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ASSESSING GLOBAL PRODUCT SUSTAINABILITY – DEVELOPMENT OF AN INTEGRATED APPROACH

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DEVELOPMENT OF AN INTEGRATED APPROACH

BY

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ABSTRACT

An increasingly important competitive factor for companies is how sustainably they operate and how sustainable their products are. Sustainability, therefore, has become an important issue in production and manufacturing research. The presence of numerous—even contradictory—complex definitions makes it difficult to capture the concept's main contents. It is even more complicated to express and assess specific goals, which is why many researchers from different areas focus their attention on the challenge of assessing sustainability. This master's thesis, therefore, pursues two main objectives. The first objective is to explore the terms sustainability and sustainability assessment by means of an extensive literature review. The integrated consideration of definitions, fundamentals (e.g., indicator frameworks), existing assessment methodologies and practical examples of industrially used assessment tools contributes to developing an inclusive scope what components are inherited in the complex concept of sustainability and how constitutive characteristics can be measured. Besides providing fundamental knowledge, the literature review aims to specify a framework to define the novel term "Global Product Sustainability", which was originally spawned to emphasize the importance of the consideration of the global distribution of sustainability impacts of products. For this reason the research focuses on product related assessments that include life cycle thinking in a global context.

It is recognized that current used assessment tools often neglect the importance of the integration of the global perspective. In general sustainability assessments nowadays are most often conducted to detect areas of improvement of processes, which is why they are built on principles from natural and engineering sciences. This requires expert knowledge and exhaustive data to complete assessments adequately. Lacks of data, a high demand of resources and great complexity are only an extract of emerging challenges of current assessment approaches.

These problems are addressed by means of the second major contribution of this thesis, which is the development of a conceptual approach that is able to overcome the weaknesses of existing approaches and can assess global product sustainability appropriately. The core principle of the newly developed concept is adapted from the overhead allocation within financial accounting. Assessments are no longer conducted by one party (e.g. focal company), but rather the result of a collaborative multi-stakeholder analysis. The idea is to circumvent detailed process analysis by considering companies involved in a production process as black boxes and allocate impacts to products by means of an economic partitioning factor. The consequence is a significant reduction of complexity. To evaluate the concept's practical suitability a trial application within the textiles and clothing sector was conducted, which showed that currently site-specific data is available only to a limited degree. Here is a starting point for future research. Furthermore software solutions that are accessible by all stakeholders are not existing, but indispensable for the practical implementation of the developed concept.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
AP	Acidification potential
ATC	Agreement on Textiles and Clothing
CEI	Core Environmental Indicators
CI	Composite Indicator
CSD	Commission on Sustainable Development
DJSI	Dow Jones Sustainability Index
E-LCA	Environmental Life Cycle Assessment
EF	Ecological Footprint
EPR	Extended Producers Responsibility
FPSI	Ford Product Sustainability Index
GPS	Global Product Sustainability
GRI	Global Reporting Initiative
GWP	Global Warming Potential
HDI	Human Development Index
ICT	Information and Communication Technology
ISO	International Organization for Standardization

LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCT	Life Cycle Thinking
MFA	Multi Fiber Agreement
NIST	National Institute of Standards and Technology
OECD	Organization for Economic Cooperation and Development
PCF	Product Carbon Footprint
PLC	Product Life Cycle
PROSA	Product Sustainability Assessment
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
S-LCA	Social Life Cycle Assessment
SETAC	Society of Environmental Toxicology and Chemistry
SMIR	Sustainable Manufacturing Indicators Repository
T&C	Textile and Clothing
TBL	Triple Bottom Line

1 INTRODUCTION

This thesis provides an extensive overview of the broad discussed topic of sustainability and sustainability assessment by means of an extensive literature review. Furthermore, a concept to assess the novel term *Global Product Sustainability* will be theoretically developed. The first section of this chapter presents the background of the study and exposes the gaps and concerns that justify research in this field. The second section describes in more detail the derived objectives of this study and the procedure by which they can be achieved.

1.1 Background, Motivation, and Related Problems

> "Sustainable development, sustainable growth, or just sustainable are genuine and deeply felt and complex. The combination of deep feeling and complexity breeds buzzwords, and sustainability has certainly become a buzzword."
>
> (Solow 1991, p.179)

Many people make associations through buzzwords without actually knowing what these terms mean. Sustainability is defined in many different ways by a myriad of organizations. In common with all is the concept that sustainability is something about humankind's obligation to the future. Definitions are vague and far from precise (Solow 1991). For example, the UNESCO proposes that "… every generation should leave water, air, and soil resources as pure and unpolluted as when it came on earth" (economist.org 2002; Solow 1991, p.180). Another definition, not as extreme but equally as vague, is to leave future generations the capacity to be as well off as the present generation in terms of three dimensions: society, environment, and economy (WCED 1987).

However, present conditions show that sustainability—despite its definition—is an issue of relevance and importance. This becomes clear if some easy considerations are taken into account. The world's population is continuously growing and has more than doubled since 1960 (United Nations 2011), and has recently exceeded seven billion. In parallel, standards of living have improved enormously and emerging economies are growing fast with the demand for many natural resources. The problem is that this demand for resources often exceeds the supply, which makes it difficult to meet needs of the present without compromising and penalizing future generations. Companies, societies, and governments have realized that the Earth is not an "unlimited store of resources," but rather comprises fragile and complex ecosystems (Graedel & Allenby 2010). Nonetheless, everyone consumes products in some form, which is why manufacturing companies are specifically targeted when talking about sustainability. There have been an increasing number of legal regulations, as well as consumer demand, to integrate sustainability into the design and development of new products. Thus, it has become an important competitive factor for companies to demonstrate sustainable operations and products. On the one hand, firms are judged externally while on the other they measure themselves by how they pursue their goals of sustainable development. However, the principle is widely accepted, if not yet widely practiced by companies (Kaebernick et al. 2003). As a consequence—to increase awareness—an enormous amount of research is being conducted in this field. In these times, sustainability is a broad, complex, controversial, and challenging issue (Richards & Gladwin 1999). This leads to the first problem:

1) How are/is sustainability and/or sustainable development defined in our globalized world? What is the meaning of the novel term Global Product Sustainability?

Definitions might usually be boring, but in the field of sustainability, they matter a lot and are necessary to transfer goodwill into actual activities, which directly lead to the next emerging issue. The question is no longer "Why is sustainability important?" but rather "How do we approach sustainability most effectively to gain advantage, leverage capabilities, and reduce future risks?" (The Boston Consulting Group 2014) "For the transition to sustainability, goals must be assessed" (Ness et al. 2007, p.498). To set up an operational concept containing useful assessment tools and practical indicators that measure product sustainability, it is important to understand how sustainability can be measured and, therefore, whether progress against targets is made (Schwarz et al. 2002). A major challenge, therefore, is to consolidate the measures for all three dimensions of sustainability (Kloepffer 2003). Furthermore, concepts like Life Cycle Thinking and Extended Producers Responsibility broaden the scope of assessing sustainability to a global level, involving various stakeholders and numerous countries and regions. The emerging questions are:

2) What are the current approaches used to assess product sustainability and meet the stated challenges? How are these approaches constructed and what are their limitations?

Methodologies to assess the social dimensions of sustainability are still in their infancy (Kloepffer 2008; O'Brien et al. 1996) and require further research. Additionally, current approaches are mostly conducted by third-party organizations or focal companies that aim to assess impacts along the entire production process and product life cycle phases. Thus, current approaches are not only time consuming, but also present opportunities to downplay or cover impacts by consciously neglecting certain impacts within the assessment, or by means of outsourcing activities (e.g., offshore hazardous processes to countries with less restrictive regulations) (Schmidt 2010). Furthermore, companies should not only bear responsibility for their own (direct) sustainability impacts, but also for indirect impacts (e.g., those caused by suppliers, post-production processes, and consumers) incurred along the global chain. Current assessment methods are not capable of capturing such impacts appropriately, which leads to the following problem:

3) What functionalities does an approach need to encompass to meet such requirements and how can these be practically implemented?

4) In this context, it is also questionable whether an *effective assessment of Global Product Sustainability might affect future location decisions.*

1.2 Objectives and Procedure

It becomes clear that this study is embedded in a field with an extensive scope. The title and larger goal of the study (to assess *Global Product Sustainability* by developing an integrated approach) initially delimits this study from certain areas of sustainability. The terms *global* and *product* indicate the inherent direction of research. To achieve the stated objective, several sub-objectives are pursued in this study. These are classified as either *general/solely theoretical* or *theoretical/conceptual*, and which are summarized below:

a. General/solely theoretical:

- Provide profound knowledge of the meaning of *sustainability*, including the term's history, its development, critical opinions, and most commonly used definitions.
- Derive an appropriate definition for the novel term *Global Product Sustainability*.
- Review the current state of (integrated) sustainability assessment (fundamental principles, assumptions, features, and examples of practical implementation) and detect possible limitations.

b. Theoretical/conceptual part

- Develop a framework/concept to assess *Global Product Sustainability* that is capable of capturing the term's entire scope.

- Discuss the applicability and usability of the developed concept within the textiles and clothing sector (as a representative industry for consumer products).

In addition, this study aims to summarize comprehensive knowledge as a basis for anyone who wants to start working in the broad field of sustainability.

The procedures followed in this study are illustrated in Figure 1-1. The general procedure orients itself toward the problem-solving cycle. Based on the problem formulation (Chapter 1), the current situation is analyzed (Chapter 2) to identify restrictions and limitations of state-of-the-art sustainability assessment methodologies. This leads to a clear understanding of the objectives and requirements that have to be fulfilled (Chapter 3). Chapter 4 concentrates on the development of a solution, which will then be evaluated by means of a trial application within the textiles and clothing sector. Chapter 6 closes with a summary and a discussion that contains recommendations for further research.

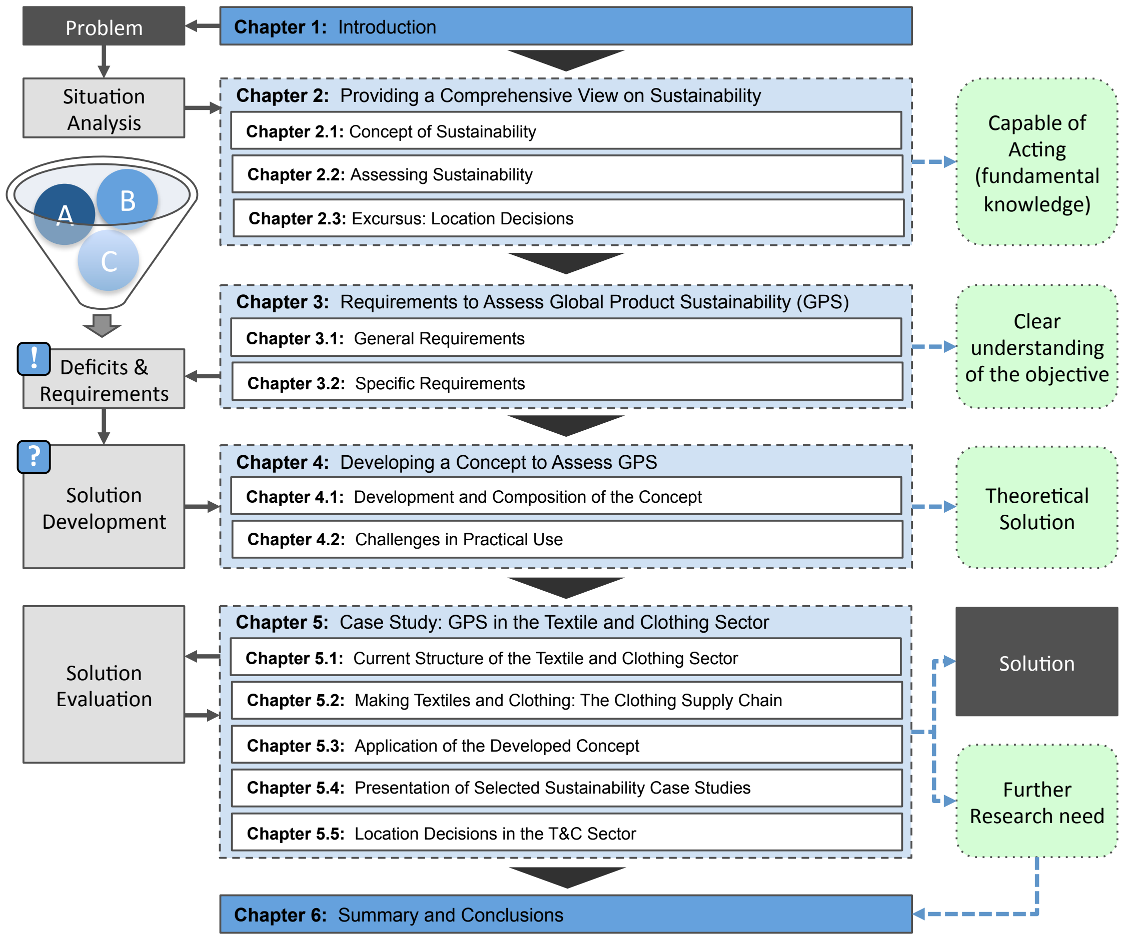

Figure 1-1: Overall procedure of the study

2 PROVIDING A COMPREHENSIVE VIEW ON SUSTAINABILITY ASSESSMENT

After addressing the objective, motivation, and structure of this work in the previous chapter, this chapter serves to provide a comprehensive overview on sustainability assessment; therefore, the necessary basics will be explained. The contents of Chapter 2 are shown in Figure 2-1.

Section 2.1 provides an extensive overview on the topic of sustainability, including a short historical background, followed by a definition of the term “sustainability” used in this work. Approaches to sustainable development are presented, followed by a critical examination of existing definitions of sustainability. The first chapter section closes with the synthesis of a novel term: “Global Product Sustainability,” or GPS, based on the previous discussion.

Section 2.2 deals with the broad topic of assessing sustainability. In a first step, major terms used in this field of research are defined and linked to each other through Section 2.2.1. The following sections then provide a progressive framework and the indicators necessary to assess sustainability. Section 2.2.3 importantly introduces prominent methods to assess all three dimensions of sustainability. These are Environmental Life Cycle Assessment, Life Cycle Costing, Social Life Cycle Assessment, as well as integrated assessment methods. Finally, the commercial tools used to assess sustainability comprehensively are explained. To provide additional clarity, Section 2.3 illustrates an excursus on location decisions. The description of models and frameworks in Section 2.3.1 is followed by a discussion on how sustainability is currently considered in location decisions.

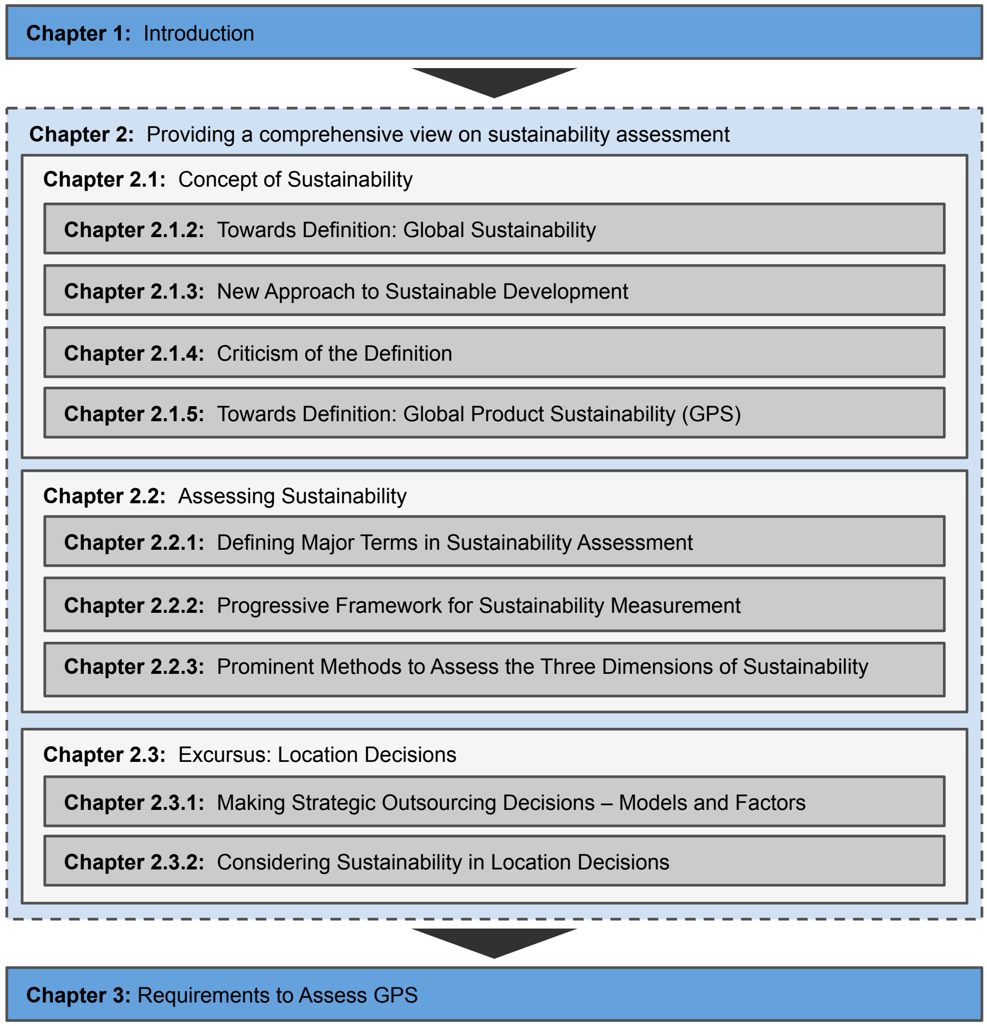

Figure 2-1: Structure of Chapter 2

2.1 Concept of Sustainability

An increasingly important competitive factor for companies in the 21st century is how sustainably they operate and how sustainable their products are. On one hand, they are judged externally (e.g. by consumers) and, on the other hand, companies measure themselves by how they pursue the goals of sustainable development. Particularly within the manufacturing industries, an increasing number of companies realize that sustainable business practices that result in environmental benefits can also bring substantial financial benefits. This is the case if fore example less waste is generated or less resources are used in production. However, the term sustainability is used in numerous contexts and disciplines. Sustainability, or the ability to sustain, has become a buzzword in media and we encounter this term in our everyday life. "The meaning of the term is strongly dependent on the context in which it is applied […]" (Brown et al. 1987, p.713). Furthermore, the "term is much-used, and sometimes misused […]" (Kloepffer 2008, p.89), which leads to the question of what sustainability, or being sustainable really is, particularly in the manufacturing context. Everyone has a concept of sustainability; however, to operationalize sustainability, the exact meaning has to be defined. According to Bond and Morrison-Sanders (2011) and Bell and Morse (2008), there is currently no agreement on a definition of sustainability. For this reason, it is inevitable that the concept of sustainability is examined to provide the basic scientific understanding necessary to focus a thesis on "Global Product Sustainability."

Historical Background of Sustainability. Nowadays, the word sustainability is used in many different contexts. To understand why sustainability has become a term of increasing interest for research and industry, a look back at the 18th and 19th century is expedient. This period is characterized by industrialization and the associated use of fossil fuels to operate machines and generate electricity. Furthermore, developments in the field of medical technology and modern sanitation systems during this age made it possible to protect large populations from diseases and illness (Hilgenkamp 2006). The consequences were an explosion of the human population and industrial, technological, and scientific growth that has never existed before. Particularly after the great depression and World War II, the developed world entered an unprecedented period of growth. Looking at the *World Populations Prospects* released by the United Nations Department of Economic and Social Affairs, the global population has grown hyper-exponentially over the past 200 years, and has more than doubled since 1960 (United Nations 2011). During this time, society has been transformed by innovations in technology and the continuing use of fossil fuels. A change of circumstances initiated by this formation was the flashpoint for a broad range of different organizations to draw attention to the impact of those developments, especially on the environment. They pointed out the environmental costs in relation to the benefits enjoyed, such as increased efficiency and wealth. In particular among these organizations, is *The Club of Rome*.

The Club of Rome, founded in 1968, describes itself as an association of personalities from fields of science, culture, economics, and politics from all regions of the world, which share a common sense for the future of humanity. Founded by FIAT manager Aurelio Peccei and the OECD General Director, Alexander King, the mission of this global think tank is to “act as a global catalyst for change through the identification and analysis of the crucial problems facing humanity and the communication of such problems to the most important public and private decision makers, as well as to the general public” (Clubofrome.org 2014). The world public came to know The Club of Rome mainly after it published the report “The Limits to Growth” in 1972. That report attempts to simulate the interactions between Earth and human systems, and their consequences on a global scale by the end of the 20^{th} century (Meadows et al. 1972; Watson et al. 2005; Loh et al. 2008). This report could be seen as the first milestone in the history of sustainability literature and a trigger for the following research.

2.1.1 Towards Definition: Global Sustainability

An article published in 1987 in the *Journal of Management* summarized the research that had been conducted in this area and tried to capture the ambiguity of the term "sustainability". The term sustainability is used in numerous different disciplines and contexts. Its meaning ranges from *maximal sustainable yield* in the context of forestry and fisheries management, to the newly applied social concepts, such as the sustainable society and a steady-state economy (Brown et al. 1987); therefore, the meaning of the term sustainability is strongly context-specific. As the number of sustainability-related terms increases, such as sustainable development, sustained use of the biosphere, and ecological sustainability, suitable definitions have also become increasingly important (Brown et al. 1987). To clarify these terms and come up with an appropriate definition, Brown et al. (1987) reviewed a wide range of articles and reports, which were published around the 1980s by prominent scientific and policymaking institutions. Examples are the *Man and the Biosphere Program* of UNESCO, the *International Geosphere*‑*Biosphere Program* of the International Council of Scientific Unions (ICSU), the *Earth Systems Science Program* of the National Aeronautics and Space Administration (NASA), and the *Global Environmental Monitoring System* of the United Nations Environment Program (UNEP). Furthermore, the relevant literature reveals that the World Commission on Environment and Development of the UN, the Population, Resources, and Environment Program of the American Association for the Advancement of Science (AAAS), and the program on Ecological Sustainable Development of the Biosphere of the International Institute for Applied Systems Analysis (IIASA), have a major focus on global environmental policy making.

The reflected and discussed topics, concepts, and definitions are: sustainable biological resource use (Tivy & O'Hare 1981), sustainable agriculture (Conway 1985), carrying capacity (World Resources Institute and International Institute for Environment and Development (WRI/IIED) 1990), sustainable energy (Anderer et al. 1981; Lovins 1977), sustainable societies and economies (Brown 1981), and sustainable development (Repetto 1985). These terms will not be explained in detail in this work. Of more interest here is the following resulting list of emerging themes, or elements, that should be considered in an appropriate definition of sustainability, with the major focus on the inclusion of a global perspective:

- The continued support of human life on earth.
- Long-term maintenance of the stock of biological resources and the productivity of agricultural systems.
- Stable human populations.
- Limited growth economies.
- An emphasis on small-scale and self-reliance.
- Continued quality in the environment and eco-systems.

The definition of sustainability can be derived from these elements in different ways. In a narrow sense, the term could be defined as the global indefinite survival of the human species. In a broader sense, global sustainability includes the goal that all humans, once born, are able to live to their adulthood with a quality of life beyond mere biological survival. An even broader definition includes, in addition, all components of the biosphere, including those with no apparent benefit to humanity (Brown et al. 1987). All these definitions portray an anthropocentric view of sustainability.

Sustainability and sustainable development gained further attention in 1987, when the United Nations World Commission on Environment and Development (WCED) published its report, *Our Common Future*, also broadly known as the Brundtland Report[1]. Its objective, or mission, comprised three main points. The first ambitious goal was to formulate a catalogue of measures to enumerate innovative, realistic, and concrete action proposals that address critical environmental issues and development. The second objective was to strengthen international collaborations regarding environment and development so that existing patterns can be altered and policy-makers influenced in the direction of necessary change. The third objective of the Brundtland Report was to enhance the understanding and commitment of individuals, voluntary organizations, businesses, institutes, and especially governments, on sustainability (WCED 1987).

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[1] Named after the former Norwegian Prime Minister Gro Harlem Brundtland.

[2] The expression was developed by environmentalist and economist J. Elkington in 1997 and describes a mode of corporate reporting that comprises environmental, social, and economic issues (McKenzie 2004).

In general, the term sustainability has caused many stakeholders (e.g., policy makers, environmentalists, and industry decision-makers) to shift and broaden their focus in many directions (Heijungs et al. 2010):

- The assessment of costs and benefits has been expanded from private to societal;
- the economic assessment has been expanded to include environmental and social aspects;
- the realization that every actor is embedded in a chain of activities has led to the incorporation of supply chains, product life cycles, and extended producer responsibility.

Irrespective of the described agenda, the Brundtland Report is widely known for its internationally recognized definition of the term sustainable development, which describes, in non-technical language, an approach to meet identified challenges of environmental protection and economic development. The following section serves to define sustainable development in more detail.

2.1.2 New Approach to Sustainable Development

The topic of sustainable development is wide-ranging, complex, highly contested, and challenging. "Sustainability in the context of sustainable development is [a] complex, controversial, and challenging [issue]" (Richards & Gladwin 1999, p.11). However, most participants of the Stockholm conference began their sustainability investigations from an environmental perspective; nonetheless, the Brundtland commission recognized that environmental conservation is not possible without human resource management in terms of poverty reduction, gender equity, and wealth redistribution. The Brundtland Report named this the concept of "needs," whereby attention is given to the essential needs of the world's poor (WCED 1987). Furthermore, the commission found that economic growth, particularly in industrial and industrialized countries, is restricted by environmental limits. Thus, the World Commission on Environment and Development proposed the hypothesis that sustainability has three dimensions that have to be integrated: environmental, economic, and social. These dimensions are also referred to as the "Triple Bottom Line"[2] (McKenzie 2004).

