer is how to valuate (impacts on) non-market goods (i.e. goods for which no market, and hence no price, exists, such as a clean atmosphere).

Monetary valuation is not a new idea. Its conceptual basis stems back to Sidgwich (1883) and was formalised by Pigou (1920). Since 1936, monetary valuation has been a common and essential practice in Cost Benefit Analysis (CBA) of public and private projects with economic, environmental and social impacts. Monetary valuation allows for the overall assessment of a project, when the total monetarised and discounted environmental, economic and social impacts are aggregated into a single score (Net Present Value, NPV). If NPV>0 the project is worth carrying out. Alternative projects can, hence, be compared and the one with the highest NPV is deemed superior to all others.

Monetary valuation methods have been developed within the utilitarian paradigm of welfare economics inherent to both neoclassical and ecological economics. Welfare economics is the study of economic efficiency, i.e. how to maximise social wellbeing. When this wellbeing is maximised among equal and autonomous agents in and across generations, the goal of welfare economics becomes identical to the goal of sustainable development.

Monetary valuation is strictly related to the concept of externalities in welfare economics. Externalities have been defined as the unaccounted costs and benefits arising from economic activities of one actor which impact on another (e.g., European Commission 1995, Pearce and Barbier 2000, Krewitt et al. 1998), but externalities can arise not only from activities, but also by a failure to act (typically for example, a government failure to ensure a regulated market). According to this definition, externalities can be divided into positive (external benefits) when they constitute a gain of human wellbeing and negative (external costs) when they constitute a loss of human wellbeing. If an optimal resource allocation is to be reached, externalities must be internalised (e.g., the value of a loss of welfare should be paid by the agent causing the externality by an amount equal to the damage cost). A key issue is then the quantification of the externalities, and this is where monetary valuation becomes relevant.

Several methodologies for monetary valuation of non-market goods have been developed in the last 40-50 years. The following monetary valuation approaches and methods have been identified and are included in our review and critical analysis:

- Market price method
- Revealed preferences approach
  - Averting behaviour method
  - Hedonic pricing method
  - Travel cost method
- Stated preferences approach
  - Contingent valuation
  - Conjoint analysis: Choice experiment[1]
- Budget constraint method
- Abatement costs method[2]

The impacts measured by Life Cycle Assessment (LCA) can be both impacts on non-market goods (e.g. human health or biodiversity) and impacts on market goods (e.g. crop yields, buildings and ecosystem services). Monetary valuation implies the identification of prices for non-market goods in surrogate or hypothetical markets. For market goods, monetary valuation may require adjustments of the market prices, to reflect the value of the externalities involved in their production, thus correcting for market imperfections.

There are significant differences between the monetary valuation methods in their ability to capture the total economic value (TEV) of the goods, as reflected in the marginal willingness-to-pay (WTP). Marginal here refers to valuing a very small (= "marginal") change in the good, so that secondary effects on consumer and producer surplus are negligible, which allows the use of market prices for valuation. The total economic value can be divided in use values and non-use values. Figure 3.1 shows this breakdown as well as further subdivisions within these.

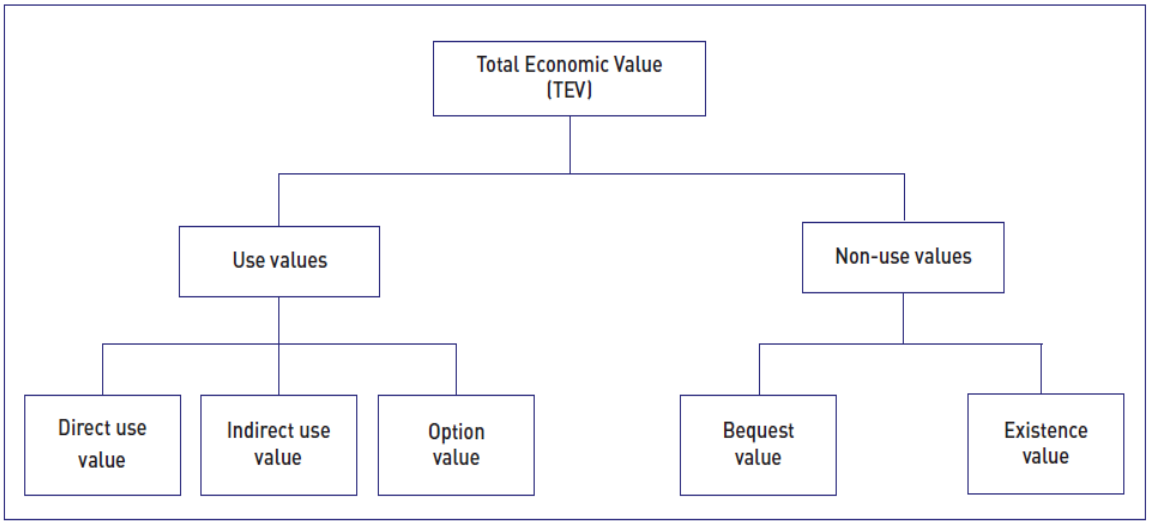

Figure 3.1. Total Economic Value (TEV) and its composition (adapted from Defra 2006)

[1] Pearce et al. (2002) identify four variants of conjoint analysis (also known as choice modeling), namely: Choice experiment, Contingent ranking, Contingent rating, and Paired comparison. However, only the choice experiment method is included in our review here, since it is the only one of the four that is consistent with welfare economics, and the only one in practice applied for monetary valuation in LCA.

[2] Formally, the abatement cost method is not a monetary valuation method, since it does not value impacts (externalities) as such, but rather a Life Cycle Costing method quantifying the potential or expected future private costs relating to a marginal abatement activity. The abatement cost method is nevertheless assessed in its use as a proxy for valuing externalities.

Use values relate to the actual or potential, consumptive or non-consumptive, use of a good. Direct use values come from the use of products and services, which typically have a market price. Indirect use values are benefits that humans derive from ecosystem services without directly intervening and often taken for granted. Option use values consist of values attached to possible future uses of a good. Taking a forest as example: its wood is used for construction and energy production (direct use value); it sequesters CO_2 from atmosphere (indirect use value); and it may be used as recreational site or natural park in the future (option value).

Non-use values essentially refer to the benefits people attach to certain environmental elements independently of their actual or future use. Existence value is associated with people's satisfaction to know that certain environmental elements exist, regardless of uses made (currently or in the future). This includes many cultural, aesthetic and spiritual aspects of humanity as well as, for instance, people's awe at the wonders of nature, such as the deep seas, which may never be witnessed without proxy. Some classifications also distinguish part of this as Altruism value, when the concern is that others may enjoy this existence. This is similar to the Bequest value, which covers the people's satisfaction that (elements of) the natural environment will be passed on to future generations.

Some LCIA methods already include aspects of monetary valuation, notably the LIME, EPS, EcoIndicator and Stepwise methods.

The objective of the current study is to evaluate the different methods for monetary valuation for their relevance in the context of Life Cycle Assessment (LCA) and provide practical guidance for their use in LCA. The specific objectives are:

1. To formulate a comprehensive set of criteria with which to assess the different monetary valuation methods in relation to LCA;
2. To review systematically, analyse critically, and evaluate the existing methods available for converting (LCA) results quantified in physical units into monetary units and assess the applicability of the different methods in LCA;
3. To assess the use and barriers associated to the use of monetary valuation by the LCA community;
4. To provide recommendations for the use of monetary valuation in the context of LCA; and
5. To ensure that the members of SCORELCA can use concrete results from the study.

4 CRITERIA FOR EVALUATION OF MONETARY VALUATION METHODS

To evaluate the different monetary valuation methods in a consistent manner, a fixed set of criteria is required. The criteria must be comprehensive so that monetary valuation methods can be characterised on all their relevant features. The criteria we have developed address issues of general relevance in the critical evaluation of any scientific method, as well as issues of particular relevance to monetary valuation.

The criteria, which are partly based on that from a similar process undertaken as part of the LCIA methods review of the ILCD Handbook (Hauschild et al. 2013), was developed through an initial discussion between the project participants, based on their previous experience with monetary valuation and based on previous examples of comparative assessment and review exercises from the scientific literature on monetary valuation (Hoyos 2010; Nijkamp et al. 2008). The discussion was extended to the members of the SCORELCA during the kick-off meeting in Paris.

The main criteria, and the relevant research questions behind each of them, and the associated sub-criteria that will be used for conducting in practice the critical evaluation/bench-marking (cf. Chapter 5), are:

4.1 Scientific foundation

How has the monetary valuation method been developed?
In addition to the classification of monetary valuation methods according to their associated background theory (e.g. willingness to pay, marginal abatement cost, environmental impact costs, restoration costs), monetary valuation methods will be assessed relative to the following sub-criteria:

1. Scientific robustness and inherent consistency
2. Peer-review and publication of model
3. Reflection of state-of-the-art knowledge on monetary valuation
4. Possibility for consistent improvement to reflect geographical and temporal differentiations
5. Clear and unequivocal identification of the objectives, underlying hypothesis, analytical approach (e.g. top-down vs. bottom-up), and principles
6. Timeframe consideration and representation by a robust and justified discount rate
7. Provision of monetary valuation values covering a significant number of inventory and/or impact flows
8. Distinction between marginal and average data
9. Robustness of monetary valuation factors
10. Ability to take into account budget constraint
11. Hysteresis (providing equal scores for cost or benefit of the same impact, whether increasing or decreasing)
12. Independence of estimate from causality (what or who caused the damage), fairness, responsibility, payment medium, risk-averse/-taking behavior, and whether compensation is actually made or not.

4.2 Documentation and reproducibility

Does the documentation allow understanding and reproducing the monetary valuation method?

1. Publication and accessibility
    i. of the model
    ii. of the model documentation
    iii. of set of characterization factors
    iv. of input data
2. Transparency of
    i. algorithms
    ii. data
    iii. factors
    iv. documentation
3. Ability to be reproduced and extended by third parties
4. Explicit statement of value choices

4.3 Completeness

What is its overall scientific relevance of the monetary valuation method?

1. Extensive coverage of biophysical and social impacts/externalities
2. Inclusion of positive and negative externalities
3. Validity across cultures and relevant to different decision-making contexts (business strategy, public policy, cost calculations / risk assessment / internalisation)?
4. Ability to be applied to site specific contexts
5. Ability to capture abstract levels of values and be applied in non-specific contexts
6. Extensive coverage by monetary valuation factors of the mechanisms and elementary flows for:
    i. Area of Protection Human Health
    ii. Area of Protection Natural Environment
    iii. Area of Protection Natural Resources
7. Closeness between object of monetary valuation and intrinsically valuable safeguard subjects
8. Spatial and temporal differentiation
9. Global scope (geographically)
10. Avoidance of double counting

4.4 Uncertainty

How, and to what extent, are the uncertainties of the monetary valuation method addressed, described and reported?

1. Identification of the principal unknowns in the theoretical structure of the monetary valuation method and of the main assumptions and choices, e.g. choice of time horizon (modelling uncertainty)
2. Explicit statement of the uncertainty associated with the final results, e.g., in terms of standard deviation, range of values, order of magnitude (quantitative uncertainty)
3. Identification of the parameters of the model that have the highest influence on the final results (sensitivity analysis)
4. Identification of the method used for the analysis of uncertainties, e.g. Monte Carlo simulation, others (uncertainty analysis)
5. High accuracy (under/over-estimation)

6. High precision

4.5 Complexity

What knowledge is required to apply the monetary valuation method in practice?

1. Level of background scientific knowledge (trans-disciplinary, cross-disciplinary)
2. Technical support required for the practical performance of the monetary valuation method, in order to arrive at new or updated monetary valuation values, such as:
   i. dedicated software
   ii. mathematical models
   iii. databases
3. General amount of data/information required

4.6 Acceptance by stakeholders[3]

How is the monetary valuation method perceived by non-developers?

1. Acceptance by practitioners
2. Acceptance by policy-makers
3. Ease of understanding and interpretation by LCA experts
4. Ease of understanding and interpretation by non-LCA experts
5. Authority of source
6. Bias to specific industry or economic groups
7. Relevance for public decision-making
8. Relevance for private decision-making
9. Reasonable sample size, time and effort to obtain monetary valuation values

4.7 Relevance to / compatibility with LCA

What is the relation between the monetary valuation method and LCA?

1. Degree to which it has been adapted to LCA
2. General compatibility with and potential for application in LCA
3. Specific compatibility with typical LCA flows, impacts and Areas of Protection
4. Specific compatibility with flows in main LCA databases (e.g. ecoinvent, ELCD)
5. Ease of application of already generated monetary valuation values by practitioners and in common LCA tools

[3] This criterion is not applied in the critical evaluation/bench-marking (cf. Chapter 5) due to lacking empirical evidence, but is instead largely covered by the survey reported in Chapter 6.

5 LITERATURE SURVEY AND REVIEW ON STATE-OF-THE-ART OF MONETARY VALUATION

This chapter provides a bibliographical review, a mapping of existing monetary valuation methods and their application in LCA, and a benchmarking of the methods and applications against the criteria developed in Chapter 2.

5.1 Classification of methods

The scope of the review includes the following inclusive list of monetary valuation approaches and methods[4]:

- Market price method
- Revealed preferences approach
    - Averting behaviour method
    - Hedonic pricing method
    - Travel cost method
- Stated preferences approach
    - Contingent valuation
    - Conjoint analysis: Choice experiment
- Budget constraint method
- Abatement cost method

This classification of methods is based on the key features of the methods, such as general principle, technical aspects and practical implementation. This allows defining each method precisely and unequivocally. The nomenclature and terminology used in the literature is not uniform. Different authors propose different groupings or classifications of methods and approaches (Bachmann 2011, Barbier 2007, Boardman et al. 2006, Nijkamp et al. 2008, Norden 2007, Pearce and Barbier 2000, Pearce et al. 2006). Different methods are referred to with the same name and the same method may be given different names or be classified within different approaches. Furthermore, the name of a specific method may have been used to define a class of methods, or vice-versa. In Table 5.1 we propose our own definitions for each approach and the related methods, since we did not find any consistent definitions in the literature.

[4] We define a monetary valuation "approach" as a class of monetarisation methods based on a specific hypothesis and principle. As "methods" we identify different versions of the same monetary valuation approach, based on the same principle but differing in the practical implementation or in technical aspects. Finally, an "LCA-application" is a version of a monetary valuation method that has been developed or can be adapted specifically for the use in LCA.

Table 5.1 Classification and definitions of monetary valuation approaches and methods.

Approach	*Principle*	*Method*	*Definition*
Observed Preferences	Determining willingness to pay in an existing market for a good	**Market price**	A monetarisation method where the marginal value of a good is identified on the basis of its market price
Revealed preferences	Determining willingness to pay in surrogate markets i.e. a market for a good that is indirectly affected by changes in availability of the primary good		A monetarisation approach where the marginal value of a good is identified on the basis of the market price of a surrogate good, i.e. a good that is indirectly affected by changes in availability of the primary good
		Averting behaviour	A revealed preference valuation method where the marginal value of a good is identified on the basis of the expenses actually made for goods that are required to prevent or offset the change in availability of the primary good
		Travel cost	A revealed preference valuation method where the marginal value of a site is identified on the basis of the expenses made by individuals to travel and visiting the site
		Hedonic pricing	A revealed preference valuation method where the marginal value of a good is identified on the basis of a regression analysis between the availability of the primary good and changes in the market price of another good with multiple attributes
Stated preferences	Determining willingness to pay in hypothetical markets or trade-off situations		A monetarisation approach where the marginal value of a good is identified on the basis of the preferences expressed in response to hypothetical trade-off questions
		Contingent valuation	A stated preference valuation method where the marginal value of a good is identified from the stated willingness to pay or accept compensation for a specified change in the availability of the good
		Conjoint analysis: Choice experiment	A stated preference valuation method where the marginal value of a good is identified on the basis of stated choices between two or more alternative goods where at least one attribute of one good is systematically varied across respondents and at least one good has a market price or market price equivalent
Budget constraint	Determining willingness to pay for an additional Quality-Adjusted Life Year in a hypothetical situation without externalities	**Budget constraint**	A monetarisation method where the marginal value of a Quality-Adjusted Life Year is identified on the basis of the potential economic production per capita per year
Abatement cost	Determining potential cost for the marginal abatement or replacement activity	**Abatement cost**	A cost estimation method where a change in availability of a good is assessed in terms of the potential costs of the marginal counter-balancing change (replacement) or marginal measure that prevents the change

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5.2 Selection of literature material

The literature used for the benchmarking of the methods was selected according to a set of criteria. We aimed at being as comprehensive as possible, under the existing time/budget constraints. Our effort was focused on covering all of the selected monetary valuation methods, and to include any documented application of monetary valuation methods or monetary valuation-based methods used in Life Cycle Impact Assessment (LCIA). When an LCIA application for a specific method could not be found, we considered applications to issues with high level of abstraction (area of protection / safeguard subject, rather than site-assessments), as these have a higher potential for generalization and, thus, for application in LCA. Consistently with this choice, we excluded specific applications of monetary valuation methods, such as case studies with low potential for generalization of results. A summary of the literature material identified is reported in Table 5.2. References are provided on the final pages of the report.

*Table 5.2. Sources for literature review (LCA applications highlighted with *)*

Method	Approach	Application/Literature reviewed (reference)
Market method	**Market prices**	EPS (focus on use of market prices of resources) (Steen 1999a, b)*; ECOVALUE08 (Ahlroth and Finnveden 2011)*
Revealed preferences	**Averting behaviour**	ECOTAX2002 (Finnveden et al. 2006)*
	Travel cost	Meta-analyses (Boardman et al. 2006)
	Hedonic pricing	(Andersen et al. 2011, Riera et al. 2006, Sander and Haight 2012)
Stated preferences	**Contingent valuation**	Contingent valuation for Human health - VOLY from ExternE (Desaigues et al. 2011, European Commission 1999, 2004) Contingent valuation for biodiversity – Case study and review of (Nunes and van den Bergh 2001, Veisten et al. 2004); ECOVALUE08 (Ahlroth and Finnveden 2011)*; EPS (Steen 1999a, b)*
	Conjoint analysis: Choice experiment	LIME1-2 (Itsubo et al. 2004, 2012)*
Abatement cost		EVR (Vogtlander and Bijma 2000, Vogtlander et al. 2001); MAC/RCA (Davidson et al. 2005, Oka 2005, Oka et al. 2005)
Budget constraint		STEPWISE (Weidema 2009, Weidema et al. 2007)*
Review/Statistical methods		Meta-analyses (Costanza et al. 1997, de Groot et al. 2012, Nijkamp et al. 2008)

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5.3 Method for benchmarking

We analysed separately monetary valuation methods as such and LCA applications. In both cases, the methods were assessed according to six main assessment criteria, each described by a number of specific sub-criteria previously defined in Chapter 4. The main assessment criteria applied are summarized in Table 5.3. An additional assessment criterion "Acceptance by stakeholders" defined in Chapter 4 was not included due to lacking empirical evidence. Instead, this assessment criterion is covered by the survey reported in Chapter 6.

