KUNGL TEKNISKA HÖGSKOLAN

Environmental Assessment in Building and Construction

Goal and Scope Definition as Key to Methodology choices

DOCTORAL THESIS

Wolfram Trinius

October 1999

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KUNGLIGA TEKNISKA HÖGSKOLAN
100 44 STOCKHOLM

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PREFACE

Entitling this thesis "Environmental Assessment in Building and Construction – Goal and Scope Definition as Key to Methodology Issues" was probably not the most obvious choice. Reading this thesis, it should become clear that the issues I worked on are mainly to be found in the field of Life Cycle Assessment, to be more precisely in the methodology issues of allocation and boundary setting. The problem is tackled on a methodological level, consequently theroretical and not too application oriented. But as other parts of my work, namely the Typology for Environmental Assessment Tools, is not within the field of Life Cycle Assessment, the scope of my work was a bit wider than LCA-"only" and clearly related to the building sector.

The background of the work underlying this thesis is to be found in the building sector. The large number of actors involved in that sector, stretching from material producers through to facility managers and policy makers, leads to large variety also in the questions that are addressed by environmental assessment studies. As the spheres of interest of these actors may be diverging from each other, these actors also have different preferences concerning for example the delimitation of analysed systems. The way the problem is identified and tackled will simply vary. The methodology choices that are addressed by my work are influenced by the purpose of the study, consequently the goal and scope of an assessment guides the assessment-practitioner towards or away from the use of certain methods or certain methodology choices within e.g. LCA.

The starting point for addressing these methodology issues was the situation in the building sector. The intention was to identify the importance of methodology choices in the field of boundary setting and allocation for the generated LCA results. Meanwhile, the field of interest is not unique to that industrial sector.

Stockholm, October '99

Wolfram Trinius

CONTEXT OF THE THESIS

During my PhD-studies, I was allowed to participate in several national and international research projects. These projects have severely influenced my work, as it was possible for me to gain an overview over the international state of the art in environmental assessment of buildings, as well as it allowed me to discuss ideas and approaches.

Initially my work was carried out within the Swedish project "miljövärdering av byggnader". Via that project I also joined the project group Brite EuRam BE 7840, developing a "framework for environmental assessment of building materials and components" and the IEA BCS Annex 31 "Energy related Environmental Impacts of buildings".

The main part of the research underlying this thesis was carried out and financed within the Swedish MISTRA program "Sustainable Building".

In the context of my emerging Licentiate Thesis, in August '98, I had the opportunity to spend a week at BRE's Centre for Sustainable Construction to intensely discuss issues concerning allocation. Following the Licentiate Thesis, I spent a 3 month period at Centre Scientifique et Technique du Bâtiment (CSTB) in Grenoble, where I started working on the "second part" of my research.

As result of a conference presentation it was also possible to join the SETAC working group on "LCA in building and construction", which gave me a further forum for discussions and exchange of ideas.

As the articles and papers presented in this thesis are produced as contributions to the named projects, presentations on conferences or as articles based on the background from these projects, certain limitations and preconditions under which the mentioned projects are defined also apply for my work.

TACK

Först och främst vill jag tacka min handledare Prof. Kai Ödeen för goda idéer och ansatspunkter samt givetvis de jämnglada kommentarer om jobbet, livet och universet som sådant. I samma andedrag ett vidare tack till Prof. Ove Söderström för rak, ibland hård, tillförlitlig och konstruktiv kritik, som har visat sig samtidigt vara ett mycket motiverande stöd.

Mina kolleger på Byma, Mathias Borg och Jacob Paulsen tackar jag för effektivt samarbete inom LCA området, infallsvinklar, bidrag och medförfattarskap samt, och där också ett tack till Martin Erlandsson, för kommentarer på denna skrivelse.

En hård arbetsbelastning har jag under åren varit för Ninni Bodin, som villigt har bearbetad alla mina reseräkningar…

Sollte ich vielleicht auch meinen Eltern, Geschwistern und Freunden danken, dass ihr mich trotz 6½ Jahren konsequenter Schwederei immer noch nicht ganz vergessen habt? Na klar!

Mes remerciements au Services Matériaux du CSTB, à Grenoble. Aux Drs. Robert Copé et Jean-Luc Chevalier, qui m'ont offert la possibilité de faire un séjour dans leur labo. A Nathalie Leyssieux pour avoir organiser tous les aspects administratifs et bien sûr au Dr. Jean François Le Téno, qui a été un collègue très sympatique et efficace pendant mon séjour et par la suite pendant l'écriture des articles. Merci aussi d'avoir jeté un oeil sur ce manuscrit là …

Mes remerciments au Dr. Sylviane Nibel du CSTB de Marne-la-vallée pour une semaine créative en bordure de Paris, et à Annick Lalive d'Epinay, ETHZ. Les discussions sur la typologie et la coopération sur l'article auront été très importantes et une grande source d'inspiration.

A warm Thank You to all members of the national and international projects I worked in. It has been a great pleasure and of undoubtable importance for me to be able to meet you and discuss with you.

Thanks to these projects I was also allowed (or forced?) to travel quite a lot, nice…

So there you go you members of BRITE EuRam BE 7840, the IEA BCS Annex 31 and the SETAC WG on LCA in Building and Construction.

INTRODUCTION TO THE THESIS

Structure of this report

The summarising report preceding the attached papers is first giving a general introduction to the topic *environmental assessment of buildings*, then a short description *of Life Cycle Assessment* methodology. In the following section, the main position and the results of the publications underlying this thesis are reflected. Special focus is consequently directed on *assessment tools and their context,* the *goal and scope definition as a key issue* in the assessment procedure and *methodology choices* in the fields of *boundary setting* and *allocation*.

Papers

This PhD Thesis is based on the following publications:

I ***The Influence of Boundary Setting and Allocation Principles on the Results of LCA***
Trinius W. and Borg M., proceedings of the International Conference on Steel in Green Building Construction, Orlando March '98

II ***Valuation Principles in Environmental Assessment of Buildings***
Trinius W., Proceedings of the Green Building Challenge, Vancouver Oct '98

III ***Influence of Life Cycle Allocation and Valuation on LCA Results***
Trinius W. and Borg, M., International Journal of Low Energy and Sustainable Buildings, Vol. 1, Stockholm April '99

IV ***Economic Life Cycle Allocation***
Borg M., Trinius W. and Paulsen J., submitted to the International Journal of LCA

V ***System Boundaries according to Decision Scope – A concept of Focal Zones***
Trinius W. and Le Téno J.F., International Journal of LCA, Vol.4 No.5, 1999
based on VIII

VI ***A Typology for Environmental Assessment Tools***
Trinius W., Lalive d'Epinay A., Nibel S., *submitted to Building Research and Information*
based on VII

VII ***Typology for Methods and Tools for Environmental Assessment of Buildings***
Trinius W. and Nibel S., published as TRITA BYMA 1999:2 and submitted as contribution to IEA BCS Annex 31

VIII ***Decision Scope Dependent System Models for LCA in the Construction Industry***
Trinius W. and Le Téno J.F., published as TRITA BYMA 1999:3 and submitted as contribution to the SETAC WG "LCA in building and construction"

Papers VII and VIII are reports underlying the articles in appendices V and VI.

ABSTRACT

Access to tools for environmental assessment is a precondition for identifying and improving the environmental performance of building sector products. With the multitude of parties involved in that sector, also the context within which assessment results are implemented varies. Such variations have to be correctly reflected in the premises under which an assessment is carried out. A wide variety of assessment tools, from simple checklists to Life Cycle Assessment (LCA) approaches, is available. The choice of assessment method has an evident influence on the character and quality of the generated results.

Without confronting the ISO framework for LCA, a large variety of methodology choices can be made by the LCA-practitioner in order to adapt the assessment to his requirements. The application context is to be reflected in the goal and scope definition of the assessment. From that definition, methodology choices are to be made concerning among others allocation procedures and the delimitation of the analysed system. The choice of allocation method has shown significant influence on the generated results, when applying LCA on highly recyclable building materials.

Within this publication, a method for deriving a link from the goal via the scope into the definition of system boundaries, and an economic allocation procedure for reuse and recycling, are proposed. Both are intended to enable a clear link between methodology choices and the goal and scope definition, which was identified as the key point in LCA. The methods presented in this publication do accord with the ISO standards.