According to the Brundtland Report, a state of sustainability, in this sense, is achievable through the approach of sustainable development, which is defined as a

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[2] The expression was developed by environmentalist and economist J. Elkington in 1997 and describes a mode of corporate reporting that comprises environmental, social, and economic issues (McKenzie 2004).

“… *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED 1987, p.9).

The foundation of this definition is a very powerful ethical imperative. Every individual and institution should consume and produce with respect to the well-being of our descendants. “The new paradigm of development demands that we take a multigenerational view in seeking to harmonize socio-economic and environmental goals” (Raskin et al. 1998, p.2). This is currently the most cited definition of sustainability and sustainable development[3]. Even if the definition, to be precise, only defines the term sustainable development, it is now commonly cited as a definition of sustainability as a whole (McKenzie 2004). Due to the above-mentioned integrated view of the three dimensions of sustainability, the concept is commonly illustrated in the literature by three overlapping circles (see illustration in Figure 2-2).

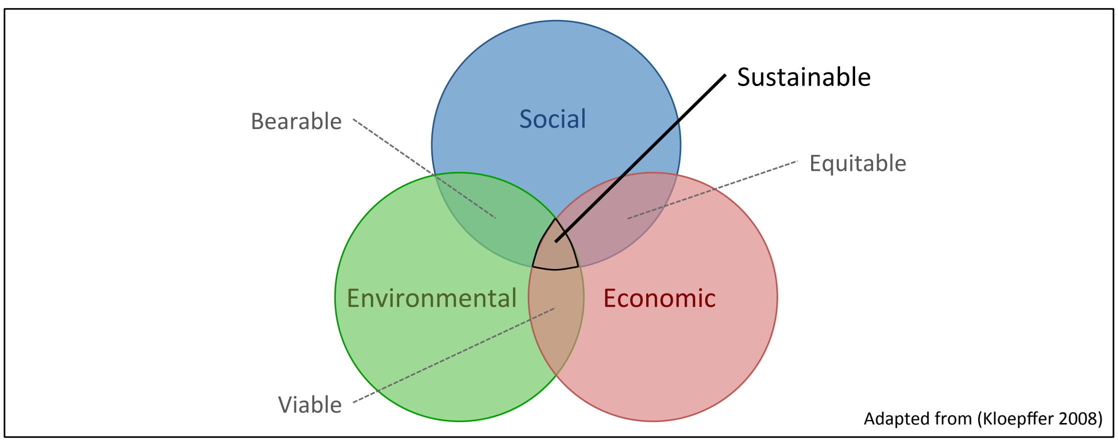


Figure 2-2: Three Spheres of Sustainability

[3] According to Google Scholar, the original Brundtland Report has been cited about 4200 times.

The publication of Our Common Future served as a major foundation for the 1992 United Nations Earth Summit in Rio de Janeiro, which characterized a third milestone toward the goal of sustainable development. The key achievements of this conference were agreements on climate change, biodiversity, and Agenda 21 (Robinson 1993). Agenda 21 is basically an action program for global sustainable development that made the concept of sustainability a formal political principle (Goethe-Institut 2014). Additionally, the Rio Declaration[4] was produced. This is a short document that includes 27 principles to guide future sustainable development (United Nations 1992). In subsequent periods, the UNCEDs Earth Summit took place every ten years. The 2002 conference focused more on social issues while its success was rather limited. The 2012 Earth Summit results were the so-called Johannesburg Declaration and included numerous international partnership initiatives meant to help achieve the Millennium Development Goals (MDGs). In summary, the MDGs are eight international development goals with specific targets and dates all 189 (currently 193) United Nations member states agreed to achieve (UNG 2000).

[4] Informally known as the Earth Summit.

2.1.3 Criticism of the Definition

The Brundtland definition of the sustainable development agenda and, particularly, the definition of sustainable development, are not only the most cited definitions, but they are also definitions that have been much criticized (McKenzie 2004). The most serious criticism is that the definitions are purposely vague with regard to the needs and interests of all stakeholders. The definition is described as a “smokescreen behind which business can continue their operations, essentially unhindered by environmental concerns while paying lip service to the needs of future generations” (McKenzie 2004, p.2). Due to the nebulosity of the definition, it becomes possible for businesses and corporations, as well as their government supporters, to pretend that they are acting in favor of sustainability while they are actually causing unsustainability (Jacobs 1999; O’Riordan 1988). Joshi (2002, p.7) argues that the focus on development in areas of poverty “tends to evade the uncomfortable issue of the need to restrain consumption on the part of the affluent.” Another thought-provoking argument is the so-called “brown-agenda”. This states that environmental destruction can only be controlled through economic development and the preservation of human capital and builds on the thesis that the worst ecological destruction often occurs in areas of high poverty and poorly developed social systems; for this reason, therefore, an increase in social capital due to development will lead to improved environmental conditions (Joshi 2002). From an environmental perspective that sounds attractive, but the proposition that sustainable developments always leads to benefits for third or fourth world countries and their citizens has also been critiqued. For example, in his paper, Banerjee explores "Who Sustains Whose Development" and argues that:

> "sustainable development, rather than representing a major theoretical breakthrough, is very much subsumed under the dominant economic paradigm. As with development, the meanings, practices, and policies of sustainable development continue to be informed by colonial thought, resulting in disempowerment of a majority of the world's populations, especially rural populations in the Third World. Discourses of sustainable development are also based on a unitary system of knowledge and, despite its claims of accepting plurality, there is a danger of marginalizing or co-opting traditional knowledge to the detriment of communities who depend on the land for their survival" (Banerjee 2003, p.144).

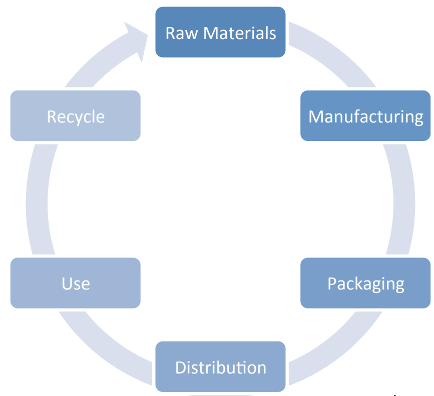
Nevertheless, despite the criticism and controversy of opinions, there is agreement in literature that there are interrelationships among the environmental, economic, and social dimensions of sustainability, and that progress can only be achieved if all are considered simultaneously (Seliger 2007).

According to the Brundtland definition, this study uses the terms sustainability and sustainable development interchangeably. However, the mentioned criticism will be considered in the following research. Specifically, Section 2.2.3.3 will pay attention to the most frequently discussed and controversial social dimensions of sustainability.

2.1.4 Towards Definition: *Global Product Sustainability* (GPS)

The focus of this study is on a concept comprising three words: “Global,” “Product,” and “Sustainability”. The term Global Sustainability (Sustainable Development) has been defined in Sections 2.1.2 and 2.1.3. However, this definition does not incorporate the required product view; therefore, this section serves to explain why it is expedient to include the product view. The goal is to close this chapter with an appropriate definition of *Global Product Sustainability* for use in the context of this study.

Based on the concept of sustainable development, the inherent term sustainable manufacturing provides a starting point for the investigation. A widely recognized definition is given by the U.S. Department of Commerce, which defines sustainable manufacturing as “the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers, and are economically sound” (U.S. Department of Commerce 2007). On one hand, this definition stipulates again the integrated view of all three dimensions: economic, social, and environmental. On the other hand, it states that sustainable manufacturing includes both the manufacture of sustainable products and the sustainable manufacturing of all products. According to the National Council for Advanced Manufacturing (NACFAM), the former definition includes “manufacturing of renewable energy, energy efficiency, green building, and other green and social equity-related products” and, moreover, emphasizes that “sustainable manufacturing of all products [has to take] into account the full sustainability life cycle issues related to the products manufactured" (NACFAM 2007). Although, at first glance, this definition considers product life cycle stages sustainable manufacturing is more process- than product-orientated, as is true of much of the research on sustainability. Nevertheless, it has become accepted that a product-oriented approach is more useful than a process-oriented one to maximize the potential of cleaner production (Weenen 1995). Basically, the concept of integrating the whole product life-cycle (PLC)—from cradle-to-grave—provides a practical framework, when the goal is to consider products from a sustainable point of view (UNEP/SETAC 2009). This approach is also referred to as life cycle thinking (LCT), and includes environmental, social, and economic impacts on a product over its entire lifetime, instead of only focusing on the manufacturing or production stage. A complete life cycle includes pre-manufacturing (raw material extraction), manufacturing (design and production), transport (packaging and distribution), usage (including maintenance), and post-use (end-of-life and disposal) (UNEP/SETAC 2009; Maxwell et al. 2006). LCT strives to achieve both the reduced use of resources and fewer emissions created during production, and simultaneously increase socio-economic performance for all life cycle stages. Phenomena like the so-called Extended Producers Responsibility (EPR) and Integrated Product Policies, which aim to hold companies responsible for impacts caused by their products, promote approaches like LCT. Recent developments show an advancement of the classic life cycle approach ("open loop" or cradle-to-grave concept) to a "closed loop" life cycle approach. Figuratively speaking, this means transforming the linear approach (ending with end-of-life or disposal) to a closed circle, which also includes product recovery and reuse (see Figure 2-3 (Ellen MacArthur Foundation 2013).



Adapted from (Ellen MacArthur Foundation 2013)

Figure 2-3: Product Life Cycle (cradle-to-grave)

Even though these concepts and their related challenges are known and broadly discussed, the focus of this discussion needs to change. Current product-oriented approaches pay too much attention to the end-of-life phase of a product and concerns like waste management, take-back, reuse, and recycling (Weenen 1995), which are basically environmental issues. In the future, special priority must be given to social concerns (e.g., working conditions) and the use phase of the PLC (Alwood et al. 2006). In summary, a broader product-oriented approach is required. Important also is the integration of sustainable product development as a kind of prevention strategy to minimize impacts across the whole PLC. Thus, the development of sustainable products is considered one of the main challenges of the 21st century (Maxwell & Vorst 2003).

To build a comprehensive theoretical foundation, the term *sustainable supply chain management* is adopted to serve as an input for commonly understood definitions in the realm of global product sustainability. In other research, sustainable supply chain management is closely linked to the establishment of life cycle management (Seuring 2004). In general, a supply chain describes a network of organizations, people, information, and resources involved in different value-added processes and activities in the form of products and services for the end user (Chen & Paulraj 2004). As described above, different stages of the production process accrue different kinds of environmental and social impacts. Nowadays, focal companies are usually held responsible for the performance of their suppliers in those terms. Apparel distributors, in particular, such as Nike, Levi Strauss, C&A, and Adidas, have been blamed for problems caused by the production of their clothes. Poor working conditions (Preuss 2001; Graafland 2002) and local environmental disruption (Seuring 2001) are mentioned as examples of these problems. With the goal to provide an overview on sustainable supply chain management, Seuring and Müller (2008) took 191 papers on this topic, published between 1994 and 2007, into account. The first realization was that the research was still dominated by environmental issues and that papers on the integration of social aspects, as well as on the amalgamation of the three dimensions of sustainability, were still rare. With respect to the present study, the most important findings from their review are: focal companies, in particular, need to concentrate more on the longer part of the supply chain, which means giving more attention to the sourcing of minor components to reduce their own risk. The need for cooperation among different companies belonging to a (sustainable) supply chain is, therefore, increased (Seuring & Müller 2008).

Building on the previously examined definitions and explanations, the term *Global Product Sustainability* can be defined as follows:

> *Global Product Sustainability is a state achieved due to products that satisfy customer needs and gain a competitive advantage in the market and are developed and designed to improve their environmental, economic, and social impact in the long run. During all phases of their product life cycles the interrelation among those three dimensions is considered in every kind of decision-making, such that the needs of the present could be met without compromising the ability of future generations to meet their own needs. Impacts causing both advantages and disadvantages for every country and region affected in the product life-cycles have to be attributed transparently to the element in charge to ensure comprehensive global objectivity.*

2.2 Assessing Sustainability

"You can't manage what you can't measure."

The American engineer, statistician, professor, author, lecturer, and management consultant W. E. Deming is often incorrectly given attribution for the quote. Quite the contrary, he stated that running a company on visible figures alone is one of the biggest diseases of management. However, even if the statement sounds like an old management adage, it still rings true. In non-technical language, you cannot know whether an activity is successful unless there are defined and traceable indicators. Ness et al. (2007, p.498) claim that "for the transition to sustainability, goals must be assessed".

There are multitude books, journal articles, and reports that address the problems faced in sustainability assessment. Currently, there are no common standards for evaluating sustainability initiatives (Searcy & Mccartney 2009; Tweed 2010). Some authors even hold that there are incompatibilities among existing sustainability performance measurement approaches (Lehtinen & Ahola 2010). One of the main reasons for this is the extensive range of this field of research, which largely reflects increasing pressure by various stakeholder groups (e.g., government regulators, community activists, non-governmental organizations (NGOs), and global acting companies). One main contribution of this thesis will be, therefore, to provide some clarity and structure and to sensibly condense the countless pieces of information that have accumulated in the process of gaining access to this ever-increasingly important field of research. A SCOPUS search at the start of this study impressively illustrates the increasing prominence of measuring or assessing sustainability. Searching for the keywords (sustainability) AND (assess OR assessing OR measure OR measurement OR metric OR indicator OR index) in the title, and further restricting results to releases after 1990, gave a total of 1541 publications in various subject area categories (most findings were in the environmental, social, agricultural, biological, and engineering domains). Furthermore, the results show a clear trend toward even more publications in these fields (see Figure 2-4).

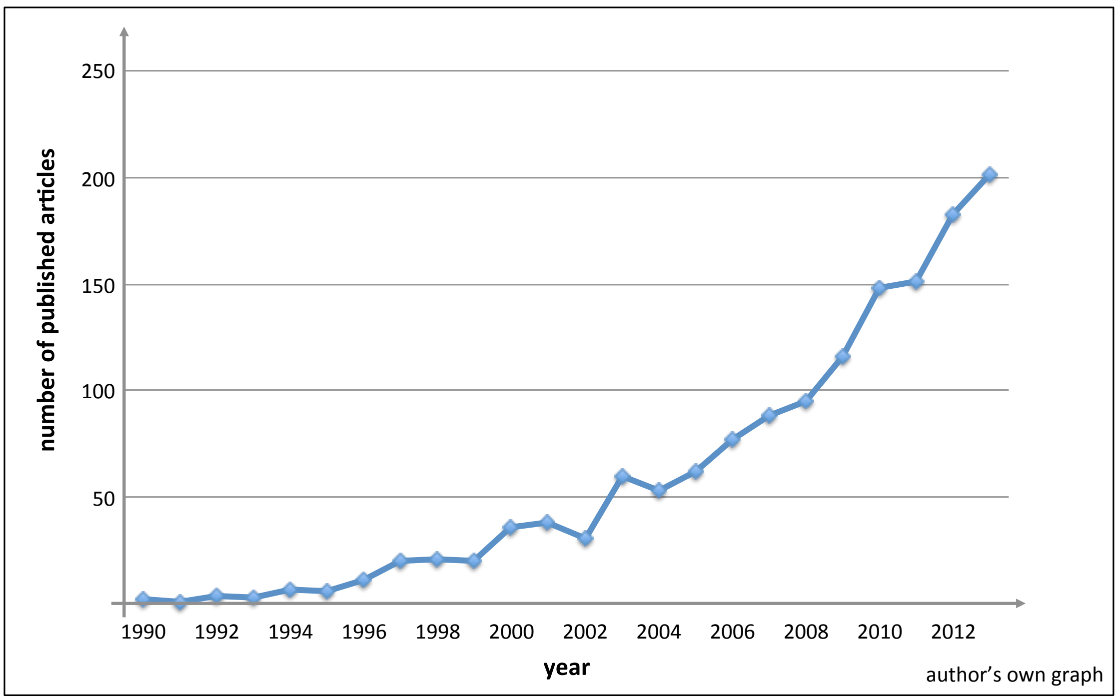


Figure 2-4: Temporal development of publications in the field of assessing sustainability

It is interesting to note that, even in its conceptual infancy, research on how to measure sustainability impacts was published. For example, Liverman et al. (1998) published an article on measuring global sustainability in which the most common measures of sustainability were discussed[5]. In spite of the fact that the term sustainability was ill-defined at that time, their study found that nearly all existing indicators failed to measure sustainability in an appropriate way. However, the objective of this study is not to face the problem of assessing sustainability from the perspective of history. For this reason, only current and groundbreaking, or innovative, publications were considered significant in this study.

[5] Measures introduced, for example, in the *World Development Report* of the World Bank (1986) (The World Bank 1986), and in the World Resources series, jointly published by the World Resources Institute and the International Institute for Environment and Development (WRI IIED 1986).

2.2.1 Defining Major Terms in Sustainability Assessment

In a first step, the most important terms used in the field of assessing sustainability should be defined or explained to provide a common understanding. While reviewing the relevant literature, it is noticeable that certain terms are used in the majority of publications. However, some terms and definitions are used in different contexts.

Tools. *Tools* are used to measure or assess sustainability. Devuyst et al. (2000, p.68) define sustainability assessment as "[…] a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable." and "which examines whether human activities will lead to a more sustainable society". More precisely, Bond and Morrison-Saunders (2011, p.2) describe sustainability assessment as "[…] the derivation of indicators [that] can be used as measures of the state of the socio-economic and biophysical environments and, therefore, used as the basis for predictions where there is a development intervention".

Framework. To provide a categorization of these tools, *frameworks* are used. Many authors have demonstrated that frameworks can be used to categorize assessment tools and methods based on numerous factors or dimensions (H. Baumann 1999; Moberg 1999; Wrisberg et al. 2002; Finnveden et al. 2009; Finnveden & Moberg 2005). For example, Ness et al. (2007) consider temporal characteristics, the focus (coverage area; e.g., product or policy) and integration of nature‑society systems as factors in their inventory. The term framework is also used at a lower level to describe a certain tool and how it is constructed (these terms can be synonymously). In such cases, frameworks typically address the three generally accepted dimensions of sustainable development and describe which criteria are listed under each dimension (economic, environmental, and social). Such frameworks are also referred to as indicator frameworks, since they include sets of indicators (Labuschagne et al. 2005). Fundamental representatives of these kinds of tools are, *inter alia*, the Global Reporting Initiative (GRI), the United Nations Commission on Sustainable Development Framework, and the sustainability metrics of the Institution of Chemical Engineers[6].

Indicators and Metrics. This leads to the next important set of terms, indicators, and indices. In general, it is useful to proceed from a high level, represented by categories or indices, through to definite aspects (e.g., greenhouse gas emissions or donations to host communities) and specific indicators (GRI 2013b). The category *Aspects* hereby describes general information related to a specific category (see above). *Indicators* are derived or translated from *criteria* (Labuschagne et al. 2005). They are simple and specific measures of individual aspects used for performance measurement (Ness et al. 2007; Clift 2003). In most cases, indicators are quantitatively measurable and represent a certain state of development (economic, social, and/or environmental) in a bounded region (Ness et al. 2007). Following Harger and Meyer (1996), indicators should have certain characteristics: quantifiable,

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[6] A detailed review on indicator frameworks is provided by Labuschagne et al. (2005).

simple to apply, broad in scope, able to identify trends, and sensitive to change. If indicators and/or indices are continuously measured and calculated, then they allow us to track trends, e.g., longer-term sustainability, from a retrospective point of view (Ness et al. 2007). In such cases, indicators and indices (see below) represent the tools[7]. When indicators are a part of a more extensive tool, they are, in turn, included in a framework (described above). In summary, indicators can have many functions and are widely used for decision-making. They enable us to summarize, emphasize, and focus, as well as condense the complexity of the dynamic (market) environment, and to make available information that is controllable, analyzable, and, therefore, useable (Godfrey & Todd 2001; Warhurst 2002). Associated with the term *indicator*, the term *metric* is often used in literature, which may lead to confusion. From the literature review, it can be concluded that both terms are used synonymously. A small difference is that indicators usually have a broader scope, whereas metrics may include narrative descriptions additional to their quantitative measures (Tanzil & Beloff 2006).

Indicator sets. To measure sustainability on a larger scale, numerous indicators can be combined into an indicator set. For example, indicators from all three dimensions of sustainability can be combined and evaluated in a joint manner (Joung et al. 2013). This allows more comprehensive conclusions than just evaluating one individual

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[7] Ness et al. (2007) provide a framework that includes indicators and indices that represent tools to assess sustainability. They are categorized into integrated, non-integrated, or regional flow indicators.

indicator. A particular risk, therefore, is that wrong conclusions may be drawn, since the interrelationships among single indicators could be highly complex and not well-defined.

Models, Indices, and Composite Indicators. In the context of assessing or measuring sustainability, the term *model* is also used regularly in the literature, particularly when trying to build composite indices to track integrated information for economic, environmental, and social performance models. When indicators are aggregated in any manner into a single score, the resulting measure is called an index. For example, Krajnc and Glavič (2005a) use a model to compose an overall index of company performance. Thereby, normalized indicators are associated into three sustainability sub-indices to finally calculate an integrated index. Accordingly, models can also be used to assess sustainability and, in turn, could be described as tools. Another example of an index is the Environmental Vulnerability Index, which combines indicators of hazards, resistance, and damage in one single score (Joung et al. 2013). Usually, specific mathematical schemes are used to calculate indices. Following the general opinion in the literature, the terms *composite indicator* and *index* (or *indices*) are used synonymously (Singh et al. 2009). An advantage of composite indicators is that they provide thorough and broad-based information. However, this is achieved at the expense of losing objectivity, since they are calculated based on various subjective assumptions. The results are highly dependent on a chosen normalization method and weighting scheme, as well as on the selected aggregation method of sub-indicators (Zhou et al. 2012). Among experts, indices are highly controversial; for example, Spangenberg (2005) claims that from a scientific point of view, it is not possible to have a comprehensive measure or index of sustainability.

Data. No matter what technique or method is used to assess sustainability, data provide a basis for successful measures and can be sourced from organizations, initiatives, or companies. Figure 2-5 provides a schematic overview of how the previously described terms are related to each other.

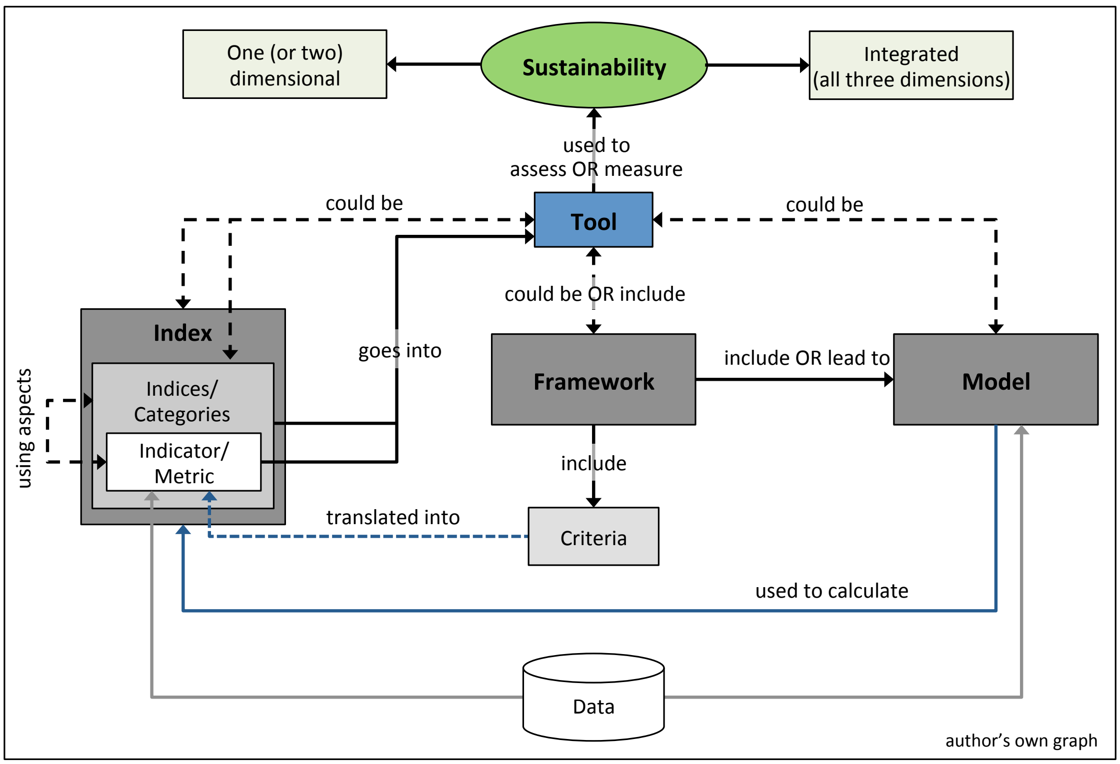

Figure 2-5: Relationship between important terms and definitions in the field of sustainability assessment

2.2.2 Progressive Framework for Sustainability Measurement

There is not only confusion on how the aforementioned terms are defined. The multitude of measures, metrics, indicators, indices, and frameworks developed in the past to analyze sustainability causes confusion among manufacturers. As pointed out by Joung et al. (2013), the selection of an operational set of indicators for assessing sustainability causes problems for enterprises. In particular, manufacturing companies struggle to decide which indicators to use when evaluating their products and processes, interpreting data, and planning improvements (Sikdar 2003). This hypothesis is substantiated by the work of Ameta et al. (2009), which criticized the inconsistency in existing metrics and claimed that sustainability-related metrics are formulated to be business-specific. This becomes clear when comparing indicator sets for assessing environmental deterioration due to human/industrial activities identified by the Organization for Economic Cooperation and Development (OECD) and the United Nations (UN) Commission on Sustainable Development (CSD). The OECD propose 46 Core Environmental Indicators (CEI) (OECD CEI 2003), whereas the CED suggest 96 indicators (United Nations 2007) to address the impact of human/industrial activities on the environment.