Table 5.3. Summary of main assessment criteria.

Scientific foundation	Scientific robustness, inherent consistency, objectives, underlying hypothesis, analytical approach (e.g. top-down vs. bottom-up), principle, background theory (e.g. willingness to pay)
Documentation	To what extent is the scientific approach of the method documented? What is the level of transparency?
Completeness	Validity, application area, overall scientific relevance (e.g. biophysical impacts covered), cross-cultural validity, relevance to decision-making context
Uncertainty	Addressing, description and reporting of uncertainties
Complexity	Required background scientific knowledge, effort, data, technical support (e.g. mathematical models, databases) for application of the method in practice
LCA relevance & compatibility	Relation between method and LCA, actual and potential application in LCA

5.4 Results of benchmarking monetary valuation methods as such

Initially, we evaluated the compliance of the valuation methods to each sub-criterion according to a 5-points compliance scale. However, this turned out to be inappropriate for some of the criteria, since for example "Completeness" is not an intended feature of all valuation methods, while it may be a desired feature when different methods are combined in an LCA application. We therefore decided to provide the evaluation result of the valuation methods as a text description (see below), while the 5-points compliance scale is still applied for the presentation of the LCA applications in Chapter 5.6.

Most of the monetary valuation methods show a solid scientific foundation: they are peer reviewed, with a clear principle and hypothesis. However, results are very sensitive to methodological choices. For the observed and revealed preference approach, the choice of the specific market data is critical. For stated preferences the most significant biases are the survey design, the interview situation, the level of information given to respondents, the strategic behaviour of the respondents, and the size of the sample.

Documentation on the different methods is generally available: most are published and several are openly accessible online.

The budget constraint approach, observed preference approach and the abatement cost approach are less complex than the stated preferences approach, but also have a more limited application area. The stated preferences approach requires a higher amount of data and knowledge to generate monetarised values but the methods are more widely applicable. Thus, there is not one method that is generally recommendable, but rather a combination of methods is required to cover all types of impact categories for LCA.

In the following, each method is described in terms of its *application areas* (with examples) and the *strengths and weaknesses* of each method. Based on the evaluation of these features, *LCA impact categories for which the method is recommendable* are identified (a full overview of midpoint impact categories and the recommended valuation methods for each is provided as Annex 1).

Market price method – Relies on observed preferences (willingness to pay the market price in an existing market). *Application areas:* Valuation of (impacts on) resources and man-made products, which typically have a market price. This includes human resources (where the market price is the gross wages) and natural resources (where the market price is the rent paid for the right to exploit the resource). Impacts that reduce the production capacity (e.g. overexploitation of an abiotic resource) can be measured in terms of the lost value added from the extraction (market price of the product, minus the extraction costs), while impacts that reduce the value of a resource or the yield of an extraction (e.g. the impacts of pollution on buildings or crop yields) can be valued directly by the market price of the lost product. The impact of trade barriers can also be partly valued by the costs of the protected production relative to the world market price (this does not account for any effects on the non-protected producers). *Strengths and Weaknesses:* The market price is a direct and actual expression of preferences, and therefore avoids the uncertainty related to more indirect measurement. The method is limited to goods for which a market exists, and accounts only for the use value of the goods. A complication may be that market prices may themselves be influenced by externalities. Market prices may be geographically specific and may fluctuate due to short-term scarcities. *LCA impact categories for which the method is recommendable:* Corrosion of man-made structures; Dissipation of natural abiotic resources; Overexploitation of natural biotic resources; Reduction in productivity from disability to work; Reduction in yields in agriculture, fishery and forestry; Soil erosion; Trade barriers.

Averting Behaviour – Relies on revealed preferences (willingness to pay for surrogate goods required to prevent or offset the change in availability of the primary good). *Application areas:* Valuation of reductions in goods, where the loss is relatively immediate and directly avoidable by individual protective expenditure. Examples are acceptance of wage reductions to avoid jobs with specific occupational hazards, and expenditures for protection against noise, burglary, unsafe drinking water (expenditures for water filter), accidents (air bag), soil erosion (expenditures for wind breaks or contouring), or degradation of specific local elements of cultural and natural heritage. *Strengths and Weaknesses:* The method observes actual behaviour and is therefore interesting when the averting behaviour can be related directly to the good to be valued. It accounts only for the use value of the good and it is not always easy to isolate the averting behaviour from other explanatory variables: the "omitted variable" problem (that e.g. wage depends not only on risk but also on age and education); "self-selection bias" (e.g., risk-seeking people self-select themselves for risky jobs (Boardman et al 2006)); concepts of fairness and responsibility that may influence averting behaviour; that individuals make multiple averting expenditures for the same risk or impact; and that secondary benefits of an averting expenditure are not accounted for (e.g., if the sound insulation also reduces heat loss). Also, averting behaviour may not be a continuous decision but a discrete one (e.g., the airbag is either purchased or not (Nijkamp et al. 2008)). It is also difficult to ensure that the averting behaviour is based on adequate information about the good to be valued, e.g. the risks and the efficiency of the averting behaviour, since this will often be hypothetical or require statistical knowledge. *LCA impact categories for which the*

method is recommendable: None, since in most cases, the averting behaviour will not cover all aspects of the values of typical LCA impact categories.

Travel Cost – Relies on revealed preferences (willingness to pay travel costs in order to enjoy the primary good). *Application areas:* In the management of tourism and public recreational sites, from natural parks to historical sites, this method may be particularly useful both in terms of assessment and communication, as it provides an immediate and sound justification of why the site has an economic value, based on a measure of the expenditure of visitors. *Strengths and Weaknesses:* When what is to be valued is the full utility of a specific site, the travel cost method may be appropriate. However, there is some concern for endogenous bias: e.g., people decide to travel to a place because it is close and not because of its value (Boardman et al 2006). *LCA impact categories for which the method is recommendable:* Degradation of specific local instances of cultural or natural heritage, or specific local physical degradation of natural flora or fauna. This would not very often be in focus in an LCA, unless the LCA is otherwise very site-specific.

Hedonic Pricing – Relies on revealed preferences (willingness to pay on a surrogate market for a product with multiple attributes, linked to the primary good in such a way that the variation in prices obtained on the surrogate market can be used to estimate the value of the primary good). *Application areas:* Hedonic pricing may be used for valuation of instances of localised air, water and soil pollution, but the requirement of full information (see under Strengths and Weaknesses) is seldom satisfied for such impacts. Also, it would only cover use value, not more abstract values. Rather, hedonic pricing is relevant for more directly observable impacts where there are only use values involved, such as using differences in house prices to value the nuisance from odour and noise, the stress from traffic or living in a crime-prone neighbourhood, and using differences in wages to value job-related nuisances such as psychological and ergonomic stress. A special application would be when the value of an impact reduction can be derived from the price premium on products with specific labelled reductions in impacts. Depending on how explicit and precise the labelling is, this may be seen as a case of direct market prices. An example of this is products labelled for improved animal welfare during production. *Strengths and Weaknesses:* Compared to averting behaviour and the travel cost methods, hedonic pricing considers multiple variables (multivariate regression model), which makes it more flexible and informative outside of a specific context. However, it still requires that an appropriate surrogate market exists. Also, the method assumes full information, a condition that is often not satisfied (e.g., on the risk or existing level of pollution) (Boardman et al. 2006). Hedonic pricing could capture use values, e.g. for recreation, but would not capture more abstract nature values and health aspects. The method observes actual behaviour and is therefore interesting when the above concerns can be satisfactorily addressed. *LCA impact categories for which the method is recommendable:* Burglary or attempted burglary; Inadequate ergonomic conditions (when possible to isolate from health impacts); Noise (nuisance aspect only, when possible to isolate this); Odour; Reduction in wellbeing of animals in human care, Stressful working conditions; Stress from threatening or traumatic traffic situations; Threats of violence or other contact crimes.

Contingent Valuation – Relies on stated preferences (expressed willingness to pay on a hypothetical market for the non-market good). *Application areas:* The method is best suited for well-specified, concrete goods for which it is possible to imagine that a market could actually be implemented, such as "safe drinking water" or specific ecosystem services. Has also been used to provide WTP for gains in life expectancy achievable by air pollution

reductions under realistic policy scenarios. For complex, multi-dimensional, or abstract goods (e.g. biodiversity), the market situation may be too difficult to depict for respondents. *Strengths and Weaknesses:* The stated preference approach (using hypothetical markets) is the only possible alternative for the valuation of most goods for which appropriate actual or surrogate markets do not exist. Compared to conjoint analysis (the other method that use stated preferences, see below), contingent valuation explicitly asks for the willingness-to-pay and thus obtains a directly stated value for the full utility of the good. A good questionnaire design and administration is important to adequately remove cognitive stress (Nijkamp et al. 2008) and potential biases in the population and its responses, as well as adequately taking into account the budget constraint. *LCA impact categories for which the method is recommendable:* None, since contingent valuation is good for simple issues where you want an explicit price for the whole good, while all impact categories not mentioned under the methods above typically affect only specific parts of complex goods, with many variables, and therefore more suited for conjoint analysis, which is also more subtle and controllable because you do not ask for an explicit price.

Conjoint Analysis: Choice experiment – Relies on stated preferences (inferred willingness to pay in a hypothetical trade-off situation involving (attributes of) one or more non-market goods and at least one good that has a market price or market price equivalent). *Application area:* All non-markets goods can be included in a conjoint analysis, but the method has its strength when applied to more complex and abstract goods. *Strengths and Weaknesses:* Compared to contingent valuation, the method can measure partial utility instead of total utility only, since it can consider multiple attributes of a non-market good. Moreover, it can measure trade-offs between these attributes and does not force respondents to state monetary values. However, the total utility of a good may not be equal to the sum of its parts (Pearce et al. 2002). Also, a choice experiment is relatively complex to design and administer and may suffer from the same potential biases as contingent valuation. *LCA impact categories for which the method is recommendable:* All impact categories not mentioned under the methods above, and also area of protection impact categories such as human and ecosystem health (high level of abstraction).

Budget constraint – Relies on knowledge of the potential income at full wellbeing (the potential annual economic production per capita in a hypothetical situation without externalities[5]) and infers the willingness to spend this income, based on the argument that the average annual consumption expenditure of a person at full wellbeing (i.e. what is paid to maintain a life at full wellbeing) must necessarily equal the average income at full wellbeing (the budget constraint). *Application areas:* The method is only applicable for valuation of human wellbeing and other goods that are expressed in QALY. The value of midpoint impact categories that can be related to the QALY endpoint value may be back-calculated from the value of the endpoint. The method can be used to reduce the uncertainty of – and thus to anchor – the value of a QALY arrived at with other methods such as conjoint analysis. *Strengths and Weaknesses:* The main advantage of the method is that it accounts explicitly for the budget constraint, which lowers the uncertainty on the valuation. However, the method is only applicable specifically to the value of human wellbeing (expressed in Quality-Adjusted Life Years; QALY). It should be noted that this value includes pain and suffering, but is *additional* to the cost of illness and the human productivity loss, as measured by the market

[5] Calculated by adding to the current gross economic product (which compared to the gross domestic product also includes the value of household and voluntary work) the value of the lost productivity from current levels of unemployment, underemployment, trade barriers, lacking education, and lost work-days from health impacts (Weidema 2009), as calculated by the direct market price method.

price method. The budget constraint method does not rely on revealed nor stated willingness to pay, but rather infers the willingness to pay from the accounting balance principle (what is earned must be spent). The uncertainty depends on the data used to calculate the potential economic production per capita. *LCA impact categories for which the method is recommendable:* Human wellbeing (area of protection impact category).

Abatement cost – Relies on the estimated potential private cost of the marginal abatement measure or replacement that would counter-balance a change in the availability of the non-market good (most often at a specified target level for the good). *Application areas:* When the abatement is expected to occur, the abatement is a part of the LCI, and the abatement costs therefore also internalised as part of the Life Cycle Costing (the parallel to the social and biophysical LCA that accounts for private costs), and should therefore not be accounted for as an externality. When damage costs are assessed by one of the other monetary valuation approaches, abatement costs can be used to determine the socially optimal extent of abatement (the point at which marginal damage costs equal marginal abatement costs). When a political reduction target has been set, abatement costs can be seen as a minimum estimate for the damage costs (i.e. the political WTP). Since the damage is not established by the use of an impact pathway, this is a very indirect way to assess damage costs, and can only be recommended as a last resort. *Strengths and Weaknesses:* The method is based on a quite intuitive concept and can be used to assess policy targets. The main limitation of the method is that it does not value utility loses (damages), i.e. it is not WTP-based, or only partly (by reflecting political rather than individual WTP). Therefore, it does not refer to a social optimum. *LCA impact categories for which the method is recommendable:* None, since (values from) WTP methods are available that better express damage cost.

5.5 LCA applications of monetary valuation methods

A number of LCA applications have been identified and reviewed. Also some potential applications have been included. Finally, for monetary valuation methods where no LCA application was identified (travel cost and hedonic pricing methods), their potential for application in LCA was assessed on the basis of other applications and the general literature.
The following applications were reviewed:

- Stepwise2006
- LIME 1-2
- Ecotax02
- Ecovalue08
- MAC/RCA
- CV for VOLY
- CV for biodiversity
- Meta-analysis
- EPS2000
- EVR
- Hedonic pricing for LCA
- Travel cost for LCA

Each of these is shortly described in the following:

Stepwise2006 (Weidema 2009, Weidema et al. 2007) - Budget constraint approach.
Principle: Given that the average annual income is the maximum that an average person can pay for an additional life year, and a Quality-Adjusted Life Year (QALY) by definition is a life-

year lived at full wellbeing, then an upper limit for the monetary value of a QALY is provided. Since a QALY also expresses everything that can be purchased to obtain an additional life year at full wellbeing, it is argued that this is also the lower limit for the WTP. Other indicators (for safeguard subjects ecosystems and resources) are then derived from/converted into QALY. *In practice:* Monetary values of indicators for three damage categories (safeguard subjects) are provided: Quality-Adjusted Life Years (QALYs) for impacts on human wellbeing, Biodiversity Adjusted Hectare Years (BAHYs) for impacts on ecosystems, and monetary units (EUR2003) for impacts on resource productivity. Conversion factors between indicators are provided. Weighting factors LCA mid-point impact categories (from EDIP2003 and IMPACT2002+) are calculated from the values of the three damage categories. *Use in LCA:* Stepwise2006 has been designed specifically for LCIA and is implemented in the SimaPro software.

LIME 1-2 (Itsubo et al. 2004, 2012) - Stated preferences approach (Conjoint analysis: Choice experiment method).
Principle: Choice experiment with four attributes corresponding to the LCA damage categories: human health (DALY), social assets (Yen), biodiversity (EINES), and primary production (NPP). A tax level (representing the WTP) is added to each vector as monetary attribute. Attributes are exemplified by using normalized values of the indicators. *In practice:* A sample of individuals is asked to choose between different vectors of five attributes, each vector being a level of damage (status quo; +1/4; +1/2). Results are converted in monetary weighting factors by using normalization factors per damage category. *Use in LCA:* designed specifically for LCIA at area of protection endpoint level.

Ecotax02 (Finnveden et al. 2006) - Revealed preferences approach (Averting behaviour method).
Principle: Different eco-taxes are used to estimate the monetary value of specific emissions on the hypothesis that the tax represents the WTP of society (political WTP) for protecting the environment. *In practice:* Different ecotaxes are used either directly as "valuation weighting factors" (e.g. CO_2-tax) or indirectly after a minor correction/recalculation (e.g. N emissions). The valuation weighting factors are then converted into characterisation factors as used in the normal LCIA practice. CML midpoint categories are used (not area of protection endpoint categories). *Use in LCA:* designed specifically for weighting in LCIA at midpoint level. Several case studies are presented like e.g. tax on incineration of solid waste, Swedish agricultural production, LCA of grenades.

Ecovalue08 (Ahlroth and Finnveden 2011) - Hybrid approach: Stated preferences (Contingent valuation method) and observed preferences (market prices method).
Principle: The overall principle is "valuation from the demand side", and the application aims at providing "welfare-based estimates based on stated preference studies for non-marketed assets". *In practice:* The application is similar to Ecotax02 but, instead of taxes, monetary estimates from several different monetarisation (mostly contingent valuation) studies from literature are used to monetarise indicators of mid-point impact categories. When WTP estimates are not available, other estimates such as market prices are used. *Use in LCA:* designed specifically for weighting in LCIA at midpoint level. Several case studies are presented like e.g. tax on incineration of solid waste, Swedish agricultural production, LCA of grenades.

MAC/RCA (Davidson et al. 2005, Oka 2005, Oka et al. 2005) - Abatement cost approach. Here, both Maximum Abatement Cost (MAC) and the Reduction Cost Approach (RCA) are included.

Principle: Monetary valuation of emissions by determination of the marginal unit reduction cost based on abatement technology. This cost may be calculated at an emission target level (RCA) or at maximum abatement (MAC). *In practice:* The monetarisation consists in three steps: (i) identification of an emission reduction target; (ii) determination of marginal reduction cost curve via hyperbolic function (*f(cost[$], emission reduction[kg])*); (iii) determination of marginal unit reduction cost at the emission target level. The difference between MAC and RCA is that RCA explicitly states that a sustainability target for the abatement of emissions has to be identified, whereas MAC only refers to maximum abatement cost, i.e. the maximum cost among the various alternatives for emission reduction (however, in practice for most emissions a target is identified). *Use in LCA:* designed for assessment of cost-effectiveness of technologies/products rather than for LCA. However, authors state that it could be potentially used as weighting method in LCA. Monetary values are calculated for emissions directly (in RCA these are then extended to midpoint categories by using the substance equivalents, e.g., CO_2-equivalents).