Keywords

Environmental Assessment, Building Sector, Life Cycle Assessment, Goal and Scope Definition, System Boundaries, Allocation, Result Variation

TERMINOLOGY

allocation	Partitioning the input or output flows of a unit process to the product system under study (ISO 14040)
allocation procedure	Procedures to determine inputs and outputs of a multi-function system attributable to one product or service delivered by this multi-function system (FRISCHKNECHT 1997)
category endpoint	Attribute or aspect of natural environment, human health, or resources, identifying an environmental issue of concern (ISO/DIS 14042)
category indicator	Quantifyable representation of an impact category (ISO/DIS 14042)
characterisation factor	factor derived from a model which is applied to convert assigned LCI results to the common unit of the category indicator (ISO/DIS 14042)
elementary flow	(1) Material or energy entering the system being studied, which has been drawn from the environment without previous human transformation (ISO 14040) (2) Material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation (ISO 14040)
environmental aspect	Element of an organisation's activities, products or services that can interact with the environment (ISO 14040)
environmental mechanism	System of physical, chemical and biological processes for a given impact category, linking LCI results to category indicators and to category endpoints (ISO/DIS 14042)
functional unit	Quantified performance of a product system for use as a reference unit in a life cycle assessment study (ISO 14040)
impact category	class representing environmental issues of concern into which LCI results may be assigned (ISO/DIS 14042)
LCI result	Outcome of a life cycle inventory analysis that includes flows crossing the system boundary and provides the starting point for life cycle impact assessment (ISO/DIS 14042)
life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal (ISO 14040)
life cycle allocation	Correct ISO terminology is "*allocation procedures for reuse and recycling* " as special case for allocation of shared unit processes

life cycle assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040)
product system	Collection of materially and energetically connected unit processes which performs one or more defined functions (the term product includes not only product systems but can also include service systems) (ISO 14040)
proxy method	Approach for valuation / weighting, where one or several quantitative measures are stated to be indicative for the total environmental impact (JENSEN ET AL 1997)
system boundary	Interface between a product system and the environment or other product systems (ISO 14040)
system expansion	In order to avoid allocation, the analysed system can be expanded. (ISO 14041) System expansion leads to new system boundaries that, compared to the original system boundaries, include additional functions.
system extension	Terminology often used in the context of allocation procedures for reuse and recycling. Instead of expanding the system and include earlier and later utilisations of recycled material in the assessment, allocation factors may be found by analysing the recycling cascade. The allocation has then not been avoided by system expansion, but a system extension for the derivation of allocation factors has been performed.
transparency	Open, comprehensive and understandable presentation of information (ISO 14040)
typology of tools	Organisation of Assessment Tools concerning certain key features, enabling a rough comparison of basic tool properties.
unit process	Smallest portion of a product system for which data are collected when performing a life cycle assessment (ISO 14040)
value choice	in ISO, values and subjectivity are referred to as "value choices" (ISO/DIS 14042)

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ENVIRONMENTAL ASSESSMENT OF BUILDINGS

Reducing the impacts our society has on the natural environment evidently necessitates addressing the building and real estate sector and its products. Buildings are part of the infrastructure; Meanwhile they use and require other parts of infrastructure as well as they require land, water, raw materials and energy during their production, utilisation, maintenance and demolition. Generally seen, buildings do affect the natural environment directly and indirectly via the use of products and services during their long life cycles.

The importance of the building and real estate sector for sustainable development can be illustrated by a set of figures valid for Norway:

> The building and real estate sector employs app. 20% of the employees in Norway. Annual investments in construction constitute app 9% of the GNP. Buildings and Construction represent 70% of the total real capital in the country. The yearly increase is 2.5% for commercial buildings and 1% for dwellings.
>
> Norwegian energy consumption is the 3rd largest in the world (per capita) after Canada and Finland. 37% of the net domestic energy consumption in Norway is ascribed to the sector. 91% of this related to the operation of buildings. 57% of the operation energy is used for heating, 15% for generating hot water, 11% for lighting, 17% for equipment.
>
> The World Watch Institute estimates that app. 40% of the raw material resources injected into the global economy are used in buildings.
>
> (BRAMSLEV ET AL 1998)

Improving the environmental performance of buildings requires among other factors, partly from (TRINIUS 1998A):

- knowledge about environmental impacts of buildings
- targets to address in order to drive the development into desirable directions
- access to analysis and assessment tools for buildings
- access to information (data concerning environmental profiles of products)
- time, economic resources, good will of all involved parties and a structure in building related decision making processes that enables the inclusion of environmental aspects in the design and management processes of buildings and real estate.

There is a large variety of tools for environmental assessment of buildings available. In their methodological approaches, they stretch from simple checklists to approaches that quantify the environmental impacts associated with buildings considering their entire life cycle. The building and real estate sector involves a large number of differents actors, with different fields of interest as well as differences in occupational and educational backgrounds. All these actor's may, or rather should, consider environmental aspects within their usual decision making. Thereof, the questions they pose to environmental assessment and the answers they expect differ in kind, quality, character and level of detail. Hence, there is a large demand for tools for environmental assessment of buildings with a large spread in the group of potential users. An introduction to methods for environmental assessment and their implementation in the building sector has been given in (TRINIUS 1998A).

LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is to a large extent specified and defined by SETAC [Society for Environmental Toxicology and Chemistry] (FAVA ET AL 1990)(CONSOLI ET AL 1993), CML (HEIJUNGS ET AL 1992), the Nordic Guidelines on Life Cycle Assessment (LINDFORS ET AL 1995) and within the ISO 14000 series (ISO 14040)(ISO 14041)(ISO/DIS 14042). A recent compilation and introduction to the methodology can be found in (JENSEN ET AL 1997). CML is currently developing a new Guideline (GUINÉE ET AL 1998). Of high importance for the development of LCA are further the reports from the Danish EDIP programme (WENZET ET AL 1997) (HAUSCHILD & WENZEL 1998) and the reports from LCANET (UDO DE HAES ET AL 1996) and CHAINET (WRISBERG & GAMESON 1998).

Definition of Life Cycle Assessment

According to the definitions in the ISO 14000 series, (ISO 14040)(ISO 14041)(ISO/DIS 14042) Life Cycle Assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product by

- compiling an inventory of relevant inputs and outputs of a product system
- evaluating the potential environmental impacts associated with those inputs and outputs
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study

It is hence one of the available methodologies for assessing the environmental impacts related to product systems. LCA studies the environmental aspects and potential impacts throughout a product's life – from raw material acquisition through production and use to disassembly and disposal. Generally considered are impacts on resource use, human health and ecological consequences associated with the input and output flows of the analysed system.

Object of an LCA

The object of an LCA is consequently, quite different from a criteria approach, not only the product itself, but the:

- product system (production facilities and supporting systems) requested to produce and deliver the product, use and maintain the product, deconstruct, recycle or dispose off the product.

Methodology description

An LCA consists of four distinct 'methodology phases' (see figure 1):

1. Goal and Scope definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation of Results

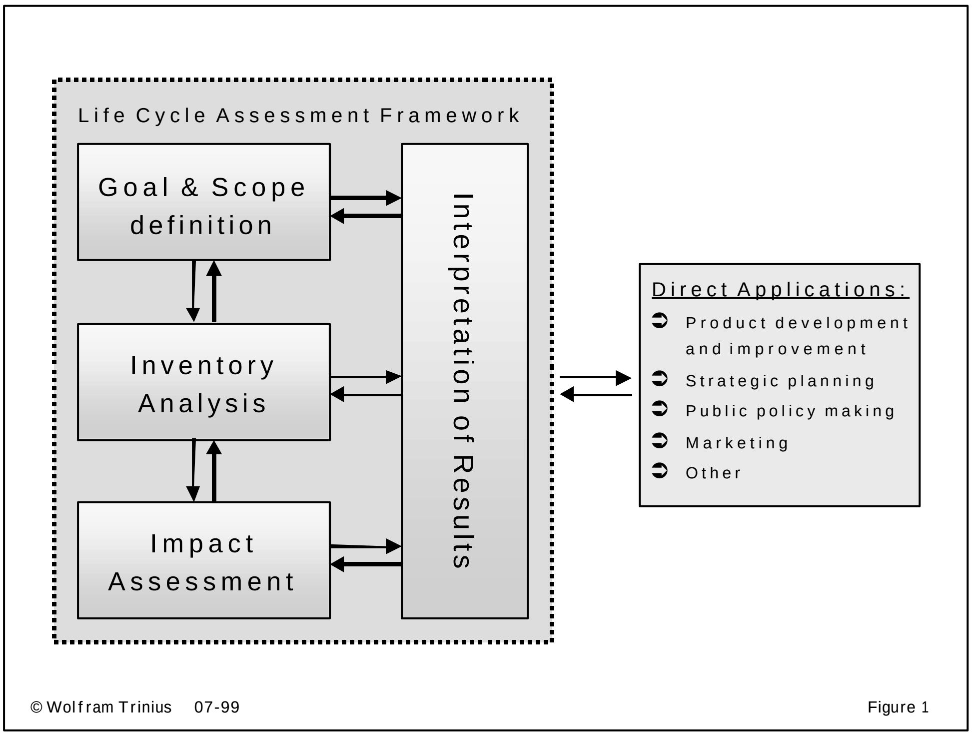

Figure 1 *Phases of an LCA* (ISO 14040)

Determining the environmental impacts that are to be related to the product's life cycle requires a clear identification of the product, its life cycle and the product system to be represented within the system boundaries.

Importance of clear Basic Definitions

Before starting with any data inventory for the investigated product, a set of definitions has to be made within the goal and scope definition. These basic definitions are needed

- to clearly identify the object and the objective of the study
- to enable a clear structure of the assessment
- for users to understand the results of the study.

These basic definitions have large influence on the following phases in the assessment procedure. Meanwhile, the character of an LCA study is often iterative, as initial definitions and intentions may have to be changed, adapted and refined during the conduction of the study. Disregarding or mistreating the first phases will necessarily lead to poor quality of the study.

Phase one – Goal and Scope definition

The first phase of any LCA is the Goal and Scope definition. For each study, definitions concerning the Goal, Scope, Functional Unit, System Boundaries, Data Quality, Critical Review Process, have to be found.

These basic definitions have to be set carefully, as the obtained results will only be valid for the found definitions. Interpretation of results in situations similar to, but varying from the preconditions of the study, may remain unsupported by the study.