To provide more transparency and clarity in this field, characterized by the existence of a myriad of indicators and disintegrated indicator sets, the US-based National Institute of Standards and Technology (NIST) established a framework called the "Sustainable (Manufacturing) Indicators Repository (SMIR)," to establish an integrated sustainability indicator categorization that supports both manufacturers and academics in assessing sustainability. Its purpose is to serve as an application as well as an educational tool, with a focus on small- and medium-sized enterprise (SME) manufacturing companies. The fundamental principle of the SMIR is an extensive review of publicly available indicator sets, such as those provided by the Global Reporting Initiative (GRI), the Dow Jones Sustainability Index (DJSI), the OECD, or the Ford Product Sustainability Index (FPSI). The NIST's sensible and centralized categorization is based on five dimensions of sustainability: the three well-established dimensions according to the triple bottom line (TBL) concept (Hacking & Guthrie 2008) (environmental stewardship, economic growth, and social well-being), and the two dimensions of technological advancement and performance management (NIST 2011; Joung et al. 2013). It should also be noted that the approach suggested by the NIST is one of many well-established and commonly accepted frameworks[8]. Figure 2-6 illustrates the top-level categories and first-level sub-categories.

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[8] Madanchi (2013) provides an overview of other established indicator categorizations.

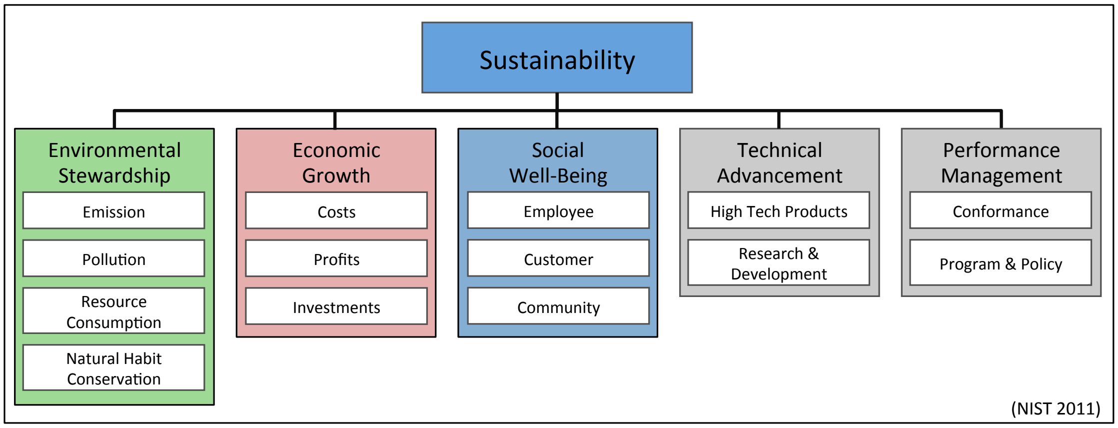


Figure 2-6: NIST top level indicator categorization structure

Environmental impacts caused by emissions, resource use, waste, and ecosystem degradation from manufacturing processes and products are covered within *environmental stewardship*. Indicators summarized in the *economic growth* dimension are designed to measure the economic aspects of sustainability, including organizational costs, profits, and investments from a particular organization (Joung et al. 2013; NIST 2011). Social well-being (Mihelcic et al. 2003) emphasizes the impact of health and safety programs, education and career development programs, and satisfaction evaluations on employees, customers, and the community. Performance management, as a representative of the less well-recognized dimensions, uses indicators designed to measure whether sustainability programs and policies are deployed and whether conformance to regulations is maintained. Finally, technological advancement accounts for the ability of companies to develop the technology to support the concepts of sustainability (Joung et al. 2013; NIST 2011).

Each subcategory, in turn, includes additional subcategories and numerous criteria, which are dependent on one or more indicator(s). An exemplary setup of the subcategory *Material*, appending to the category *Resource Consumption*, which belongs to the dimension *Environmental Stewardship*, is shown in Figure 2-7.

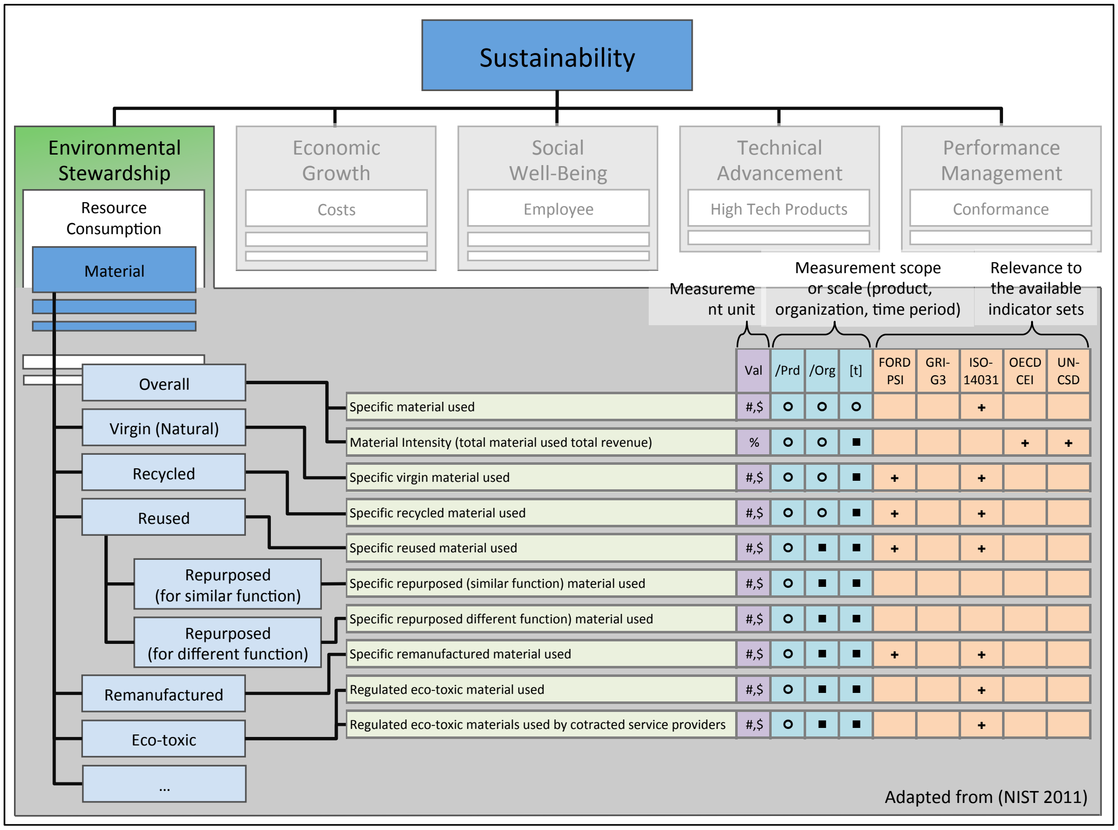


Figure 2-7: Example analysis of indicators (NIST)

The NIST's objective is to provide common access for academicians and SMEs to a repository of practice-oriented design parameters. Each indicator has a concise and individual name, brief definition, defined measurement unit, measurement scope or scale (product, organization, time period); furthermore, its original placement (e.g., GRI, FPSI, DJSI) is denoted. The latter allows companies to evaluate the importance of the indicator. The more frequently an indicator is used in one of the underlying indicator sets, the higher its significance. It is worth noting that 77 indicators belong to the category *environmental stewardship* and almost as many (70 indicators) to the *social well-being* dimension. This proves the progressive character of the SMIR, since most approaches still do not include social issues in an appropriate manner. The performance management dimension comprises 30 indicators, with 23 belonging to the *economic growth* dimension, and a further 12 in *technological advancement management*. A comprehensive register, including all 212 indicators, can be found at mel.nist.gov (NIST 2011; Joung et al. 2013).

2.2.3 Prominent Methods to Assess the Three Dimensions of Sustainability

Indicators alone are not able to measure sustainability. To make them instrumental, certain methodologies, or so-called assessment tools, have been developed and deployed. The next paragraph will explain the most commonly used assessment tools, their characteristics, unique elements, limitations in functionality, and emerging issues in more detail. Theoretically, any company can claim that its products or services are produced in a sustainable manner, and vice versa any NGO can disclaim this. For this reason, scientifically based tools and analyses are necessary to provide a rational basis for sustainability-related decisions and arguments (Heijungs et al. 2010). This knowledge is fundamental and helpful when introducing this paper’s conceptual approach to assessing GPS.

Consistent with the evolution of the term sustainability, the least developed methods focus on its environmental aspects. Over the last decades, many different tools (and indicators) have been developed for this purpose (Finnveden & Moberg 2005; Ness et al. 2007). The following assessment tools are main examples in this category: Life Cycle Assessment (LCA), Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Cost-Benefit Analysis (CBA), Environmental Risk Assessment (ERA), Material Flow Analysis (MFA), and Ecological Footprint (EF).

Material Flow Analysis (or Accounting) is used to determine the stocks and flow of resources within a well-defined system. MFA is a family of different methods (Bringezu et al. 1997). Three commonly used types are the Total Material

Requirement (TMR), Material Intensity per Unit Service (MIPS), and the Substance Flow Analysis (SFA). Different MFA methods have different objectives and can be used on different spatial and temporal scales (Finnveden & Moberg 2005); for example, this method allows the reconstruction of historical flows and emissions as well as forecasting and decision-support. Furthermore, MFA can account for material flows of a different scope. Whole industries, connected ecosystems, as well as indicators of societies, countries, or regions can be determined. For example, TMR focuses at the country-level as the object of study. Known approaches differ, particularly in terms of the inputs considered in the calculation. Some include both direct and hidden inputs (e.g., mining wastes) and consider total outputs and changes of stocks of nations, whereas others only consider certain factors. Even if TMR and MIPS are described as bulk-MFA methods, the MIPS objectives are focused on products and services. This relates MIPS to LCA, as described below (Finnveden & Moberg 2005). Both approaches were developed in the 1990s and consider five main impact categories in their assessment: abiotic materials, biotic materials, water, air, and soil (Spangenberg & Hinterberger 1999). A regional flow indicator is, for example, the SFA (Ness et al. 2007), which focuses on specific substances within a region (e.g., the flow of steel in a certain country). In general, MFA is based on two well-established scientific principles: the mass balance and the system approach. Applying these two principles to the socio-economic process makes the MFA a special method (Bringezu et al. 1997), and one that has the aim to support dematerialization and a reduction in loss. The most standardized tool for MFA in different regions is the economy-wide MFA, which was developed by Eurostat. Even if it is mainly used on the national level, it can be applied at other spatial levels. Eurostat created guidelines as to how MFA is applied to an economy. The proposed method balances physical inputs into an economy (material accumulation) with outputs to other economies, or back to nature. This principle is illustrated in Figure 2-8 and concentrates mostly on environmental aspects (Ness et al. 2007; Eurostat 2001).

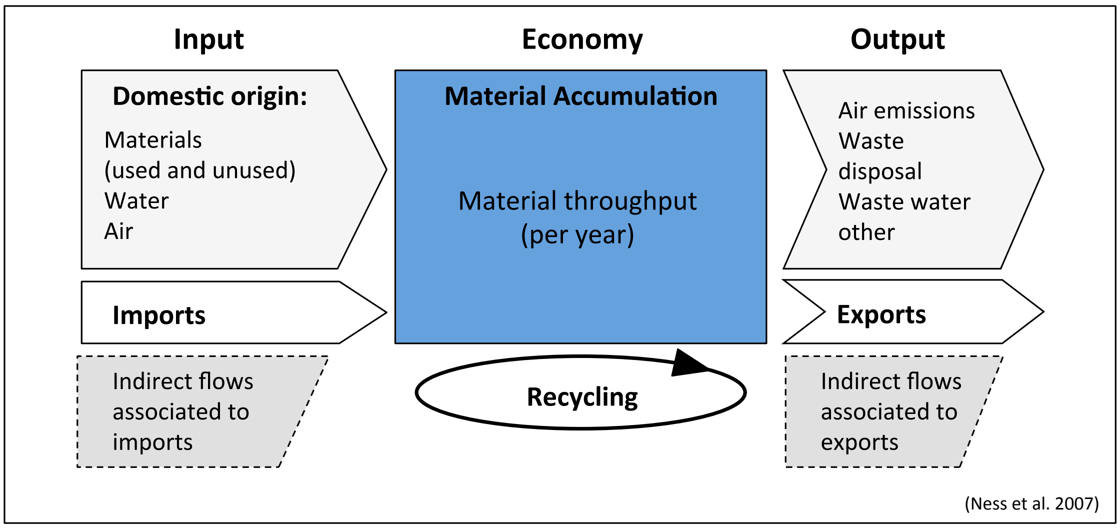


Figure 2-8: Simplified general material balance scheme

The results of a MFA are, in most cases, shown in the form of detailed flow diagrams. In contrast to the Life Cycle Assessment (LCA), MFA focuses on a single material that is used in many different products. The LCA examines various material demands and subsequent impacts caused by a specific product. If LCA studies are scaled up to cover, for example, a whole market, then some parallels occur in both methods; moreover, feedback from industry (e.g., flows of scrap) must be considered. Since the focus of this study is to assess global product sustainability, which has a clear product focus, the following section describes the LCA in more detail.

2.2.3.1 Environmental Life Cycle Assessment (E-LCA)

Like most of the terms used in the context of sustainability, the terms *life cycle* and *life cycle assessment* (or *analysis*) are used in many different ways in the literature. According to an official and often-quoted definition proposed by the International Organization for Standardization (ISO), LCA is the "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle" (ISO 1997; ISO 2006a). It basically quantifies the use of physical resources as inputs and environmental degradation as outputs. Before going into the details, a life cycle should be defined. The term life cycle shows up in various disciplines; even in the product context, different meanings of the term life cycle are prevalent. Coming from the design perspective, the life cycle of a product starts with the generation of an idea and ends with its commercialization. From an entrepreneurial perspective, a product's life cycle starts with market crystallization and ends with market termination. The cost perspective focuses on R&D costs and disposal, or recycling costs (Heijungs et al. 2010). The ISO defines life cycle as the "consecutive and interlinked stages of a product system, from raw material acquisition, or generation of natural resources, to the final disposal" (ISO 1997; ISO 2006a). As mentioned before, a cradle-to-grave life cycle includes the following stages: raw material acquisition, product manufacturing, transport, distribution, product use, and, finally, disposal or recycling. This cradle-to-grave analysis, in combination with the use of a functional unit for comparative studies, is the most important feature of LCA (Kloepffer 2008).

The ISO-14040 standards for LCA represent the reference for almost all foundational work (Heijungs et al. 2010); however, Hertwich and Pease (1998) suggest these standards are incomplete and, in some ways, ambiguous and contradictory. To address this criticism, the first version of these standards on environmental management (ISO 14040-14043) were published at the turn of the millennium, and slightly revised in October 2006 (ISO 14040 + 14044). It is worth noting that recent publications (e.g., UNEP/SETAC 2011) constitute LCA as environmental LCA or E-LCA. The main reason for this is that it was first developed in the late 1960s and early 1970s to understand the environmental impacts of several packaging options. However, there was a need for further differentiation, since sustainability assessment was no longer viewed as primarily environmentally focused. As a result, assessments were developed to measure the economic (LCC) and social dimensions (S-LCA) of sustainability. Following the ISO standard, there is a standardized procedural framework for conducting (E-LCA) assessment studies that contains four normally independent steps, as illustrated in Figure 2-9.

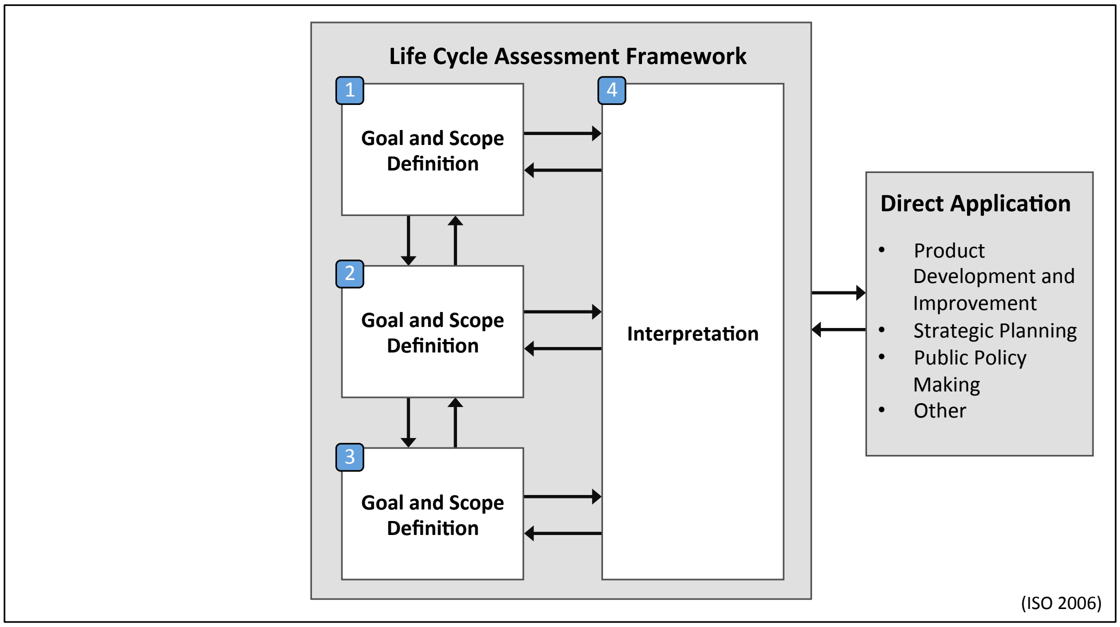


Figure 2-9: LCA-Framework according to ISO 14040

1. **Goal and scope definition**: The first step of an E-LCA study is to explicitly state the goal and scope of the evaluation and provide an appropriate context for the assessment. This includes, for example, the defining of stakeholders, which means defining to whom and how the results should be presented. Furthermore, technical information has to be detailed in this step. System boundaries, as well as the functional units of analysis (the basis for all calculations of the assessment), assumptions, (de)limitations of the study, considered impact categories, and methods (e.g., allocating environmental burdens if there is more than one product or function) have to be defined (UNEP/SETAC 2011).

2. **Inventory of resources and emissions analysis:** In the second step, the product system and its entire component unit processes are described. The objective is to quantify and evaluate exchanges with the environment along

the whole product life cycle. Inputs (resources extracted from the environment), as well as outputs (emissions released into the environment), which are so-called elementary flows, are grouped into an inventory. Due to the extensive experience in the field of (environmental) LCA, numerous libraries exist (e.g., GaBi, EcoInvent, NERL) that comprise generic life cycle data about processes and resources. This life cycle data serves as a major input for the next phase.

3. **Life cycle impact assessment (LCIA):** In the third phase the Life Cycle Inventory (LCI) results, the indicators of environmental exchanges are translated into environmental impacts; therefore, a certain impact assessment method is used. In general, impacts can be assessed at the mid-point or end-point level, which allows classification by aggregated grades (see Figure 2-10). The gathered data regarding the elementary flows (environmental interventions) are assigned to mid-point impact categories. Examples of such categories are climate change and human toxicity. This step is called classification and is followed by the so-called characterization. Characterization converts all elementary flows within the same category to a common unit of assigned elementary flow. Therefore, certain characterization factors are used. At the end-point, impact categories are linked with damages to human health, ecosystem quality, and the resource base. Depending on the goal and scope of the study, different characterization models can be used to link the inventory results via the mid-point and endpoint (damage) categories.

The overall UNEP/SETAC scheme (derived from (Jolliet et al. 2003)) of this procedure is illustrated in Figure 2-10. According to ISO 14040 and 14044, the optional steps are normalization, aggregation, and weighting. Normalization is used to convert differing units into a dimensionless format to show the contribution of each impact category in comparison with a reference. Aggregation and weighting use numerical factors to convert and aggregate indicator results across impact categories (UNEP/SETAC 2011). An example of a weighted and aggregated impact category is Global Warming Potential (GWP), which determines the environmental impact of atmospheric gases. Therefore, the greenhouse effect of a specific gas (1 kg) is translated into a certain amount of CO_2 gas that has the same effect (*x* kg).

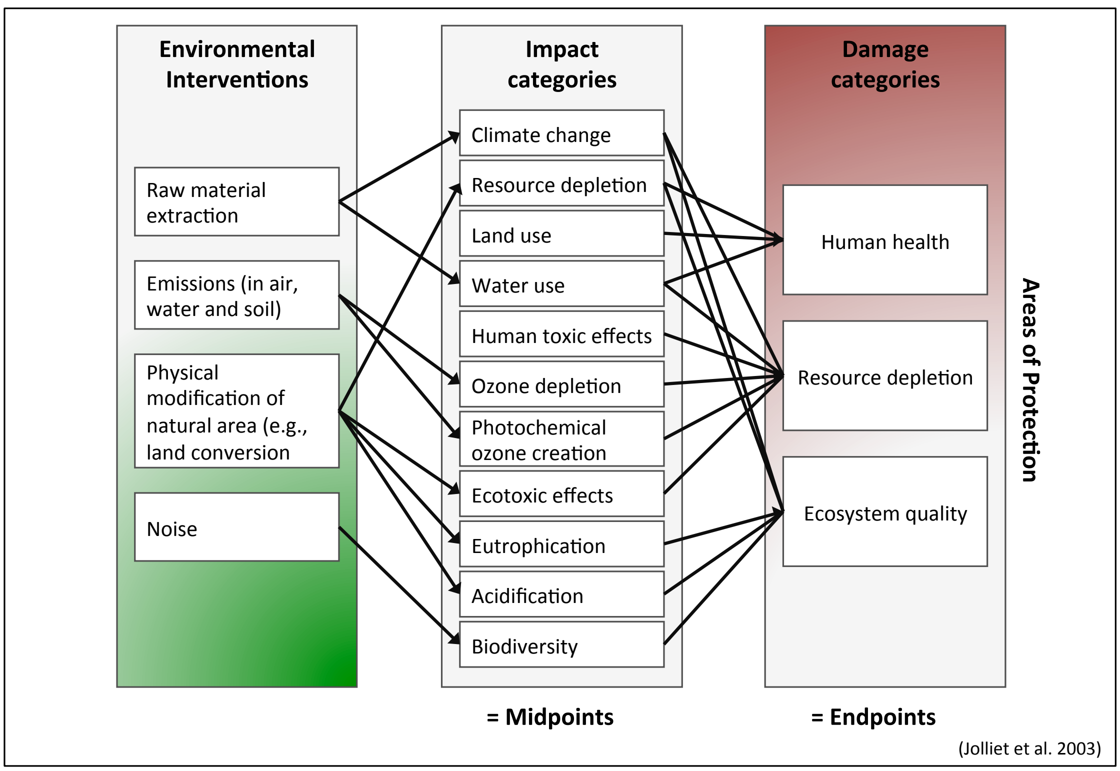


Figure 2-10: Overall UNEP/SETAC scheme of the environmental LCIA framework

4. **Interpretation:** At the end of an E-LCA, the results of the LCI and/or LCIA are interpreted to identify, quantify, and evaluate information generated from the analysis. This step happens with respect to the initially defined goal and scope. As a result of the interpretation, conclusions and recommendations should be generated. Furthermore, additional analyses, such as sensitivity analysis, consistency checks, and/or limitation evaluations, should be performed to evaluate the results with respect to certain assumptions, aggregation methods, conditions, etc. According to the ISO standard, a critical review (CR) is mandatory, if the results of the E-LCA should be made available for public.

In summary, the LCA/E-LCA method has developed and matured during the recent decades. The interested reader may take a look at an article published in 2009 by Finnveden *et al*. (2009) in the *Journal of Environmental Management*, which reviews and discusses in detail recent developments in life cycle assessment. A major finding was that the often-noted limitations of the approach are reduced and that some limitations will always remain (e.g., uncertainty in methodological choices). Particularly with regard to databases (e.g., for LCI), quality assurance and consistency developments have been made. However, due to data insensitivity and difficulties in obtaining necessary data, LCA remains a very time-consuming process (Zhou et al. 2012). Overall, there is a growing confidence in using E-LCA, which is supported by the fact that new application areas now require environmental impact assessments on products and services and the increasing development and sales of software used to manage LCA (Finnveden et al. 2009).