CV for VOLY, ExternE follow-up (Desaigues et al. 2011, European Commission 1999, 2004) - Stated preferences approach (Contingent valuation method).
Principle: CV to estimate WTP for avoiding mortality/extending life expectancy. *In practice:* contingent valuation survey in 9 European countries with a questionnaire designed to address air pollution mortality and to estimate VOLY. Respondents are asked about their WTP for gains in life expectancy achievable by air pollution reductions under realistic policy scenarios. *Use in LCA:* Used in the ExternE project[6] and in some LCIA methods based on monetarisation, e.g. EPS2000.

CV for Biodiversity (Nunes and van den Bergh 2001, Veisten et al. 2004) - Stated preferences approach (Contingent valuation method).
Principle: CV estimate of WTP for biodiversity. *In practice:* Several contingent valuation studies exist on the monetarisation of biodiversity, with different levels of detail regarding the type of biodiversity considered (genetic, species, groups of species, biome, and ecosystem services). Here the study of Veisten (2004) is used as example, not because it is a high level of abstraction but rather because different scopes (levels of biodiversity) are considered, as well as the effect of the choice of scope on final results. More general considerations about the use of contingent valuation in the monetarisation of biodiversity are taken from the work of Nunes (2001). *Use in LCA:* Not applied in LCA (but intended for decision support in policy making context).

Meta-analysis (Costanza et al. 1997; de Groot et al. 2012; Nijkamp et al. 2008) - example for biodiversity/ecosystem services
Principle: Aggregation and summary of monetary values calculated with a mixture of methods, with prevalence of contingent valuation and market prices. *In practice:* Both qualitative (review) and quantitative (statistic) approaches are included. A large number of studies are collected and reviewed, eventually from existing databases, then information is classified and synthetized e.g. by calculating mean values among studies dealing with the same subject. The final results of the valuation studies are aggregated (without weighting; each study count with

[6] The ExternE (externalities of energies) project was launched by the European Commission, in collaboration with the U.S. Department of Energy. The aim was to use a 'bottom-up' methodology to evaluate the external costs of energy, depending on different fuels. This project began in 1991 with five European teams, and has extended to more than 50 teams from 15 different countries. Phase III of the project was completed in 1997. It provided an opportunity to develop a methodology to quantify in monetary terms the effects of air pollution (impact pathway). This method is now a reference in this field, at least in Europe. This method was then used to calculate the external environmental costs of different energy sources.

equal weight) to obtain a synthetic result. No use have been made of advanced meta-analytic approaches, such as aggregating the raw data (samples) from various studies to obtain an increased sample, and then re-calculating a new and more robust statistic (monetary value). *Use in LCA:* Not applied in LCA (but intended for decision support in policy making context).

EPS2000 (Steen 1999a, b) - Mix of approaches: observed preferences, abatement cost, stated preferences (Contingent valuation method), revealed preferences (Averting behaviour method).
In practice: WTP for human health estimated via contingent valuation (values taken from ExternE); market prices are used to estimate WTP for Ecosystem Production Capacity (e.g. for crops, etc.); abatement cost approach used for WTP of abiotic resources (what is the cost of producing the same resource in an alternative and sustainable way); Public expenditures of Sweden for protection of species used as a proxy for WTP for biodiversity (Averting behaviour). All values converted into ELU (= EUR) units. *Use in LCA:* Designed specifically for LCIA at area of protection endpoint level.

EVR (Eco-costs/Value Ratio; Vogtlander and Bijma 2000; Vogtlander et al. 2001) - Abatement cost approach.
Principle: Monetarisation is done on a "what if" basis, based on the cost of the technical measures required to lower the current pollution and resource depletion to a sustainable level. *In practice:* "Eco-costs" are estimated as the sum of (i) the "marginal prevention costs" of each type of pollution (most expensive measure our society is prepared to take to reduce pollution) and (ii) the costs of measures for prevention of material and energy depletion. For instance, the "eco-costs of energy" is equal to the costs of the renewable energy system which has to replace the current (fossil fuel-based) system. *Use in LCA:* Designed specifically for LCA; can be seen as a combination of LCC and LCA.

Hedonic Pricing for LCA (Andersen et al. 2011, Riera et al. 2006, Sander and Haight 2012) - Revealed preferences approach (hedonic pricing method)
Principle: Monetarisation of an attribute is done by observing changes in market price for a product that has variable amount of the attribute. *In practice:* Mostly house markets (price of properties close to natural/polluted sites) or labour markets (higher wage for higher risk) are considered; statistical regression models are applied to control for several variables. In practice hedonic pricing uses econometric techniques such as panel regression analysis. *Use in LCA:* No LCA related applications identified. Case studies with high level of abstraction: hedonic pricing for estimating of Value of Statistical life (VSL), via wage-risk or other risk-related markets (e.g. airbags and car accidents); hedonic pricing for valuation of ecosystem services (e.g. cultural services). One example found of hedonic pricing combined with impact-pathway approach (based on dose-response functions) to calculate external costs of nitrogen emissions.

Travel Cost for LCA (Boardman et al. 2006) - Revealed preferences approach (Travel cost method).
Principle: The total costs of visiting a site are used as a measure of the value of this site. *In practice:* The travel costs can be correlated with certain attributes of the site with a statistical regression model, in which case this is identical to the Hedonic Pricing method. *Use in LCA:* no LCA related applications identified. Typical applications are e.g. the valuation of recreational sites such as lakes, forests, etc.

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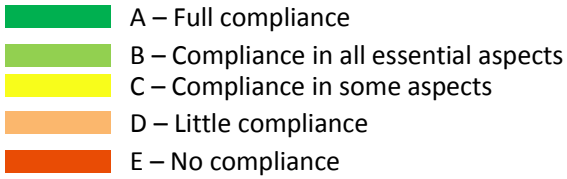
5.6 Results of benchmarking LCA applications of monetary valuation

We evaluated the compliance of the LCA applications (and potential LCA applications) to each sub-criterion according to a 5-points scale as in Hauschild et al. (2013):

A) Full compliance
B) Compliance in all essential aspects
C) Compliance in some aspects
D) Little compliance
E) No compliance

*Table 5.4. Heat map showing the benchmarking of LCA applications (and potential LCA applications) of monetary valuation methods. Darker shades of green colour (and higher numbers) indicate higher compliance with the criteria, and vice versa darker shades of red colour (and lower numbers) indicate lower compliance. 1 = no compliance and 5 = full compliance. Note that numbers are for communication purposes only and not intended as additive. *Potential LCA application*

LCA Application	Reference	Approach	Method	Scientific foundation	Documentation	Completeness	Uncertainty	Complexity	Relevance for LCA
STEPWISE2006	(Weidema, 2009; Weidema et al., 2007)	Budget constraint	Budget constraint	4.50	4.80	4.08	3.63	4.40	5.00
LIME 1-2	(Itsubo et al., 2012; Itsubo et al., 2004)	Stated preferences	Conjoint Analysis	4.00	4.10	3.58	4.25	3.80	5.00
ECOTAX2002	(Finnveden et al., 2006)	Revealed preferences	Averting Behavior	3.67	4.20	3.17	2.63	4.40	5.00
ECOVALUE08	(Ahlroth and Finnveden, 2011)	Mix	Contingent Valuation and market prices	3.25	3.50	3.58	2.50	4.20	4.00
MAC/RCA	(Davidson et al., 2005; Oka, 2005; Oka et al., 2005)	Abatement Cost	Abatement Cost	2.92	3.30	2.50	1.00	4.20	3.00
EPS2000	(Steen, 1999a, b)	Mix	Contingent Valuation market prices and abatement cost	3.00	4.70	3.67	3.50	4.00	5.00
EVR	(Vogtlander and Bijma, 2000; Vogtlander et al., 2001)	Abatement Cost	Abatement Cost	3.17	3.20	2.67	1.00	3.20	4.00
HEDONIC PRICING*	(Andersen et al., 2011; Riera et al., 2006; Sander and Haight, 2012)	Revealed preferences	Hedonic pricing	3.75	2.70	3.08	4.00	3.60	2.33
Travel Cost*	(Boardman et al., 2006)	Revealed preferences	Travel Cost	3.67	3.00	2.50	3.75	3.40	1.67
CV of VOLY*	(Desaigues et al., 2011; European Commission, 1999, 2004)	Stated preferences	Contingent Valuation	4.17	4.10	3.00	3.75	3.60	3.83
CV of biodiversity*	(Nunes and van den Bergh, 2001; Veisten et al., 2004)	Stated preferences	Contingent Valuation	3.83	4.10	2.83	3.75	3.60	3.00
META-ANALYSIS*	(Costanza et al., 1997; de Groot et al., 2012; Nijkamp et al., 2008)	Mix	Contingent Valuation and market prices	3.25	4.00	3.42	3.75	4.00	3.17


A – Full compliance
B – Compliance in all essential aspects
C – Compliance in some aspects
D – Little compliance
E – No compliance

A specific motivation for assigning a point to each criterion was given. This material is included in the spreadsheet file accompanying this report. For a simple summary representation of the benchmarking, we chose to use a "heat map", since this is an intuitive and easy to understand graphical tool. To obtain the heat-map, it is necessary to shift from a qualitative to a quantitative assessment. A numeric value was assigned to each point, where A = 5 and E = 1. An average score value was subsequently calculated for each criterion based on the results of the sub-criteria. Each sub-criterion is thereby implicitly assumed to be equally important, i.e. no weighting between criteria was performed. We stress that this semi-quantitative approach was chosen for communication purposes, rather than for evaluation purposes (i.e. not for assigning an absolute score to each method).

The overall results of the assessment are provided in Table 5.4 for each LCA application as a heat-map based on the review of specific literature sources. Note that numbers are for communication purposes only and not intended as additive.

The observed preferences approach is not extensively applied in LCA. Partial applications of the observed preferences approach (market price method) in LCA are EPS (Steen 1999a, b) and Ecovalue08 (Ahlroth and Finnveden 2011). The limit of this method is the availability of appropriate market-price data that can be linked to the environmental impacts in LCA. This method has been applied mostly to valuation of resource depletion. The monetarisation is usually performed at the level of individual substances, and then the results may be extrapolated to the midpoint level. Although the method is simple, we observed problems of geographical consistency and poor coverage of impact categories.

Among the methods of the revealed preferences approach, the averting behaviour method has the largest potential biases (single-variable concept) and has only been applied in an LCA context by one author (by the use of eco-taxes, representing a political rather than individual WTP). The hedonic pricing method appears more robust than the averting behaviour method, and can be applied to the monetary valuation of both human health and ecosystem quality. However, we did not find any examples of its use in LCA. Therefore, its potential for application was reviewed based on the work of Andersen et al. (2011), Riera et al. (2006), and Sander and Haight (2012) only. Typically, the hedonic pricing approach is used in the evaluation of ecosystem services provided by specific sites, instances of localised air, water and soil pollution, and nuisances from odour or noise. The most abstract applications of hedonic pricing are evaluations of the value of statistical life (VSL) based on regression models correlating wage with risks (fatality risk, injury risk) and other variables (education, age, etc.) in specific labour markets (Boardman et al. 2006, Riera et al. 2006). Similar considerations are valid for the travel cost approach, which is mostly used to determine the total value of specific sites rather than of abstract goods. We were not able to find any documented application of the travel cost method to LCA. Therefore, we evaluated its potential for applicability in LCA based on the information provided by Boardman et al. (2006). In general, both hedonic pricing and travel cost methods appear to be too geographically and temporally specific for most typical LCA applications. The revealed preferences approach can only assess use value, not more abstract values and is therefore better fit to monetarisation at midpoint level than at the level of areas of protection.

Several different LCA applications exist of the abatement cost approach: EVR (Vogtlander and Bijma 2000, Vogtlander et al. 2001); MAC/RCA (Davidson et al. 2005, Oka 2005, Oka et al. 2005). High uncertainties and a substantial level of bias have been observed. Examples of

critical sources of uncertainty are the choice of abatement technology and the definition of future scenarios. The general critique of the abatement cost approach (that it does not value utility loses (damage costs), i.e. that it is not WTP-based) also applies to the LCA applications. These issues are usually poorly addressed in the LCA applications.

There is a scattered application of the contingent valuation approach in LCA. Ecovalue08 (Ahlroth and Finnveden 2011) and EPS (Steen 1999a, b) are examples of LCA applications. Among the potential LCA applications, we also included the work of Desaigues et al. (2011), which is a follow-up of the ExternE study (European Commission 1999, 2004) where contingent valuation is applied to the monetarisation of health impacts in terms of Value of Life Years lost (VOLY). Another example of potential LCA application of contingent valuation is the work of Nunes and van den Bergh (2001) and Veisten et al. (2004) where this approach is used to monetarise biodiversity. The approach has been applied extensively to several specific case studies, and meta-analysis (both qualitative and quantitative, by applying statistical techniques) has also been used to extrapolate more general results from specific case studies (at a higher level of abstraction) or improve the robustness of the analysis (Costanza et al. 1997, de Groot et al. 2012, Nijkamp et al. 2008).

Conjoint analysis could be considered so far the most appropriate method of the stated-preferences approach for application in LCA. The method allows for multi-attribute valuation and for more subtle measurements of trade-offs between different impact categories. Differently from contingent valuation, conjoint analysis has been applied to cover several areas of protection in LCA. However, only Itsubo and co-workers, with the first and second version of LIME (2004, 2012), have applied conjoint analysis in the context of LCA. Therefore, there is a need for additional applications to test the robustness of the method's results. This should focus e.g. on different choices regarding the number and type of impact categories included, their relative indicators, and the spatial coverage provided by the sample of respondents.

The budget constraint method represents a relatively new alternative, which also finds its application in LCA in Stepwise2006 (Weidema 2009, Weidema et al. 2007). The main motivation behind developing this method was to overcome the uncertainty of stated preference approaches by directly using the budget constraint, which can be determined with higher precision. The Stepwise2006 application uses the more precise determination of the budget constraint – and thus the value of a Quality-Adjusted Life Year (QALY) – to provide an anchoring for the cross-issue valuation capability of conjoint analysis as used in LIME. This results in some clear advantages, such as high consistency and the possibility of full conversion between weighting factors calculated for different areas of protection.

5.7 Comparison of monetary values from different LCA applications

Table 5.5 shows the differences in characterisation factors (CF) provided by different LCA applications of monetary valuation methods. These differences do not appear significant, taking into account the uncertainties of the monetary valuation. For example, an uncertainty range of 62,000–84,000 Eur_{2003} per QALY is estimated by Weidema (2009), and of 25,000-100,000 Eur_{2010} per VOLY by Desaigués et al. (2011). However, the specific features of each method should be taken into account when comparing CFs across methods.

Table 5.5. Comparison of monetary values in LCA applications of different monetary valuation methods. Not all methods provide CFs for the same impact categories. Since different units are used for CFs of different applications, a conversion of some CFs has been performed. The conversion is either a simple change of currency, or a change of reference substance. Values are not adjusted for inflation, the reference year is thus reported. VOLY: value of a life year; DALY: Disability Adjusted Lifetime Year; BAHY: Biodiversity Adjusted Hectare Year.

LCA Application	**STEPWISE2006**	**LIME 1**	**LIME 2**	**ECOTAX02**	**ECOVALUE08**	**RCA**	**VOLY (Desaigues et al. 2011)**	**EPS2000**	**EVR**
Euryear	Eur_{2003}	Eur_{2004}	Eur_{2010}	Eur_{2002}	Eur_{2010}	Eur_{2005}	Eur_{2010}	Eur_{1999}	Eur_{1999}
DALY [eur/DALY]	74,000	73,720	111,720	-	-	-	40,000	85,000	-
Biodiversity (eur/specie)	30,800,000,000	36,480,000,000	107,920,000,000	-	-	-	-	110,000,000,000	-
BAHY [eur/BAHY]	1,400	1,658	4,905	-	-	-	-	-	-
Global warming [eur/kgCO_2eq]	0.08	-	-	0.07	0.23	0.05	-	-	0.11
Ozone depletion [eur/kgCFC11eq]	100.00	-	-	139.56	-	30.00	-	-	-
Acidification [eur/kgSO_2eq]	0.00015	-	-	2.09	3.49	4.00	-	-	6.40
Eutrophication [eur/kgPO_4eq]	1.20	-	-	3.32	25.35	9.00	-	-	3.05
Photochemical oxidation [eur/kgC_2H_4eq]	0.00056	-	-	55.82	4.65	2.00	-	-	15.00
Abiotic Resources [eur/MJ]	0.00400	-	-	0.02	0.00047	-	-	-	-
Human-toxicity [eur/kg1.4DBeq]	0.00154	-	-	0.17	1.40	-	-	-	-

With the exception of Stepwise2006, all monetary CFs at the level of areas of protection are provided through stated preferences. Both the ExternE follow-up study of Desaigues et al. (2011) and the LIME application are based on stated preferences. The calculation of DALY and Biodiversity loss estimates in the EPS2000 method is also based on contingent valuation, with values taken from the original ExternE study (European Commission 1999, 2004). In principle, all these methods can measure the use and non-use value of non-market goods. Values of endpoint indicators are similar across methods (same order of magnitude). For Disability Adjusted Life Years (DALY), the lowest value is obtained in Desaigues et al. (2011). This study provided lower estimates compared to the original results of the ExternE project that are instead used in the development of EPS2000. The difference between the two contingent valuation studies is that the follow-up study is a multi-country application of contingent valuation, with the specific objective of estimating VOLY directly, and not indirectly e.g. starting from estimates of Value of Statistical Life (VSL), as in the first study of the ExternE series (European Commission 1999, 2004).

An important difference between applications is the geographical scale, or spatial and cultural scope. LIME is developed for Japanese conditions, whereas the ExternE follow-up estimates of VOLY are valid for European conditions only. The interviewees of the conjoint analysis performed in the LIME studies were all selected randomly within the Japanese population, and the LCA normalisation factors were calculated based on the Japanese environmental status quo (e.g. the annual amount of greenhouse gases emitted yearly in Japan and the amount of DALY lost yearly in Japan). Similarly, in the VOLY study of Desaigues et al. (2011) only individuals selected randomly within the European population were interviewed. The Stepwise2006 application provides values that are valid globally. Therefore, both cultural differences and differences regarding the environmental conditions may contribute to the differences in the final monetary CFs at the level of areas of protection. This makes the different applications hardly comparable in terms of geographical and cultural scope.