Life Cycle Definition

According to the definition of LCA, the entire life cycle of the product is to be included in the assessment, this means that those systems demanded for generating, using and dismissing the product are to be included. This “cradle to grave” approach necessitates an identification of the product's life cycle and of the processes participating in it. Especially in case of products with long service life, such as buildings, the definition of the product’s life cycle incorporates assumptions or estimates of the:

- functional service life time
- use and maintenance scenarios
- repair and replacement of components
- major refurbishment or renovation scenarios for the building
- demolition and recycling scenarios
- scenarios for technology development of supporting product systems, such as e.g. electricity generation or transportation systems

Functional Units

The usefulness of a product is identified through its Functional Unit, which can be expressed by various measures. It has to be clearly identified and measurable. The FU serves as basis for comparison and as normalisation reference for the input and output flows.

As the functional unit is strongly related to the “product in its application”, hence its functionality, the identification of the product’s life cycle as well as a useful description of a functional unit may, especially in case of application on lower system levels such as building materials, be difficult.

In comparative studies, fair comparison of different products or design solutions can only be obtained if the products fulfil the same functional unit. Also the analysed product systems must be comparable in that case. Hence the ISO standard states that "in comparative studies, the equivalence of the systems being compared shall be evaluated before interpreting the results" (ISO 14040).

System Boundaries & Data Quality Requirements

According to the goal and the scope of the study, the system boundaries are to be set in order to identify the extent to which processes are included or excluded. The system boundaries define and structure the system under focus for the assessment. System boundaries must be drawn concerning geographical boundaries, boundaries between life cycles and the boundary between technosphere and biosphere (LINDFORS ET AL 1995).

An inventory of inflows and outflows is to be performed over all processes within the system boundaries. Concerning the quality of gathered data requirements can be defined and quality indicators can be established (see e.g. LINDFORS ET AL 1995). Special attention has to be drawn to the spatial, temporal and technological coverage and validity of applied data (GUINÉE ET AL 1998).

Critical Review Process

A critical review process may serve to ensure the quality of the study. If reasonable, a reviewer or a review panel may be consulted in order to ensure that (ISO 14040):

- methods used are consistent with ISO standards
- methods used are scientifically and technically valid
- data is appropriate and reasonable in relation to the goal

- made interpretations reflect the limitations and the goal
- the report is transparent and consistent.

Phase two – Inventory Analysis

Inventory Analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. The Inventory Analysis phase consists of data collection, refining of the system boundaries, involves calculation, allocation and relation of data to the specific system under study, as well as a validation of the applied data. Refining the system boundaries has to be carried out carefully and in consideration of the defined scope of the study, and shall result in a limitation of data handling to those input and output data that are significant for the goal of the study. This refining may involve exclusion of life cycle stages or subsystems and certain in- or output flows in case of insignificance, but it may as well involve the additional inclusion of unit processes that show significance.

Inventory data shall consist of elementary flows that are to be related to reference flows for each unit process in order to quantify and normalise inputs and outputs to the studied functional unit. Data will then be aggregated in order to result in an input-output table for the studied product or service.

Resulting data from the Inventory Analysis constitutes input to the following Impact Assessment phase, or, depending on the goal and scope of the study, interpretation may be drawn directly from these data via:

- Checklists that verify whether certain substances or emissions are to be found in the tables,
- Criteria evaluation, where key data are assessed or specially promoted and interpreted,
- Indicator approach, where data contributing to certain key aspects is used to represent a first estimation of the actual environmental impact.

Significant calculation procedures carried out within the Inventory Analysis phase are (ISO 14040):

> **Allocation procedures** that are needed when dealing with systems involving multiple products. The material and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures, which shall be documented and justified.
>
> The **calculation of energy flow** should take into account the different fuels and electricity sources used, the efficiency of conversion and distribution of energy flow as well as the inputs and outputs associated with the generation and use of that energy flow.

The term *Life Cycle Inventory Analysis* (LCI) is often used as name for phases one and two (Goal and Scope Definition + Inventory Analysis).

Phase three – Impact Assessment

The Impact Assessment phase "is aimed at evaluating the significance of potential environmental impacts using the results of the Inventory Analysis" (ISO 14040) and can be subdivided into four sub-steps, category definition, classification, characterisation and weighting.

Category definition

The aim is to provide guidance for selecting and defining the environmental categories addressed by the study. The selection should be rather complete and shall not avoid or disguise environmental issues or concerns. The selection of categories should be consistent with the goal and scope of the study. Commonly addressed Impact Categories are (LINDFORS ET AL 1995)(JENSEN ET AL 1997):

- Abiotic Resources
- Biotic Resources
- Land Use
- Global Warming
- Stratospheric Ozone Depletion
- Ecotoxicological Impacts
- Humantoxicological Impacts
- Photochemical Oxidant Creation
- Acidification
- Eutrophication

Classification

(ISO 14040): assigning of inventory data to impact categories

The classification step is performed to assign elementary flows quantified in the inventory to the defined impact categories. It is a qualitative step based on scientific analysis of relevant environmental mechanisms, and the result is that inventory data is assigned to so-called “impact categories”. Classification is regarded as the minimum step of Impact Assessment.

Characterisation

(ISO 14040): modelling of the inventory data within impact categories

For each impact category, the relative importance of the contributing substances is modelled and determined, based on the involved environmental mechanisms. This relative importance is expressed relative to a category-internal reference substance by an equivalency factor.

The characterisation step necessitates the ability to model the categories in terms of indicators that provide the basis for category internal aggregation. The chosen indicator represents the overall change or loading in the category. Equivalency factors do not yet exist for all impact categories.

The result of the characterisation step is the expression of contributions to impact categories in terms of equivalent amounts of emitted reference substance for each impact category.

Weighting

(ISO 14040): aggregating the results in very specific cases and only when meaningful

As comparison of the characterisation result may still not be obviously possible, and if, depending on the goal of the study, further aggregation of the result is demanded, Impact Assessment results may be grouped, ranked and weighted. Where ranking may be directly based on value judgements, weighting is obtained by application of numerical factors based on ethical or societal value judgements. As ranking and weighting facilitate value choices rather than scientific information, these are not objective procedures. Weighting factors for result aggregation may be based on:

- Proxy Methods
- Monetarisation
- Authorised goals or standards, e.g.:
  - Environmental State Indicators
  - Environmental Political Goals
- Authoritative Panels

Concerning Impact Assessment, ISO 14040 states that:

> There is subjectivity in the life cycle impact assessment phase such as the choice, modelling and evaluation of impact categories. Therefore, transparency is critical to impact assessment to ensure that assumptions are clearly described and reported.

In ISO/DIS 14042 it is stated concerning weighting:

> The application and use of weighting methods shall be consistent with the goal and scope of the LCA study and it shall be fully transparent. Different individuals, organisations, and societies may have different values, therefore it is possible that different parties will reach different weighting results based on the same indicator results. In an LCA study it may be desirable to use several different weighting methods and to conducts sensitivity analysis to assess the consequences on the LCIA results of different value choices and weighting methods.

The term *Life Cycle Impact Assessment* (LCIA) is often used as name for steps one to three.

Phase four – Interpretation of Results

Interpretation of results will incorporate an identification of significant environmental issues, an evaluation of the underlying study and the generated information and is supposed to lead to conclusions and recommendations. The applied methodology will have to be evaluated for its completeness, sensitivity and consistency. Any interpretation of results has to reflect the definitions made in the Goal and Scope definition phase.

POSITION AND MAIN RESULTS OF THIS THESIS

Methodology Choices Causing Result Variation

The general recognition of environmental assessment being a field of fast development both regarding development and implementation of different methodologies, methods and tools for environmental assessment of buildings has been a basis for the layout of the research underlying this thesis. As this development leads to a variety in available methods that produce results of varying character, it has been of major interest to identify differences, find reasons for their existence and to indicate the relevance of such differences for the generated results.

Improving the environmental performance of products necessarily requires the existence of analysis and assessment tools. LCA is one of the available methodologies, and this thesis is mainly focussing on LCA in its application on building sector products. In order to correctly interpret LCA and other environmental assessment results, it is necessary that the interpreter understands the preconditions under which a study is carried out, as well as he understands the relevance of methodology choices that are made in a study. Otherwise, the fact that different studies may produce widely varying results even though they study the same product, in combination with non-understood reasons for such result variation may seriously jeopardise the credibility of environmental assessment and LCA in itself (TRINIUS 1998A).

In the meantime it is of course a necessity that LCA practitioners are aware of the methodology choices they have to make during the conduction of an LCA study. Based on earlier studies, key points in environmental assessment that we assumed as being outmost relevant for such result variation are (TRINIUS 1997) (TRINIUS 1998A) (PAPER I) (PAPER II):

- Definition of Goal, Scope and Focus
- Assessment Method / Methodological Approach
- System Boundaries and Allocation Procedures
- Impact Assessment and Valuation Method, Normalisation and Aggregation of Results

More implicitly, in tools for environmental assessment of buildings, these reasons can be related to (PAPER VI)

- the suitability for certain questions arising in the design process;
  the intended user of the tool, the suitability for application at a certain stage in the design process, how decision related questions are addressed by the tool
- the needed input and the produced output sets;
  the accuracy, date, origin, format and amount of information to be inserted by the user, and the character of the generated results
- the methodological background of calculation and assessment;
  how the technical system is delimited and modelled for the assessment, to what degree information is aggregated in the calculations

- the represented environment;
  concerning which environmental aspects the assessment is carried out, how the technical system's influence on that environment is modelled
- produced output sets and interpretation of results;
  what kind of information is communicated as result to the user

When applying existing methods for environmental assessment it is a precondition for obtaining relevant results that these methods are intended for the application at hand. The goal, scope and level of detail of an applied method have to coincide with the goal scope and focus of the decision-maker initiating the assessment. Based on related methodology choices, tools can be more or less appropriate for different purposes or at different stages in the planning process, since the questions asked and the requested level of detail in the assessment vary with the purpose of the study. (TRINIUS 1997) (KOCH ET AL 1998) (PAPER VI)

This defines the need for a common basis towards which methods and tools for environmental assessment can be compared. As the building and real estate sector encounters numerous actors, who all can be regarded as potential tool users, there also is a manifold of main fields of interest of these different actors. Consequently, such a common basis for tool comparison shall consist of a set of points of departure representing certain fields of key interest. Within the IEA BCS Annex 31 "Energy Related Environmental Impacts of Buildings", we have developed a "Typology for Methods and Tools for Environmental Assessment of Buildings" by roughly analysing a tool's modus operandi and main field of application (PAPER VI) (PAPER VII).