2.2.3.2 Life Cycle Costing (LCC)

Life Cycle Costing is another life cycle technique and is considered to be the oldest, since it was first mentioned in the 1930s. It is also known as Full Cost Accounting (FCA), or Total Cost Assessment (or Accounting) (TCA) (Hunkeler et al. 2003; Norris et al. 2001). LCC is an assessment technique used to estimate the total cost of ownership. This considers and sums the total costs of a product, process, or activity over its entire lifetime. When talking about lifetime or life cycle in economic science, care must be taken with how it is defined. Usually, economic analyses consider the phases of product development, production, marketing/sales, and the end of economic product life as the life sequence. This life cycle is often shorter than the cradle-to-grave life cycle used in LCA (Norris et al. 2001). However, taking into account the entire (economic) life cycle means considering both the financial cost, which is relatively easy to calculate, and the environmental and social costs, which are far more difficult to quantify and assign numerical values. Thereby, only negative cash flows (expenditures) are of interest while revenues are neglected. Typical costs considered in the calculation are for planning, design, construction, acquisition, operations, maintenance, renewal and rehabilitation, depreciation and cost of finance, and replacement or disposal. At this point, a short example will be introduced to point out once more the kinds of costs considered to be financial, environmental, or social. When comparing two different asset types, development and capital costs are first taken into account. Furthermore, it is important to consider financial costs that occur in the later stages of the product life cycle (e.g., maintenance and disposal). Already at this point, the LCC approach exposes interrelationships, e.g., between low development costs that result in high maintenance cost, and vice versa. Using environmental costs in the life cycle analysis leads to even more precise assessment results. Depending on the exhaust filtration technology used, different costs for gas purification might occur. In general, all costs directly covered by an actor in a product's life cycle (e.g., supplier, producer, user, etc.), and that relate to real money flows, have to be included in a LCC. The latter is necessary to avoid an overlap between E-LCA and LCC, which, for example, would occur if environmental damages were monetized in LCC (Kloepffer 2008). Today, different types of LCC exist; however, they differ about their objectives and temporal scope. The main difference between these types is the extent to which external costs (e.g., costs due to an expected new tax) are monetized (UNEP/SETAC 2011). Even if LCC is older than LCA, there is no standard defined yet (Kloepffer 2008). However, a scientific working group on LCC within the Society of Environmental Toxicology and Chemistry (SETAC) prepared a manuscript in which different types of LCC are described and defined. A major achievement and input for this guideline was to provide a cost assessment for a product across its entire life cycle, according to the procedure of an E-LCA and to ISO 14040 (Swarr et al. 2011). In 2008, Kloepffer (2008) pointed out that LCC is performed on a basis analogous to LCA. Both approaches are steady state in nature, which means they include the definition of a functional unit and have similar system boundaries (both are based on interconnected material flows over a single life cycle). It is known that LCA and LCC are based on different methodological approaches and conceptual foundations (Blanchard 1978); however, recent developments, like the aforementioned UNEP/SETAC guidelines, which build on the ISO 14040 standard, facilitate the complementary execution of both techniques based on four different phases.

1. **Define a goal, scope, and functional unit**: Accordingly to phase 1 in E-LCA, the first step of LCC is to define the goal of the study, describe the system boundaries, define a functional unit, etc. Most tasks are similar to what needs to be done in an E-LCA; however, the difference is that it is important to define a distinct point of view for the life cycle actors (e.g., supplier, producer, user). This is a challenge, since a wide variety of viewpoints is necessary for a comprehensive investigation (Franzeck 1997), which, in turn, leads to a large number of methods used for life cycle costing (Finkbeiner et al. 2010). Furthermore, a cost breakdown structure (CBS) has to be implemented in this phase to ensure consistent and easier collection of data along the life cycle. If cost flows in the future are considered, then it is necessary to convert them into present costs using a certain discount rate, which must also be defined in the first step.
2. **Inventory costs:** In this phase, costs are inventoried on a unit process level. Since most companies produce more than one product, costs are allocated to each product. There is no consensus or defined rule on how to allocate costs

to different products. An option proposed by the UNEP is to distribute overhead costs proportionally to the number of working hours it takes to manufacture a certain product, or according to the income received by each product observed.

3. **Impact Assessment:** Phase 3 aggregates costs by defined cost categories. When examining supply chains, a big challenge arises from the definition of those cost categories, as well as from the development of inventory.
4. **Interpretation of results:** The interpretation of resulting costs is the final step of LCC. To illustrate the results, a three-dimensional representation is recommended. The three dimensions are: a) the life cycle stage (e.g., design and development, production), b) the cost category (e.g., labor costs), and c) the product/work breakdown structure (e.g., power supply). This representation allows a distinct allocation of costs (UNEP/SETAC 2011). A main advantage of this representation method is that the detailed results of the life cycle phases will not be lost during the aggregation of costs. In general, the result is calculated as a cost per functional unit, which is expressed in a certain currency (Kloepffer 2008; Swarr et al. 2011).

In summary, LCC provides a useful tool to influence and support (consumer) decisions. There is no question that sustainable or sustainably produced products (e.g., low-energy light bulbs) are usually more expensive than commonly produced substitute products and that buying decisions are often price-driven. The information given by LCC, including, for example, the costs accrued in the use phase of a product, may lead to better decisions in the sense of sustainability (Kloepffer 2008). Due to the similar boundaries and interconnected material flows examined by LCA and LCC, it is tempting, and theoretically possible, for the LCC to address the economic impact of a product being assessed for its environmental impacts in an E-LCA. Since there is no current standardized procedure for conducting a LCC, it is still in its infancy compared with the E-LCA, and, therefore, requires care in its usage, particularly for the challenges of data accuracy and the monetization of environmental impacts (Swarr et al. 2011; Cole & Sterner 2000). Further challenges (e.g., methodological choices) that may arise in the practical application of LCC can be followed in Cole and Sterner (2000).

2.2.3.3 Social Life Cycle Assessment (S-LCA)

Social Life Cycle assessment is the last pillar needed to measure impacts in all three dimensions of sustainability. It is the least developed life cycle method and also considered to be in its infancy (Kloepffer 2008). Discussions on integrating social and socio-economic criteria of products into sustainability started in the 1980s (UNEP/SETAC 2011). In business, the three-dimensional view of sustainability gained international recognition due to John Elkington’s expression “triple bottom line,” which basically describes a mode of integrated corporate reporting (encompassing environmental, economic, and social concerns). Elkington (1999) himself points out that businesses tend to overlook social justice, since they mainly focus on economic prosperity and environmental quality. That there is still a great need for research becomes additionally clear when taking a look at the indicators used to assess social sustainability. Thus, the Global Reporting Initiative (GRI), for example, noted, “reporting on social performance occurs infrequently and inconsistently across organizations” (GRI 2006, p.33). There are numerous other articles to support this view (Labuschagne et al. 2005; Joung et al. 2013; OECD 2008; Barron et al. 2002). However, particularly due to those deficits, there has been a massive increase in the number of papers published and submitted that integrate social aspects in sustainability assessment. Subject areas examined range from the development of frameworks for S-LCA (Dreyer et al. 2006) to extending existing approaches like LCA (Norris 2006; Weidema 2006) and developing explicit indicators (Labuschagne & Brent 2006) and case studies (Hunkeler 2006). A general overview of recent and ongoing research regarding S-LCA is provided by Kloepffer (2008). According to the previously described tools, the UNEP/ SETAC provide a guideline for the S-LCA. Its development was triggered by a feasibility study for the integration of social aspects into LCA, which was prepared by Grießhammer et al. (2006) for the UNEP/ SETAC Life Cycle Initiative in 2006. After recognizing the need to integrate social aspects into LCA, the UNEP/SETAC Life Cycle Initiative published its Guidelines for the Social Life Cycle Assessment of Products in 2009 (UNEP/SETAC 2009). It should be noted that the procedure and findings published in this guideline can not be considered as a (international, e.g., ISO) standard. Kloepffer (2008, p. 92), for example, stated that it is “clearly too early for a standardization of SLCA [and only] a certain level of harmonization could be achieved”.

Social or socio-economic Life Cycle Assessment (S-LCA) is defined as a social impact assessment technique, with the objective to assess both positive and negative social and socio-economic impacts of products along their entire life cycle. Like LCC, it can be applied to either complement E-LCA, or be used on its own. Major similarities with E-LCA and LCC are the technique's focus on products and services and the consideration of all life cycle phases. However, these aspects constitute the main differences to other (social) impact assessment techniques, which is why they make S-LCA relevant to this study, in that it focuses on GPS. Impacts assessed using S-LCA are usually those that directly affect stakeholders; however, indirect aspects on stakeholders could also be considered. Stakeholders can also be consumers, value chain actors, workers, societies, or local communities (Ciroth et al. 2011). Impacts are linked to socio-economic processes, enterprise behavior, and impacts on social capital (UNEP/SETAC 2009). S-LCA does not aim to be a decision-making tool (i.e., used to make choices regarding whether a product is produced or not). S-LCA is more an informal technique, which has the scope to provide information on social and socio-economic aspects that may be relevant for decision-making. Furthermore, it helps to expedite dialogue on the socially relevant aspects of production and consumption; thus, S-LCA can contribute to improvements of organizational sustainability and, in the end, the well-being of stakeholders (UNEP/SETAC 2011).

Following the UNEP/SETAC guidelines, S-LCA procedures are subdivided into four different phases: a) goal and scope of the study; b) inventory; c) impact assessment;

and d) interpretation. This also conforms to the ISO 14040 framework, which is the foundation for LCA.

1. ***Goal and scope definition:*** The first S-LCA phase is very similar to the one in E-LCA. A functional unit, as well as the system's boundaries, goal, and scope, have to be defined here. Besides the definition of impact categories and corresponding indicators (e.g., child labor, fair salary, social benefits, etc.), it is of importance to define stakeholder categories and sub-categories. Analysis has shown that there are only a few indicators that can be assigned to products. Most of the currently used indicators, such as the Human Development Index (HDI), are applied to countries or regions (Finkbeiner et al. 2010). Table 2-1 provides an overview of main stakeholders to illustrate how extensive and complex the scope of S-LCA can be. Since S-LCA is much more site-specific than E-LCA, it may, in rare cases, require site-specific LCIA. Furthermore, information about politics is required since attributes and laws will vary from country to country (UNEP/SETAC 2009; UNEP/SETAC 2011).

Table 2-1: Main stakeholders within S-LCA

Stakeholder Group	Subcategories
Workers	Freedom of association and collective bargaining
	Child labor
	Fair salary
	Working hours
	Forced labor
	...
Local Community	Access to material/immaterial resources
	Delocalisation and migration
	Cultural heritage
	Safe and healthy living conditions
	...
Society	Public commitments to sustainable issues
	Contribution to economic development
	Prevention and mitigation of armed conflicts
	Technology development
	Corruption
	...
Value chain actors	Fair competition
	Promoting social responsibility
	Supplier relationships
	Respect for Intellectual Property Rights
	...
Consumers	Health and safety
	Feedback mechanism
	Consumer privacy
	Transparency
	End-Of-Life responsibility
	...

(UNEP/SETAC 2009)

In general, each form of classification is used to simplify the operationalization of variables. The presented stakeholder categories reflect the entire life cycle of a product. Their definition is of major importance since all impacts examined in S-LCA are consequences of social interactions in the context of, e.g., production and other actions induced by (in)direct stakeholders. Additionally, a distinct definition of stakeholders allows identifying and deriving impact categories and respective subcategories, which ultimately lead to a defined set of indicators.

2. ***Inventory analysis:*** The focus of phase 2 is the development of the inventory. If not yet done, subcategories are finally defined in this phase according to the categorization of identified stakeholders. Otherwise, it would not be possible to proceed with the inventory. Considering two different publications from the UNEP/SETAC on (social) sustainability assessment (UNEP/SETAC 2009; UNEP/SETAC 2011), there seems to be uncertainty around the definition of categories and subcategories carried out in phase 1 or phase 2. However, the main activity carried out in phase 2 is the collection of data. At this point, S-LCA differs from E-LCA because its data collection and use present more challenges. On the one hand, the data will differ among different stakeholders. The required data for analysis are at country, regional, sector, company, and site-specific levels. Possible sources are shown in Table 2-2. On the other hand, there is more variation in the nature of the data itself. More activity variables are needed, thus, the balance between qualitative, quantitative, and semi-quantitative data will be different. Another striking difference regarding E-LCA is the high amount of subjective data (e.g., the perceived level of environmental quality, or worker-controlled schedules). Although this comprises the accuracy, objective data is not available in many cases; therefore, neglecting subjective data would result in even greater uncertainty. Additionally, S-LCA data is often subjective in nature and necessary to render and mirror realistic and accurate images of social conditions (UNEP/SETAC 2009). Methods appropriate to handle data gaps are,

for example, to use sector data to estimate a situation within a company, to transfer site-specific data to another site in the same country, or to calculate average values to account for the missing data (Ciroth et al. 2011). A resulting consequence is that steps and methods used to collect data will also vary within S-LCA.

Table 2-2: Possible Data Sources for S-LCA

Data Level	Data Source
Country/regional	U.S. Department of Labor (country reports)
	ILO
	CIA (The World Factbook)
	The World Bank (development indicators, environmental data, and statistics)
	Amnesty International
	OECD, ITUC, WHO, etc.
	NGOs
Sector	Sector associations
	Trade unions
	ILO
	OECD
	Gos
	NGOs
Company/site	Corporate websites and corporate reports
	Trade unions
	NGOs
	Interviews with management and employees/workers

(Ciroth et al. 2011)

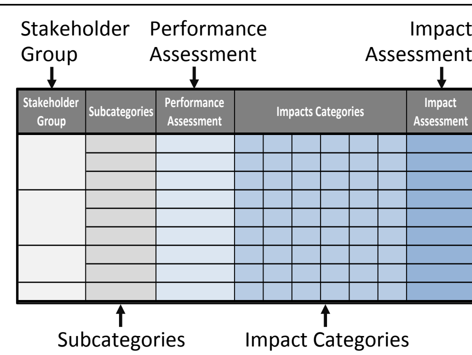
The large amount of time needed to gather the necessary data in an appropriate manner is one reason why S-LCA is not used in many situations, particularly by SMEs. Since an assessment tool is only of value if it is used, a prioritization can be conducted to identify so-called hotspots, which represent stakeholders that are of most importance in a product's life cycle. To reduce the risk of possibly neglecting meaningful problems or stakeholders, random on-the-spot visits may be conducted.

3. ***Life cycle impact assessment:*** With regard to the impact assessment, the UNEP/SETAC guidelines do not propose any impact assessment methods or models. Apart from this, the literature review revealed no currently accepted social impact assessment method. This finding is supported by Ciroth et al. (2011). However, there is an increasing volume of research in progress to close this gap. The main reasons given for this gap in standardized methods and models may be the following. First, the characteristics of models vary. These are, in layman's terms, the formal approaches used to aggregate each type of impact category (Wu et al. 2014). They describe a basic aggregation step to bring inventory information together into a single summary, or to summarize quantitative (social and socio-economic) inventory data within a certain category (UNEP/SETAC 2009). An extensive and up-to-date overview of the characteristics of frameworks/methods that incorporates characterization models (and S-LCA in general) was published by Wu et al. (2014) and may serve as an input for future method developers and S-LCA practitioners. Second, further complexity may be added to characterization models due to so-called reference points that require additional information. Reference points, or performance reference points, may be internationally set critical values, or goals according to best practices or conventions. For example, in examining the subcategory *fair salary*, a reference point might assume that the wage level affords a decent standard of living (minimum wages are often not sufficient). Finally, S-LCA includes both positive and

negative impacts that a product has during its life cycle (in E-LCA there are only negative impacts). The general aim of the LCIA is to assign inventory data to single subcategories (e.g., *fair income*, *working hours*, etc.) and impact categories (e.g., *working conditions*) using a classification process. According to the E-LCA, this step is followed by the characterization process to aggregate the inventory data within the previously selected subcategories and categories to determine the results for the indicators.

In practice, there are techniques to overcome the mentioned challenges. For example, GreenDeltaTC developed an in-house approach that builds on two assessments: performance assessment based on performance reference points, and an impact assessment that uses social cause-effect chains. Qualitative, quantitative, and semi-quantitative data are then evaluated, based on an intuitive color rating scale (see Figure 2-11 left). In a next step, results are collected in an LCIA-table (see Figure 2-11 right). Due to the use of numerical factors, these results can also be aggregated and summarized (Ciroth et al. 2011).

Performance Assessment	Color	Impact Assessment
Very good performance	1	Positive effect
Good performance	2	Lightly positive effect
Satisfactory performance	3	Indifferent effect
Inadequate performance	4	Lightly negative effect
Poor performance	5	Negative effect
Very poor performance	6	Very negative effect



(Ciroth et al. 2011)

Figure 2-11: LCIA evaluation table and LCIA-table

4. **Interpretation:** Following the ISO 14040 procedures, the last step is the interpretation of results. Besides the identification of social hotspots, information on the quality and validity of data, the relevance and completeness of the study, as well as the measurement method used, should be included. It is also recommended to discuss uncertainties and limitations of the study in a critical review prior to providing stakeholder-specific recommendations.

Kloepffer (2008) summarizes problems in S-LCA and stated five critical questions:

- How can existing indicators be quantitatively related to the functional units of the system?
- How are the necessary site-specific data for the S-LCA obtained?
- How are indicators chosen?
- How can all impacts be quantified properly?
- How should the results be valuated?

It is also worth noting that there have been efforts to combine S-LCA with E-LCA to create a method called the Social and Environmental Life Cycle Assessment (SELCA), as described by O'Brien et al. (1996). However, authors like Kloeppfer (2003) mention that this approach introduces multiple challenges to combine data and concepts from different fields (sociology and technology); it is, nonetheless, a worthy method to pursue.

2.2.3.4 Integrated Assessment and Composite Indicators

The efforts described above combine two or more different life cycle assessment tools to achieve a more broadly based analysis (Wrisberg et al. 2002). The two major options available include environmental Life Cycle Assessment, Life Cycle Costing, and Social Life Cycle Assessment to an approach called Life Cycle Sustainable Assessment (of products) (LCSA)[9]. The first option is the simultaneous, but still separate, use all three described assessment tools (E-LCA, LCC, and/ or S-LCA) (Dreyer et al. 2006).

LCSA = E-LCA + LCC + S-LCA

The LCSA requires identical system boundaries. The ideal would be if the three methods were standardized, as is the case with LCA (ISO 14040 + 14044). However, the guidelines provided by UNEP/SETAC at least help to harmonize the three approaches, which provides a solid foundation for their concurrent use.

Option two is to define the Life Cycle Sustainable Assessment as a new approach. This concept includes LCC and S-LCA as additional impact categories in the phase of Life Cycle Impact Assessment (LCIA) within the standardized E-LCA. A main advantage would be that, in the first phase of the assessment (definition of goal and scope), only one LCI model would have to be defined. Communities related to life cycle

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[9] The combination of two different approaches (e.g., S-LCA and E-LCA) to assess sustainability is, for example, discussed by O'Brien et al. (1998). However, in the view of the authors, approaches that have an integrated view (according to the triple bottom line approach), are more relevant and contemporary for this study.

assessments are currently discussing whether option one or two, or a completely new international eco-efficiency standard, should be developed (Kloepffer 2008). The ISO 14040 leaves room for interpretation, as exemplified in its wording: "LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described […] may be applied to these other aspects" (ISO 2006a). In view of this, both options may be possible. The ISO standard for E-LCA is already bulky and long, such that separate standardization of LCC and S-LCA would be expedient. It is also theoretically possible to expand the existing standard (Kloepffer 2008). Regardless of how LCSA is practically applied and eventually standardized, the approach is a combination of three existing assessment methods. This, in turn, requires the application of evaluation schemes, such as multi-criteria decision analysis (MCDA), like already used in the field of location decisions. This first requires addressing the variable target levels (which may be conflicting), as well as the indicator scales to be used. Second, the weighting between them must be determined. In terms of LCSA, there exist at least two different weighting problems (Finkbeiner et al. 2010):

- Weighting among the three pillars of sustainability (environmental, economic, and social), which results from the use of three different approaches;
- Weighting within each of the three sustainability dimensions, which means between indicators themselves (e.g., between two different indicators to assess the environmental dimension, such as global warming potential and resource dissipation).

A major problem arises from target variance and the conflicts it creates. This makes decision-making in the field of sustainability diverse and complicated. On the one hand, it is a challenge to consider the numerous and diverse goals and, on the other hand, there are often trade-offs between goals. To achieve a sustainable balance among the three dimensions of sustainability, appropriate procedures and methods, such as multi-criteria analysis, should be implemented with utmost care (Schuh 2001; Günther & Schuh 2003). Finkbeiner et al. (2010) intensively studied the development of LCSA. The focus, therefore, was on maintaining transparency between the three dimensions (not combining all dimensions implicitly into a single score), comprehensibility, and the possibility to consider quantitative as well as qualitative criteria in the same assessment. The authors developed a LCSA evaluation scheme that allows calculating a single score as well as a three-dimensional score, using criteria weights and criteria scores (Finkbeiner et al. 2010). The basic scheme is shown in Figure 2-12.

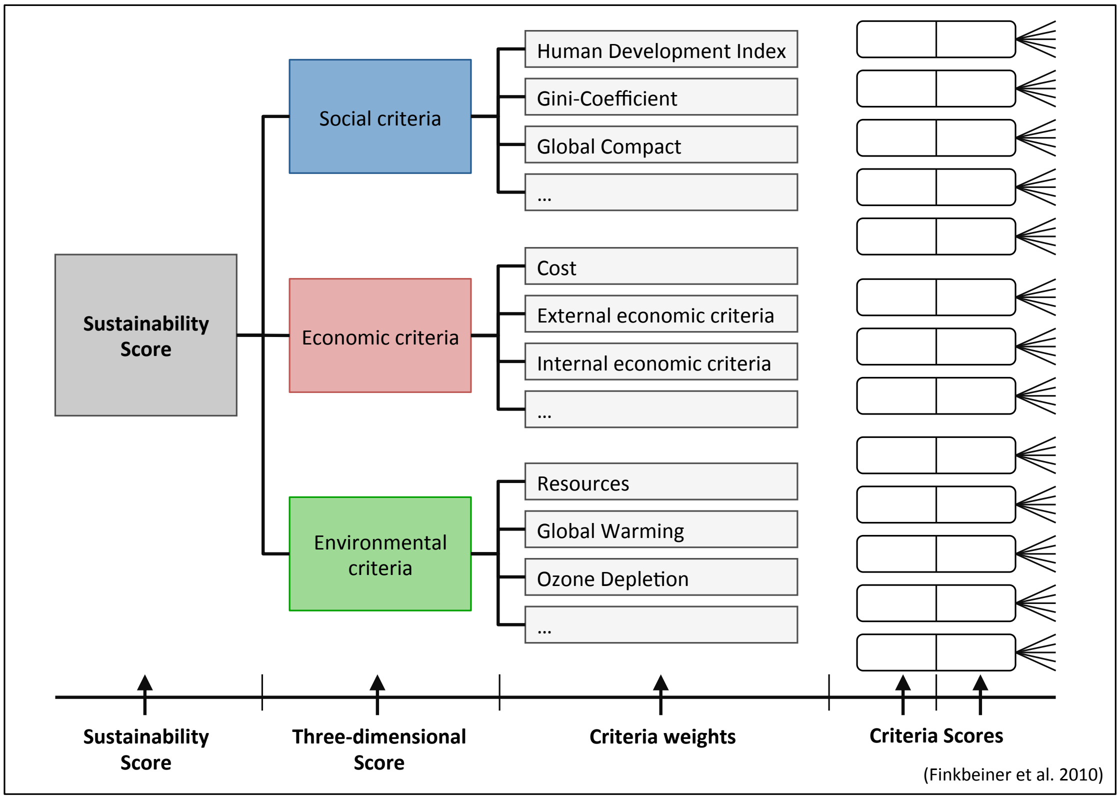

Figure 2-12: LCSA evaluation scheme addressing all three dimensions of sustainability

Comprehensibility is of primary importance for informed decision–making: key stakeholders are seldom experts and are only interested in the relevant results; thus, an effective final presentation of assessment results constitutes a challenge in the application of LCSA (Traverso et al. 2012).

Two approaches for this purpose are introduced briefly in the Life Cycle Sustainability Triangle (LCST) and the Life Cycle Sustainability Dashboard. Hofstetter et al. (2000) introduced the idea of the *Life Cycle Sustainable Triangle* in 2000 to compare different choices, or product alternatives, based on their environmental impact (damage-oriented). The basic concept of a weighting triangle (or mixing triangle) derives from its usage in the chemical industry, where it represents different chemical mixtures. Therefore, relative weights are attributed to (up to) three decision criteria. In the final step, different alternatives are compared with respect to assigned weights. Reviewed case studies show that the triangle approach is practical as a graphical interface to support communication between LCA practitioners and decision-makers, since it allows interrelationships among indicators to be simplified and clarified (Hofstetter et al. 2000). Finkbeiner et al. (2010) adopted this approach for the LCSA. For this to be achieved, the weighting has to be conducted between the environmental, economic, and social dimensions of sustainability. Figure 2-13 illustrates an exemplary weighting triangle for the comparison of two alternatives, A and B. The three corners represent the weighting factors for each dimension of sustainability, whereas a point inside a corner represents a state wherein one dimension has a value of 100% and the remaining a value of 0%; thus, any weighting preference can be visualized. Alternatives to compare are represented as dominance areas, which indicate where certain alternatives are superior for specific weighting sets. Dominance areas are separated by straight lines (here, two alternatives perform equally) (Finkbeiner et al. 2010; Hofstetter et al. 2000). Further case study information on detailed calculations and the weighting triangles used in practice may be obtained from Hofstetter et al. (2000).