Again concerning conjoint analysis, there is a difference between the two versions of the LIME method. LIME2, the second version, provides systematically higher estimates than LIME1, the first version, for the area of protection impact category indicators DALY and BAHY. These differences may be related to the study design. A different sample (400 individuals in LIME1 versus 1000 in LIME2) and different model (conditional logit model for LIME1 versus random parameter logit model for LIME2) were used. This shows that although the LIME studies were performed with a higher degree of consistency (same research team, same location, and same procedure), differences in study design may largely influence the final results of the conjoint analysis.

Table 5.5 compares midpoint CFs provided by Stepwise2006, RCA, EVR, Ecotax2002, and Ecovalue08, which are LCA applications of different monetary valuation methods. CFs provided for the Global Warming Potential midpoint impact category are similar across different LCA applications. Given the differences between methods (both in principles and calculation procedures) this similarity must be regarded as coincidental rather than pointing to any implicit convergence. Regarding other midpoint impact categories, Stepwise2006 gives lower values for CFs for acidification, human toxicity, and photochemical oxidation. The main difference between Stepwise2006 and the other applications is that a top-down approach is applied, as monetary CFs at midpoint are

calculated starting from the initial monetary estimates of DALYs and BAHYs, so that no direct monetary valuation is made for each specific midpoint impact category. In general, the differences between values could be explained by the choice of reference substance for the midpoint impact category and its monetary value obtained specifically for this. In Ecotax2002, for example, Cadmium is chosen as reference substance for the toxicity categories, and then its monetary value in [eur/kgCd] (which is based on Swedish tax on content of cadmium in fertilizers) is converted into [euro/kg1-4DB-eq.] by using the relative toxicity of the two substances. Different choices are made in the other applications. Last, also in the case of midpoint CFs the geographical scope is hardly comparable. While Stepwise2006 has a global scope, Exotax2002, Ecovalue08, and EPS2000 are limited to Swedish conditions and EVR to Dutch conditions.

5.8 Conclusions and recommendations from the literature review and benchmarking

Different methods for economic valuation have different strengths and weaknesses that make them more or less suited for valuation of specific goods or impacts. Thus, not one method is generally recommendable, but rather a careful combination of methods is required. The appropriate method strongly depends on the object the study seeks to value. A recommended valuation method has been identified for each *LCA impact category*. Annex 1 provides the full lists of midpoint impact categories and the recommended valuation methods for each.

In general, conjoint analysis is identified as the most appropriate method for the majority of LCA impact categories, when directly observable market prices are not available. The budget constraint method can be used to minimise the uncertainty on the monetary value of a human life year and thereby for anchoring the values obtained by the conjoint analysis. The hedonic pricing method is recommended for impact categories where the impacts are directly observable and only use values are involved, such as the nuisance from odour, noise, traffic, or living in a crime-prone neighbourhood, and job-related nuisances such as psychological and ergonomic stress. All other monetary valuation methods are not recommended for LCA, except in very specific situations.

In practical LCA applications, conjoint analysis has unfortunately only been scarcely used in LCIA methods, pointing to the need for more studies to confirm the practical usability of conjoint analysis for monetary valuation in LCA. In contrast, there are many LCA applications of the abatement cost method, which is not recommended by our assessment, mainly because it does not provide valuation of damages. The widespread application may be due to its relative simplicity and intuitive appeal. Out of the available LCA applications, Stepwise2006 and LIME scores best when viewed across all assessment criteria.

Although some sets of monetary valuation factors are available and not difficult to use, expert knowledge in monetary valuation methods is needed to judge the robustness of valuation factors and to adapt or supplement these when appropriate.

6 CURRENT STATE OF APPLICATION OF MONETARY VALUATION IN LCA PRACTICE

We carried out two web-facilitated surveys to collect primary information on
a) The extent of monetary valuation used in LCA,
b) Which monetary valuation methods are used, and
c) The opinions of the practitioners and decision makers.

The first survey targeted all LCA consultants, who were asked if they have used monetary valuation, have considered it, or intend to use it. Additional questions asked the LCA consultants to specify which monetary valuation methods were used/considered, and to provide examples/references. Furthermore, the LCA consultants were asked if they are interested and willing to participate in the second survey.

The second survey targeted LCA practitioners and decision-makers that have used LCA and inquired specifically their opinions on monetary valuation. The questions investigated the reason for using or not using monetary valuation; the importance given to the different appraisal criteria (developed in Chapter 3); the relation of monetary valuation to other weighting methods (distance-to-target, direct weighting of impact categories by panels, software-supported or otherwise formalised Multiple Criteria Decision Making); their opinions on, or perceptions of, specific monetary valuation methods in terms of relevance, application area, and perceived problems/obstacles.

Before implementation, the web-surveys were tested on a small sample of the target group, in order to test the length of the surveys and adjust any problems of understanding the questions.

The final survey questions are reproduced in the Figures and Tables in this Chapter together with the summary statistics of the quantifiable responses.

The LCA consultants and practitioners were identified by using publicly available lists of practitioners, via scientific associations, and the network of the project participants. Moreover, the surveys were advertised on popular LCA forums (e.g., the Pré LCA discussion list, LinkedIn). The target number of respondents was 100-200 for the two surveys.

A total of 209 people responded to the surveys, 10 of which were the small sample of the target group where the survey was tested.

Since the survey was conducted anonymously and on the web, the representativeness of the response population is unknown: However, it can be reasonably expected that the respondents have stronger opinions on the subject than the non-response population.

Only 92 completed the whole survey. The drop-out (112) was exclusively on question 3: "What is your practical experience with monetarisation?" which was intended to discern practitioners from users. Here we lost all non-practitioners. This is likely to have been caused by a flaw in the questionnaire jumping behaviour, since the intended jump for

non-practitioners to the second survey (see Chapter 6.2) did not work properly, which meant that non-practitioners were sent on to questions that they had no reason to answer. This implies that also the second survey was in practice only answered by practitioners, rather than as intended by both practitioners and decision-makers. However, it can reasonably be expected that the opinions of the practitioners also largely reflect those of the decision-makers, since practitioners work for the decision-makers. Nevertheless, it would be interesting if an additional survey could be carried out with a specific focus on how decision-makers perceive and use both aggregated and disaggregated, monetarised and non-monetarised information provided for the same LCA study.

6.1 The use of monetary valuation in LCA practice

6.1.1 Primary affiliation of the respondents (Question 1/7)

The primary affiliation of the respondents is given in Table 6.1 and Figure 6.1.

Table 6.1. Primary affiliation of the 209 respondents in numbers. The "other" category was re-distributed over the 4 categories based on the specified replies of the 8 respondents, to arrive at the re-distributed column and the percentages used in Figure 6.1.

Affiliation	Numbers	Re-distributed	Percentage
Consultancy	77	80	36.8%
Industry	36	37	17.2%
Academic	80	83	38.3%
Government	16	17	7.7%
Other (please specify)	8		

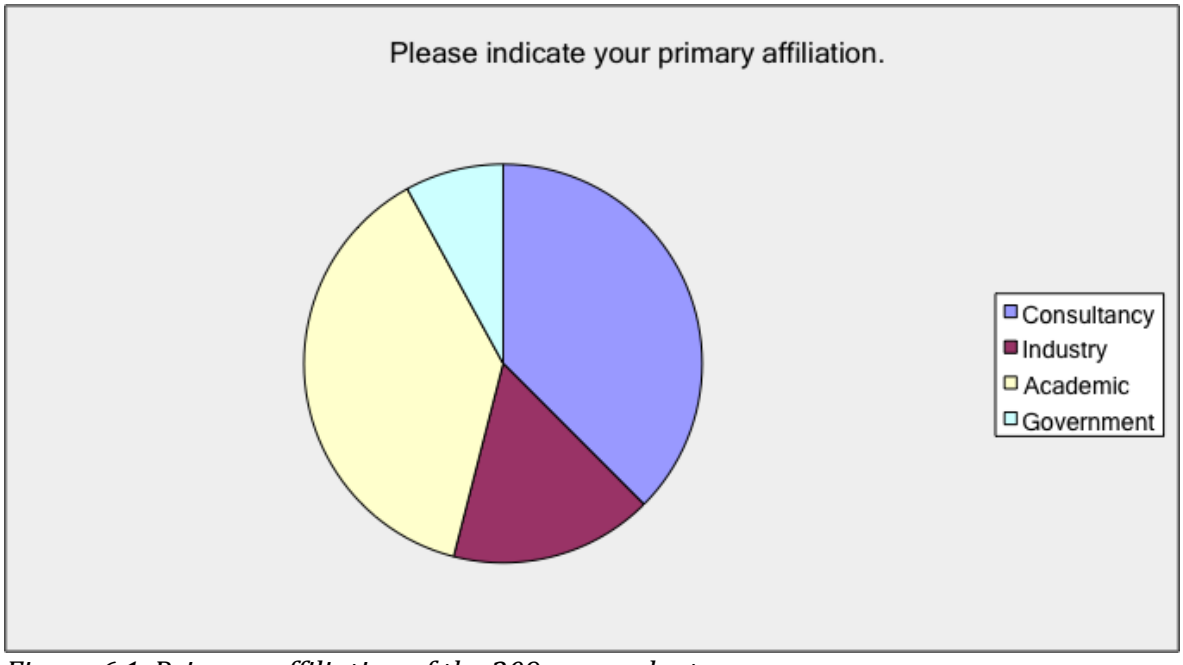


Figure 6.1. Primary affiliation of the 209 respondents

6.1.2 Main experience with LCA (Question 2/7)

The respondents were asked if their main experience with LCA was as a tool provider/developer, methods developer, practitioner or user. The replies are given in Table 6.2 and Figure 6.2.

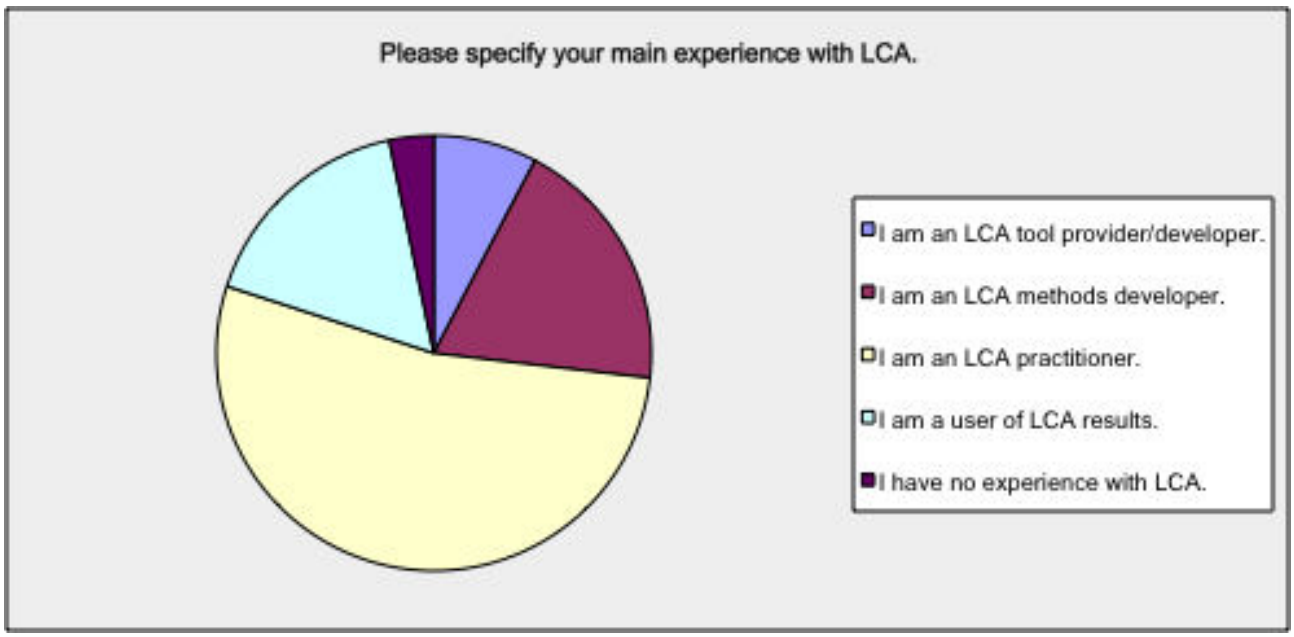


Figure 6.2. Main LCA experience of the 209 respondents.

Table 6.2. Main LCA experience of the 209 respondents.

Please specify your main experience with LCA.		
Answer Options	**Response Percent**	**Response Count**
I am an LCA tool provider/developer.	7.7%	16
I am an LCA methods developer.	19.1%	40
I am an LCA practitioner.	53.1%	111
I am a user of LCA results.	16.7%	35
I have no experience with LCA.	3.3%	7

From question 3 onwards, only 92 of the above 209 respondents continued to complete the review. The drop-out was complete for the two groups "I am a user of LCA results" and "I have no experience with LCA" while the remaining drop-out was evenly distributed over the other 3 groups.

6.1.3 Practical experience with monetarisation (Question 3/7)

As shown in Figure 6.3 and Table 6.3 only 13 (14%) of the 92 respondents to this question have *not* considered using monetarisation, and more than half (52%) have experience with practical application, 1/3 of the respondents in an LCA context.

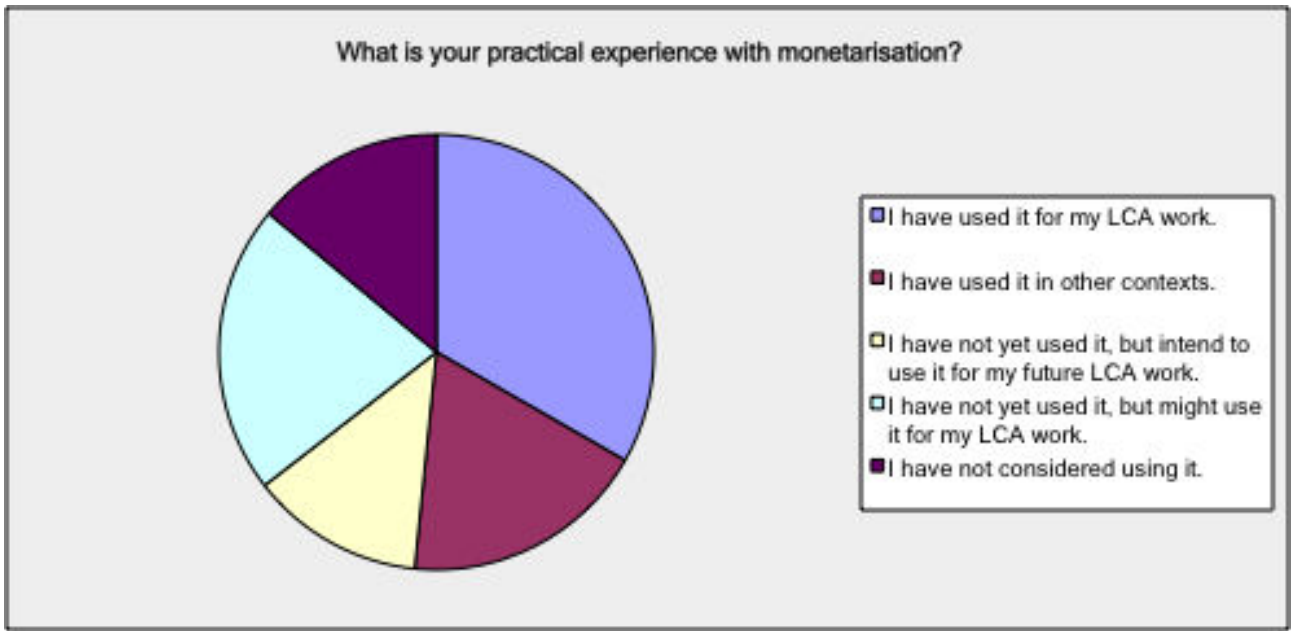


Figure 6.3. The practical experience with monetarisation of the 92 respondents that completed the surveys.

Table 6.3. The practical experience with monetarisation of the 92 respondents that completed the surveys.

What is your practical experience with monetarisation?		
Answer Options	**Response Percent**	**Response Count**
I have used it for my LCA work.	33.3%	31
I have used it in other contexts.	18.3%	17
I have not yet used it, but intend to use it for my future LCA work.	12.9%	12
I have not yet used it, but might use it for my LCA work.	21.5%	20
I have not considered using it.	14.0%	13

6.1.4 Types of monetarisation methods applied (Question 4/7)

The respondents were asked which monetarisation methods/approaches they have used. It was possible to select one or more pre-defined methods/approaches, as well as to indicate "Other(s) (Please specify)".

The 53 responses in the "Other(s)" category were:

a) indicating methods already listed OR unspecified OR all (13)
b) methods not normally regarded as monetarisation, e.g. LCC, MFCA, ecoefficiency (7)

c) providing more detailed comments on the methods already selected (6)
d) pointing out the error in the jumping behaviour of the survey design (27)

The unedited result is shown in Figure 6.4.

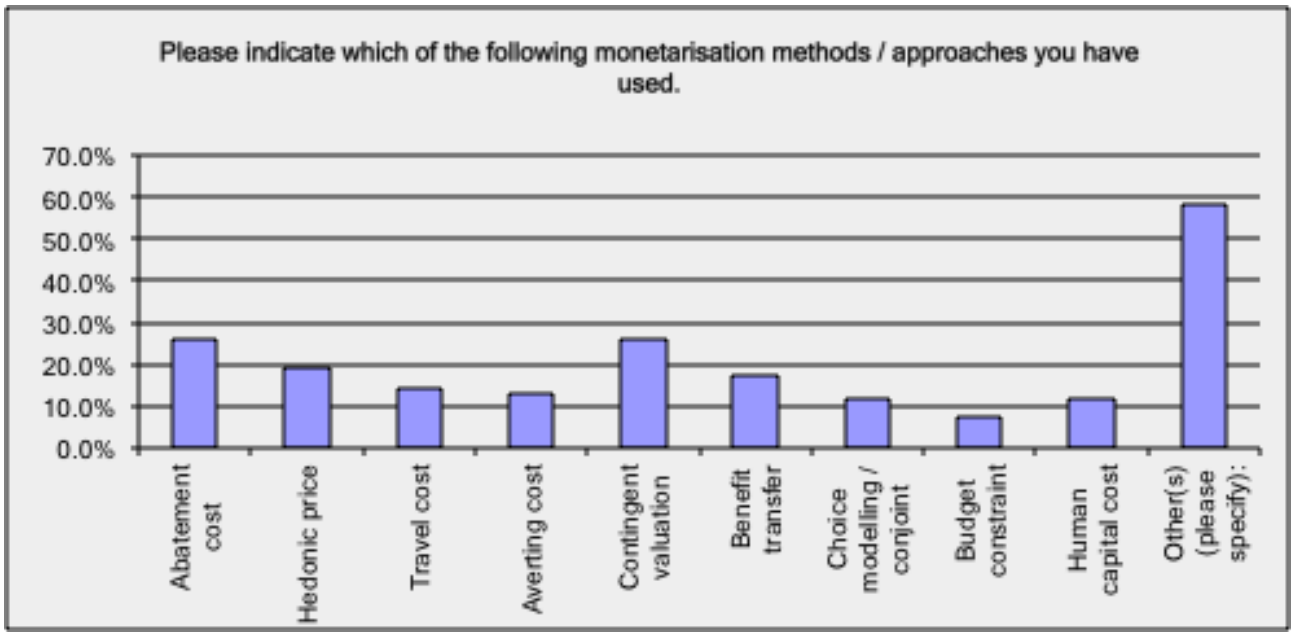


Figure 6.4. The monetarisation methods/approaches used by the 92 respondents that completed the surveys.