Typology for Methods and Tools for Environmental Assessment of Buildings

As of today, numerous methods and tools for environmental assessment of buildings are available. These show significant differences in their intended field of application, in their methodological approach and in the results they produce. Generally it can be said that the application of different tools on the same building generates incomparable results, even though the studied object is the same. Structured analyses of differences in assessment tools can be found in the forthcoming report of the IEA BCS Annex 31 (IEA BCS ANNEX 31 1999) and in related works, such as e.g. (LALIVE ET AL 1997), (KOCH ET AL 1996) and (CHATAGNON 1999).

The range of methodological approaches represented in tools for environmental assessment of buildings stretches from simple checklists to complete life cycle assessment approaches. As these and other differences of the assessment tools lead to incomparable results, also the choice of assessment tool turns into a decisive activity when identifying and assessing the environmental performance of a building (PAPER VI). If not properly understood, such manifold in assessment tools, methodological approaches and resulting differences may confuse the reception of environmental assessment tools as being useful. Meanwhile, in order to adapt the assessment to its context, there is a necessity for either a variety of tools intended for application in certain niches, or for highly flexible assessment tools. To enable correct tool application and reasonable interpretation of gained results, tools have to be transparent regarding their methodology, scope, limitations and assumptions. Further, the user has to possess certain knowledge about environmental assessment methodology issues to be able to identify key aspects for assessment tool performance and to understand the importance of certain differences (PAPER VI) (RIALHE & NIBEL 1999).

Assessment tools have to merger two "spheres of reality" (NIBEL 1998) (LALIVE ET AL 1997) (LE TÉNO 1996), namely the tool context in the decision making process, expressed as the *actor's operational context* and the assessed object's physical context in the technical system and the environment. The performance of an assessment tool cannot satisfactorily be described without recognition of these contexts. Our typology has, as well as the typology developed by (CHATAGNON 1999) the following main areas of interest underlying the typology definition:

- function, aim and objectives of the tool
- operational framework of the actor, expressed in roles and decision making
- technical system (objects / scale / life cycle stages)
- modelling of the represented environment
- generated results

The development of our typology is based on the conceptual picture on how an assessment tool operates in its context, (see figure 2).

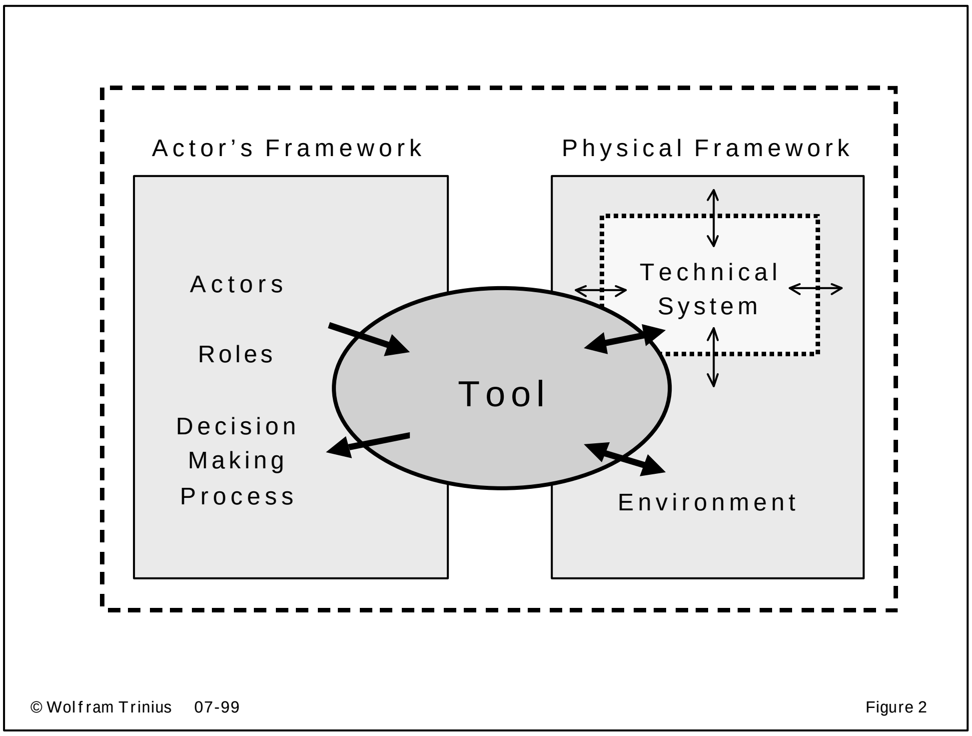

Figure 2 *A tool for environmental assessment in its context* modified from (LALIVE ET AL 1997)

Concerning the structure for our typology, we found that deriving a typology from a single starting point seemed inappropriate, as (PAPER VI):

- There are in fact different points of departure on how to address key features of assessment tools. These coincide with key interests of various actors and potential tools users.
- It appeared not possible to find a hierarchy with only one starting point. Identified typology-criteria do overlap and features within one view angle are inter-dependent with other features of a tool.

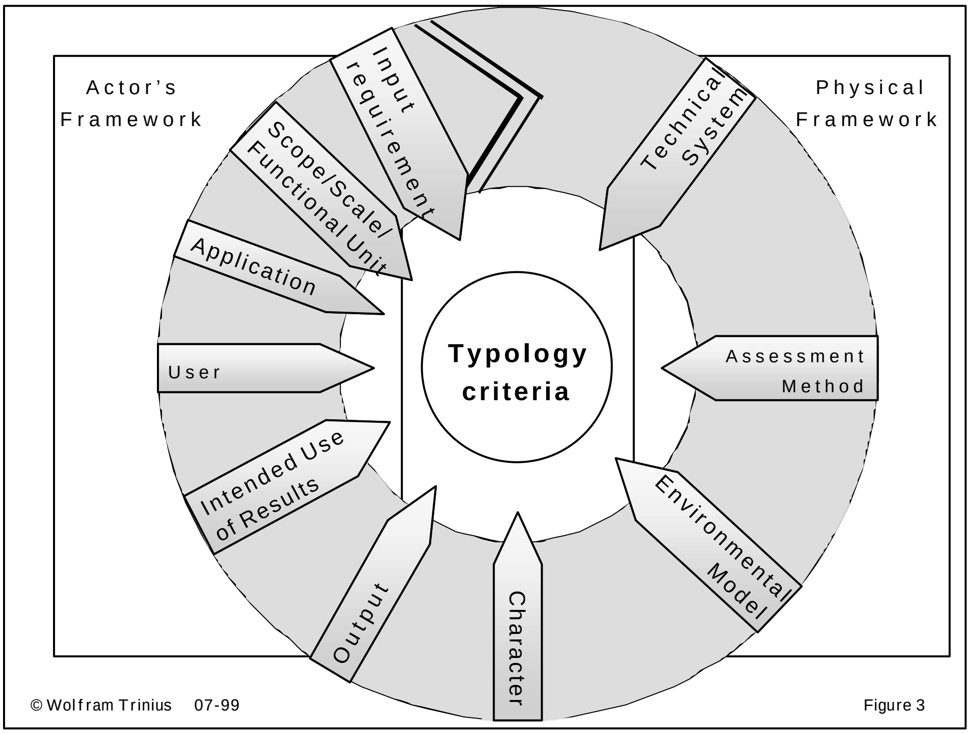

Figure 3 Circular structure for Typology View Angles

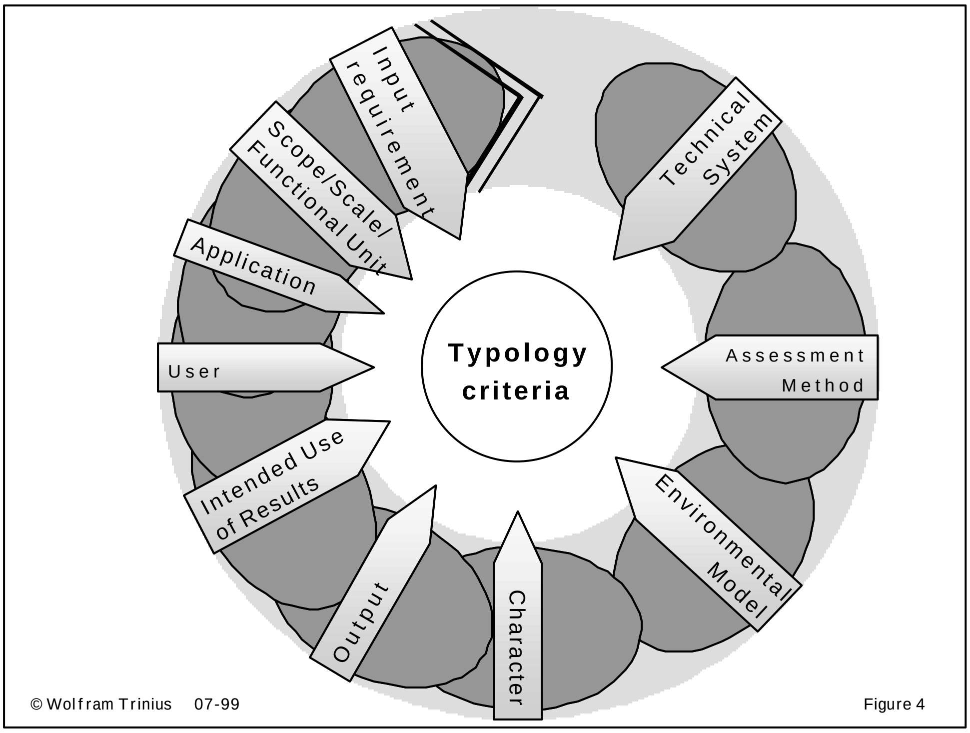

Figure 4 Overlapping Zones of View Angle Criteria

We have therefore chosen to develop a circular structure for a typology that follows the information flow through an assessment tool (see the arrows in figure 2). Putting figure 2 into superposition with figure 3 explains the circular approach of the typology. View Angles, compare block arrows in figures 3 and 4, are derived from key points of interest during the assessment procedure. The criteria associated with the established view angles, *see table 1 in* (PAPER VI), are not independent of each other, further there are overlaps between the view angles, (see figure 4).