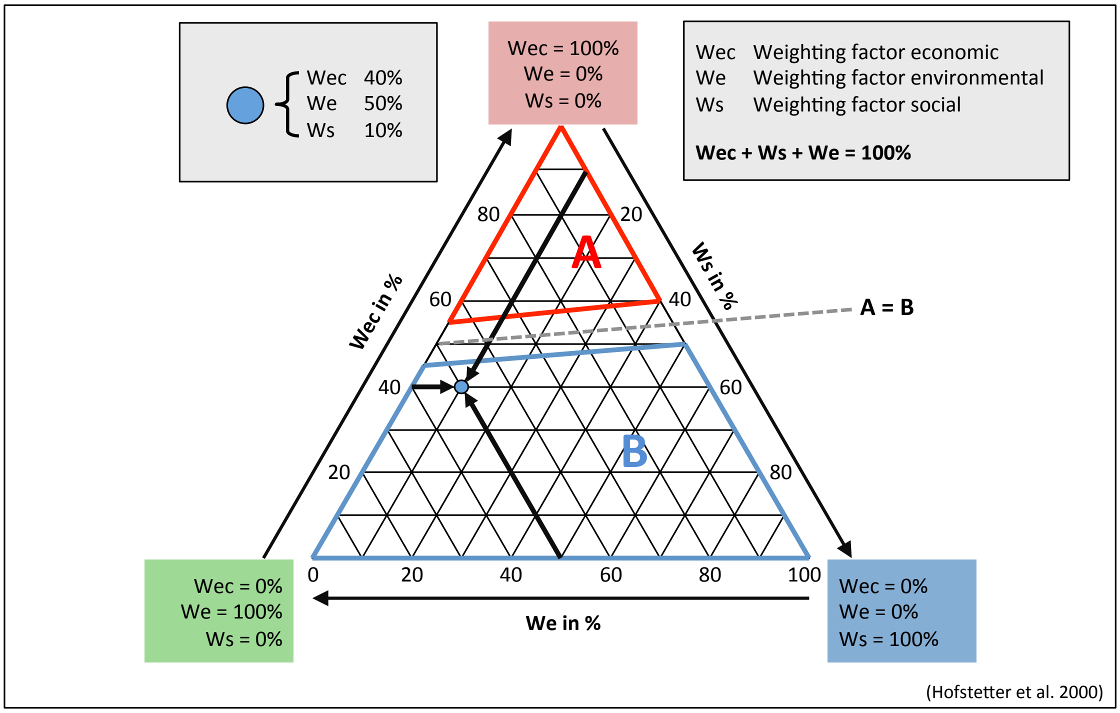

Figure 2-13: LCST graphical scheme for a comparison of two alternatives A and B

The Life Cycle Sustainability Dashboard (LCSD) also aims to compare different products and support decision-making using a straightforward and comprehensive illustration of LCSA results. This approach was first introduced by the Joint Research Centre (JRC) of Ispra, Italy (Jesinghaus 2000) and is scientifically supported by the International Institute for Sustainable Development (IISD); in addition, it pursues the ambitious goal of consolidating an internationally accepted composite sustainable development index (SDI). The necessary software is available for free at the IISD's homepage (IISD 2009). Traverso et al. (2012) picked up the approach in 2009, as they analyzed disaggregated and opaque LCSA results. Since decision-making often involves stakeholders from various backgrounds and with varying degrees of specific knowledge, there is a need to support decision-makers in making more sustainability-oriented decisions (not whether a product should be produced or not!). The LCSD allows comparing alternatives by an overall sustainability index, using individual factors for each sustainability dimension, as well as by three groups of indicators. This structure ensures that the LCSA results are presented in a comprehensive manner, without losing transparency or traceability with regard to dimension-specific results. Besides the ability to present an overall index (the so-called policy performance index, which builds on the application of E-LCA, LCC, and S-LCA), the tool's major strength is the graphical representation of results. Using a cartogram with a chromatic scale and ranking score (see Figure 2-14), the sustainable performance of a product can be displayed. Dark colors (red) indicate poor conditions while light colors (green) indicate good conditions. Additionally, a ranking score gives information on the performance. Like the Life Cycle Sustainable Triangle, the LCSD weights indicators to specify their importance. After their definition, the software calculates the scores automatically (Traverso et al. 2012). Its functionality is based on an indicator value ranking. Basically, the best-performing product scores a value of 1000 for a certain indicator, whereas the worst performing product scores 0 points. The remaining values of the same indicator are then linearly interpolated between these boundaries. The results are factors that represent a weighted average of all considered indicators. A complete LCSD includes a graphical scheme for each dimension of sustainability, as well as an overall dashboard (Finkbeiner et al. 2010); thus, stakeholders and decision-makers can evaluate different alternatives intuitively. For more information on the LCSD's operating mode and its use in case studies, see Traverso et al. (2012), Finkbeiner et al. (2010) and IISD (2009).

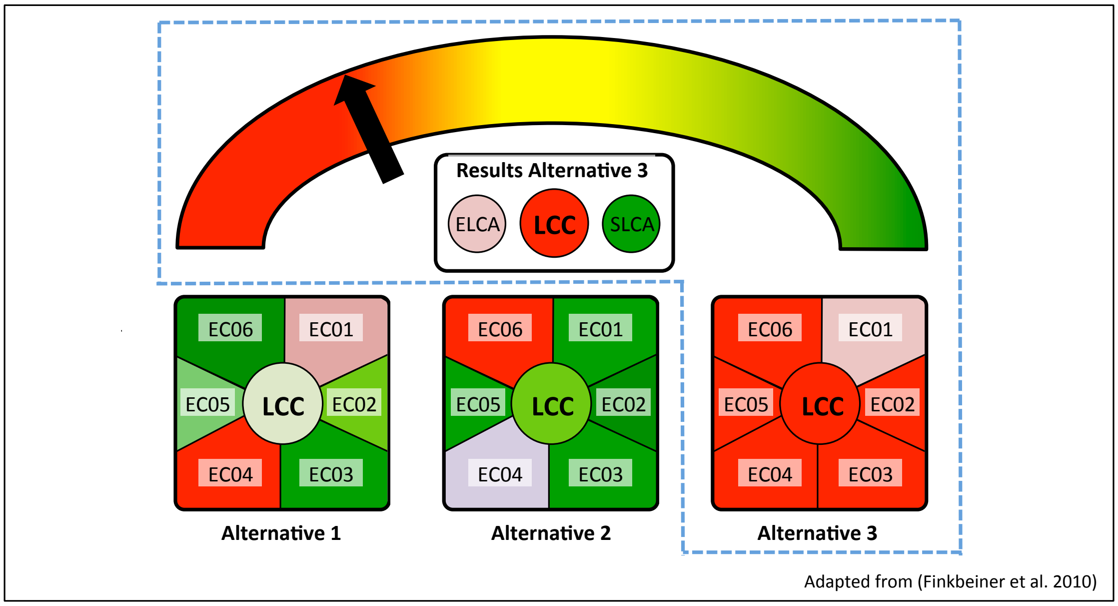

Figure 2-14: Sustainability Dashboard for LCC and alternative 3

In conclusion, no matter how well developed and progressive these approaches may seem, a significant gap remains in assessing sustainable performance (considering all three dimensions), particularly with a focus on products and processes; thus, more research is needed (Finkbeiner et al. 2010). However, the graphically based methodologies described here are able to bypass the disadvantage expressed by Ness et al. (2007) that the LCSA approach is not capable of displaying the overall results in an integrated manner. Following Finkbeiner et al. (2010, p.3320) "[…] the concept of LCSA is ultimately the way to go".

At present, **composite sustainable indices** are mainly used to assess sustainability on a cross-national and quantitative level to make comparisons among environmental, economic, social and/or sustainable progress factors. In contrast to the previous approaches to assess LCSA, a composite indicator does not necessarily provide information on its individual components. Well-known composite indicators in this field are, for example, the following (Krajnc & Glavič 2005a):

- *Environment*: Environmental Performance Index (EPI) (YCELP 2014), Pilot Environmental Performance Index (WEF 2002), Index of Environmental Friendliness (Statistics Finland 2003), Eco-Indicator 99 (Goedkoop & Spriensma 2001)
- *Economy*: Internal Market Index (Tarantola et al. 2002), Composite Leading Indicators (OECD 2002), Index of Sustainable and Economic Welfare (Daly 1994), Gross Domestic Product (GDP)
- *Society*: Human Development Index (UNDP 2014), Overall Health System Attainment (Murray et al. 2001)
- *Sustainability*: Dow Jones Sustainability Index (DJSI 2014)

An increasingly discussed research topic is the integration of sustainable assessment at the company or industry level. For example, Krajnc and Glavič (2005a, 2005b), and Zhou et al. (2012), denote the development of an appropriate method for this purpose as a major driver to meet the challenges of sustainability. The literature discusses different frameworks aimed to integrating all three dimensions of sustainability into one composite indicator. By now, numerous different frameworks that focus on the sustainability performance of companies have been recommended (Krajnc & Glavič 2005b). The major topics discussed, therefore, are the procedures for calculating the index, its effectiveness, necessary data, and the possibilities of practical application. Here, as well, the motivation is to provide integrated information to support decision-making and increase public participation in sustainability-related topics and based on performance evaluation. For instance, Krajnc and Glavič (2005a) proposed a framework that uses the concept of analytic hierarchy process (AHP)[10]. In a first step, indicators from each sustainability dimension are consolidated into sub-indices before there are finally condensed into an overall composite indicator of company performance. Assumptions regarding the understanding of sustainability assessment are based on the commonly accepted approaches defined by the Global Reporting Initiative (GRI). The controversial topics are the methodologies used for the aggregation, normalization, and weighting of indicators. The developed general procedure of calculating the composite index consists of seven steps ranging from the selection of indicators via grouping, judgment, normalization, and weighting, and calculation of the sub-indices; finally, these are aggregated into an overall index. Detailed information on the mathematical formulations, and two case studies of the practical application of such composite indicators, may be taken from Krajnc and Glavič (2005a, 2005b). It has to be noted that developing appropriate methodologies can be used to satisfy all target groups interested in sustainability assessment (scientists, decision-makers, and individuals) (Braat 1991). Depending on the level of aggregation of normalized indicators (normalized individual indicator, sub-indices, or overall index) and the scope (comparison of companies or timely development), different results can be

[10] See Section 2.3: AHP is also used in location decision-making.

presented. A graphical representation of the results from the case studies are shown in Figure 2-15 and Figure 2-16. The former shows a comparison between two companies with the aid of normalized indicators while the latter illustrates the performance of a composite Sustainable Performance Index and three sub-indices over time.

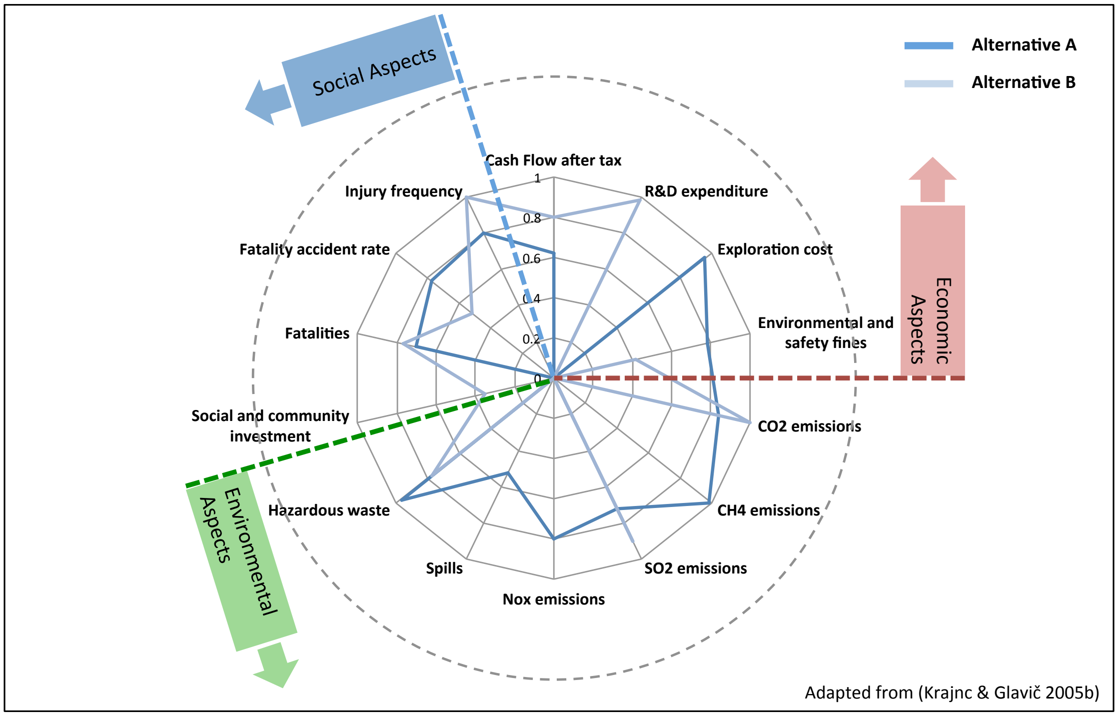

Figure 2-15: Graphical representation of a comparison based on normalized indicators

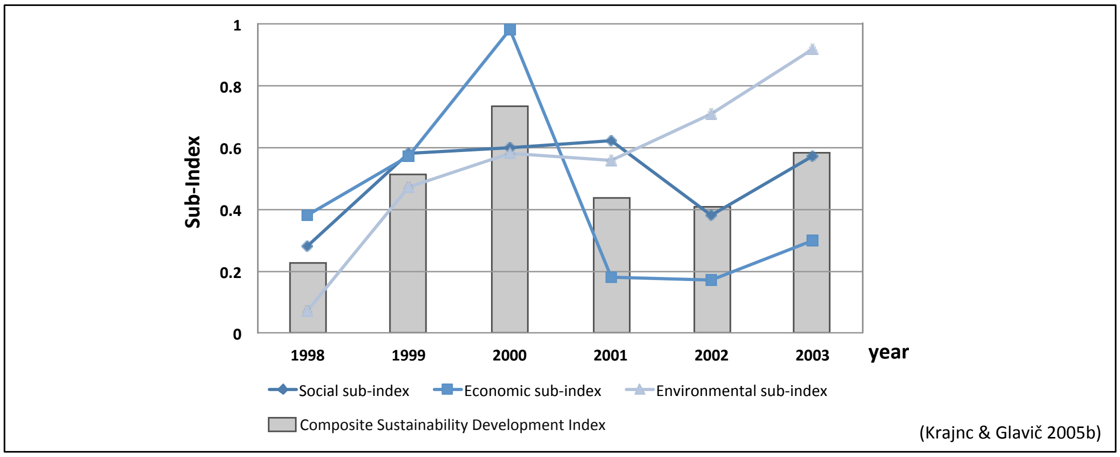

Figure 2-16: Timely performance of an overall sustainability index and sub-indices

Another interesting article relevant to this study was published by Hassini et al. (2012) in 2012, which discusses the measurement of sustainable performance in supply chains by means of a composite indicator. In contrast to the previously discussed approaches, their proposed framework provides a product-specific composite sustainability assessment. The article's focus is less on definitions (e.g., mathematical formulations), and more on the challenges for different strategies, competencies, and types of supply chain parties. The proposed framework is based on the triple bottom line concept and includes the whole supply chain (supplier, manufacturer, distributor, retailer, and consumer). Basically, each supply chain actor has to collect measures on each dimension, which align with their strategic goals. In the next step, individual sub-indicators have to be calculated, which, in a final step, are then aggregated into one composite indicator (Hassini et al. 2012). This procedure is illustrated in Figure 2-17. However, the proposed framework is not validated yet, but its assumptions and ideas served as a major input for the concept developed in this study.

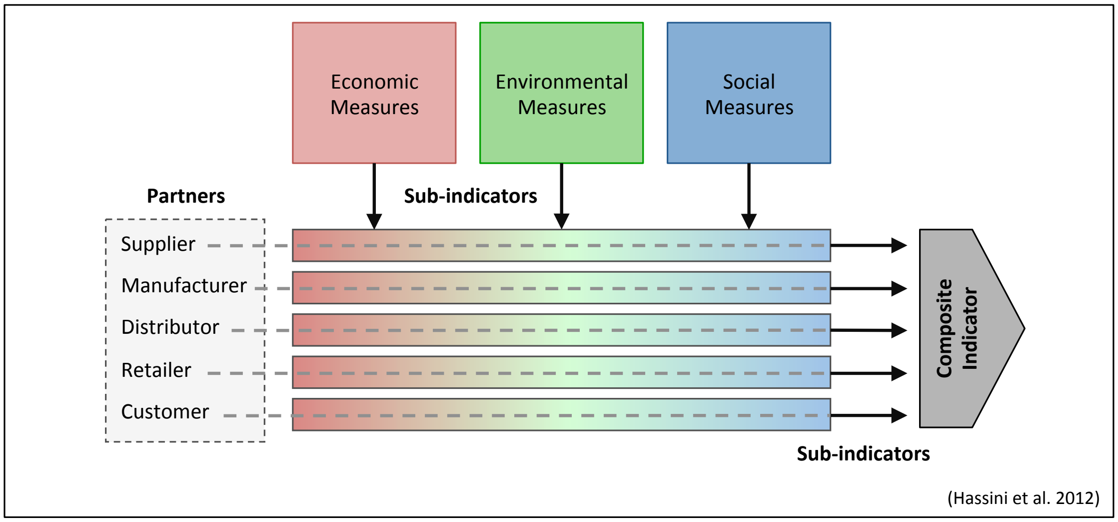

Figure 2-17: Framework for sustainable supply chain metrics

2.2.3.5 Snapshot of Industrially Used Tools

Based on the previous chapters, a solid foundation for assessing sustainability, including the definition of important terms, the introduction of frameworks for indicators, as well as the presentation of commonly used tools and current developments, has been created. Finally, some industrially used tools, guidelines, or initiatives should be introduced briefly to add the last decisive piece, which is necessary to achieve an adequate level of prior knowledge for deriving a concept around global product sustainability assessment. Approaches introduced in this Section are chosen because of their usage of aspects that were explained before, their inclusion of Life Cycle Thinking, and/or their focus on products and processes: the Global Reporting Initiative (GRI), the Ford Product Sustainability Index (FPSI), the BASF SEEbalance, and the Product Sustainability Assessment (PROSA).

Global Reporting Initiative (GRI). As mentioned before, considerable published research has been conducted in the field of sustainability assessment. The main input for any approach are indicators and metrics. Since introducing the importance of assessing sustainability in the mid-twentieth century, many authors and scholars want to make a valuable contribution to this field, and this can lead to some confusion.

With the aim of eliminating uncertainties in assessing sustainability, the Coalition for Environmental Responsible Economics (CERES) and the United Nations Environment Programme (UNEP) established the Global Reporting Initiative in 1997. According to their own guidelines, the GRI has the aim of "enhancing the quality, rigour and utility of sustainability reporting" (Hussey et al. 2001; GRI 2006; GRI 2013a). The GRI does not have a specific product focus; however, it still contributes to this study for other reasons. The main reason is that this non-profit organization contributes one of the world's leading frameworks for sustainability reporting, which is recognized by all kinds of organizations around the globe (corporate businesses, SMEs, public agencies, NGOs, etc.). The main purpose of the framework is to enable greater organizational transparency and to allow comparisons of companies regarding their sustainable performance (Hussey et al. 2001). To achieve this, the framework includes the "Sustainable Reporting Guidelines" and "Sector Guidance." The guidelines assist organizations in the preparation of sustainability reports while the latter basically makes the guidelines more practical and user-friendly for different industrial sectors and stakeholders (GRI 2014). The current guidelines are called G4 Sustainability Reporting Guidelines and consist of reporting principles and standard disclosures, as well as an implementation manual. A major part of the guidelines is an indicator framework that includes 93 indicators from all three dimensions of sustainability, which is periodically reviewed and updated. The guidelines are translated into various different languages and are freely available to the public. For more information on the guidelines, see GRI (2013a).

Particularly important for this study is the fact that the GRI contributes the most indicators to the previously introduced indicator classification done by the NIST (see Section 2.2.2). In general, many experts conclude that the GRI indicator framework is one of the most comprehensive (Zhou et al. 2012; McKenzie 2004; Feng et al. 2010; Labuschagne et al. 2005; Veleva & Ellenbecker 2001; Krajnc & Glavič 2005a).

Ford Product Sustainability Index (FPSI): Among the many existing corporation-specific indicators found in the literature, the Ford Product Sustainability Index stands out because of its primary focus on products and processes when assessing sustainability or sustainable manufacturing. The FPSI is defined as "a holistic Design for Sustainability approach that incorporates societal and economic aspects as well as environmental aspects into [Ford's] life cycle design approach" (Ford USA 2011). It is a sustainability management tool that is used in the development of all new (European) vehicles. Even if all three dimensions of sustainability are considered, the approach is compliant with ISO 14040 (Ford UK 2014). In contrast to many other assessment tools, Ford's PSI only uses eight indicators (Joung et al. 2013), which enable customers to compare specific performance and areas of improvement for each Ford Model developed by Ford Europe. Key sustainability elements are measured from the earliest stages of a car's development. An environmental indicator is, for example, the global warming potential (mainly CO_2 emissions). The indicator considers emissions of CO_2 and other greenhouse gases from raw material extraction, production (material, parts, and vehicle), usage (driving period of 150,000 km), and recovery. To include the economic dimension, the lifecycle cost of a car is calculated, which includes the vehicle price and three years of service (fuel cost, maintenance cost, taxation), less the car's residual value. The exterior noise impact (drive-by noise) is an indicator that relates to the social dimension (Ford USA 2011). Detailed reports of this sustainability analysis can be downloaded for free at Ford UK's website (Ford UK 2014). The FPSI has been used for more than ten years (introduced 2002) and still represents one of the very few tools that assess the micro-level sustainability of products, which makes the approach interesting for this study. Particularly how this index is anchored in the company's management system is progressive. Before using the PSI, Ford used a so-called Multi-Panel Chart, where all vehicle attributes were tracked throughout all development milestones. Engineers tracked this information against certain vehicle program targets. A LCA specialist from Ford developed a comprehensive and simple spreadsheet to introduce the FPSI, which is used today. This approach basically just uses data already available from the Multi-Panel Chart. Furthermore, the fact that no LCA specialists or experts are needed to provide the necessary data, but responsible engineers are able to understand and work with the concept, characterizes this approach as very lean and practical. Currently, the Ford Motor Company uses different sustainability indicators for different corporate functions to reduce the administrative burden to a minimum (e.g., the Manufacturing Sustainability Index for manufacturing). Advantages of this decentralized concept are reduced complexity, increased accountability, and the concentration of necessary know-how (Schmidt & Taylor 2006). A shortcoming of the approach is its limited scope. The considered indicators are not sufficient to provide a comprehensive view on sustainability in the sense of GPS, especially since social aspects do not receive the required attention. As proposed by Krajnc and Glavič (2005a), a spider chart (see Figure 2-18) can be used to present assessment results and allows an intuitive comparison of, for example, different model years of a certain vehicle.

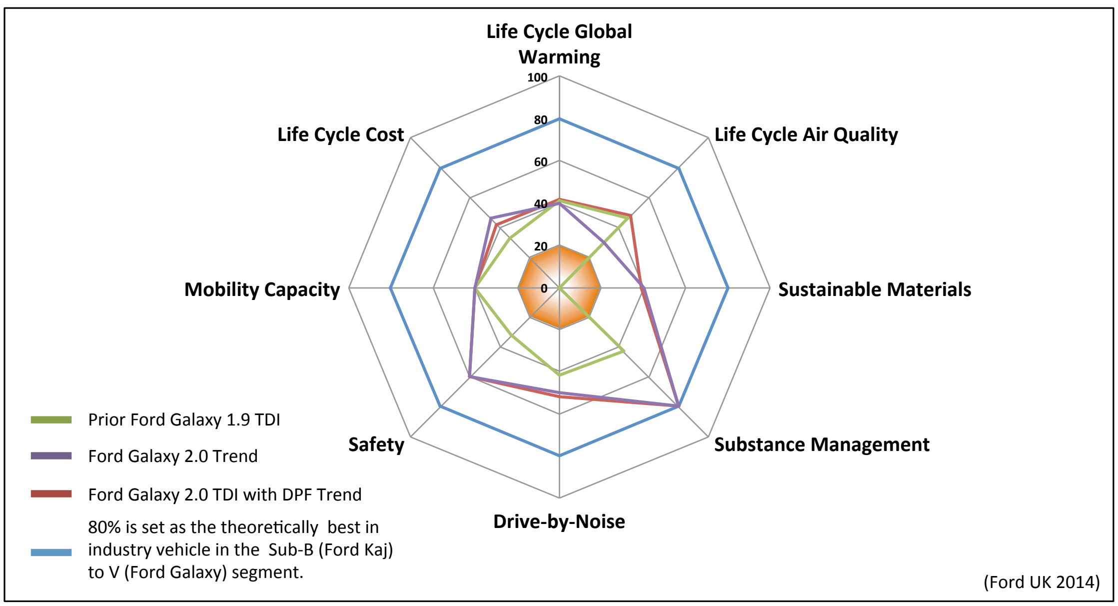

Figure 2-18: Graphical representation of Ford's PSI

BASF SEEbalance. BASF, one of the world's leading chemical companies, has been a pioneer in applying life cycle assessment methods. For decades, BASF has used the Eco-Efficiency Analysis (EEA) to assess the environmental and economic impacts of its products and processes. The EEA is based on the integration of Life Cycle Assessment

(+ Carbon Footprint) for environmental impacts and the Total Cost of Ownership approach to assess the economic dimension (BASF 2014). Thus, the EEA is used to compare environmental and economic advantages and disadvantages of different products and services while considering the entire life cycle. This methodology serves to show that some alternatives can provide a certain customer benefit more efficiently than others can (environmentally and financially). This methodology has been validated by the US National Sanitation Foundation (NSF) and by the German TÜV Rheinland in 2002 (Saling et al. 2010). For additional information on the EEA (procedure and practical use), see Uhlman and Saling (2010). The SEEbalance goes a step further and integrates the third pillar of sustainability (society). “The aim is to quantify performance of all three pillars of sustainability with one integrated tool in order to direct—and measure—sustainable development in companies” (BASF 2014). Like the EEA, the SEEbalance is a comparative method and used by BASF and its customers “to assist strategic decision-making, facilitate the identification of product and process improvements, and enhance product differentiation as well as to support the dialogue with opinion makers, NGOs, and politicians” (Saling et al. 2010, p.1). This tool is especially innovative, as it integrates the social dimension in an appropriate way in its analysis. This is achieved through the integration of several social indicators, which are classified according to five stakeholder categories, each with different subcategories. This procedure is quite similar to the procedure proposed by the UNEP/SETAC in their guidelines for S-LCA (see Section 2.2.3.3). The stakeholder groups considered in the SEEbalance are consumers, employers, national community, international community, and future generations. For each of these stakeholder categories, numerous measurable indicators, such as occupational accidents occurring during production or number of employees, are defined. Additionally, indicators to assess, for example, risks involved in the use of the product by the consumer are considered. In a next step, the stakeholder-specific indicators are weighted and subsequently aggregated to form an overall value per stakeholder category. Considered impacts are, thereby, normalized with respect to one another. The procedure is basically the same as introduced before for the LCSD (see Section 2.2.3.4). The difference is that possible values could only lie between zero and one (while zero indicates the least favorable alternative). The last step of the social analysis is to summarize all societal indicators in the so-called social fingerprint and presented this as a spider web diagram. These results are combined with the environmental and economic results from the Eco-Efficiency analysis. To illustrate how different alternatives perform from a holistic view that considers all three dimensions of sustainability, the BASF developed the SEE Cube (Saling et al. 2010; Uhlman & Saling 2010; Guillez 2009). This cube, shown in Figure 2-19, allows placing compared alternatives within the volume of the cube, where each corner represents an extreme characteristic of one dimension. The green far right top corner, for example, represents the best socio-eco-efficiency.