Removing the responses of type b), c) and d) from the "Other(s)" category, each respondent used on average 1.7 methods/approaches. Approximately 25% used abatement costs and 25% used contingent valuation.

It is interesting to note that, among those 31 respondents who answered "I have used it for my LCA work" in Question 2:

- on average, 2.4 methods/approaches were used per respondent,
- the spread was rather even, with only a 50% peak for Contingent Valuation and both Abatement Cost and Hedonic Pricing being high (39%), and
- also Travel Cost was used by 25% (7 respondents), which is surprising since we did not find any published LCA applications of this method, and generally have assessed this method as seldom relevant in an LCA context (see Chapter 5).

6.1.5 Details provided on the methods used (Question 5/7)

22 respondents provided more detail on their method (e.g. Abatement Cost methods, ExternE, LIME, Contingent Valuation, own methods, etc.). This information has been included in the literature review and the critical evaluation of the methods (Chapter 5).

6.2 Opinions and knowledge of monetary valuation for LCA practice

6.2.1 Arguments for and against monetarisation (Question 1/4)

The respondents were asked to indicate their agreement/disagreement with a number of arguments for using or not using monetarisation. The score was a 5-point scale

Table 6.3. The agreement/disagreement of the 92 respondents with some arguments for and against monetarisation. Answers that indicate a strong negative opinion on monetarisation has been highlighted in red and bold, while answers that are generally positive towards monetarisation has been highlighted in green and italics.

Please indicate your agreement / disagreement with the following arguments for using/not using monetarisation.						
Answer Options	**Agree**	**Mostly Agree**	**Neither Agree nor Disagree**	**Mostly Disagree**	**Disagree**	**Don't Know**
It is immoral to associate money prices with human beings or nature	**11%**	**8%**	14%	20%	41%	7%
Monetarisation assumes that all values can be traded off against each other	34%	30%	14%	9%	7%	6%
Monetarisation is too uncertain to be used in LCA	**17%**	**8%**	19%	26%	21%	9%
Monetarisation oversimplifies or misrepresents uncertainty	17%	26%	13%	16%	15%	13%
Monetarisation can include and compare all impacts relevant for decision-making	*8%*	*24%*	17%	17%	28%	5%
Monetarisation can be used to compare different types of impacts, although not all of them	*27%*	*38%*	10%	**10%**	**9%**	5%
Monetarisation generally is not sensitive to cultural differences	22%	15%	9%	20%	17%	16%
Monetarisation assumes that the utility of a person is as valuable as any other person's utility	12%	27%	21%	9%	10%	21%
Monetarisation gives more weight to rich people than to poor people	**9%**	**14%**	21%	12%	27%	17%
Monetarisation is the best way to account for people's values	*10%*	*14%*	27%	15%	29%	5%
Because of discounting, monetarisation does not appropriately take impacts on future generations into account	17%	19%	20%	*15%*	*19%*	10%
Monetarisation generally reflects the trade-offs people are actually willing to make	*17%*	*42%*	19%	3%	8%	10%
Monetarisation avoids dominating influences of specific stakeholders	*12%*	*23%*	20%	15%	14%	16%
Monetarisation helps deciding how to allocate resources most efficiently	*28%*	*31%*	12%	**12%**	**12%**	6%
Monetarisation is only relevant for decision-makers who focus on money only	**9%**	**19%**	9%	28%	33%	2%

(Agree; Mostly agree; Neither agree or disagree; Mostly disagree; Disagree) with an option also for selecting "Don't know". The questions were formulated without particular bias for or against monetarisation (a respondent with a favourable opinion towards monetarisation would have to answer both agree and disagree to different questions) and were presented in a random order to the respondents. The results are presented in Table 6.3.

A more detailed analysis was performed on the possible existence of any specific patterns in the answers (clusters of respondents, cf. Chapter 6.3). However, already from a superficial initial analysis it appears that there is both a (smaller) group with strong negative opinion on monetarisation and a (larger) group that is generally positive.

The strong negative opinion is demonstrated by 19% of the respondents agreeing or mostly agreeing that monetarisation is "immoral". We find a similar proportion of the respondents disagreeing or mostly disagreeing that "monetarisation can be used to compare different types of impacts" and "monetarisation helps deciding how to allocate resources most efficiently", and agreeing or mostly agreeing that monetarisation "is too uncertain to be used in LCA", "gives more weight to rich people than to poor people" and "is only relevant for decision-makers who focus on money only".

The generally positive opinion is demonstrated by the 41% that disagree that monetarisation is immoral. We find a similar proportion of the respondents agreeing or mostly agreeing that "monetarisation can be used to compare different types of impacts" (65%) and even "all impacts relevant for decision-making" (32%), and further agreeing or mostly agreeing that monetarisation "is the best way to account for peoples values" (24%), "avoids dominating influences of specific stakeholders" (35%), "generally reflects the trade-offs people are actually willing to make" (59%) and "helps deciding how to allocate resources most efficiently" (59%).

The questions do not distinguish between how monetarisation is practiced today and how it should/could be practiced (best practice). It is likely that an explanation of best practice would increase the positive answers.

In general there is a large spread in the answers, which points to the need for more education/information.

6.2.2 Monetarisation in relation to other methods to weight or compare different impacts (Question 2/4)

To assess the preference for monetarisation relative to other methods to weight or compare impacts, the respondents were asked to express their preferences in pairwise comparisons of these methods. The 3 pairwise comparisons, each with a Yes/No preference option, give a total of 8 possible preference orders. Seven of these are represented in Figure 6.5, in that there were no respondents that preferred Distance-to-target (DTT) to all other methods.

How do you evaluate monetarisation relative to alternative methods to weight or compare different impacts, when a trade-off is required?
Distance-to-target (DTT) methods are preferable to monetarisation (Yes/No)
Panel methods are preferable to monetarisation (Yes/No)
Multiple Criteria Decision Analysis (MCDA) is preferable to monetarisation (Yes/No)
If you answered "yes" to any of the above statements, please justify (free text)

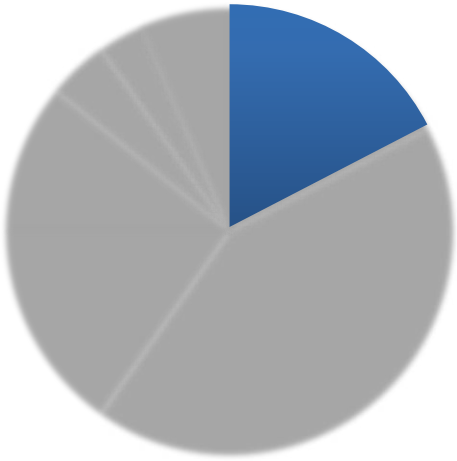


Figure 6.5. Monetarisation evaluated by the 92 respondents relative to other methods for weighting or comparing impacts.

The answers to this question confirm that the survey's respondents are composed of a larger group that has a very positive opinion on monetarisation (42%), and another rather large – although smaller – group (18%) that is strongly opposed to monetarisation.

There is also a rather large group (15%) that prefers Multi-Criteria Decision Analysis (MCDA). From the free comments that respondents were allowed to make to this question, we can see that this group regards MCDA as a procedural process that is preferable because it involves stakeholders and can be informed by monetarisation. Some say that in a business environment, the socially optimal solutions should not always be sought.

Other arguments given for alternatives to monetarisation are:

- They do not aggregate to one number and thus show that it is very different issues that are being compared and does not make things look simpler than they are;
- Distance-to-Target is seen by one respondent as representing urgency for action;
- Monetarisation is seen by one respondent as incomplete (i.e. not covering all impact categories).

6.2.3 Knowledge about monetarisation methods (Question 3/4)

The respondents were asked about the monetarisation methods that they have heard about. Only 88 respondents replied to this question, i.e. 4 respondents jumped this question. The answers, shown in Figure 6.6, confirm that the most used methods (Contingent Valuation and Abatement Costs, cf. Figure 6.4) are also the best known.

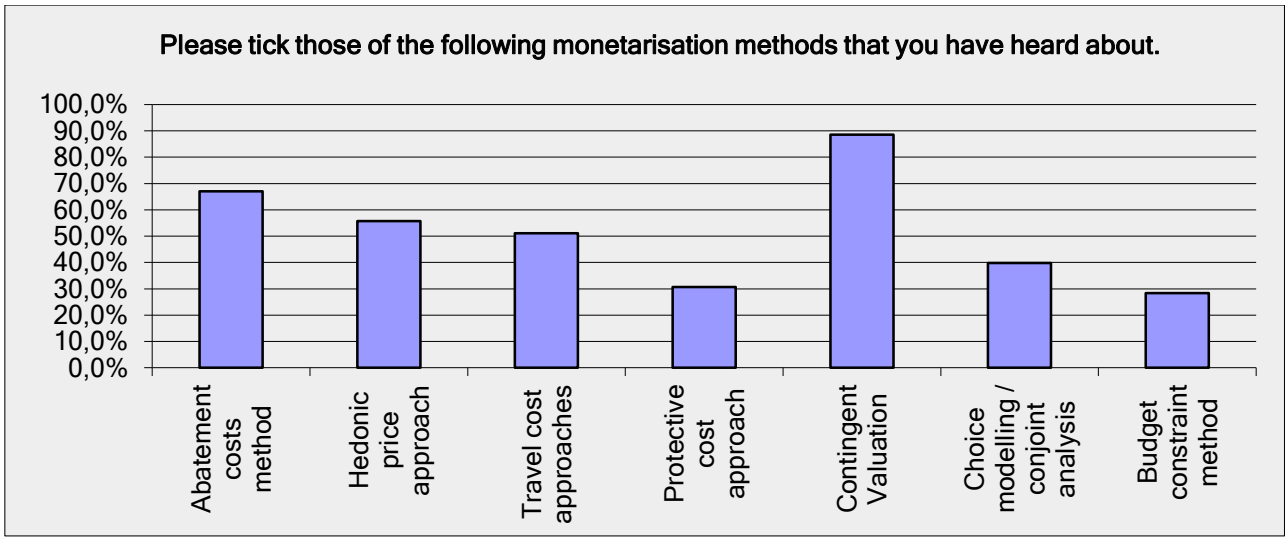


Figure 6.6. Knowledge of monetarisation methods by 88 respondents that answered this question.

6.2.4 Free-text comments to Questions 2 and 3

For both questions 2 and 3, respondents were encouraged to provide more detail in the form of free text. We highlight some of these free-text comments here:

Some comments were on specific methods:

- Abatement cost was seen by some respondents as most easy to understand and often seen as more objective and therefore easier to communicate and more acceptable;
- Abatement cost is seen by some respondents as logically flawed (not valuing impacts and not expressing Willingness-To-Pay)
- The LIME conjoint analysis was criticised for bias in sampling in cities, gender bias and age bias.
- One respondent wrote: "I don't think we can trust any method based on 'willingness to' or interviews of stakeholders. One thing is what we say and a very different one what we do."

Other comments were on monetary valuation in general:

- Some respondents reject the idea of socially-optimal decisions in itself and regard self-interest as legitimate:
    - "Preparing an environmental assessment of impact is an independent activity that should not be altered, perverted or modified by financial pressures. The decision to follow or reject an assessment is a legitimate business decision and should be made in consideration of regional

economic realities. Not all pathways that show life cycle benefits should be followed";
    - "using monetization usually means to use an average structure of preferences that sometimes can be different from those of the involved stakeholders";
    - "giving weight to social and environmental impacts is very much dependent on the geographical location, the scenario where the study is being taken and the company´s views on social and environmental impacts. Therefore, the monetarisation could pass an impact result that is not truly representative of the product."
- Some respondents reject neo-classical economics as a basis:
    - "Our current economic structures are one of the main reasons that we have so many environmental problems, i.e. the failure of economic systems to protect the natural environment. By tacking moneterisation onto the Impact Assessment phase of LCA, we merely support "more of the same" in decision-making.";
    - "Most of these methods are bad science based on false assumptions trying to constrain natural systems to behave like relationships between humans are supposed to be, by using the narrow approach of neo-classical economics."
- Monetarisation may also be too anthropocentric for a valuation of nature:
    - "People are more willing to pay to look after themselves than the environment"
- Monetarisation may be incomplete:
    - "Monetisation oftentimes focuses on a small range of impacts only, increasing the risk of burden shifting."
- Uncertainty in and across monetary valuation methods is also a concern:
    - "The dependence of the results on the way in which questions are asked, who is asked, and variations in peoples' perceptions of monetary value over time, means that any results are likely to be useless for supporting decision-making."
- Some respondents warn that monetarisation may appear more objective than it is:
    - "The main problem with monetisation is that the flaws are less apparent than with the other (methods)";
    - "monetarisation that try to simplify LCA results and interpretation by putting all parameters on one scale are a disservice to decision-makers. Complicated decisions require consideration of the complicated details";
    - "Decision makers also need to gain a better systems understanding, so the complexity of the topic requires approaches that reflect it".

6.2.5 The importance of different criteria for evaluating monetarisation methods (Question 4/4)

Finally, the respondents were asked to distribute 100 points among the 7 main criteria from Chapter 2. The result is shown in Figure 6.7. This confirms the dominating importance of two concerns: On the one hand the scientific soundness (foundation,

documentation, reproducibility) of the methods and on the other hand the applicability and acceptance in the specific context.

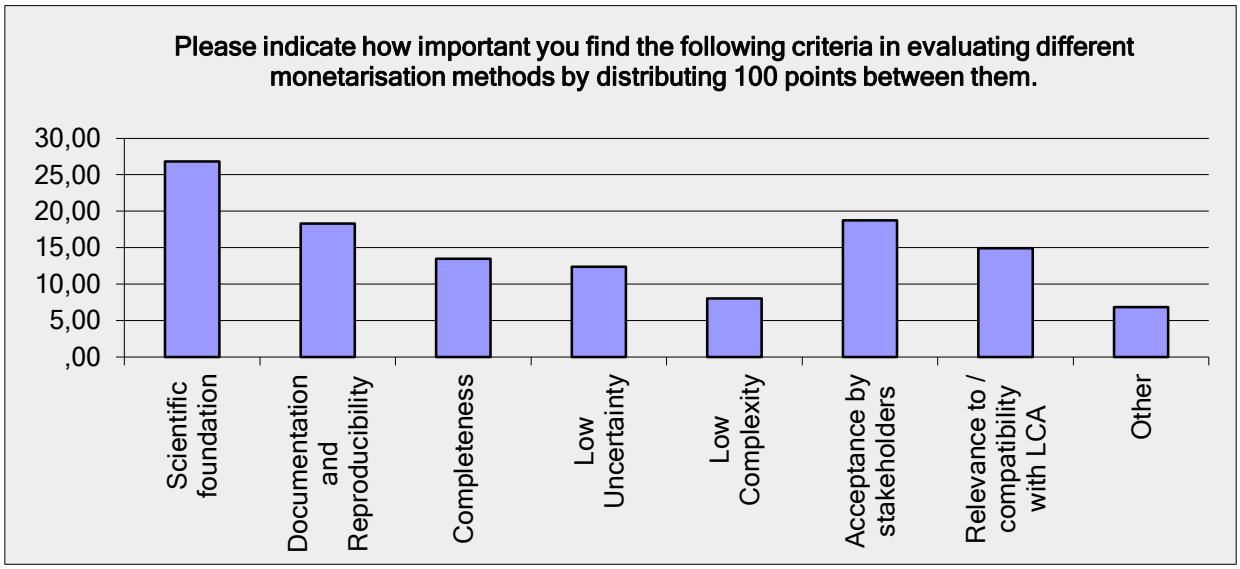


Figure 6.7. Relative importance of different criteria for evaluating monetarisation methods, as assigned by the 92 respondents that completed the survey.

6.3 Cluster analysis

The results from the web-facilitated surveys were further analysed using partition clustering, in which the clusters are grouped with respect to their Euclidean distance. This is also known as k-means clustering and aims to partition observations into clusters by assigning them to the cluster with the nearest mean, and hence minimise the within-cluster sum of squares (squared Euclidean distance).

The analysis was performed on the 92 respondents who completed the entire survey. First, the responses for all questions that could be analysed numerically were normalised, so that each question received the same weight. A first cluster analysis was performed across all questions, but did not yield any clearly distinguishable groups. The analysis was then limited to the responses to questions 1, 3 and 4 of the second survey. The first question asked the respondents' level of agreement or disagreement with 15 arguments for and against monetarisation (see Section 6.2.1), the third question compared monetarisation to other methods to weigh or cross-compare impacts (see Section 6.2.2), while the fourth question asked respondents to attribute 100 points between different criteria in evaluating monetarisation methods (see Section 6.2.5).

Although in general there were no strong agreements or strong disagreements with any argument, the cluster analysis identified a larger group of respondents (63% or 57 respondents in Cluster A) that is generally positive towards monetarisation and a smaller group (38% or 35 respondents in Cluster B) that is generally not in favour of monetarisation. Figures 6.8 to 6.10 shows the centre of the clusters A and B for each of the three questions.