Successful use of an assessment tool and the generation of useful and comprehensible results require that an appropriate tool is chosen for application. Using a typology to identify key criteria in the actor's main field of interest can assist in understanding the modus operandi of assessment tools and by this in identifying appropriate tools. Before choosing a tool for application, the potential user can identify user-relevant key features of the tool. Concerning these, properties of available tools can be compared. Based on the agreement between the user's desires and the tool's properties, an appropriate tool can be chosen for application.

"Tool users" may either be those who actively use a tool in order to perform an environmental assessment, or those who use the gained results in some form of decision making. These two may or may not be the same person. (RIALHE & NIBEL 1999). Especially for the second group of more "passive" tool users, it is of considerable difficulty to gain insight into preconditions of the gained information.

We regarded it necessary to stress that there is no ultimate typology. Already those defined within the context of the IEA BCS Annex 31 vary slightly when comparing them to each other (PAPER VI) (PAPER VII) (CHATAGNON 1999) (KOCH ET AL 1996) (KOCH ET AL 1998). The differences are to be related to the fact that the interest and consequently the structure and the considered criteria (tool features that are included in the comparison) vary in-between the fields of interest of concerned parties. Consequently, typology-definitions will vary with the context for which they are defined, as the main focus may be laid on different aspects of tool performance, resulting in consideration of different criteria.

Concerning the variety of available tools, it has to be concluded that (PAPER VI):

- The mere existence of a manifold of interests and planning process situations with different actors posing a variety of questions to environmental assessment studies lead to different purposes with environmental assessment.
- Lacking "the one" or "universal purpose" there can not be "the one tool" for all application situations.
- Hence, tools for environmental assessment have either adaptable features, or they are products for application in a certain niche.

Valuation Principles applied in Environmental Assessment of Buildings

Valuation is an important step during the determination and communication of the assessed environmental performance of buildings. By definition, valuation is related to other ethic values present in society (FINNVEDEN 1997), or to personal preferences. Thereby, and similar to other value choices, the choice of valuation approach is most unlikely to be appreciated as being objective.

The choice of valuation principle is not directly dependent on the choice of assessment methodology. Theoretically, all valuation principles may come to use in whatever method is chosen. There is, however, a certain affinity of criteria based assessment tools to implement key issue or top down assessments involving opinion-related weightings of different criteria against each other. This, as it practically can be difficult to implement e.g. environmental effect based valuation principles in assessment methods based on a direct evaluation of product features, as the environmental effects first would have to be related to those features (PAPER II).

The determination of environmental political goals is nowadays strongly related to the conventions found at the Rio conference on sustainable development and its successors. Considerable work, e.g. (NVV 4858 1999) (BRAMSLEV ET AL 1998), is now evolving in the field of interpretation of the Factor 4 and Factor 10 concept (SCHMIDT-BLEEK 1994)

(WEIZSÄCKER ET AL 1995). These publications mainly aim at staking out the targets and translating them into operational goals for different sectors of society.

Goal and Scope Definition as Key Activity in LCA

Within the LCA framework, as staked out by SETAC (FAVA ET AL 1990)(CONSOLI ET AL 1993), the Nordic Guidelines (LINDFORS ET AL 1995) and the ISO standards (ISO 14040), the LCA practitioner has numerous possibilities on how to conduct a study without confronting the framework definitions. Methodology choices have, according to the transparency requirements stated by ISO (ISO 14040), to be justified and analysed in their relevance for the generated results.

As methodology choices may involve *value choices*, it is of outmost importance to clearly state all values involved in the decisions made concerning the assessment procedure. Lack of clear statements may lead to incomprehensible results.

The first phase in LCA, the *Goal and Scope Definition* is clearly to be identified as the key activity within which methodology and value choices are to be anchored. From clear statements concerning the purpose and the chosen approach, as well as the context within which an LCA is performed, the identified intrinsic values can be followed into the later methodology choices.

This recognition was strengthened after having analysed a set of life cycle allocation methods and their influence on LCA results (PAPER I). The choice of life cycle allocation method appeared, for the chosen case study, as being of higher importance for the result than the choice of weighting method (PAPER III). Facing such influence on LCA results, the question of reasonable choice of allocation method occurs. An answer to this question cannot be given from a general methodological point of view; most of the analysed methods fulfil the requirements of ISO. Consequently, the question has to be traced back to other values according to and coinciding with which "acceptable" and "justifiable" results can be obtained. Hence, the trace leads back to the goal and scope definition and the context of the assessment, where among other factors (see scope definition below) also the choice of allocation method and the definition of system boundaries are to be justified. By this, the *Goal and Scope Definition* is the LCA phase, within which the methodology choices that are addressed in this thesis are to be anchored. Other recent research also agrees with this identification and connects for example the choice of relevant product systems to the time-scope of the decision to be taken (FRISCHKNECHT 1998).

Goal and Scope Definition as Key Activity in ISO Definitions

When reading the ISO standards in the field of LCA, statements like "… has to be conducted in accordance with the goal and scope definition" are to be found frequently. The relevance of the goal and scope definition for the succeeding phases of an LCA should be clear from the following ISO quotes:

ISO 14040:

> The scope, boundaries and level of detail of an LCA study depend on the subject and intended use of the study. The depth and breadth of LCA studies may differ considerably depending on the goal of a particular LCA study. However, in all cases, the principles and framework established in this International Standard should be followed.

ISO 14041:

> The goal and scope definition phase is important because it determines why an LCA is being conducted (including the intended use of the results) and describes the system to be studied and the data categories to be studied. The purpose, scope and intended use of the study will influence the direction and depth of the study, addressing issues such as the geographic extent and time horizon of the study and the quality of data which will be necessary.

Scope Definition

The definitions to be made within the scope definition are (JENSEN ET AL 1997):

- Function of the System
- Functional Unit
- System to be studied
- System Boundaries
- Allocation Procedures
- Impact Assessment Method
- Data Requirement
- Assumptions
- Limitations
- Initial Data Quality Requirements
- Type of Review
- Type and Format of Report

Concerning all the above aspects, definitions have to be found and justified. The methodology choices addressed in this thesis, namely allocation and boundary setting, are to be made in the Scope Definition of an LCA. As the goal and scope have to be identified for each LCA study individually, it seems to be reasonable to assume that also the choice of system boundaries and allocation methods will vary with the purpose of the study.

Definition of System Boundaries

System boundaries that clearly define and structure the technical as well as the environmental system considered for the analysis have to be found in accordance with the goal and scope definition of the study. The definition of system boundaries has to find a balance between practicability of the assessment and validity of the gained results (PAPER V). System boundaries in the technical system identify the analysed product and those upstream and downstream processes related to the analysed product, that are to be included in the life cycle inventory. In order to obtain a faster, simpler and more cost effective LCA procedure, practitioners often strive after "streamlining" the assessment. There are numerous approaches for streamlining LCAs, e.g. disregarding life cycle stages, upstream compounds or to recognise inputs and outputs of a certain kind only, like e.g. in the MIPS concept (Mass Intensity Per Service-unit) (SCHMIDT-BLEEK 1994). An analysis of the reliability of approaches for streamlining LCA is underlying the statement that use of qualitative or less accurate quantitative data in fields of relatively low concern is one of the most promising methods for streamlining an LCA (HUNT ET AL 1999). The below-presented *Concept of Focal Zones* introduces an approach for the identification of zones of higher, indifferent and lower concern. The aim was also to enable a decision concerning which of the included processes within the system boundaries can be filled with data of lower quality, in order to streamline LCA – depending on the decision context.

Concept of Focal Zones for System Boundary Definition

As already mentioned, system boundaries have to be found in accordance with the goal of an LCA study. Studies carried out at CSTB (PAPER VIII) strove after identifying mechanisms that link the goal definition with the system model underlying the assessment. The goal of an assessment has to be identified from the context in which an assessment is carried out and from the context within which the generated results will come to use.

During the scope definition a reasonable goal-dependent compromise between two extremes has to be found (PAPER V):

- One of these extremes would be to implement a “whole system model”, where all links to other product systems, influences on infrastructure, product replacement scenarios, marginal effects on other facilities and so on are to be included.
- At the other extreme, we can identify a restriction of the system model to those processes that are directly influenced by the decision to be taken, or to those processes for which the decision-maker is liable.