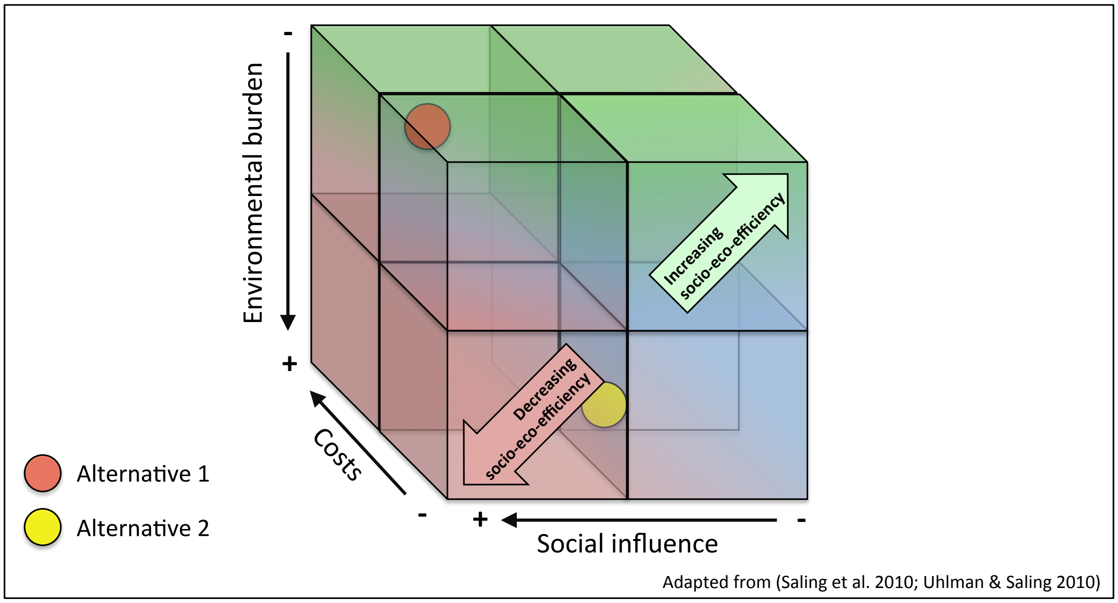

Figure 2-19: Comparing two alternatives by means of the BASF SEE Cube

This very simple and self-explanatory form of representation allows all stakeholders, regardless of experience, to interpret and communicate the results of the SEEbalance. BASF uses the SEE Cube to support decision-making in several areas, such as marketing and R&D, as well as for strategy and political issues.

Until 2010, more than 450 such analyses had been conducted within the BASF group (Saling et al. 2010). The SEEbalance's focus on products that are analyzed using a cradle-to-grave approach made the tool interesting for this study. A significant shortcoming is that the tool only allows relative comparisons among products and, thus is not directly useful in terms of assessing GPS. However, the SEEbalance has the potential to contribute to a more sustainable world by supporting companies in making sustainability-focused decisions. Even if the approach is not suited to assess GPS, many ideas and concepts may be drawn from this tool. The interested reader may take a look at Guillez (2009), or the BASF website (BASF.com), which provides several publications and information on assessing sustainability within the chemical industry. An extensive work on socio-economic assessment using the SEEbalance (and its modification and development), with a focus on normalization and weighting, was carried out by Kölsch in 2010 (Kölsch 2010; Kölsch 2009).

Product Sustainability Assessment (PROSA). The last tool introduced in this study is PROSA. PROSA is a guideline developed by the German Oeko-Institut e.V. – Institute for Applied Ecology. Product Sustainability Assessment is a method for strategic analysis and evaluation of products, product portfolios, and services. The objective of the method is to identify system innovations and opportunities for action in the direction of sustainable developing (PROSA 2005). Its development goes back to 1987, when the Oeko-Institut e.V. designed the so-called Produktlinienanalyse (comprehensive product system assessment) for the integrated analysis of environmental, social, and economic aspects along a product line (Grießhammer et al. 2007). However, this method was ahead of its time and is only rarely used compared with other methods like, for example, the Ecobalance. The currently available guideline is the result of a continuous improvement and enhancement process. Many approaches promoted in the guideline are based on the previously described methods (e.g., E-LCA, LCC and S-LCA). PROSA involves the whole product life cycle and analyzes and evaluates the ecological, economic, and social opportunities and risks of future development paths. The timely structure of this analysis is based on typical phases of a strategy formulation processes: goal definition, market and environmental analysis, idea generation, sustainability analysis, and, finally, strategic planning. For each phase, several well-established tools can structure the necessary decision processes and reduce complexity to a minimum. Usable tools are, for example, megatrend and scenario analysis, LCA, LCC, and a version of S-LCA. Furthermore, tools that support the user when conducting and interpreting a product sustainability analysis are embedded in the guideline (Checklists, ProfitS – interpretation framework). The basic structure of PROSA is shown in Figure 2-20 (Grießhammer et al. 2006; 2007; PROSA 2005).

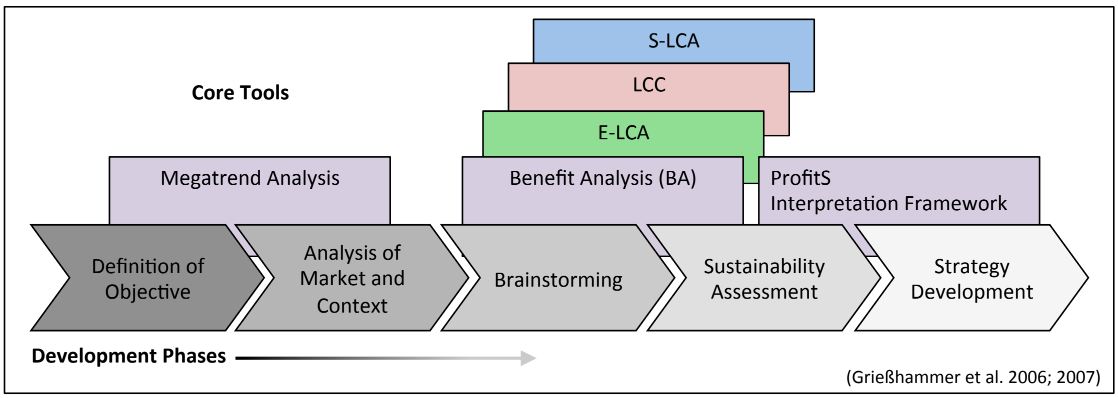

Figure 2-20: Basic structure of PROSA

ProfitS, which stands for Products-fit-to-Sustainability, is an integrated assessment model that combines all assessment tools and, thereby, assesses the observed product in all three sustainability dimensions to provide an overall impact. Comparable with other integrated approaches, this is achieved using the weighting and aggregation of numerous lower-level analyses and the results can be presented either via a bar or spider web diagram.

Like the BASF SEEbalance, PROSA does not aim to assess or evaluate products in absolute terms, but rather to provide decision support or to identify opportunities and risks regarding sustainable product development. In 2007, the revised guidelines for PROSA 2.0 were published (Grießhammer et al. 2007). Based on international (information) exchange (expert workshops, study tours in Europe, USA, Asia), as well as case studies, the method has made significant progress in important fields. A special focus was on the further development of Social Life Cycle Assessment, since this field is still characterized by the research gap described above. Detailed information on its development methodology, including methods, functions, and recommended usage, is contained in the comprehensive and extensive guidelines available online (www.prosa.org).

By this point, the reader has gained systematic and comprehensive insight into the extensive field of assessing sustainability. Starting from a very high level, with the definition of *Global Product Sustainability* based on the concept of sustainability, the focus has been concentrated toward a more product-specific view. Commonly used and accepted indicators and frameworks were introduced, as well as basic assessment tools. The previous description of industrially used tools and guidelines finally provides the last necessary piece to form a solid foundation to derive the requirements for assessing GPS.

2.3 Excursus: Location Decisions

One hypothesis stated at the beginning of this study was that *the effective assessment of Global Product Sustainability might affect future location decisions*. This raised the question of how location decisions are currently made and what factors influence them. For this reason, a short excursus on location decisions should be given. With respect to the further considered textile sector, which is characterized mainly by relocating facilities to developing countries, offshore outsourcing and offshoring decisions will be considered.

2.3.1 Making Strategic Outsourcing Decisions - Models and Factors

As mentioned before, and according to the OECD alternatives in offshoring activities exist; outsourcing to an existing location abroad, offshoring to a newly built plant or company, and outsourcing to a subcontractor in a foreign country that is not affiliated with the organization (OECD 2007). To evaluate these alternatives, the current research knows basically two different approaches or models. First, the model focuses on the company's choice of organizational form (Antràs & Helpman 2003; Grossman & Helpman 2004; Grossman & Helpman 2001; Grossman & Helpman 2005; McLaren 2000). This type of model belongs to the domain of international trade theory and could be used to support decision-making on a macroeconomic level. The main purpose is to make a choice between outsourcing or integration and the location choice between abroad and home. Due to the model's macro perspective answers to specific outsourcing problems regarding single firms are not addressed with these models (Dou & Sarkis 2008). This is where the second group of models comes into play, which is at firm-level. Not many models can be found in this segment (Ruiz-Torres & Mahmoodi 2008) and the few that do focus on outsourcer selection and evaluation (Cao & Wang 2007; Almeida 2007; Araz et al. 2007). The basic theoretical approach is closer to supplier selection models (Sarkis & Talluri 2002; Narasimhan et al. 2006). Except for some models (Chan & Kumar 2007), location factors (e.g., political stability and economic condition) are usually not included in supplier selection models. In conclusion, both types neglect the respective strength of each other. Offshoring supplier selection models at the firm level are not able to capture facility location factors, whereas models for facility location models neglect supplier selection factors (Dou & Sarkis 2008). For this reason, Dou and Sarkis (2008) constructed a model for evaluating and selecting different offshoring alternatives by simultaneously considering facility location factors and supplier selection metrics. Methodologies used in current models for facility location and supplier selection decisions vary from a simple matrix and scoring methods to advanced mathematical programming and game modeling approaches. These authors chose the analytic network process (ANP), which is basically a general form of the analytic hierarchy process (AHP), and used in multi-criteria decision analysis (MCDA). The main advantage of this approach is that it does not require the complexity of mathematical modeling, but leads to more robust solutions than simple scoring or matrix methods (Sarkis & Sundarraj 2000). The exact functionality of ANP, which uses pairwise comparisons of factors as a main input, is not of further interest for this work.

However, of increased importance for this study are factors or indicators used to make offshoring decisions. Since the goal is to provide decision-makers with a holistic and integrated model, facility location factors have to be considered as well as supplier selection factors[11].

Facility location decisions are broadly discussed in the recent literature (Mudambi 1995; Brush et al. 1999; Prasad et al. 2000). From this, it appears that following the three employed approaches for location decisions—neo-classical, behavioral, and institutional (Hayter 1997)—decision models subsequently concentrate on economic, behavioral, or institutional factors. Neo-classical approaches aim at cost minimization and profit maximization as the main decision drivers and specify factors like labor costs, transportation costs, market size, and locational business climate as main influencers. Behavioral approaches, in contrast, focus more the dynamic processes of how decisions are made. The basic idea is that “the best way to study decision-making is to observe it while the decision is being made” (Redlawsk & Lau 2012, p.18). The main explanation for facility location decisions is, therefore, a company’s perception and evaluation of a certain information base (Hayter 1997). In common with both is the assumption of a static environment, which is the reason why both

[11] The term “supplier selection factors” will be used to represent “outsource selection factors” or “subcontractor selection factors.”

approaches have received significant criticism (Brouwer et al. 2004). The institutional approach, however, focuses on strategic factors like competition, current facilities, and market penetration (Hayter 1997)[12].

Common factors for supplier selection as a critical strategic challenge, imposing significant competitive advantages (Simpson et al. 2002), are quantifiable criteria. Examples of such supplier-evaluating criteria are cost, quality, and delivery times (Sarkis & Talluri 2002). Furthermore, there are qualitative and intangible criteria that become increasingly important (e.g., supplier‑customer relationship development) (Kannan & Tan 2002; Simpson et al. 2002). In general, the literature groups supplier selection factors into two different groups: strategic performance metrics, which have been identified as major competitive priorities (cost, quality, time, flexibility, and innovativeness) (Wheelwright & Hayes 1985), and organizational factors (culture, technology, and relationships), which focus more on organizational capabilities and characteristics. Organizational factors are especially important to form a solid partnership between companies and their suppliers[13].

It is conspicuous that neither in the conventional literature on location and outsourcing decision-making, nor in the textile and clothing related literature (Section 5.5), are sustainability-related factors emphasized in an appropriate manner. The following section will shed some light on this rarely investigated field.

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[12] For detailed facility location decision factors see Dou and Sarkis (2008).

[13] For detailed supplier selection factors see Dou and Sarkis (2008).

2.3.2 Considering Sustainability in Location Decisions

Even in the field of location decision-making, sustainability relates mostly to environmental aspects. In location research, for example, environmental regulations and cost reduction are a major focus of sustainability considerations (Daly 1995; Hayter 1997; Min & Galle 1997). Nowadays, multinational companies in particular are criticized when offshoring business processes to developing countries. Allegations made against firms are, among others, taking advantage of low-wage workers, capitalization on lax environmental regulations, and weak workplace standards, as well as contributing to social and environmental degradation (Doh 2005). Even though an increasing number of authors have addressed environmental aspects in the field of supplier selection (Min & Galle 1997; Noci 1997; Handfield et al. 2002; Humphreys et al. 2003), there is still a substantial lack of integration among all dimensions of sustainability (according to the Brundtland definition), including the social dimension, in the supplier and location decision process (Dou & Sarkis 2008).

Recent offshoring decisions by organizations and researchers have focused on strategic outsourcing subcontractor selection. While subcontractor selection is mainly based on factors such as cost, quality, delivery, and flexibility, sustainability factors are traditionally not given significant emphasis. In addition, more holistic offshoring and outsourcing decision would take into account other metrics like facility location factors, rather than a sole consideration of supplier or subcontractor selection factors. Pressure comes from governments as well as from consumers, who point to the commitment to sustainability in a firm’s policy. Issues of interest are, for example, corruption, child labor, and human rights (Rivoli 2003). Taking a closer look at supplier selection decisions, it can be seen that environmental, and some social sustainability factors, are considered on a firm level (not from a regional locational perspective) (Dou & Sarkis 2008). Both environmental and social factors can be grouped as two categories. Environmental factors can be categorized into, first, environmental practices, which comprise procedures like monitoring of discards or routine audits and, second, environmental performance, which covers, for example, the amount of resources used and waste produced. According to Gil et al. (2001), a commonly accepted categorization of environmental practices is to differentiate between pollution prevention and pollution control. A summary of environmental factors (on an organizational level) is provided by Dou and Sarkis (2008) (adapted from (Klassen & Whybark n.d., p.606; Gauthier 2005, p.204).

Following Gauthier (2005), categories for social factors are internal and external social criteria. Internal social criteria incorporate any employment practices. This means gender diversity (female labor), labor sources (child labor), and occupational health and work safety. Relations with contractual stakeholders (e.g., suppliers and customers) and relationships with, for example, local communities and NGOs, are referred to as external social criteria. Due to the focus on assessing the social dimension of sustainability, these factors are of significant interest and summarized in Table 2-3, which provides an overview of various social factors (and sub-factors) that could be used in supplier selection decisions. These factors are summarized from a number of different sources (Gauthier 2005; Presley et al. 2007; GRI 2013a; GRI 2013c; GRI 2006; Labuschagne et al. 2005).

Table 2-3: Social metrics in supplier selection decision

Categories	Factors	Sub-factors
Internal Social Criteria	**Employment Practices**	Disciplinary and Security Practices
		Employee Contracts
		Equity Labor Sources
		Diversity
		Discrimination
		Flexible Working Arrangements
		Job Opportunities
		Employment Compensation
		Research and Development
		Career Development
	Health and Safety	Health and Safety Incidents
		Health and Safety Practices
External Social Criteria	**Local Communities Influence**	Health
		Education
		Housing
		Service Infrastructure
		Mobility Infrastructure
		Regulatory and Public Services
		Supporting Educational Institutions
		Sensory Stimuli
		Security
		Cultural Prosperties
		Economic Welfare and Growth
		Social Cohesion
		Social Pathologies
		Grants and Donations
		Supporting Community Projects
	Contractual Stakeholders Influence	Procurement Standard
		Partnership Screens and Standards
		Consumer Education
	Other Stakeholders Influence	Decision Influence Potential
		Stakeholder Empowerment
		Collective Audience
		Selected Audience
		Stakeholder Engagement

Source: according to (Gauthier, 2005; Presley et al., 2007; GRI, 2013a; Labuschagne et al., 2005)

Facility location decisions require a broader perspective, with a focus on the community or regional level. Analyzing, for example, cities, towns, or even larger communities, has led to numerous terms like sustainable cities, sustainable urban development, and sustainable communities (Beatley 1998). Always bear in mind that the ultimate purpose of these community concepts is to combine economic growth, social equity, and environmental symbiosis (Lin & Lee 2005). Based on these concepts, social and environmental factors for location decisions can be derived. An overview of environmental factors (mostly based on the Environmental Performance Index (EPI)) can be found in Dou and Sarkis (2008). Table 2-4 gives an overview of social factors and sub-factors in facility location decision. (Bossel 1999, p.17; United Nations 2007, pp.10–14).

Table 2-4: Social factors and sub-factors in facility location decision

Factors	Sub-factors
Poverty	Income Poverty
	Income Inequality
	Sanitation
	Drinking Water
	Access to Energy
	Living Conditions
Governance	Corruption
	Crime
Health	Life Expectation at Birth
	Health Care Delivery
	Nutritional Status
	Health Status and Risks
	Old Age Provisions
Education	Educational Level
	Literacy
Demographics	Population Growth
	Tourism
Natural Hazards	Vulnerability to Natural Hazards
	Disaster Preparedness and Response
Individual Development	Civil Liberties and Human Rights
	Equity
	Individual Autonomy and Self-determination
	Right to Work
	Social Integration and participation
	Gender and Class-specific role
	Material Standard of Living
	Qualification
	Specialization
	Family and Life Planning Horizon
	Leisure and Recreation
	Arts
Community Development	Security Sense
	Cultural Properties
	Social Cohesion
	Social Pathologies

Source: according to (Bossel, 1999, p.17; United Nation;s 2007, pp.10–14)

A selected number of introduced factors is further used in the ANP methodology proposed by Dou and Sarkis (2008). To make a final location outsourcing decision, seven different steps have to be conducted; the first step identifies and selects the most salient factors. This is important to enable a pairwise comparison of the selected factors, which is then followed by a calculation of relative importance of the factors. Based on this formulation and a defined decision network, a supermatrix will be formulated. If reasonable, then a sensitivity analysis will be used to evaluate whether changes regarding the assumed weights (feedback loop) are necessary. Based on this defined approach, a location decision can be made[14].

In the framework of this study, the individual steps are not as important as the composition of previously described factors, and the general way of approaching the location decision problem could serve as a significant input for this work. There are many similarities between sustainability factors considered in location decisions and indicators used to assess sustainability (of products). Since manufacturing facilities are build to produce products (or provide services) and impacts therefore are caused by products or rather should be accounted to products the hypothesis that *the effective assessment of Global Product Sustainability might affect future location decisions* could theoretically be answered affirmatively. Thus, an effective and successful assessment of GPS might be able to replace the consideration of sustainability factors in location decisions by the aggregated consideration of results from assessing GPS. However, if sustainability issues are ought to affect location decisions the methodology used to consider sustainability aspects is not decisive yet.

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[14] Detailed information on the ANP methodology (calculations and case) can be found in (Dou & Sarkis 2008).

In a first step it is crucial to accomplish the need to consider sustainability in location decisions on a higher level (politics, governments and consumer behavior).

3 REQUIREMENTS TO ASSESS GPS

The objective of this chapter, and the overall study, is to provide a concept through which *Global Product Sustainability* can be assessed. The most difficult challenges arise from the massive scope and size of almost every field that is affected by the research question/objective. For this reason, Chapter 3 summarizes the major requirements that must be considered in the concept and its further development. As shown in Figure 3-1, the general requirements on assessing sustainability and assessment are described in Section 3.1 while Section 3.2 emphasizes the specific requirements necessary to assess GPS. Thus, this section serves to lay the foundation on which the concept will be built.

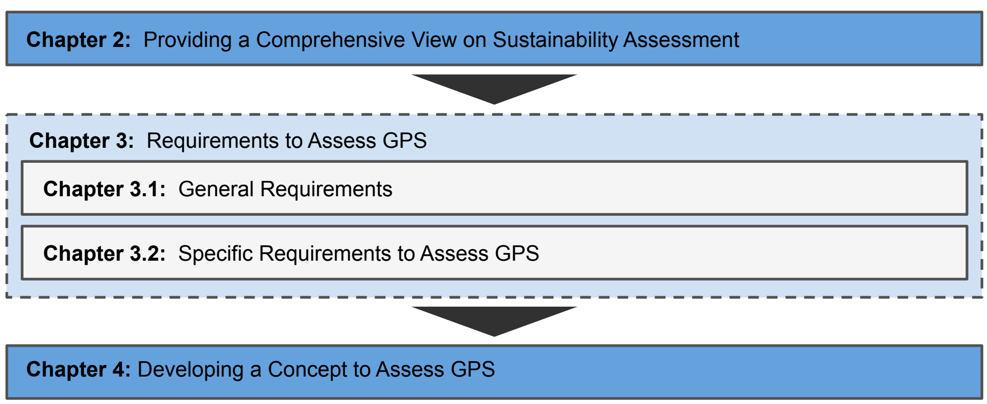

Figure 3-1: Structure of Chapter 3

Figure 3-2 summarizes all 21 requirements identified. These are mostly derived from the literature. Other requirements are based on the author's own experience and logical consequences from the thesis objective. It should be noted that the classification of requirements is subjective and that it is not always possible to clearly distinguish between general and specific. Overlapping is possible and not a problem.

Since the discipline of sustainability assessment has been discussed over several decades, and assessment methods like E-LCA have been successfully implemented in business, a major focus will be on the specific requirements for assessing GPS. However, the goal of Chapter 3 is to provide the reader with an idea and understanding of what to expect of the concept introduced in this study.