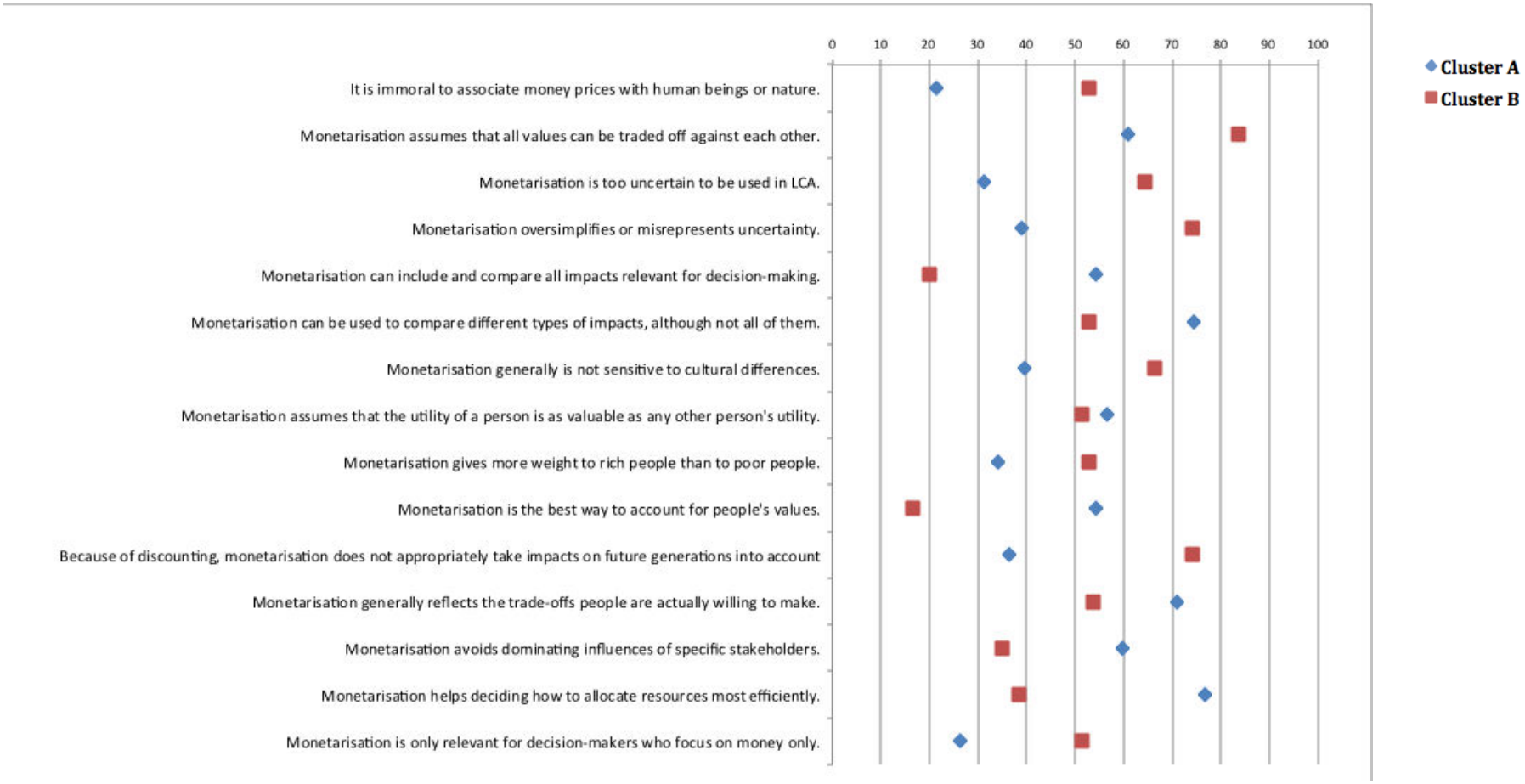


Figure 6.8. Position of the centre of each cluster to each statement of question 1: "Please indicate your agreement / disagreement with the following arguments for using/not using monetarisation." The x-axis represents agreement with the statements, from strong disagreement (0) to strong agreement (100).

In Figure 6.8 it can be seen that the divergence of opinions between the two clusters is particularly large for the following statements of the first question:

- Monetarisation helps deciding how to allocate resources most efficiently (A agrees; B disagrees)
- Monetarisation is the best way to account for people's values (A neither agrees nor disagrees; B disagrees)
- Because of discounting, monetarisation does not appropriately take impacts on future generations into account (A disagrees; B agrees)
- Monetarisation oversimplifies or misrepresents uncertainty (A disagrees; B agrees)
- Monetarisation can include and compare all impacts relevant for decision-making (A neither agrees nor disagrees; B strongly disagrees)
- Monetarisation is too uncertain to be used in LCA (A disagrees; B agrees)
- It is immoral to associate money prices with human beings or nature (A disagrees; B neither agrees nor disagrees)

Less significant differences can be found in the importance they attribute to the remaining statements.

For the third question, where monetarisation is compared to other methods to weigh or cross-compare impacts (see Section 3.2.2), the only clear difference between the two clusters is that Cluster A almost always prefers monetarisation, while cluster B does not (see Figure 6.9).

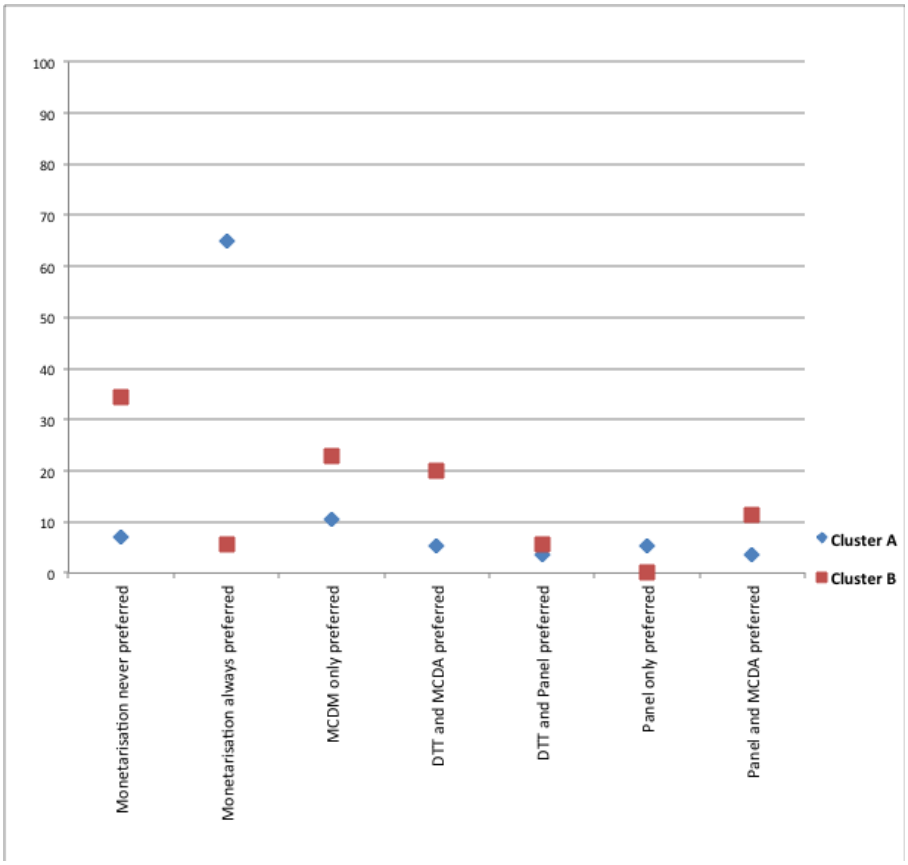


Figure 6.9 Position of the centre of each cluster in the preferences from question 3. The y-axis represents preferences for methods to weigh or compare different impacts, from preference (100) to no preference (0).

For question 4, there was no significant difference in the importance the respondents attribute to the different criteria for assessing monetarisation methods (see Figure 6.10).

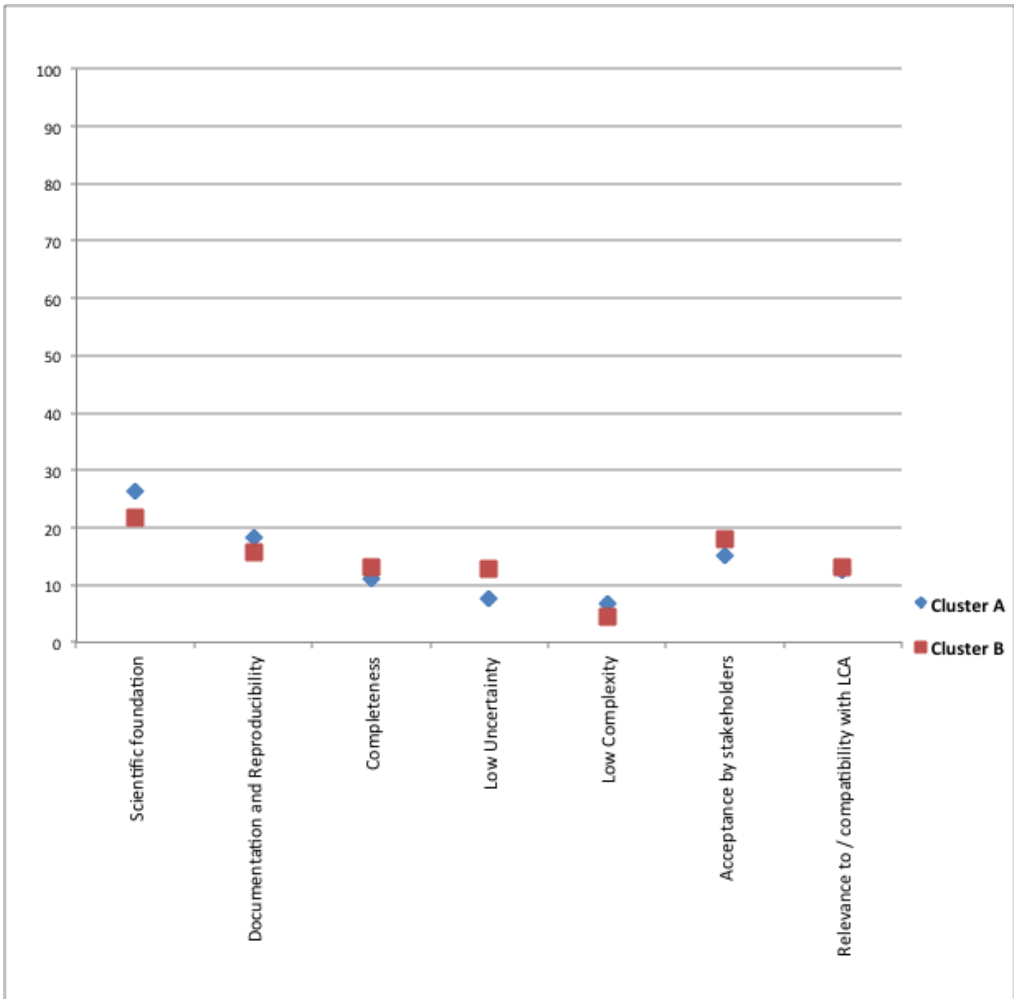
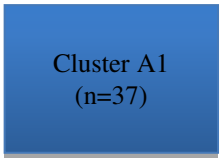


Figure 6.10 Position of the centre of each cluster regarding the importance of the different criteria in assessing monetarisation methods from question 5. The y-axis represents points out of a total of 100 distributed over the different criteria in the x axis.

Subsequently, a further disaggregation of the two clusters was attempted. Disaggregating Cluster B did not yield clear patterns, but disaggregation of Cluster A highlighted an interesting difference between the two sub-clusters (A1 and A2, of 20 and 37 respondents, respectively). Thus overall, three clearly separate clusters were identified. Clusters A1, A2 and B are composed of 37, 20 and 35 respondents, respectively. Figure 6.11 gives an overview of the three clusters identified.


Cluster A1
(n=37)

For the other two questions (1 and 4), no significant differences were found between the sub-clusters.

6.4 Conclusions and reflections from the surveys

Generally, the results of the surveys show that there is a large interest in, and support for, monetary valuation. However, there are also many legitimate objections to monetary valuation: some fundamental (to the idea of social efficiency) and some in terms of how it is practiced. The latter type of objections criticizes bad practice in monetary valuation, but is not necessarily fundamentally opposed to it.

Furthermore, it is generally recognized that stakeholder involvement and acceptance is important, e.g. through MCDA and other participatory procedures. This is not in conflict with monetary valuation *per se*, which can inform these procedures.

Regarding the knowledge and use of the different monetary valuation methods, some modern and new approaches to monetary valuation (e.g. conjoint analysis and the budget constraint method) are still not well known among the LCA practitioners.

In conclusion:

- It appears important to improve the practice of monetary valuation in order to address the different points of criticism, and especially to improve the transparency and the way in which monetary valuation is introduced into the decision-making process.
- There is a need for education and information to correct some misunderstandings about what monetary valuation is and does, and to elucidate its strengths and weaknesses in relation to decision making.

7 GOOD PRACTICE RECOMMENDATIONS, EXAMPLE AND EDUCATION NEEDS

7.1 Good practice recommendations

For practical application of monetary valuation in LCA, the decision tree on the following pages is suggested. The decision tree takes into account both the scientific and procedural aspects identified as important in the surveys and in the literature review. Each point in the decision tree is described in more detail in the following sub-sections.

7.1.1 Is there a trade-off?

If all impact categories show a lower impact of one alternative compared to the other alternatives, monetary valuation of the impacts is unnecessary, as is indeed any weighting method. If there is no trade-off to be made, monetarisation has no relevance, and the monetarisation exercise can be discontinued.

7.1.2 Stakeholder involvement in valuation?

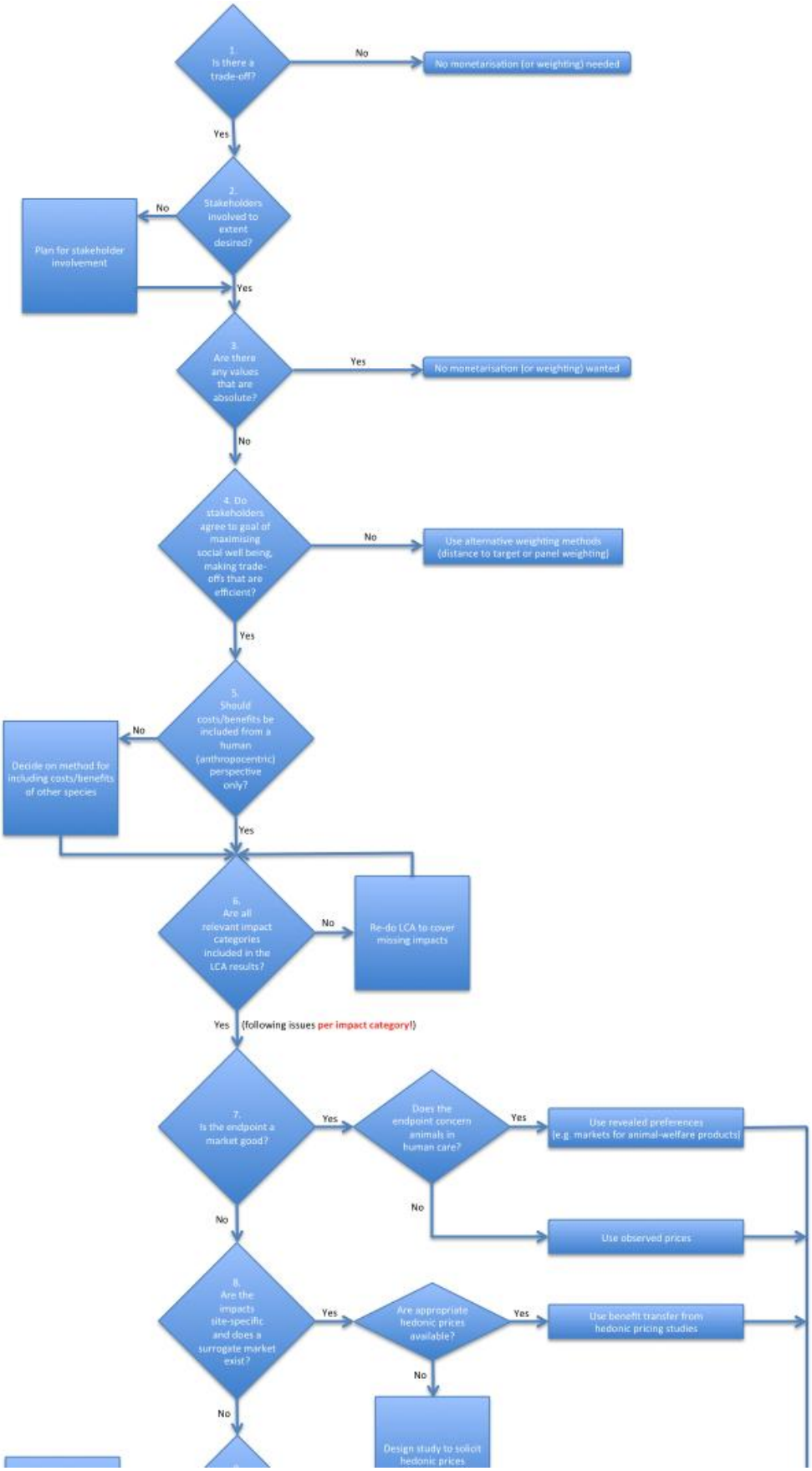
The decision maker (the commissioner of the LCA study) must decide on what stakeholders to involve in the valuation, and to what extent they should be involved. It is important to state a clear objective for the stakeholder involvement: Is it to establish a dialogue, i.e. a true learning experience? Is it to empower the stakeholders to assist in the valuation or the later decision? Is it to prevent future problems in acceptance of the result and its implementation? The objective determines which stakeholder groups are relevant to include and what degree of involvement is required in the following steps.

7.1.3 Absolute values?

Attaching a monetary value to human life or biodiversity may raise ethical questions. Some objections to monetary valuation stem from a position that regards some values as absolute.

From one perspective, this is not in conflict with monetary valuation, since monetary valuation is not concerned with absolute values: For example, monetary valuation can be used to estimate how much individuals are willing to pay to protect one additional plant species from extinction, whereas the absolute economic value of this species in itself is meaningless in the context of monetary valuation, as each species is in principle irreplaceable. In the same way, monetary valuation does not seek to provide a measure of the *absolute* value of human life, but rather the *marginal* value that individuals are willing to pay for a small change in life expectancy or life quality. Monetary valuation recognizes that individuals – in everyday life – do value the changes in availability of non-market goods. It models this valuation in economic terms, to render it more explicit. Thus, monetary valuation supports informed decision-making and can be used to correct market failures.