LCA studies often address the task of quantifying the environmental impacts associated with a product by implementing a "whole system model" approach. This gives for obvious reasons the most accurate modelling of the physical context of the analysed product. Meanwhile, the amount of data to be handled during the assessment becomes quite vast and the relation to the goal of the study can often be doubted. Further, the presented result may be difficult to apply in decision making. Consequently, with having the application of LCA in decision making in the building sector in mind, there is a necessity for stronger links from the decision context, represented in the goal of the study, and the system model underlying the assessment.

Neither the well-established “whole system model” nor a stringent restriction to a small number of processes seems appropriate in all application situations. In order to better structure system models, and in order to highlight the product system under the influence of the current actor, the system can be divided into a *core model (Kernmodell)* and a *complimentary model (Komplimentärmodell)* (BRAUNSCHWEIG ET AL 1993) or *foreground* and *background* system (CLIFT ET AL 1998). Still, these two part-models together add up to a "whole system model". The concept of focal zones introduces a non-static identification of a study-individual goal-dependent compromise between the "whole system model" and a "minimum model" assessment. In order to find such a reasonable goal dependent compromise in system delimitation we suggest to consider the actor's priorities, preferences and constraints in decision making. From this decision scope, or the influential sphere of the actor, processes related to the analysed product are positioned in one of three focal zones. For these focal zones, the requirements on accuracy and quality of data as well as on the resolution of unit processes considered in the assessment can be set at various levels.

This enables a streamlining of the LCA procedure in two means (PAPER V):

- Processes and aspects that are outside the decision scope of the actor will not be included in the decision scope related system model, as decisions will not include aspects that are in advance ruled out as being not relevant for the decision maker or his client. Such exclusion of processes leads to a departure from the "whole system model", except for "global" goals , and has to be considered when interpreting the generated results.
- With larger distance form the main sphere of interest or influence, the quality and resolution of the assessment can decrease. Lower requirements on data quality in the zone of secondary focus enable the inclusion of less accurate data that often can be retrieved from literature. This is "the most promising approach" for streamlining an LCA (HUNT ET AL 1998).

The positioning of processes in one of the focal zones is usually not depending on the analysed product, but entirely depending on the decision scope. Consequently, when regarding different assessments of similar products in different contexts, this positioning of processes will vary.

Choice of Allocation Procedures for Reuse and Recycling

Allocation is the activity of "partitioning the input or output flows of a unit process to the product system under study" (ISO 14040). Attributable shares of multi-functional processes are to be found by a chosen allocation procedure and are to be ascribed to the product under study. The allocation problem arises, as "most industrial processes yield more than one product, and they recycle intermediate or discarded products as new raw materials. Therefore, the materials and energy flows as well as the associated environmental releases shall be allocated to the different products according to clearly stated procedures" (ISO 14041).

Such multi-functional processes may be of two kinds:

- Processes delivering multiple functional products more or less at the same time, like for instance in the case of co-production of electricity and heat.
- Processes delivering or contributing to the delivery of functional products that succeed each other in time, like for instance production of materials that are utilised in numerous products with reuse or recycling loops between the utilisations.

In our studies, we are focussing on and addressing the second type of multi-functional processes, the allocation in that situation we denoted as "Life Cycle Allocation".

In order to enable allocation, the processes shared with other product systems have to be identified (ISO 14041). This identification of processes participating in the allocation procedure is giving the reason for the connection between the methodology topics of allocation and boundary setting. An illustration for this connection can be found in (LINDEIJER & HUPPES 1999) where the relation of system delimitation and allocation on economic basis is discussed. Before allocating, it also has to be decided which material and energy flows represent burdens – that are to be allocated – and which material and energy flows represent functions – to which these burdens are to be allocated (EKVALL 1999).

ISO 14041 defines a stepwise allocation procedure, where the avoidance of allocation by dividing unit processes into smaller subprocesses or by expanding the system boundaries to include the additional functions receive highest priority. If such avoidance of allocation is not possible, or not feasiable, as e.g. the inclusion of further functions in the assessment may be contradictory to the goal and scope definition, an allocation of environmental burdens shall be carried out.

For such allocation, there is a manifold of principles available; five are given by Finnveden (FINNVEDEN 1996):

- Allocation according to technical cause
- Allocation according to social cause
- Expanded system boundaries
- Allocation according to physical quantities
- Allocation based on arbitrary numbers

The last mentioned allocation principle is often applied in Sweden, specifically in the "50/50-method" (EKVALL 1994). Implementing arbitrary numbers as allocation procedure for recycling does however not fully comply with ISO 14041, stating concerning this allocation situation:

> The allocation procedures for the shared unit processes should use, as basis for allocation:
>
> - Physical properties
> - Economic value
> - The number of subsequent uses of the recycled material

As the allocation principle on which allocation procedures are based may represent value choices, also the choice of allocation method involves a variety of subjective aspects that are then underlying the presented inventory results. The choice of allocation method is often not given second thought, even though *value choices* underlying the choice of allocation principle are to be justified according to ISO 14040. Concerning the choice of allocation procedure it is there stated that:

> Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach. The allocation procedure used for each unit process of which the inputs and outputs are allocated shall be documented and justified.

This means in other words, that whenever allocation is performed based on one chosen allocation procedure, the consequences for the generated results *should* be indicated by presenting corresponding results generated by use of alternative procedures.

Result Sensitivity for Choice of Allocation Procedure for Reuse and Recycling

In order to enable an indication on the result sensitivity for the choice procedure for allocation in case of recycling, we have chosen to analyse a case study that is representing a "worst case" scenario. This in the sense of addressing a case study where we initially anticipated to find a high response on the chosen method. Addressing a highly recyclable building material on the material level enabled us to show the effect the choice of allocation method has on the displayed results. Meanwhile these results themselves should be interpreted very carefully, as the case study *is chosen to prove* large influence. For other materials with different recycling characteristics and production processes with other differences between production based on primary material and production based on secondary material, of course the spread will be different.

The study is based on LCI data for Swedish cold rolled hot dipped galvanised sheet steel production (BORG 1997). For the case study, three succeeding life cycles were anticipated (PAPER I):

Life Cycle #1	Steel production based on primary raw material (20% scrap). Material is made available for post usage material recycling.
Life Cycle #2	Steel production from secondary (post usage material recycling) material. Material is once again made available for post usage material recycling.
Life Cycle #3	Steel production from secondary (post usage material recycling) material. Material is not made available for further recycling, it is disposed off instead.

To these sets of data, different allocation methods are applied. To avoid an unhandy mass of data to be handled, the study only regarded four airborne emissions, CO_2, NO_x, SO_2 and dust, as well as the energy inputs.

The outcome of that case-study showed that the choice of allocation method is of major importance for the generated results. As different allocation methods facilitate different allocation principles, they handle the distribution of environmental loads in-between the involved products in very different ways. The figure below, (figure 5) displays the distribution of CO_2 emissions that are allocated to the respective product by each allocation method. The presented result shall not be generalised for other products, as the emission profiles for the involved processes vary, but it can be seen as a principle description of how the allocation methods distribute the "responsibility" for environmental loads.

The values represented in the allocation methods chosen for this study varied from *“penalise the user of virgin material”* via an *“even split between all parties”*, *“use of virgin material and disposal of material penalised equally”* to the attitude *“disposal of material is to be penalised”*. Allocation involves value choices and consequently according to ISO, the choice of allocation method has to be unambiguously justified. As usual with results incorporating value judgements, these risk being only agreed upon by people who understand and share the represented values (PAPER I).