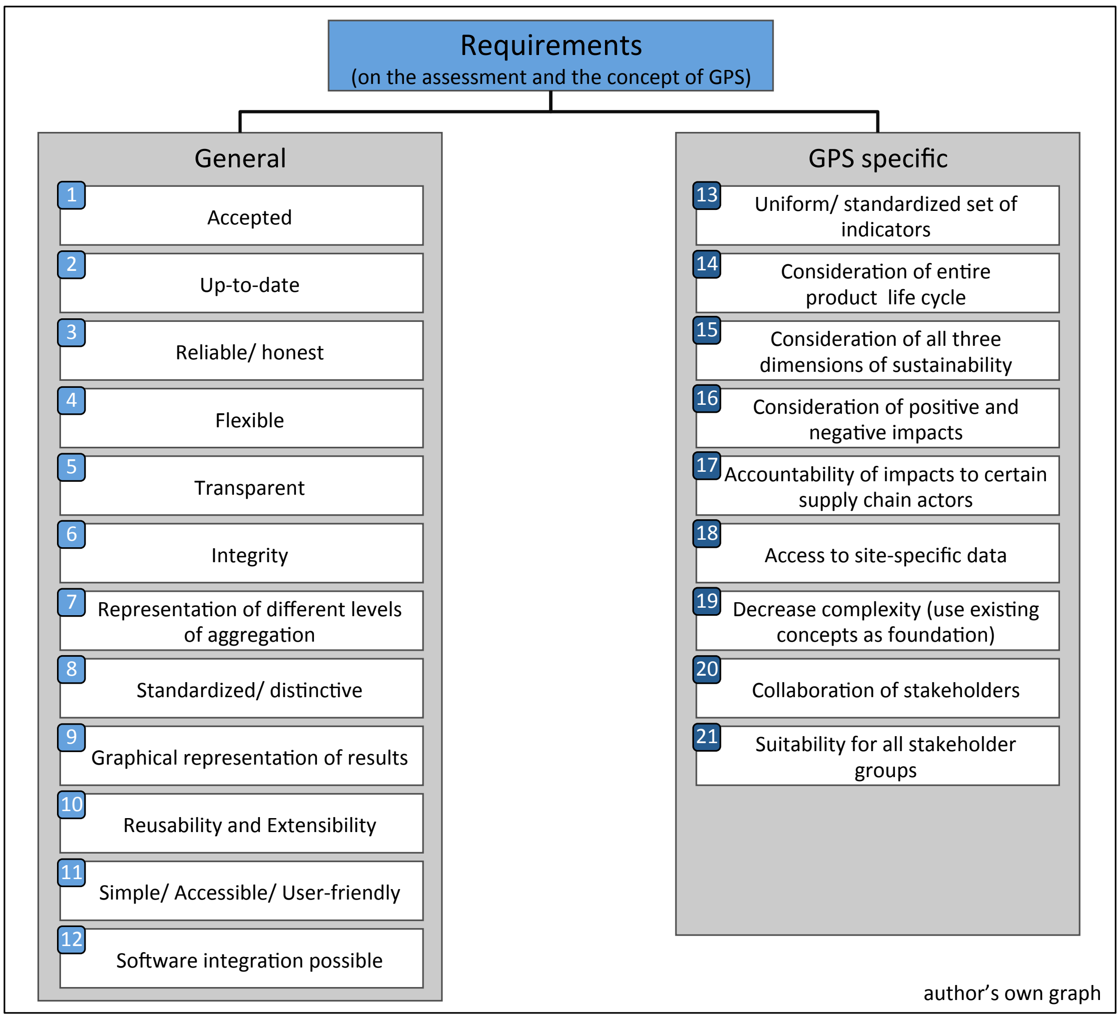

Figure 3-2: Requirements to assess GPS

3.1 General Requirements

The general requirements are not necessarily related to the topic of sustainability. However, these will be explained in this context. It is important that the methods, assumptions, and underlying indicators are acceptable in the field of research and business (Requirement 1). Furthermore, the data must be up-to-date (Requirement 2). If different data sources have to be used, or studies are not revised continuously, then their results do not allow meaningful interpretation and will not be comparable with other studies (Cotton Incorporated and PE International 2012; Schmidt 2010). This requirement is closely related to Requirement 3 (data reliability), since data has to be trustworthy (Feng et al. 2010). This problem is, for example, stressed by Grießhammer et al. (2006), who argue that, especially in complex supply chains, where small companies have only a limited overview of all companies involved, obtaining reliable data is a problem. This is particularly true in less-developed (and non-democratic) countries, where data are often restricted at nearly all levels. Flexibility (Requirement 4) is also important in the assessment of sustainability. For example, in the textile and clothing supply chain, flexibility is important since retailers expect a high level of responsibility from suppliers (Adhikari & Yamamoto 2005). Consumers nowadays demand a high level of product availability. If fast management decisions are required (e.g., failure of a supplier), then decisions have to be made quickly while also taking into account sustainability issues. Transparency and integrity (Requirements 5 and 6) ensure that each company within a certain supply chain is able to evaluate the reliability of the data provided. Opaque business structures prevent this from occurring. The ability to provide data on different levels of aggregation (Requirement 7) is important because assessment results should be transferable to different decision applications. Different companies have different objectives, which causes the divergence of focus within the supply chain. The possibility to aggregate certain parts of an assessment allows stakeholders to understand specific information (see the black box principle). Data has to be useful and must fit the purpose of the assessment (Feng et al. 2010). For example, using the Life Cycle Costing approach, a large number of possible viewpoints may need to be integrated into one assessment (Finkbeiner et al. 2010). A standardized approach (Requirement 8), which is based on distinctive assumptions, is necessary to guarantee the generalization of results. Only when every stakeholder has a clear idea of how the results are generated, and the underlying conditions, can a meaningful interpretation be possible. Additionally, the use of standardized and commonly used methodologies (e.g., standardized by the ISO) increases confidence in an assessment, which, in turn, has a positive effect on the acceptance of results. Graphical representation (Requirement 9) is particularly important for communicating the impacts of alternate sustainability decisions (e.g., location decisions) at a high organizational level. This is closely related to Requirement 5: transparency. The higher the position in a company, the greater the decision-making power, but the lower the demanded level of details. An appropriate graphical representation allows these decision-makers to focus on the major assessment statements, and can significantly influence the decision-making process. Reusability and Extensibility

(Requirement 10) are required to enhance institutional usability of the instrument. If, for example, only one assumption of an assessment is changed, then it should be possible to consider the impact of the change without conducting the entire assessment a second time. The same holds true if new data are integrated in the assessment, or if additional supply chain actors need to be considered. A user-friendly format, simplicity, and availability (Requirement 11) are of major importance; in particular, companies with limited resources would not use assessment methodologies that require significant resources in time and money. The assessment has to be based on accessible data (ideally from existing sources) (Feng et al. 2010). It is important to provide data at an appropriate level and not to pretend pseudo-accuracy with an assessment (e.g., when determining a PCF) (Schmidt 2010). Assessments should be understandable by everyone (e.g., the community and other non-expert stakeholders) (Feng et al. 2010). In considering, for example, the textile industry, companies involved in the supply chain differ significantly about skills and resources. To provide reliable and usable data it is, however, necessary that each company provide data with an appropriate level of quality. This leads directly to the final Requirement 12: software integration. Effective software integration addresses many of the previously described challenges and requirements. For example, a collective database might increase flexibility and positively influence transparency. An interesting approach in this field might be open source software, which is based on a standardized foundation (e.g., indicator framework, available normalization, and weighting methods), but allows for company-specific adaptations and expansion. It is crucial to bear all these requirements in mind when using or developing an assessment approach. Although not all of them are equally important, they should, however, be considered in some way.

3.2 Specific Requirements to Assess GPS

The following introduced specific requirements are related to the objective of assessing *Global Product Sustainability*. They are either based on the literature or derived from the author’s experience. As previously elucidated, sustainability research has many facets, and can be approached from several perspectives. The literature review revealed countless journal articles, books, and reports that deal with the general topic of sustainability. Even after defining appropriate search terms and phrases for the literature review, and applying practical screening criteria to reduce the output articles, numerous articles of relevance remained. For example, there is a multitude of indicator sets, indicators, and metrics that each claim to be the most suitable to assess sustainability. Some are developed by different organizations, companies, or researchers according to different objectives and scopes (e.g., firm-level, product-level, life-cycle stage, or country and region). To assess GPS in an appropriate way (in accordance to the general requirements) a uniform and standardized set of indicators must be defined (Requirement 13) that considers both branch- or industry-specific characteristics, and the entire Product Life Cycle (from cradle-to-grave) to assess GPS (Requirement 14). Additionally, the concept should consider external effects[15]. Taking into account the triple bottom line concept (Requirement 15), which encompasses the impacts caused in each of the

[15] For externalities see Section 4.1.3.2.

three dimensions of sustainability, describes another specific requirement. Within these dimensions, and the various life-cycle stages, different impact categories are prevalent that can have positive as well as negative impacts. Both manifestations have to be considered in a meaningful assessment (Requirement 16). Going a level deeper, complex supply chains or production networks are necessary to fulfill the different functions required to produce, maintain, and recycle a product. Each stage, in turn, can include several companies or sub-supply chains. A major challenge arises from the fact that each company involved in a supply chain, or the production network of a certain product, may also be involved in other supply chains or networks related to producing other products. For example, a textile mill, which is indeed a very elementary example, may produce different textiles for different purposes (clothing, textiles for the automotive industry, textiles for private consumers), which can be further diversified according to each individual buyer. It is a very complex, but necessary, task to account for the impact that each sustainability dimension has on a certain production stage (supply chain actor) (Requirement 17). Additionally, site-specific data must be gathered on this level (Requirement 18). Because companies, suppliers, or their functions and activities are now located wherever in the world they can contribute the greatest value to a product, additional challenges to assess global product sustainability arise. Companies of various sizes, ranging from only a handful of employees to thousands of employees, may be involved in producing a certain product. They could be located in any and various countries of the world, including developing countries. Under these conditions, it is necessary to reduce complexity as much as possible, without risking the loss of important information and validity (Requirement 19). To guarantee a successful assessment, stakeholder-specific characteristics need to be consolidated. For this reason, it is of key importance that all supply chain parties collaborate (Requirement 20) and work with the developed assessment approach (Requirement 21). This objective cannot be reached without the participation of all stakeholder groups and cannot be imposed by a focal company. Figure 3-3 summarizes this complex environment, in which the term *Global Product Sustainability* is embedded and that justifies most of the requirements described above.

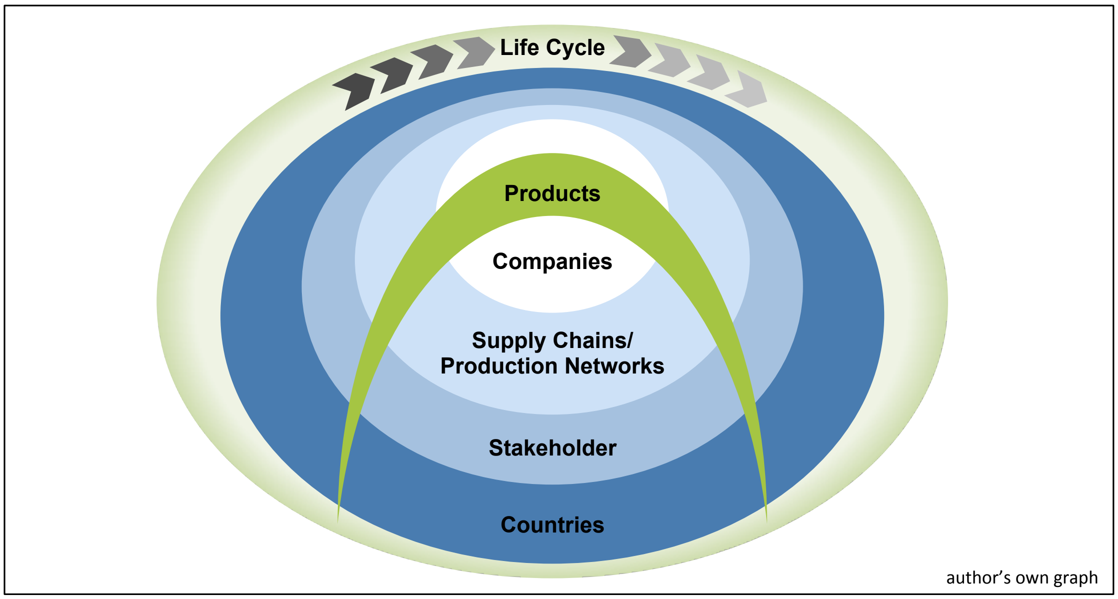

Figure 3-3: The context of *Global Product Sustainability*

In summary, assessing *Global Product Sustainability* affects a large number of stakeholders, with disparate roles within the product life cycle, and a variety of production structures. For that reason, data procurement represents a challenging task that must be considered at the conceptual development stage. For example, developed countries possess equipment that is more advanced and knowledge to measure required indicators than less developed or developing countries. The aggregation of data along the supply chain (without losses) can also be seen as a major challenge. Finally, the goal of justifiable attribution of product impacts across the range of dimensions (economic, environmental, and social), raises complex questions.

4 DEVELOPING A CONCEPT TO ASSESS GPS

Due to the above-described range of requirements, challenges, questions, and problems, the objective is not to come up with a practical applicable tool, but rather develop a concept that provides a starting point and framework for future research and to face the final challenge of assessing *Global Product Sustainability* in the described sense. A particular focus is on developing a concept that is universally understandable; thus, as many known and accepted elements and concepts as possible should be used instead of increasing complexity through introducing yet another completely new approach.

The structure of Chapter 4, which basically deals with the development of a concept to assess GPS, is presented in Figure 4-1. Section 4.1 deals with the development and the composition of the concept. Starting with the description of the methodological approach used to come up with an appropriate concept in Section 4.1.1, Section 4.1.2 follows with a brief description of the basic concept and how major ideas from the overhead allocation were derived. Section 4.1.3 illustrates the structure of the developed concept and focuses on the economic assessment of GPS, how the entire product life cycle is integrated, and the way graphical representation is used to visualize results. Section 4.2 aims to address challenges that might occur if the concept should be used in practice. A distinction between challenges arising from data and software (Section 4.2.1) and organizational challenges (Section 4.2.2) is made.

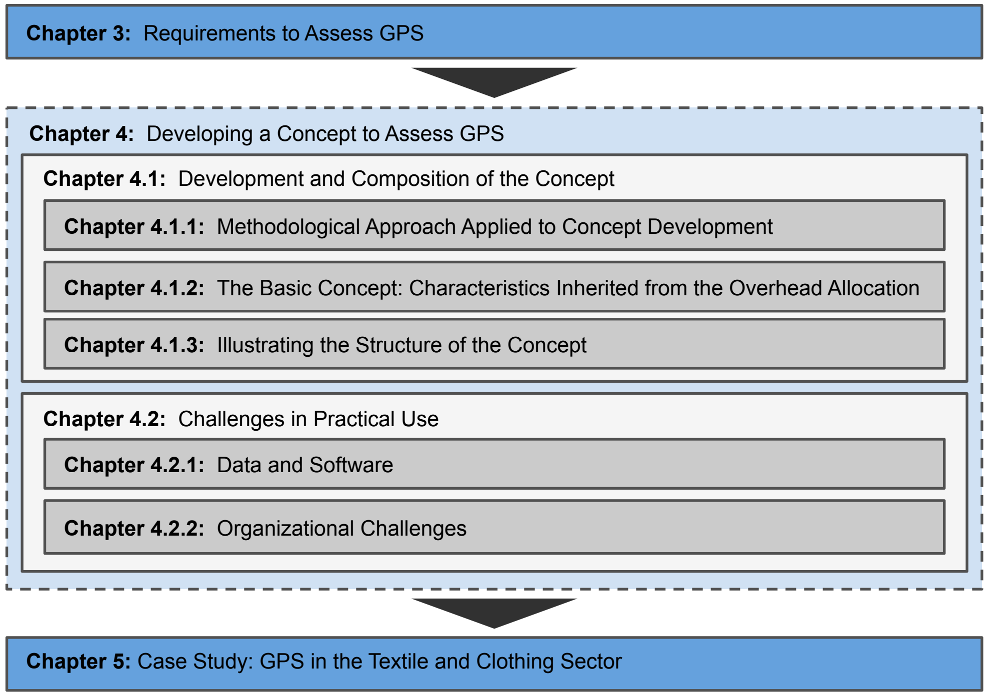

Figure 4-1: Structure of Chapter 4

The initial step is to create a common understanding of the term *concept* in the context of this work. The term concept is derived from the Latin word *concipiere*, which means to capture. In the present context, it means draft or design a provisional (not meticulously detailed) plan. In the current work environment, however, the term is used differently. It may be possible that a concept should lead to a specific design; however, a concept should not be described as a design in general. The term concept does not have a coherent definition. For this reason, we must define the objectives of a concept and clarify the perceptions that are associated with that concept, rather than try to fill the term with content. There are many reasons that could lead to the need to construct concepts. In practice, for example, changes of environmental conditions or internal structures may require a conceptual approach, or changes of actual concepts. Irrespective of the aimed level of detail, it is crucial to ensure a structured proceeding in developing a concept (AD HOC 2014).

4.1 Development and Composition of the Concept

A commonly used and helpful tool to create concepts is the so-called problem-solving cycle, which is similar to the procedure for defining a business strategy (PROSA in Section 2.2.3.5 and shown in Figure 4-2).

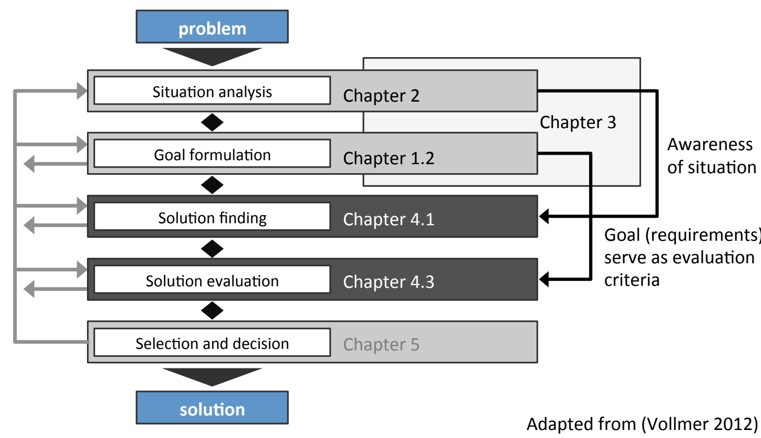

Figure 4-2: Problem-solving cycle

Following the situation analysis (see Section 2.2), the main purpose is summarized once again in Table 4-1, based on the problem statement and the formulation of objectives (see Section 1.2); the next step is to find a solution, which is the overall function of Chapter 4.

Table 4-1: Questions answered within the situation analysis

	Questions	Description
Situation Analysis	What is currently going on? What is the problem? What do we want to change? What prevents us to reach the desired state? What do we need to change? How is currently dealt with the issue/ the problem? What would happen if we do nothing?	Look at the problem from different angles Analyse possible stakeholder groups determine the most important influential factors and the context of the problem Define weaknesses Unvcover potential risks **In summary: Diagnosis**
	Used sources	
	Extensive Literature Review Brainstorming Expert Interviews	

4.1.1 Methodological Approach Applied to Concept Development

In a time of increasing complexity, success is largely determined by whether recognized problems and needs are properly identified and whether creative solutions for these can be found (Vollmer 2012). To directly generate new ideas and visions to meet the identified challenge of developing a concept to assess GPS, the methodology of synectics was used. The word *synectics* is derived from Greek and means "the joining together of different and apparently irrelevant elements" (Gordon 1981, p.5). The basic idea of this problem-solving methodology is to stimulate unconscious thought processes and to make them comprehensible for the user. The aim is to provide new patterns of thinking through the reorganization of objectively discontiguous and different knowledge (Biermann & Dehr 1997). The procedure of synectics consists of ten consecutive steps, which are usually carried out in small groups. The initial step serves to identify the problem (S1), clarify basic questions of comprehension and gather information on the problem. In the next step, the problem will be described to all participants of the synectics group and, additionally, first spontaneous solutions and ideas are collected (S2). The reformulation of the original problem, based on the generated spontaneous approaches from step 2, is the function of step three (S3). These first three steps are summarized as the problem analysis phase. Steps four to seven form the core of the methodology and serve the formation of analogies. This phase is also referred to as the alienation phase. First, direct analogies (S4), for example, from nature, are formed. The formation of personal analogies (S5) is followed by the formation of symbolic analogies (S6). In the last step of the alienation phase, technical analogies (S7) are developed for the newly formulated problem. It should be noted that analogies are not necessarily found in all alienation steps. Step eight is conducted to select, describe, and analyze preferred analogies (S8). The following step is necessary to link selected analogies back with the original problem (S9). The final, and most important, step serves to develop and evaluate practical solutions (S10) and then document them (Biermann & Dehr 1997; Schawel & Billing 2012).

The goal of the described multi-level alienation process is to associate new sectors with the original problem. Thus, the area of knowledge, which is accessible and usable to solve the problem, is significantly larger than if using conventional methodologies for problem-solving (Biermann & Dehr 1997). The reformulation of the problem is necessary to distance it from the original problem and, thus, less restricted in finding new solutions.

The main objective here is to assess *Global Product Sustainability*. However, it is noted that the scope of this objective is very broad and consists of several sub-problems, which in turn define the sub-objectives. These can be derived from the requirements presented in Chapter 3. Figure 4-3 shows major sub-objectives. Whereas the light grey highlighted pillars represent objectives, which could already be satisfied to a large extent due to existing approaches (considering all three dimensions of sustainability and the whole product life cycle and evaluating individual products), the dark grey colored objectives cannot yet be achieved. In particular, the lack of fairness in attributing sustainability impacts among all supply chain actors marks a fundamental deficit. The high degree of transparency and usability needed by all supply chain actors and stakeholders to calculate impacts, is limited in existing measurement tools. For those reasons, the solution finding process of synectics focused on only two objectives.

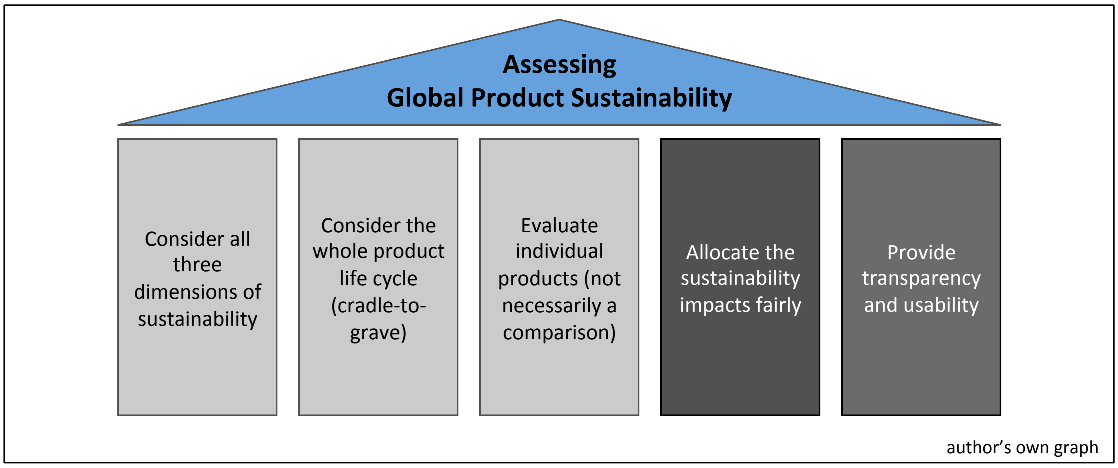

Figure 4-3: Overall objective and major sub-objectives

This breakdown of the main objective can be seen as a reformulation of the original problem, since there is no longer a connection to the topic of *Global Product Sustainability*. The new formulated goal, which serves as the initial step for the synectics, is: *Allocate process consequences (impacts) fairly, objectively, and transparently between different involved parties*.

The results from the synectics alienation phase, which was conducted in the context of this study, are shown in Table 4-2.

Table 4-2: Results from the alienation phase within synectics

Goal: Allocate process consequences fairly, objectively and transparently between different involved parties.		
No.	**Process step**	**Results from alienation**
4	**direct analogies** (e.g. from nature)	food chain, fishbone (diagram)
5	**personal analogies**	trial, cause-effect diagram, disaster/ emergency management
6	**symbolic analogies**	(Really) adding by subtracting, miss the forest for the trees, Darwin's rule
7	**direct analogies 2** (e.g. from technique)	Cost causing principle, overhead allocation

According to the previously introduced procedure of synectics, the next step is to select the best fitting analogies to describe and analyze. Only some of the analogies discovered were chosen to be relevant. For example, the analogy *food chain* does not really meet the requirement of being fair. Bearing in mind the original problem, the food chain may represent a fair model in the sense of nature; however, in reference to supply chains, it cannot be presumed "fair" that only the "strongest survive." The same applies to the symbolic analogy, Darwin's rule (survival of the fittest). A personal analogy is disaster or emergency management, which strives to plan for and coordinate all required resources (personal and materials) to mitigate the effects of, or recover from disasters. It does not matter if these are natural, man-made or, for example, acts of terrorism (MEMA 2007; Drabek 1991). Even if studying threats is an important field of disaster management, it neither averts nor eliminates those threats. Important principles in emergency management are, for example, comprehensiveness, integrity, collaboration, and flexibility (Lawrence 2007). Another personal analogy is the cause-effect, fishbone, or Ishikawa diagram. This analogy depicts the causes of a specific event by means of five categories (people, machines, methods, materials, measurements, and environment), and is used for quality improvement, especially for defect prevention (Ishikawa 1982). Symbolic analogies are characterized by a particularly high level of abstraction. With respect to the original problem, the saying “sometimes less is more,” or “it is (really) adding by subtracting,” may be associated with the problem of opaqueness. The same applies for the proverb “missing the forest for the trees,” which is an analogy for a large number of indicators that obfuscate the assessment process. Technical analogies seem to be the best aligned. The chosen analogies refer to existing cost allocation problems or methodologies. The cost-by-cause principle states that costs are allocated to reference values only when there is a cause-and-effect relationship linking them. Thus, only costs that would not have occurred without the presence of the reference value can be counted. Therefore, in practice, there are different approaches. Another principle is the so-called overhead allocation, which is used to allocate certain overhead costs to produced goods. Overheads and overhead expenses are business terms used to describe ongoing operational expenses. Examples are rent, electricity, gas, and labor burden. These expenditures are inevitable to ensure the continued functioning of a business, but cannot be directly related to the products produced (contrary to variable costs). The question that emerges is whether overhead costs can be allocated in a precise and logical manner. Different methods are used to meet this challenge.