But from another perspective, the fact that monetary valuation is not concerned with absolute values can be seen as a problem: If the decision maker and/or stakeholders regard the value of some goods as absolute (so-called lexicographic preferences), there can be no trade-off and the only option is to place a constraint on the analysed systems to avoid the impact on these goods at any cost, which makes monetary valuation of the impact – and any other form of weighting – irrelevant.


1. Is there a trade-off?
No
No monetarisation (or weighting) needed
Yes
2. Stakeholders involved to extent desired?
No
Plan for stakeholder involvement
Yes
3. Are there any values that are absolute?
Yes
No monetarisation (or weighting) wanted
No
4. Do stakeholders agree to goal of maximising social well being, making trade-offs that are efficient?
No
Use alternative weighting methods (distance to target or panel weighting)
Yes
5. Should costs/benefits be included from a human (anthropocentric) perspective only?
No
Decide on method for including costs/benefits of other species
Yes
6. Are all relevant impact categories included in the LCA results?
No
Re-do LCA to cover missing impacts
Yes
(following issues per impact category!)
7. Is the endpoint a market good?
Yes
Does the endpoint concern animals in human care?
Yes
Use revealed preferences (e.g. markets for animal-welfare products)
No
Use observed prices
No
8. Are the impacts site-specific and does a surrogate market exist?
Yes
Are appropriate hedonic prices available?
Yes
Use benefit transfer from hedonic pricing studies
No
Design study to solicit hedonic prices
No

continues…

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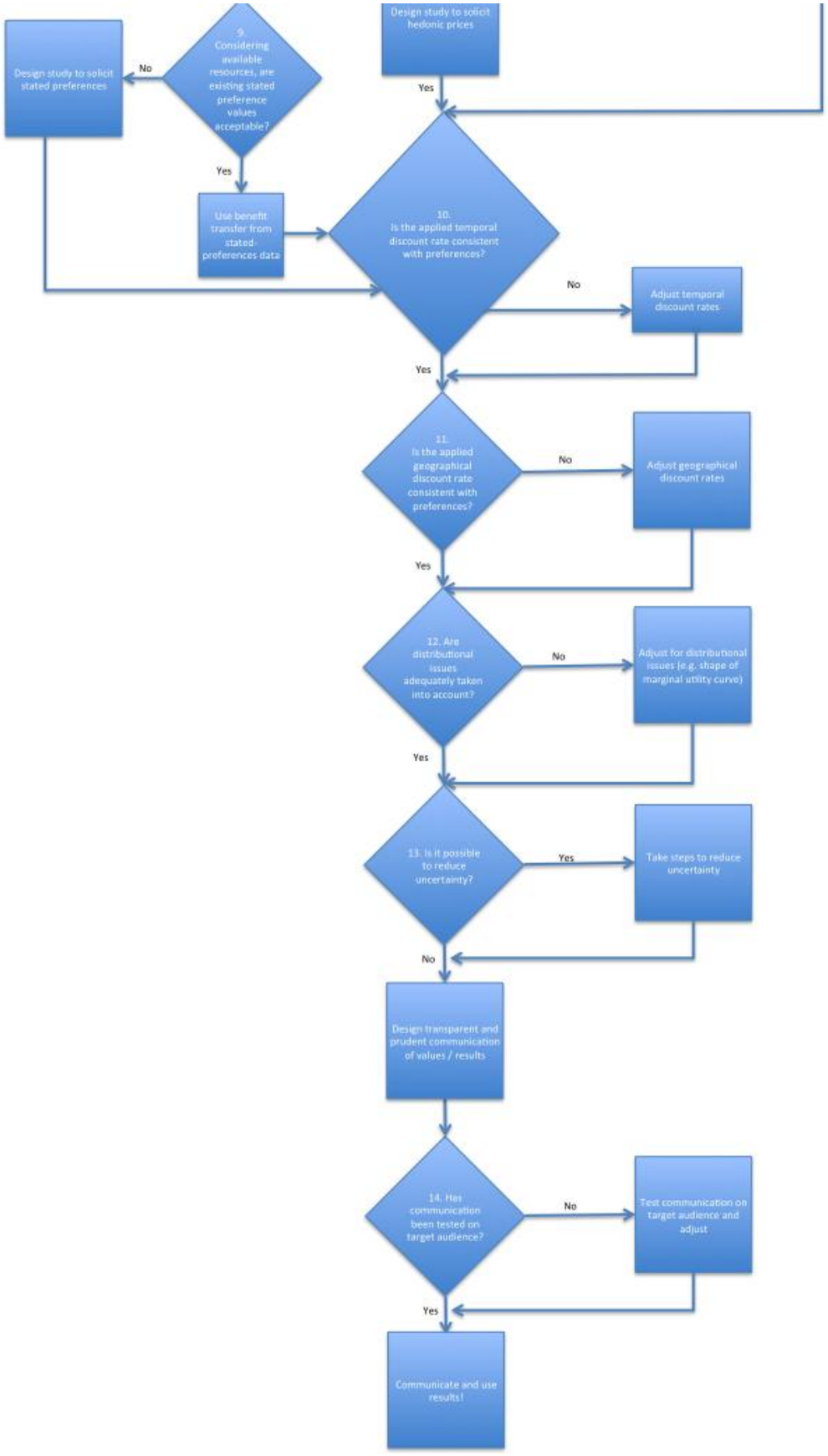

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7.1.4 Agreement to the goal of maximising social wellbeing

Monetary valuation rests on the premise that the preferences (willingness to pay) of individuals can be used to determine economic efficient trade-offs and thereby maximise social wellbeing. The alternative approaches for weighting of impact categories in LCA also rely on the expression of preferences, but these preferences are not those of the general public, but rather of specific individuals (panels of experts or laymen, or politicians) that are implicitly assumed to better represent the interests of the decision makers and/or stakeholders. So-called "panel methods", or more generally Multi-Criteria-Decision-Making methods, essentially determine weights that express the importance of a damage, which can be seen as a non-monetary parallel to the importance expressed by the prices in monetary valuation. In contrast, Distance-To-Target methods (methods that weight impacts by the ratio of the current level of each impact and a target level for the same impact) do not give importance to the damage itself (since the target does not necessarily express the importance of the damage), but only to the distance to the target level: The larger the distance, the more important an impact is. Distance-to-target methods can therefore be seen as an expression of a rule-based ethic, while monetary valuation is based on utilitarian ethics.

7.1.5 Is an anthropocentric assessment acceptable?

That monetary valuation is too anthropocentric for a valuation of nature is a well-known critique (Yu & Lei 2009), which is also voiced in the surveys reported in Chapter 6. The classical counter-argument is the circular reasoning argument: That any solicitation of values must necessarily be human, and thus only human beings can assign value to nature. Another argument is that an anthropocentric position is not necessarily connected to a low valuation of nature; nature does have high value for humans, both use value (today often referred to as ecosystem services) and non-use values (existence value and bequest value).

If desired, it is possible to directly include costs and benefits for other species, by introducing a currency of conversion, e.g. a species discount rate based on brain size. However, since any such discount rate would have to be decided by human beings, this would not be able to escape the circular reasoning problem.

In practice, it appears very difficult to design a truly non-anthropocentric valuation scheme, but that does not make it unimportant to raise the issue and seriously contemplate its relevance when deciding on the design of a monetary valuation methodology. Regarding animals in human care, there is a more direct responsibility for their individual wellbeing, leading to a concern that is already directly or indirectly observable in markets for products labelled for improved animal welfare during production, see Section 7.1.7.

7.1.6 Extent and completeness of impact categories

LCA has historically focussed on biophysical impact pathways, starting from physical inputs of natural resources and emissions, through to impacts on human health and biological diversity. More recently social impacts (on human wellbeing and cultural heritage) and impacts on human and man-made resources have been included in LCAs (either in separate social or socio-economic LCAs or in complete Life Cycle Sustainability Assessments that also include Life Cycle Costing). It has also recently been made explicit that economic externalities (e.g. the free provision of infrastructure,

education, accident and health services, that are already paid for, but where this direct economic relationship does not match the physical, causal relationship, so that the person paying and the person benefitting is not the same), are in most cases already internalised in the Life Cycle Inventory as intermediate inputs to the activities that receive the free good (Weidema et al. 2013). If any biophysical, social or resource impact categories are left out of an LCA or an LCIA method, it is important to justify this and make it explicit. The lists in Annex 1 can be used for this purpose.

7.1.7 If the endpoint is a market good

The next step is to decide on the appropriate economic valuation method for each impact category, see also Annex 1. If the endpoint (the good to be valued) is a market good (resource or manufactured product) where only the current or future use value is of interest, it is possible to use directly observed market prices. This is preferable because the market price is a direct and actual expression of preferences, and therefore avoids the uncertainty related to more indirect measurement. However, also observed market prices may be uncertain and may need to be adjusted for any influence from externalities, geographical differences and short-term fluctuations. The market price for human resources is the gross wages. The market price for natural resources is the rent paid for the right to exploit the resource. Sometimes it is the difference in prices that is of interest. For example, the difference in market prices for products labelled for improved animal welfare may provide directly observable prices for specific aspects of animal welfare, although it may be necessary to use regression analysis as in the hedonic pricing method to derive meaningful values for the overall willingness to pay for animal welfare.

7.1.8 Site-specific impacts with surrogate markets

As with direct observable markets, observing preferences on surrogate markets is preferable to more indirect measurement, when the conditions for an unbiased observation are fulfilled. This requires that the impact to be valued is very site-specific, directly observable, only involves use values, and that an appropriate surrogate market exists, where it can be reasonably assumed that the actors have full information about the variable to be valued. The hedonic pricing method is recommended for valuing nuisances from odour, noise, traffic, crime, and psychological and ergonomic stress. Values from existing studies can be transferred when the similarity in site characteristics, markets and affected population is high, or when there is adequate information on the underlying variables to adjust the transferred values accordingly. This of course involves considerable uncertainty (Navrud & Bergland 2001) and therefore requires that this uncertainty does not exceed the level required for an unambiguous comparison between the investigated alternatives of the LCA. When this requirement is not fulfilled, a specific hedonic pricing study must be performed to obtain the values with adequate precision.

7.1.9 Stated preferences

When neither observed nor revealed preference values are obtainable, the stated preference approach (using hypothetical markets) is the only possible alternative. Again, values from existing studies can be transferred when the similarity requirement is fulfilled, or when there is information available to adequately adjust the transferred values without this leading to unacceptable uncertainty levels.

To ensure consistency between the monetary valuation of the large number of elementary exchanges and impact categories in LCA, it is preferable to perform the valuation as far along the impact pathway as possible. Case- and site-specific issues can still be included in the characterisation factors of the impact pathway leading up to the endpoints. If preferences are elicited early in the impact pathway, additional effort is required to ensure consistency in methods and assumptions.

The value for human wellbeing from the budget constraint method can be used as an anchor to improve the accuracy of comparisons involving both human wellbeing and other endpoint values obtained by conjoint analysis.

In general, conjoint analysis is the recommended method to obtain stated preferences, due to the complex nature of the impacts and goods to be valued. A good questionnaire design and administration is important to adequately remove cognitive stress and potential biases in the population and its responses, as well as adequately taking into account the budget constraint. Pearce et al. (2002) provide a good guideline for applying the conjoint analysis method, but see also Section 7.1.13.

7.1.10 Temporal discounting

When calculating the net present value of private investments and their future returns, it is relatively uncontroversial that the future costs and returns should be discounted at the rate determined by the opportunity cost, i.e. the rate of return from the alternative marginal investment. Although higher values are often found in the literature, a sober assessment will estimate this at 2-3% annually, since the rate of return on marginal investment is lower than that on average investment (since the most profitable investments are made first) and the rate of return on marginal investment cannot in the long term be higher than the growth rate of the economy (Rabl 1996).

Also for the social discount rate, to be used for assessing future costs and benefits of societal investments and especially those affecting future generations, there appears to be increasing consensus and both empirical and theoretical justification for a positive social discount rate that decreases over time (Groom et al. 2005) in the form of:

- empirical evidence of individual time preferences,
- theoretical analyses of the consequences of assuming different discount rates under different scenarios of growth (affecting both the marginal utility of consumption and the ability and willingness to pay to avoid or compensate impacts), and
- the uncertainty of the growth rate, which itself leads to decreasing discount rates over time (see e.g. Philibert 2003).

One of the most recent theory-consistent, empirically based calculations of the average social discount rate is that of Gollier et al. (2008), where the initial discount rate decreases from an initial value between 3.5 and 4.2% to 2% at 150 years and 1.6% at 400 years.

A complication for applying discounting to LCA results is the lack of tradition for specifying the timing of the impacts. However, for some impact categories, like Global Warming, there are underlying models that do specify the timing of impacts relative to the time of emissions, which imply that discounting can be applied. Alternatively, rough

estimates must be made of the minimum and maximum duration of each step in the impact pathway.

7.1.11 Geographical discounting

It has been a widespread practice in Cost Benefit Analyses of national policies to look in isolation on impacts within a specific country and ignore impacts abroad, i.e. no discounting within the national boundaries, and full discounting abroad, with the argument that it is the national governments that are responsible for impacts within their own territory. In contrast, LCA has in general had a more global perspective, where impacts have been given the same weight irrespective of the geographical location. This does not exclude the use of geographically-dependent characterisation factors, based on differences in exposure pathways and sensitivity of the receiving environments. The more global perspective of LCA is better aligned with the concern for equality that is implicit to sustainable development.

7.1.12 Distributional issues

Even when giving equal weight to the same safeguard subject across geographies, there is still a question of whether this equality is seen as an equality in voice (equal right and means to voice an opinion), in preference weight (each person's preferences weighing equally), in utility (same value of a QALY for all persons), and/or in marginal utility (constant marginal utility across incomes). The latter would disregard distributional issues and would be at odds with empirical data that shows decreasing marginal utility with increasing income.

Analysing distributional issues related to impacts faces some of the same problems as temporal discounting, namely that LCA results are typically not specifying which societal groups are affected. In general, it is assumed that pollution affects the disadvantaged more due to the location and nature of their homes, their diet, their work, and prior susceptibility, but empirical evidence is inconclusive (Pearce 2003).

Note that the elasticity of the marginal utility (the percentage reduction in marginal utility when consumption is increased by 1%) also acts as a multiplier on the social discount rate, so that an empirically founded elasticity of marginal utility of 1.4 (Evans 2005) applied to a purely growth-based discount rate of 3% would lead to a social discount rate of 1.4*3% = 4.2%. This implies an increased emphasis on impacts on the current, poor population and a decreased emphasis on future impacts.

7.1.13 Reducing uncertainty

When data from monetary valuations are applied in a new context, the uncertainty added by the transfer can be reduced by adjusting the transferred values using the available information on the underlying variables in the original study and in the new application context (Navrud & Bergland 2001).

When performing new monetary valuation studies, it is particularly important to select carefully the relevant population from which or for which values are to be elicited, to decide on the relevant sample size, to design an unbiased sampling strategy including adequate measures for handling non-response, to carefully design and test any questionnaires or experiments as well as individual questions to reduce cognitive stress and ambiguity in interpretation, and to consider how to avoid any bias in the way

questionnaires or experiments are administered; see also Biemer & Lyberg (2003) and Lehtonen & Pahkinen (2003).

7.1.14 Transparent, prudent and tested communication

Clarity and transparency are essential aspects of successful communication. Transparency includes making available the underlying data before monetary valuation, as well as any data sources used for the monetary valuation. It is important to be aware of and seek to bridge any credibility gaps between the sender of the information and the intended audience.

Considering that monetary valuation is still a controversial issue, it is important to be prudent in the communication: to clearly state any limitations and reservations to the methods and results, trying to avoid making them look more objective than they are.

Even if stakeholders have not been involved in the previous steps (see Section 7.1.2), it is relevant to consider how different stakeholders should be addressed when communicating monetary valuation results, in order to anticipate and counteract any prejudice or other barriers to an effective communication. Testing the communication on a small sample of the intended audience is a useful technique to discover any such concerns. It is important to have a prior strategy on how to react to responses and concerns of the different stakeholders.

7.2 Example of the use of monetarisation in LCIA

The following example shows how the good practice recommendations from Chapter 7.1 are applied to a case of trade-off between emissions of nitrogen oxides (NOx) and emissions of soot (particulates). This trade-off is a well-known issue in diesel combustion engines (Heywood 1988) and is chosen for its relative simplicity.

The starting point is an LCI result of 1 Mg (tonnes) of NOx emission versus 0.2 Mg of particulate emission[7]. The location of the emissions is unspecified.

7.2.1 Is there a trade-off?

The emission of NOx is the starting point for many different impact pathways:

- NOx is a precursor for secondary particulate matter which causes heart and lung diseases when inhaled (midpoint impact category: Respiratory inorganics)
- NOx is an acidifying substance that contributes to the acidification of soil and water bodies (midpoint impact category: Acidification) and corrosion of man-made structures, especially buildings (midpoint impact category: Corrosion).
- As a nitrogen-containing compound, NOx contributes to aquatic and terrestrial nutrification, which is undesired impact in natural terrestrial areas (midpoint impact category: Eutrophication, terrestrial) and in water bodies (midpoint impact category: Eutrophication, aquatic), and desired impact on agricultural land (midpoint impact category: Fertiliser effect).

[7] The relative size of the emissions has been chosen to make an interesting case for a trade-off. In reality, the relative size of the particulate emission is likely in most cases to be lower.

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- NOx is a precursor for ozone formation. Ozone has impacts on human health (midpoint impact category: Respiratory organics), natural vegetation (midpoint impact category: Photochemical ozone, vegetation), and on crops (midpoint impact category: Photochemical ozone, crops).

The emission of particulates contributes only to the midpoint impact category Respiratory inorganics.

The impact pathways from emission to midpoint impact categories are covered by different fate, exposure and effect models. No monetary valuation is done in this step. So at the midpoint level we have data (for average European conditions) expressed in different units. Table 7.1 shows these characterised midpoint values.

From Table 7.1, it can be seen that there is indeed a trade-off, since the characterised results for Respiratory inorganics and Corrosion and soiling are higher[8] for the particulate emission than for the NOx, but lower (in fact, zero) for the other impact categories.