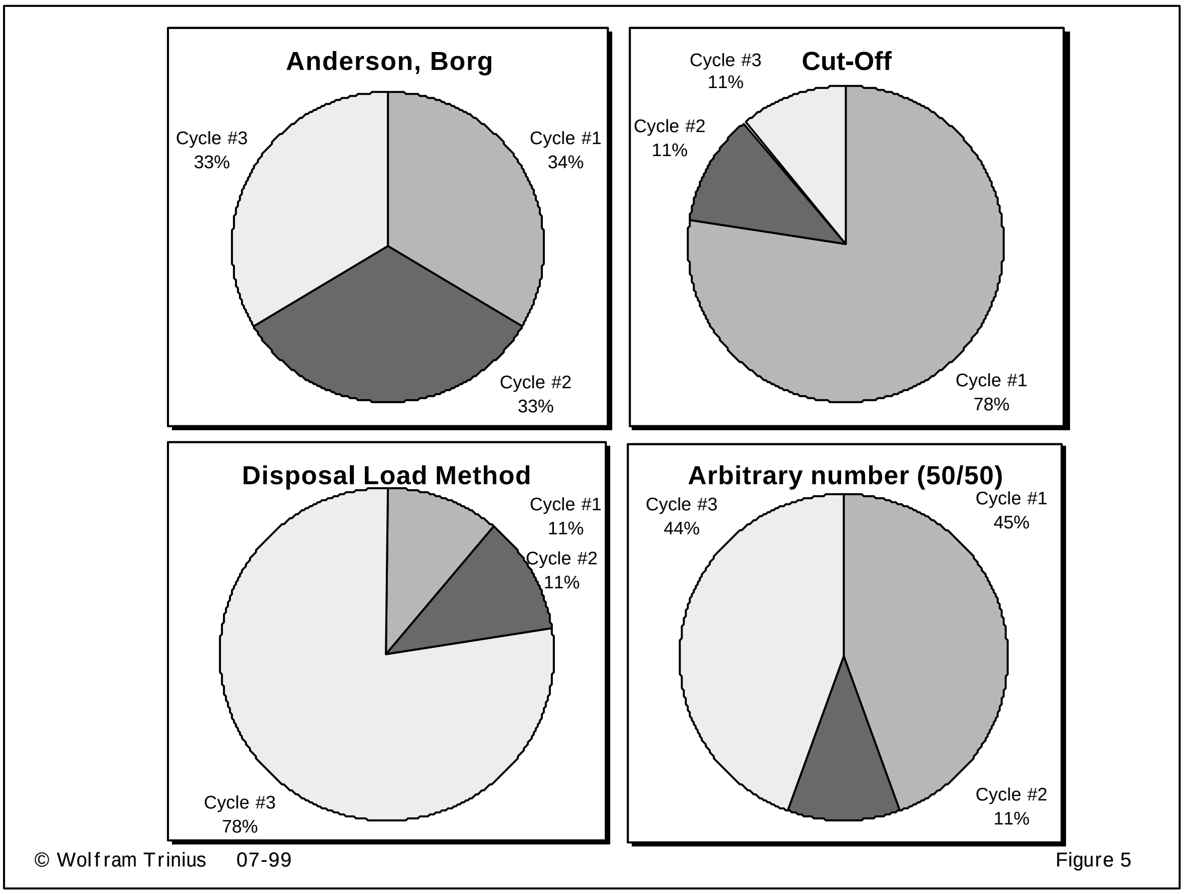

Figure 5 *Distribution of CO_2 emissions between 3 succeeding life cycles* (PAPER I) *Total Load, life cycle 1+2+3, equals 100%*

Applied Allocation methods:

- *Anderson and Borg* (ANDERSON & BORG 1998)
- *Cut-off* (EKVALL 1994)
- *Disposal Load* (ÖSTERMARK ET AL 1995)
- *50/50* (EKVALL 1994)

In a further study we have addressed more environmental loads and have compared the result spread caused by the earlier analysed allocation methods with the result influence of a set of valuation methods applied to the allocated data (PAPER III). As the goal of the study was to determine the relative importance of applying a number of allocation and valuation methods in combination with each other, we were not focussing on the final magnitude of environmental assessment "scores". The obtained result is a comparison of the result spread caused by life cycle allocation and the one caused by valuation, expressed in relation to each other.

We concluded that the presented comparison of results shows that environmental loads associated with the material steel to a large extent depend on the applied method for life cycle allocation. Within the spread of results (see figure 6) generated by such allocation, the influence of the choice of valuation method is clear, but the choice of allocation method has – in that case study – shown to be more apparent.

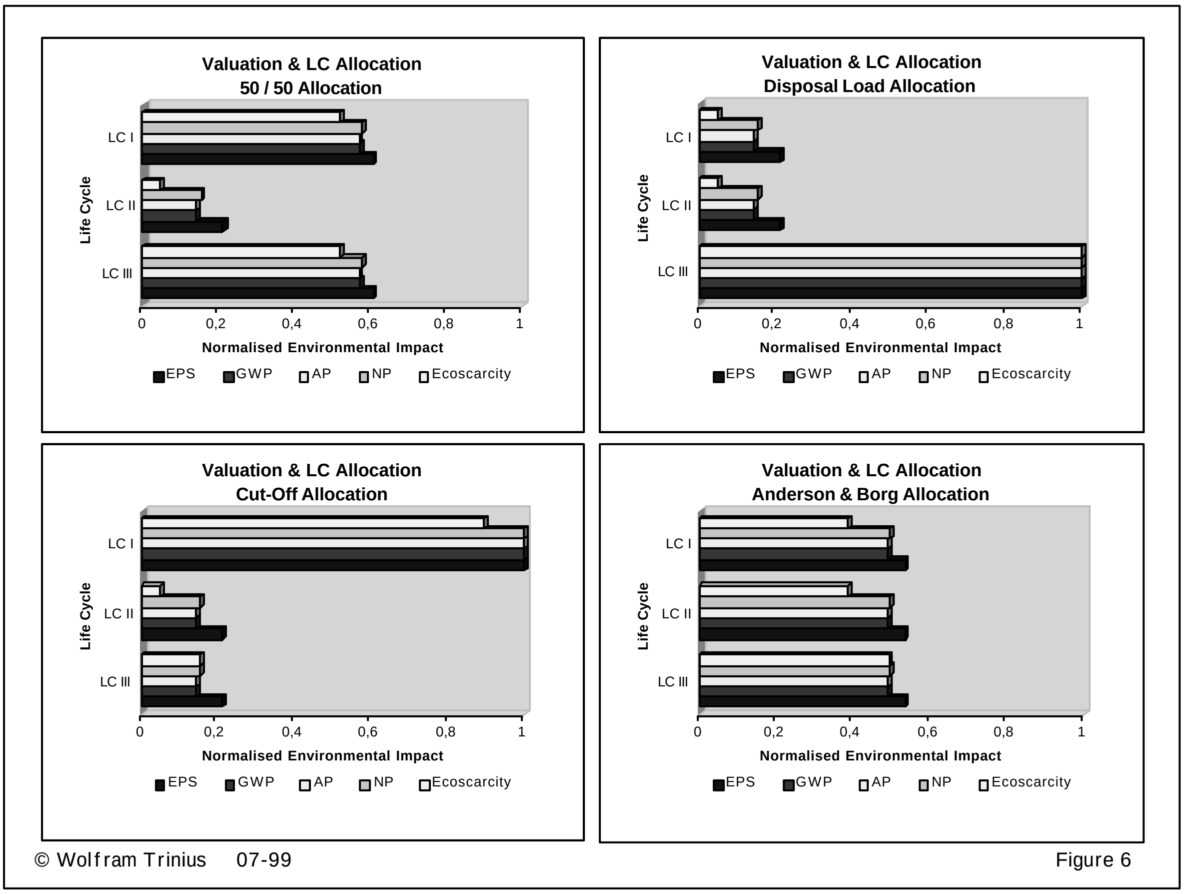

Figure 6 *Normalised relative results after allocation and valuation of LCI data* (PAPER III)
Presented values are normalised to the highest value for each life cycle separately. This enables cross comparison between the four figures.

Applied Allocation methods:

- *Anderson and Borg* (ANDERSON & BORG 1998)
- *Cut-off, 50/50* (EKVALL 1994)
- *Disposal Load* (ÖSTERMARK ET AL 1995)

Applied Valuation methods:

- *EPS* (RYDING ET AL 1995)
- *GWP, AP and NP from EDIP* (WENZEL ET AL 1997)
- *Swedish adaptation of the Swiss Ecoscarcity Method* (REFORSK 1993)

Economic Allocation Procedure for Reuse and Recycling

The in the above presented studies indicated large influence on LCA results caused by different approaches for life cycle allocation emphasises the importance of a consciously chosen approach for such allocation. The choice of approach for allocation has to be stated and related to the goal and scope definition (ISO 14040), also in order to avoid intentional or unintentional manipulation of LCA results.

ISO sates requirements concerning the reporting of the choice and justification of approach for allocation, as well as ISO lists preferences on how allocation shall be performed. Further, there is a list of criteria for "good allocation" methods by (KLÖPFFER ET AL 1996) (EKVALL & TILLMAN 1997). Facing these and with the background of the above stated two studies (PAPER I) (PAPER III), we started to develop an allocation procedure for reuse and recycling that should reflect those criteria. Further, the new method should relate to the decision taker's realities concerning the kind of information that is available, and it should embed into economic considerations decision takers face daily.

As life cycle allocation methods distribute environmental loads, or the responsibility for them, between products participating in recycling loops, approaches that consider "recycling potentials" have the tendency to move this responsibility into the future. Whether or not the scenarios underlying the assessment are realistic or not, is then not relevant for the generated environmental profile. In other words, a *potential environmental benefit* is accounted for as if being *real.* Life Cycle Allocation *methods facilitate opinions, expectations or experiences of reality.*

If allocation methods are to be generally applicable to building sector products, it is necessary that they are not based on information that is only available or relevant for certain types of materials or products. It is an ISO requirement to embed the choice of allocation method in the scope definition (ISO 14040). As part of the goal and scope definition, it is hence related to the decision making process. We chose to base this allocation method on an economic allocation principle, as it fulfils the ISO demands as well as it meets realities of decision makers. In contrast to the "market based allocation procedure" proposed by Ekvall (EKVALL 1999), that analyses the market elasticity as reaction on changes in the availability of products due to changed recycling rates, our method for life cycle allocation is based on the recyclability of materials or products in combination with the economic value of the residuals (PAPER IV). In our approach, we neither have to consider the entire chain of cascade materials, products and activities (SCHNEIDER 1994), nor the changes in the overall market situation (EKVALL 1999), unless they are reflected in the economic value of the residuals. This may lead to the implication that our approach is not comparably well-suited for strategic planning as the approaches of Schneider and Ekvall. But, with the intention of better relating to decision makers realities, we propose a method that is operational with information available during decision making. We chose recyclability and the economic value of the residuals as basis for the allocation procedure, as the market value of residuals will solve the problem of giving bonuses for fictitious recycling potentials. If there is no market for the residuals, the market value will be zero, or even below in case of waste material, and consequently there will be no environmental loads distributed to the following (possibly non-existent) use. Consequently, there will be no bonus given for "fictitious" future recycling potentials.

The general principle of this allocation method is to allocate environmental loads to a product in relation to how well and efficient resources are used in the product and made available to further post-user utilisation, expressed in terms of recyclability and economic values. The relation of material value before use and the value of comparable residuals at the same time are the key to this economic allocation principle. As economic values are considered at "today's" market situation, these values do not need to be adjusted into current value expressions. On the other hand, development in e.g. the field of recycling, taking place during the long life span of the product is by this not taken into consideration.