Impact category	Unit of characterised result	1 Mg NOx emission	0.2 Mg particulate emission
Respiratory inorganics	PM2.5-equivalents	127	200
Acidification	m^2 unprotected ecosystem	6400	0
Corrosion and soiling	kg Zn-equivalents	0.93	0.97
Eutrophication, terrestrial	m^2 unprotected ecosystem	33000	0
Eutrophication, aquatic	kg NO_3-equivalents	70	0
Fertiliser effect	kg N	143	0
Respiratory organics	person*ppm*hours	110	0
Photochemical ozone, vegetation/crops	m^2*ppm*hours	1600000	0

Table 7.1 Characterised impacts of the two alternatives. Mid-point characterisation models from Hauschild & Potting (2005), except for Respiratory inorganics (Jolliet et al. 2003), Corrosion and soiling (inferred from Rabl 1999, Watkiss et al. 2001, Krewitt et al. 2001), and Fertiliser effect (calculated from 12/32 mol N per mol NO_2 and 38% of emissions deposited on agricultural soil).

7.2.2 Stakeholder involvement in valuation?

For the purpose of this example, we do not involve stakeholders.

7.2.3 Absolute values?

The two alternatives (NOx emission and particulate emission) affect human health to different extent. Particulates do not – at least with the current LCIA characterisation models – affect ecosystem health. If ecosystems were seen as having absolute (lexicographic) value, this would mean that it would be immediately possible to prefer particulate emissions, even disregarding the size of the two emissions.

It is less obvious what would be the recommended action if human health were seen as having absolute value, since this either would require taking one more step in the impact assessment to express the overall health impact of the alternatives in a common unit, or it would indicate that neither alternative is acceptable, i.e. that diesel combustion should be avoided altogether, but since this would also be likely to lead to human health impacts, this would require an expansion of the analysis.

[8] The values are averages for Europe, provided without uncertainty. In a real study, the uncertainty on the characterised values should of course be included.

For the purpose of this example, we assume that there are no values that are absolute, so that a trade-off is accepted.

7.2.4 Agreement to the goal of maximising social wellbeing

For the purpose of this example, we assume that the principles of monetary valuation are accepted, i.e. that social wellbeing can and should be maximised by determining economic efficient trade-offs based on the preferences (willingness to pay) expressed by individuals.

7.2.5 Is an anthropocentric assessment acceptable?

For the purpose of this example, we assume that the value of nature can be adequately included through the preferences expressed by humans.

7.2.6 Extent and completeness of impact categories

The example involves a simple technical change, with purely biophysical impacts. We assume that the traditional LCA impact categories of Table 7.1 provide a sufficiently complete description of the relevant impacts.

7.2.7 Endpoints that are market goods

The endpoint of the impact category *Corrosion and soiling* is man-made structures, which essentially have to be maintained more often due to the corrosion and soiling. Watkiss et al. (2001) provide data for the maintenance efforts (costs) for different surfaces, which have been used to characterise the corrosion and soiling of different pollutants in Zn-equivalents. We can therefore use the monetary value of the maintenance related to Zn corrosion from Watkiss et al. (2001): 25 EUR per m^2 corroded to the critical level of 50 micrometres that induces maintenance. We can then apply this to the mass loss of 0.357 kg Zn/m^2 to arrive at the monetarisation value of 25 EUR / 0.357 kg Zn = 70 EUR/kg Zn-equivalent (uncertainty[9] estimated to 14-170 EUR).

The endpoint of the impact category *Fertiliser effect* is already expressed in units that can be directly monetarised with the 5-year average market price: 1.4 EUR/kg N (0.9 - 3.5 EUR/kg). Since the fertiliser effect is a not a cost, but a benefit, its sign should be negative (i.e. -1.4 EUR/kg N) when adding this to the other monetarised impacts, which are all expressed with a positive sign even though they are costs. Note that benefits are often not included in traditional LCA studies.

The endpoint of the impact category *Photochemical ozone, crops* is likewise monetarised using the production value of agricultural crops in Europe (1.7E11 EUR). Of this, 10% is estimated to be lost as a consequence of the current emission levels in Europe ($6*10^{13}$ m^2*ppm*hours from Hauschild & Potting 2005), so we arrive at a monetarisation value of $2.8*10^{-4}$ EUR/m^2*ppm*hour ($2.6*10^{-4}$ – $3.2*10^{-4}$ EUR/m^2*ppm*hour)

Also the lost productivity of human health impacts are best monetarised by the price of labour, which we here derive from the GDP per capita for EU25 (33000 EUR). If we express human health impacts in QALY, we thus have a monetarisation value of 33000

[9] Note that uncertainties here and in the following are only the uncertainty of the monetary valuation itself, not including the uncertainty of the preceding inventory and characterisation steps.

EUR/QALY (27000 – 37000 EUR/QALY). Note that this is independent from the loss of wellbeing expressed via stated preference methods (see Section 7.2.9).

7.2.8 Monetarisation of site-specific impacts with surrogate markets

The example is site-generic and does not include any impact categories for which the revealed preference approach is recommended (see Section 7.1.8).

7.2.9 Stated preferences

The midpoint impact categories not already covered in Section 7.2.7 can be further modelled to the endpoint impact categories human wellbeing (in QALY) and ecosystem health (in BAHY; Biodiversity Adjusted Hectare Years), using the characterisation factors in Table 7.2.

Impact category	Unit of characterised result	QALY per characterised unit at midpoint	BAHY per characterised unit at midpoint
Respiratory inorganics	PM2.5-equivalents	7.0E-04	
Acidification	m^2 unprotected ecosystem		5.5E-06
Eutrophication, terrestrial	m^2 unprotected ecosystem		7.9E-07
Eutrophication, aquatic	kg NO_3-equivalents		7.2E-5
Respiratory organics	person*ppm*hours	2.6E-06	
Photochemical ozone, vegetation	m^2*ppm*hours		6.59E-08

Table 7.2 Characterisation factors at endpoint (QALY and BAHY per characterised unit at midpoint) from Weidema et al. (2007), except for Respiratory inorganics where the value from (Jolliet et al. 2003) is applied.

The calculated endpoint impacts for the two alternatives are shown in Table 7.3. This is simply the result of multiplying the characterised impacts at midpoint from Table 7.1 by the endpoint characterisation factors from Table 7.2. This step does not involve any monetarisation.

The endpoint modelling avoids performing the monetary valuation at the midpoint level, where impacts are less tangible for the respondents, and more effort would be required to ensure consistency in methods and assumptions.

Impact category	QALY per 1 Mg NOx emission	QALY per 0.2 Mg particulate emission	BAHY per 1 Mg NOx emission	BAHY per 0.2 Mg particulate emission
Respiratory inorganics	0.0891	0.14		
Acidification			0.035	
Eutrophication, terrestrial			0.294	
Eutrophication, aquatic			0.005	
Respiratory organics	0.0003	0		
Photochemical ozone, vegetation			0.105	
Sum	*0.0894*	*0.14*	*0.439*	*0*

Table 7.3 Human health and ecosystem health impacts of the two alternatives. The values are obtained by multiplying the values from Table 7.1 with those in Table 7.2.

The human health and ecosystem health impacts from Table 7.3 can be monetarised using the values of 74000 EUR/QALY (62000 – 84000 EUR/QALY) from the budget constraint method (Weidema 2009) and the 1500 EUR/BAHY (350 – 3500 EUR/BAHY) calculated from the LIME conjoint analysis (Itsubo 2004, Weidema 2009). The choice of these values is based on the high relevance and low uncertainty on the QALY value from the budget constraint method and the relative values from the conjoint analysis method.

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The result of multiplying these monetarisation values onto the values from Table 7.3 can be seen in Table 7.4.

Impact category	Human health impacts in EUR per 1 Mg NOx emission	Human health impacts in EUR per 0.2 Mg particulate emission	BAHY per 1 Mg NOx emission	BAHY per 0.2 Mg particulate emission
Respiratory inorganics	6593 (5520-7480)	10360 (8680-11760)		
Acidification			53 (12-120)	
Eutrophication, terrestrial			441 (103-1030)	
Eutrophication, aquatic			8 (2-18)	
Respiratory organics	22 (19-25)			
Photochemical ozone, vegetation			158 (37-370)	
Sum	*6615 (5540-7500)*	*10360 (8680-11760)*	*660 (154-1540)*	*0*

Table 7.4 Monetarised human health and ecosystem health impacts of the two alternatives. The values are obtained by multiplying the values from Table 7.3 with the monetarisation values 74000 EUR/QALY and 1500 EUR/BAHY.

The total monetarised result, including the values from Section 7.2.7, can now be established, see Table 7.5. The result is dominated by the impact of respiratory organics, which makes it favourable to avoid particulate emissions. Only a very high valuation of impacts on nature can challenge this conclusion.

Impact category	1 Mg NOx emission	0.2 Mg particulate emission
Respiratory inorganics (values from Table 7.4 plus 33000 EUR/QALY from lost productivity)	9533 (7900-10800)	14980 (12500-17000)
Acidification (values from Table 7.4)	53 (12-120)	0
Corrosion and soiling (values from Table 7.1 multiplied by 70 EUR/kg Zn-equivalent)	65 (13-158)	68 (14-165)
Eutrophication, terrestrial (values from Table 7.4)	441 (103-1030)	0
Eutrophication, aquatic (values from Table 7.4)	8 (2-18)	0
Fertiliser effect (values from Table 7.1 multiplied by -1.4 EUR/kg N, from Section 7.2.7)	-200 (-130 – -500)	0
Respiratory organics (values from Table 7.4 plus 33000 EUR/QALY from lost productivity)	32 (27-35)	0
Photochemical ozone, crops (values from Table 7.1 multiplied by $2.8*10^{-4}$ EUR/char. unit)	448 (420-510)	0
Photochemical ozone, vegetation (values from Table 7.4)	158 (37-370)	0
Sum	*10538 (8000-13000)*	*15048 (12500-17000)*

Figure 7.5. Monetarised values for all impacts of the two alternatives (the results from Table 7.4 as well as the values from Section 7.2.7).

7.2.10 Temporal discounting

As mentioned in Section 7.1.10, LCA impact assessment methods in general do not specify the timing of the impacts relative to the time of the emission. This is particularly problematic for emissions of long-lived substances, like CO2 or heavy metals. But also for the substances in this example, which have much shorter lifetimes (e.g. particulates have half-lives of days to weeks, while NOx and the indirectly formed ozone have day-time half-lives around 4 and 0.5 hours), some impacts can occur long time after the exposure (particulates cause mortality from cardiopulmonary diseases and lung cancer as well as decreased lung function and chronic respiratory diseases years after exposure; nutrients emitted to soil or water can stay for decades or centuries depending on the exchanges in the water and biomass cycles; impacts on biodiversity can last for centuries to millennia).

The impact from respiratory organics, which dominates the undiscounted result above, could be discounted using the life tables method, developed in the ExternE Project and later further developed by Miller & Hurley (2006). We did not perform this detailed calculation, since a rough calculation, assuming that discounting could halve the monetary value of the impact from Respiratory inorganics, shows that this could not change the conclusion of the example.

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7.2.11 Geographical discounting

Geographical discounting is generally dissuaded (see Section 7.1.11) and has not been applied in this example. The calculations have been made for an average European situation.

7.2.12 Distributional issues

The value of a Quality-Adjusted Life Year has been calculated as being the same for all persons and all ages.

WHO (2003) reports that results from long-term studies suggest that socially disadvantaged and poorly educated populations respond more strongly in terms of mortality to exposure to ambient particulates. Even without quantifying the consequences of this, it can be said that this would emphasise the conclusions in this example.

7.2.13 Reducing uncertainty

The uncertainty from the overall monetary value of the example results is dominated by the uncertainty on the value of human health impacts. We have expressed the health impacts in QALYs and monetarised the value of a QALY using the budget constraint method (Weidema 2009). The main opportunities to reduce the uncertainty of this method is by improving the data used to calculate the potential economic production per capita, i.e. the value of household and voluntary work, the value of the lost productivity from current levels of unemployment, underemployment, trade barriers, lacking education, and lost work-days from health impacts.

In terms of the trade-off between NOx emissions and particulate emissions, the main issue is the relative value of ecosystem health to human health. Here, we relied on the values from the LIME 1 study (Itsubo et al. 2004). The absolute values were nearly doubled in the LIME 2 study (Itsubo et al. 2012), but the relative values remained largely the same. However, it would be good if more, independent reproductions could be made of the conjoint analysis of human and ecosystem health/biodiversity, investigating the influence of different experiment variables.

7.2.14 Transparent, prudent and tested communication

The example has not been prepared for communication outside of the context of this report. All data sources and assumptions have been reported in the previous Sections. No testing of the reporting has been made.

7.3 Need for education

The surveys reported in Chapter 5 demonstrated the need for more information and education on several issues:

- How monetary valuation is distinct from other economic tools, such as Life Cycle Costing, Material Flow Cost Accounting, Ecoefficiency, etc., and how these tools relate to each other, see also the glossary in Chapter 2.
- How abatement cost methods are different from monetary valuation methods seeking to assess utility losses (sometimes referred to as Willingness-To-Pay methods) and clarifying their application fields and relations to Life Cycle Inventory, see also Chapter 5.4.
- The relative merits of monetary valuation in relation to other methods to weight or compare different impacts; see also Chapter 7.1.4.
- The monetary valuation methods available, their applicability and recommendations on their use, see also Chapter 5.4.
- The good practice and limitations of monetary valuation, as outlined in Chapter 7.1.

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ANNEX 1. RECOMMENDED MONETARY VALUATION METHODS PER IMPACT CATEGORY

Traditional LCA midpoint impact categories:

Impact category (damage caused by:)	Recommended valuation method
Acidification	Conjoint Analysis: Choice experiment
Dissipation of natural abiotic resources	Market price
Ecotoxicity, aquatic	Conjoint Analysis: Choice experiment
Ecotoxicity, terrestrial	Conjoint Analysis: Choice experiment
Eutrophication, aquatic	Conjoint Analysis: Choice experiment
Eutrophication, terrestrial	Conjoint Analysis: Choice experiment
Global warming	Conjoint Analysis: Choice experiment
Human toxicity, carcinogens	Conjoint Analysis: Choice experiment
Human toxicity, non-carcinogens	Conjoint Analysis: Choice experiment
Ozone layer depletion	Conjoint Analysis: Choice experiment
Photochemical ozone, vegetation	Conjoint Analysis: Choice experiment
Respiratory inorganics	Conjoint Analysis: Choice experiment
Respiratory organics	Conjoint Analysis: Choice experiment

Midpoint impact categories often not included in LCA or only in social LCA:

Impact category (damage caused by:)	Recommended valuation method
Addictive diseases	Conjoint Analysis: Choice experiment
Antibiotic resistance	Conjoint Analysis: Choice experiment
Biological contamination of food or drinking water	Conjoint Analysis: Choice experiment
Bonded labour	Conjoint Analysis: Choice experiment
Burglary or attempted burglary	Hedonic pricing
Changes in soil water balance	Conjoint Analysis: Choice experiment
Child labour	Conjoint Analysis: Choice experiment
Corrosion and soiling of man-made structures	Market price
Degradation of cultural heritage	Travel cost (specific); Conjoint Analysis (general)
Degradation of natural heritage	Travel cost (specific); Conjoint Analysis (general)
Electromagnetic fields	Conjoint Analysis: Choice experiment
Excessive work	Conjoint Analysis: Choice experiment
Forced migration	Conjoint Analysis: Choice experiment
Genital mutilations	Conjoint Analysis: Choice experiment
Inadequate access to contraception	Conjoint Analysis: Choice experiment
Inadequate access to health care	Conjoint Analysis: Choice experiment
Inadequate access to pensions or social security	Conjoint Analysis: Choice experiment
Inadequate education	Conjoint Analysis: Choice experiment
Inadequate ergonomic conditions	Hedonic pricing (nuisance only)
Inadequate physical exercise	Conjoint Analysis: Choice experiment

Inadequate physical infrastructure	Conjoint Analysis: Choice experiment
Inadequate social infrastructure	Conjoint Analysis: Choice experiment
Incarceration	Conjoint Analysis: Choice experiment
Infectious diseases, non-sexual	Conjoint Analysis: Choice experiment
Infringement of freedom of expression	Conjoint Analysis: Choice experiment
Infringement of indigenous people's rights	Conjoint Analysis: Choice experiment
Interpersonal or communal violence	Conjoint Analysis: Choice experiment
Malnutrition	Conjoint Analysis: Choice experiment
Natural disasters, avoidable impacts from	Conjoint Analysis: Choice experiment
Noise	Hedonic pricing (nuisance only; does not cover health aspects fully)
Odour	Hedonic pricing
Overexploitation of natural biotic resources	Market price
Participation restrictions	Conjoint Analysis: Choice experiment
Physical degradation of natural flora or fauna	Travel cost (specific); hedonic pricing (general; but covers only use value, not more abstract values)
Radioactivity	Conjoint Analysis: Choice experiment
Reduction in productivity from disability to work	Market price
Reduction in wellbeing of animals in human care	Market price; Hedonic pricing
Reduction in yields in agriculture, fishery and forestry	Market price
Soil erosion	Market price
Species dispersal	Conjoint Analysis: Choice experiment
Stressful working conditions	Hedonic pricing (nuisance only; does not cover health aspects fully)
Thermal pollution	Conjoint Analysis: Choice experiment
Threatening or traumatic traffic situations	Hedonic pricing
Threats of violence or other contact crimes	Hedonic pricing
Torture	Conjoint Analysis: Choice experiment
Trade barriers	Market price (Changes in production costs; does not include effects on non-protected producers)
Trafficking	Conjoint Analysis: Choice experiment
Unemployment and underemployment	Conjoint Analysis: Choice experiment
Unequal opportunities and transaction conditions	Conjoint Analysis: Choice experiment
Unintentional fires	Conjoint Analysis: Choice experiment
Unintentional injuries	Conjoint Analysis: Choice experiment
Urban heat island	Conjoint Analysis: Choice experiment
Warehousing of refugees	Conjoint Analysis: Choice experiment

Area of protection impact categories:

Impact category (damage to:)	**Recommended valuation method**
Human wellbeing	Budget constraint
Ecosystem health / Biodiversity	Conjoint Analysis: Choice experiment

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