It is clearly demonstrated in figure 7, that a high recycling potential is often credited by other methods even for the third scenario (S3). This scenario leaves the product to waste disposal regardless the material's recycling potential. Allocating environmental loads to non-existent future uses in this scenario means that the environmental loads in practice "disappear" – they are not associated with any product. For the here presented allocation method, this problem does not occur.

This method for economic allocation can be applied not only in case of material recycling, but also in case of product reuse. The differences in applying the method in these cases are lying in the choice of processes that are to be included in the allocation procedure. We suggest application of an allocation procedure for reuse and recycling based on the recyclability and the economic value of the residuals in comparison to new material, as such information incorporates factors of high importance, such as:

- Whether or not there is a demand for secondary material of that kind and
- The quality status of the product/material/residual at hand.

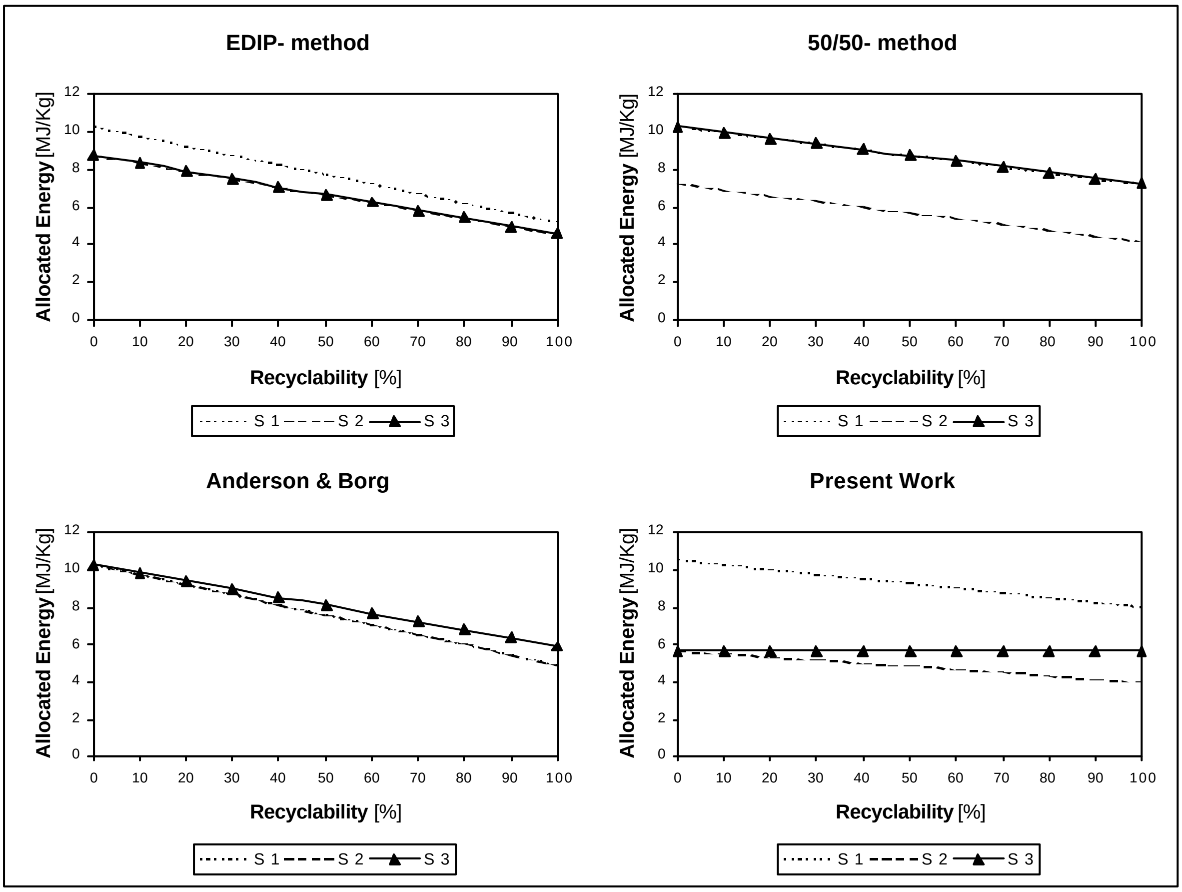

Figure 7 *Four different Life Cycle Allocation methods and their distribution of energy demand for 3 product cycle scenarios S1, S2 and S3*. (PAPER IV)

*Scenario 1 (S*1): Material based on virgin steel (20% scrap), post-usage recycling of the material

Scenario 2 (S2): Material based on recycled steel (average steel production data), post-usage recycling of the material

Scenario 3 (S3): Same as S2, but material is NOT recycled after use.

Applied Allocation methods:

- *Anderson and Borg* (ANDERSON & BORG 1998)
- *50/50-method* (EKVALL 1994)
- *EDIP allocation method* (WENZEL ET AL 1998)

Whether or not the use of recycled materials itself is beneficial for the environment and hence should be promoted by an allocation method is a question that can be addressed by chain anlysis (SCHNEIDER 1994). It is though a question that should neither be answered during the development, nor for the choice of an allocation method. In contrary, an allocation method should clearly state based on what principle any allocation is performed. Based on the represented allocation principle, the LCA practitioner should then choose an allocation method. If the allocated environmental loads then prove recycled products being favourable compared to products based on virgin material or vice versa, this result is then obtained based on the represented value choices and should not be generalised as being globally true.

CONCLUSIONS

Improving the environmental performance of products in the building and real estate sector is an important section to address when striving after sustainable development in general. Buildings affect the natural environment directly via exchanges of elementary flows with the environment, and indirectly via the use of products and services all over their life cycles. Improving the environmental performance of buildings requires among others:

- knowledge about environmental impacts of buildings
- targets to address in order to drive the development into desirable directions
- **access to analysis and assessment tools**
- access to information
- time, economic resources, good will of all involved parties and a structure in the decision making process that enables the inclusion of environmental aspects in the design and management processes of buildings and real estate.

This thesis concentrates on the third point, analysis and assessment tools. There is a large variety of assessment tools available for application in the building sector. The methodological approaches represented in these tools stretch from rather simple checklists to full life cycle assessment approaches. As the building and real estate sector involves a large number of parties, there are considerable differences in the purposes of carrying out environmental assessment studies. These differences are to be reflected in the approach and breadth of the assessment, as well as in the kind, quality, character and level of detail of generated results. Consequently, differences in tools and approaches can be related to their intended field(s) of application.

Topic	Conclusion and Result	Further Research Needs
Typology for Assessment tools	From differences in assessment tools and from the fields of key interest of involved actors, view angles for tool analysis can be identified. Analysing assessment tools concerning these view angles can assist to identify an appropriate tool for the intended application.	Implementation, development and refining, rather than further research demanded to arrive at the objective "to assist tool users in choosing an appropriate tool meeting their demands"
Context of an LCA	The context of the object of the LCA is to be identified in the scope definition; the context of the application of the LCA results is to be identified in the goal definition. The application context has strong influence on the scope. Further, the definitions made in the Goal and Scope Definition phase of an LCA are to function as anchor for later methodology choices, such as e.g. the choice of allocation procedure.	Clear guidance for users, how to identify relevant goals and how to link these through the scope definition into methodology choices. The ultimate result would be to increase the applicability of LCA results by enabling a stronger and clearer relation of methodology choices to the premises of the assessment.

Topic	Conclusion and Result	Further Research Needs
Goal and Scope Definition phase as key to methodology choices	The delimitation of the analysed system and the allocation procedures to be used during the assessment must be identified within the Goal and Scope definition phase. Further, the choice must be justified (ISO requirements). Concerning the methodology issues addressed in this thesis, the Goal and Scope definition is consequently the key to methodology choices.	
Allocation	The magnitude of presented LCA results has, for highly recyclable building materials, shown to be largely depending on the chosen procedure for allocation of environmental loads in-between the participating recycling products. In our case study, the choice of allocation method had larger importance for the magnitude of the results than the choice of valuation method.	Further case studies in order to verify the degree to which this result variation depends on recyclability. Supposedly, the result sensibility depends on material characteristics and on the parameters included in the allocation method.
Economic Allocation	A method for allocation for reuse and recycling has been proposed. The method is based on a combination of the recyclability of residuals and the economic value of these residuals. Recycling factors can be found without identification of the entire recycling cascade. From a predominant view of LCA as a model for the physical context of the assessed object, this exclusion of the entire cascade may be regarded as a weakness, whereas it is a strength when having the application context as starting point.	As the life cycle of a building can be very long, and as we are treating economic values, the question of discounting has to be addressed. Further, the proposed method has to be developed into an applicable procedure and it has to be tested for applicability and result stability. A comparison to other economic allocation procedures, namely those that address other economic relationships than ours, is desirable
System Boundaries	The "concept of focal zones" has been developed in order to better relate the analysed system to the sphere of interest of the actor at hand. This is done by identifying priorities, preferences and constraints of the decision maker	A link of the concept to economic approaches, where the monetary flow and its direction is used as inclusion/exclusion criteria can be developed.

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V ***System Boundaries according to Decision Scope – A concept of Focal Zones***
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VI ***A Typology for Environmental Assessment Tools***
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VII ***Typology for Methods and Tools for Environmental Assessment of Buildings***
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VIII ***Decision Scope Dependent System Models for LCA in the Construction Industry***
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Papers VII and VIII are reports underlying the articles in appendices V and VI.