In compliance with the procedure of synectics, the next step is to connect the described analogies with the original problem. As previously described, some analogies are easier to transfer than others. For example, the cost-by-cause principle quickly reaches its useful limits, since fixed costs cannot be considered appropriately in this approach (Wirtschaftslexikon24.com 2014). Sustainability impacts, however, have more in common with fixed costs than with variable costs because most often their occurrence cannot be distinctly associated with one reference value (e.g., a certain product or service). Conversely, that is exactly the purpose of overhead allocation, which is why the author evaluated this analogy as the most meaningful for solving the original problem. For example, the emission of greenhouse gases from a manufacturing company are, on the one hand, highly dependent on the number of units produced, but is not solely product-related: there are fixed overheads as well, such as heating office spaces. However, all impacts have to be allocated to the product somehow, since its production is the actual reason for a company's existence. Thus, traditional methods of allocating manufacturing overheads will be introduced at a later point. Even if it seems to appear a little philosophical, the symbolic analogy "miss the forest for the trees" can be linked to (one of) the original problem(s), which was to provide more transparency and user friendliness. As explained in Section 2.2.2, there is currently a multitude of different frameworks and indicator sets discussed in the literature. Beyond that, an increasing number of guidelines are developed to explain and standardize certain methodologies. This study serves as testament to the breadth of sustainability assessment as a topic of research. In particular, small- and medium-sized enterprises (SMEs) have problems applying complicated tools and implementing extensive guidelines, due to insufficient expertise and capacity. Transferred to the original problem, this means concentrating on a well-established framework, and reducing the number of required indicators to a minimum. Furthermore, to avoid increasing complexity, no new indicators or general redevelopments of methodologies should be introduced. The opposite is true, namely, to reuse as many standardized, accepted, and well-known approaches (e.g., E-LCA, LCC, S-LCA, and LCSA) as possible in a new solution for assessing Global Product Sustainability.

In conclusion, the described and analyzed analogy‑problem linkages lead to the following points that will be considered in the concept development:

- Use an approach derived from the **overhead allocation methodology** to attribute sustainability impacts.
- Measure the impacts of all three dimensions due to the application of **existing sustainability assessment methods** if possible (e.g., E-LCA, LCC, S-LCA).
- Use **a reduced indicator framework**, which only comprises major impact categories.
- Put a focus on the global distribution of impacts.

Based on these characteristics, and the fact that the main advancement of the approach is to allocate sustainability impacts, this concept is named the **Global Life Cycle Impact Assessment (Global LCIA)**.

4.1.2 The Basic Concept: Characteristics Inherited from the Overhead Allocation

Due to the integration of the concept to treat sustainability impacts, like overheads, a completely new search parameter within the scope of this study, particularly in the field of financial business and cost accounting, has been raised.

Classic cost accounting. A broadly discussed topic in classic cost accounting is what balancing principles to apply in the allocation of costs within companies. The overall question is how costs (indirect and direct) can be allocated causal to the objects that are being balanced (e.g., cost centers, cost units). In a manufacturing environment, the balanced objects are usually products, which have to gain enough revenue in the market to defray all expenses. This question becomes of particular interest if a company that produces a variety of different products is the object of examination. Looking back in history, this problem was addressed decades ago by the German engineer, Kurt Rummel[16], whose findings are still often quoted in business management literature (Rummel 1947). Due to his industrial background, his viewpoint was shaped by the principle of causality, which says that a certain effect has a direct and clearly identifiable cause. In general, there are different components of costs that can be structured by different attributes. A commonly used principle within cost accounting is the differentiation between variable or direct costs, and fixed costs, or overheads. The principle of causality is used to allocate variable costs

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[16] Rummel's research was based on Schmalenbach (1927).

to cost units. These costs vary in relation to changes in output volume. Especially in the early Industrial Age, most of the costs occurred when conducting a business were variable costs. Examples are costs for direct labor or materials, which can easily be quantified and traced to a product. During the Industrial Revolution, which was characterized by the increasing complexity of running a business, fixed costs became more important in accounting practice. Examples of fixed costs are the depreciation of buildings and equipment, costs for maintenance, costs of support like production control, purchasing, quality control, research and development, etc. (Kaplan 2014). These costs are incurred irrespective of activity levels. In contrast to the allocation of variable costs, the allocation of overheads is controversially discussed in the literature (Schmidt 2009b) and cannot be allocated to cost units using the principle of causality alone (Rummel 1947; Schmalenbach 1927). Traditional methods of allocating manufacturing overheads are to allocate via direct labor hours or via departmental machine hours. Due to global competition and increased productivity in the new manufacturing environments, modern companies need to determine costs more accurately to inform decision-making. A widely used and reviewed approach within classic cost accounting is the so-called activity-based costing (ABC) method, which, in simple terms, aims to allocate overhead costs to different activities[17]. Required methodologies are explained in more detail as required.

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[17] For more information on activity-based costing, see Gunasekaran and Sarhadi (1998) and Gunaskaran and Singh (1999).

Allocating environmental burden. It is striking that there are similarities to other disciplines, like the field of environmental sciences, for which these methodological issues also play an important role. There is an analogy between cost accounting and environmental accounting (Möller et al. 1998). In either case, the benefit of an economic activity is linked to an expenditure (e.g., economic or ecological).

As long as there are methodologies for environmental balancing, such as, Life Cycle Assessment (LCA), the problem of allocation remains (BUS 1984; PGL 1992; Huppes & Schneider 1994). Within the ISO 14044 guidelines, allocation is defined as "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 2006b, p.4). Depending on the allocation methodology used, a different focus might be present (e.g., regarding the importance of by-products or recycling in the life cycle of a product). There is no question that allocation is necessary at different stages within the (environmental) impact assessment, which is why there are different approaches to addressing this topic.

The allocation problem, in general, occurs within a combined or coupled production process. This means that a minimum of two different products results from one process. Often there is one desirable, or good product (for which the production process was set up originally) and other by-products, which may be unwanted (bad), neutral, or positive (i.e., can be sold for further profit). A major characteristic of combined production is that the primary product cannot be produced without the by-product. This type of production is frequently encountered in the chemical, agricultural, mining, and petroleum refining industries (Hottenroth et al. 2013). In such a production system, it is necessary to allocate inputs and outputs, e.g., energy flows, material flows (Materials Flow Cost Accounting) or greenhouse gas emissions (determining the carbon footprint), to the various products. As pointed out by Hottenroth et al. (2013) and Möller et al. (1998), a major problem is to allocate inputs and outputs “fairly,” given that the word *fairly* implies that the allocation cannot be performed according to purely objective scientific or technical criteria. Therefore, a general recommendation is either to avoid the allocation, or at least define clear rules for the allocation of inputs and outputs. To get an overview on currently used allocation methodologies, a second literature review on cost accounting, particularly environmental cost accounting, was conducted like shown in Figure 4-4.

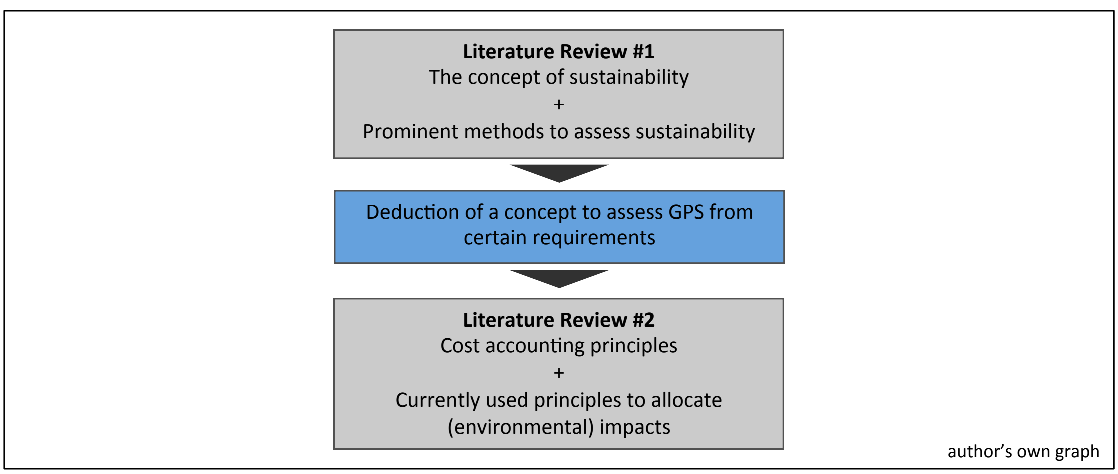

Figure 4-4: Procedure to refine the proposed concept for GPS assessment

In the literature, the topic of environmental impact accounting is broadly discussed, and it is addressed by the ISO in their ISO 14044 guidelines in LCA. However, due to the presence of various existing methodologies in the field of (environmental impact) allocation, the process is opaque and vulnerable to arbitrariness (Schmidt 2009a). "Science does not dictate a method of co-product allocation" (Boguski et al. 1996, p.2.19).

4.1.2.1 Currently Discussed Principles to Allocate Ecological Impacts

The second literature review of currently used principles for allocating sustainability impacts reveals that the problem is currently not addressed in an integrated manner (i.e., considering all three dimensions of sustainability). At present, the allocation problem is only discussed for the purposes of E-LCA and the Product Carbon Footprint (PCF) (Schmidt 2012; Huppes & Schneider 1994; Schmidt 2009b; Schmidt 2009a; Möller et al. 1998; Walk et al. 2009). Figure 4-5 provides a holistic overview on the principles of accounting.

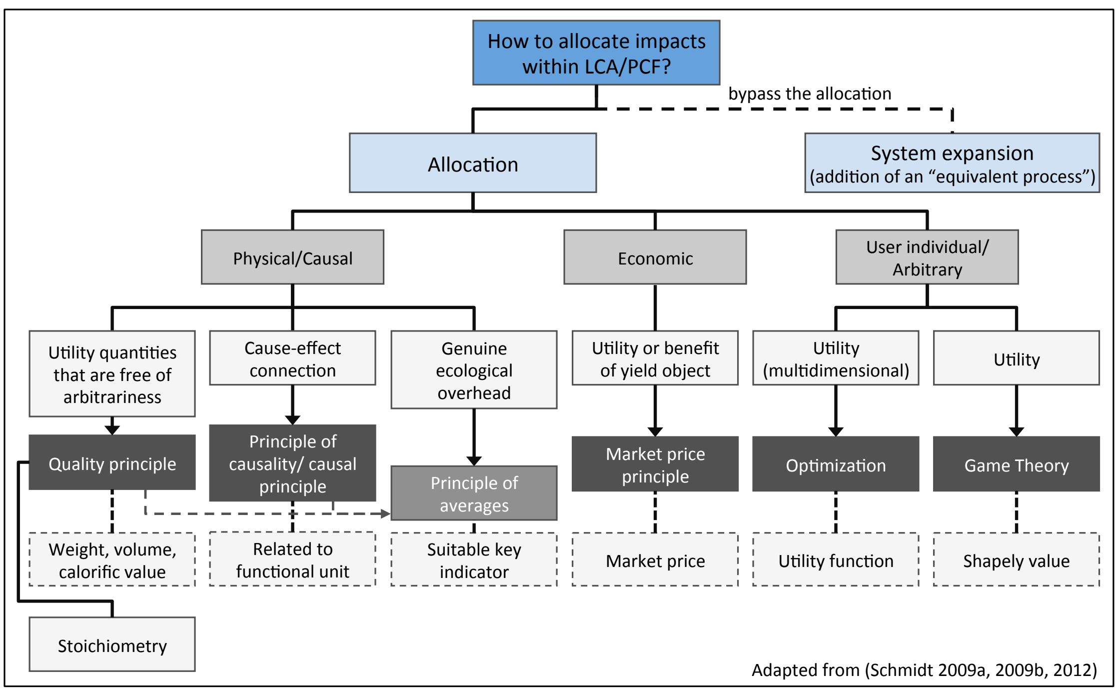

Figure 4-5: Principles of accounting used within LCA/PCF

At the top level, one approach avoids the allocation problem by means of a system expansion. This principle is illustrated in Figure 4-6. If a process were characterized by co-production, then the process would not be divided using allocation; instead, the additional product is added to the functional unit being compared. This leads to the difficulty that, in a reference process, the co-product might not occur (or at least in another quantity), such that a system extension by an appropriate equivalent process becomes necessary to establish comparability (Mampel 1995; Schmidt 2009a). However, this procedure is criticized, since it only replaces the question of what allocation methodology should be used with the question what equivalent process is appropriate (Frischknecht 2000). This makes it questionable why the ISO 14044 and other authors prefer this methodology compared with allocation (ISO 2006b; Weidema & Norris 2002).

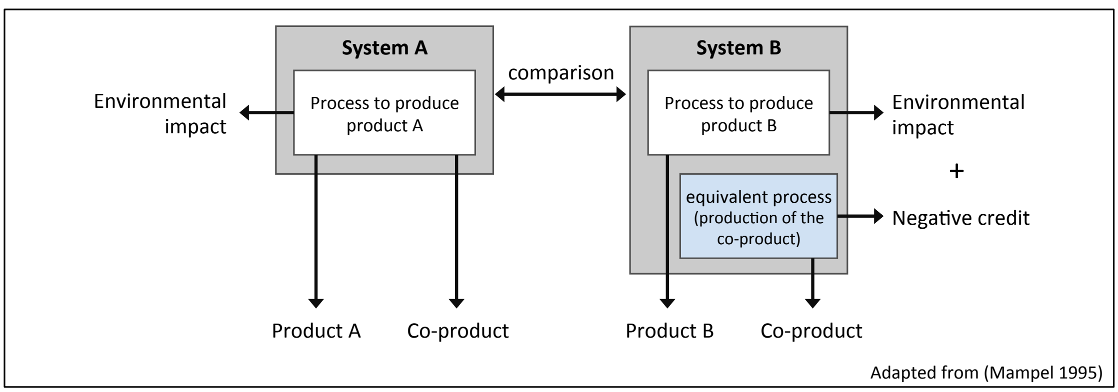

Figure 4-6: Avoiding allocation by using a system extension

Taking into account the categorization of allocation principles, there are three different types: physical or causal principles, economic principles, and arbitrary or subjective principles. Depending on different factors (system characteristics, objective of the allocation), different approaches can be used to allocate the environmental impacts to various products. The most commonly used and widely accepted methodologies are based on scientific-technical principles. The major argument, therefore, is that the Life Cycle Impact Assessment (LCIA) within the LCA also uses physical parameters to determine impacts (Boguski et al. 1996).

A typically used representative of this category is the **quality principle**, which uses utility quantities like mass, volume, etc. to allocate ecological expenditures (Bachem 1997). The idea is to assign impacts in relation to a specified utility quantity (clear and free of arbitrariness) that is applied to all yield objects. The procedure becomes clear in the example of a waste incineration plant. The question arising is how emissions should be ascribed to the different forms of waste that serve as the process input. The goal is to distribute environmental burden to various utilities (in this case, the different types of waste). Since waste is usually never incinerated in its pure form, but as a mixture of different types, various combustion products result. This process is illustrated in a simplified form in Figure 4-7.

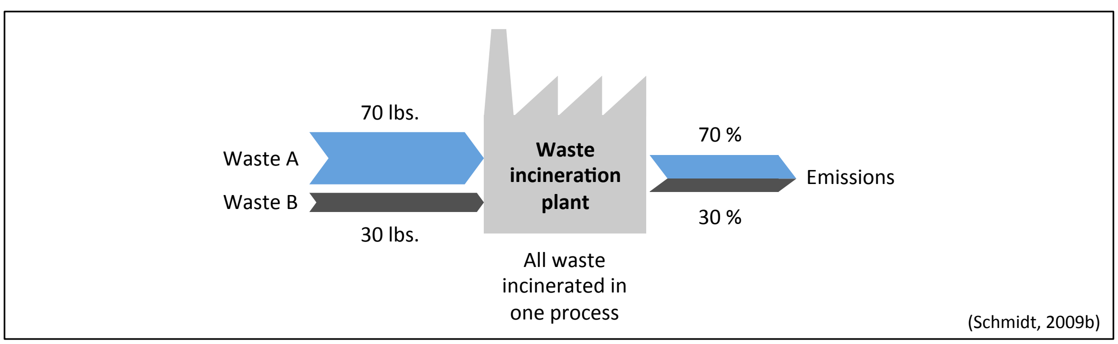

Figure 4-7: Allocation of emissions to two types of waste based on mass

If two different types of waste are incinerated in the same single process, then the emissions that result could be allocated to the both input materials in proportion to their specific masses. In the illustrated case, 70% of the emissions are allocated to waste A and 30% to Waste B, which corresponds exactly to the ratio of their input weights. Nevertheless, there is a major shortcoming in this principle, which can be explained using the same example. As mentioned before, waste that comes to an incineration plant is, in reality, composed of numerous different kinds of waste, whose ingredients are untraceable to the source. If, however, a certain type of waste, e.g., containing heavy metals, is incinerated, then this leads to specific emissions that should not be allocated to other waste. Figure 4-8 illustrates how specific heavy metal emissions are only allocated to Waste A, which cannot be achieved by using the quality principle.

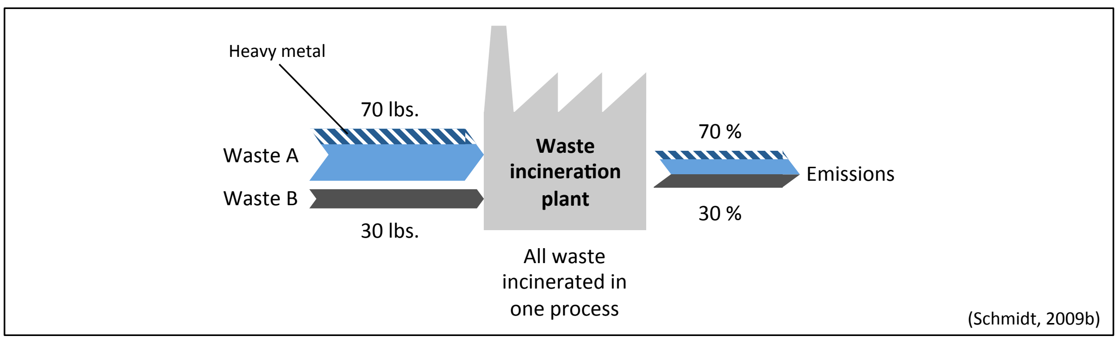

Figure 4-8: Allocation of heavy metal emissions only to one waste

This leads to the **principle of causality**, which theoretically allows a distinct allocation of impacts based on causation. Particularly in the engineering sector, it is often referred to as the causal principle (Riebel 1994). The use of this principle requires a cause-effect connection between the ecological expenditures and the yield object (e.g., a product). A major assumption is that ecological impacts and the quantity of a functional unit behave correspondingly; thus, a lower production quantity of the yield results in decreased ecological expenditure. Since there might even be a proportional relationship between input and output, the principle is sometimes mentioned as the principle of proportionality (in cost accounting) (Heinen 1958). It should be noted that the causal principle in the environmental context is controversially discussed; thus, selection of this terminology requires care. A classic cause-effect relationship calls for a chronological order: the effect follows the cause. In the present case of ecological impact allocation, a product is normally considered the cause and the resulting impacts represent the effects of its production. Scientifically speaking, this can hardly be described as a cause-effect relationship since the cause (the product) results mostly after the effect (the consumption of resources), and vice versa for the environmental impact (Schmidt 2009b). However, there is a problem associated with the practical implementation of the principle of causality since only in the rarest cases are detailed data available, which is inevitable for its use[18]. A practical field of application is in the field of in-house ecological material flow management, which aims to reveal concealed improvement potential by mapping technical processes using detailed models. The goal is to increase efficiency due to the comprehension of quantitative connections between input and output factors (Schmidt 2009b).

[18] Even in the case of (financial) overhead allocation, this principle is ruled out since the necessary data are nearly impossible to gather.

A more sophisticated methodology from a practical point of view is the **principle of averages.** This can be applied without knowledge of concrete causal relationships when genuine “ecological overheads” exist (Schmidt 2009b). As with financial overheads, expenditures do not disappear if the process output (e.g., production of a product) is reduced. The entire overhead is allocated across the output according to a certain key indicator. Thus, there are several different possibilities for how the principle of averages can be applied. As depicted in Figure 4-5, this principle shares common features with both the principle of causality and the quality principle (e.g., weight could be an appropriate key indicator).

4.1.2.2 The Pioneering Approach: Principle of Market Prices

However, concrete examples show the limits of physical allocation approaches. In respect to the focus of Chapter 5 on the textile and clothing sector, the example of producing cotton should serve to illustrate the principal weaknesses of the previously explored allocation principles (Jungmichel & Systain Consulting 2010; Jungmichel 2009; Hottenroth et al. 2013).

In cotton production, cost allocation is necessary to distinguish two major outputs. After harvesting the seed cotton, the cottonseeds must be isolated to obtain the raw cotton. Both, cotton fiber and cottonseeds are products that can be further processed. The cotton is processed to yarn while the seeds are pressed to get oil. The weight distribution between cotton wool and cotton seeds is about 35:65 (ecoinvent Centre 2010). Based on a physical point of view, the larger share of ecological (and financial) expenditures resulting from the cultivation has to be attributed to the seeds. This, however, contradicts the primary intention of producing cotton, namely, to produce cotton fibers, which is the actual value-adding process that yields economic benefit for producers (expressed by the market price). Accordingly, in such cases, an allocation relative to the market price of the product and co-product is reasonable (**market price principle**). The respective distribution of market prices between product and co-product is 85:15 (Hottenroth et al. 2013). Thus, the majority (85%) of all environmental impacts from the production will be attributed to the cotton fiber. The explained circumstances are summarized in Figure 4-9.

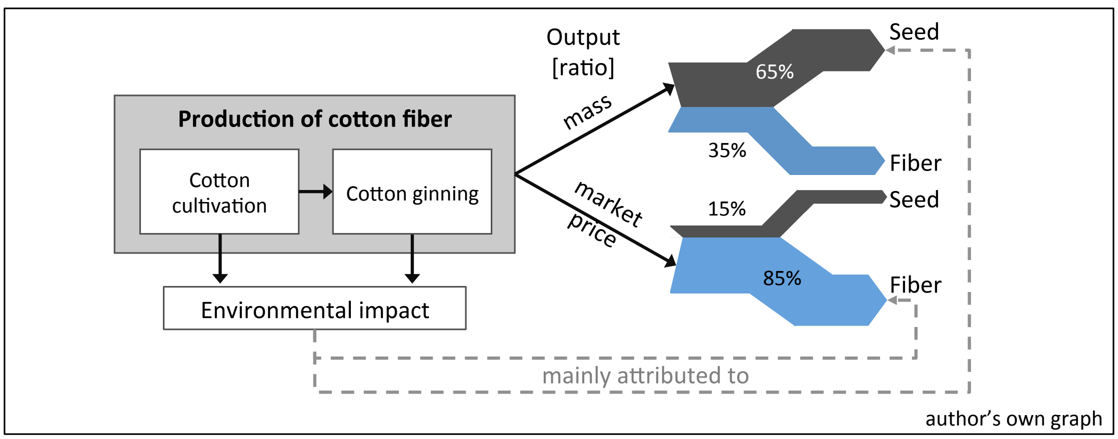

Figure 4-9: Quality versus market price principle in cotton production

Schmidt (2009a) and Jungmichel (2009) present another interesting case from the textile sector that focuses the handling of co-products along the textile supply chain. Nowadays, suppliers located in developing countries, such as China and India, produce most textiles and clothing distributed on the western markets. The value added by these companies is mainly generated from the supply business with clients in industrial countries. However, it happens that a considerable quantity of production from supply companies goes into regional markets. Usually, the prices charged on regional markets are significantly lower than export prices. A research project conducted by the German Federal Ministry for Environment and the Federal Environmental Agency, in cooperation with the Oeko-Institut (responsible for the PROSA guidelines, see Section 2.2.3.5), and the Otto-Group, lead to the result that a classic t-shirt with a product weight of 222 grams "causes" 1.65 kg of by-products along the whole supply chain (e.g., textiles sold on regional markets). If the greenhouse emission from the PCF were allocated according to the weight ratio (instead of market price), then the PCF for the t-shirt, would, in turn, be 45% less. Thus, the locally used by-products would be further burdened, even if it were obvious that the entire production just takes place based on the export business. Particularly from the viewpoint of sustainable development, a strict allocation by physical principles alone is, therefore, not reasonable.

Critical and contradicting opinions. Even if there is so much evidence that the market price principle has numerous advantages in the field of (ecological) impact allocation, there are still some contradicting opinions. For example, Boguski et al. (1996, p. 219) point out "allocation on the basis of economic value is generally discouraged because the LCI methodology is based on the measurement of physical parameters, and economic value is not a physical parameter". The ISO 14040 shares this view and indicates that economic allocation methodologies should only be used as a last resort (ISO 2006a, p.14). Other institutions, like the European Commission, also discuss the use of economic allocation principles and state "a frequent error for this type of allocation is to apply the allocation at the wrong point. This is most often related to the use of market price as a criterion. Prices should, in fact, refer to the value immediately after the production ... and not the price at the consumers that, instead, reflect other external factors" (European Commission 2010, pp.264–265). Controversially discussed is the robustness of the allocation method. Boustead et al. (1999) endorse the physical allocation whenever possible and prefer it against other approaches. Their main argument is that physical partitioning is more reliable. Their analyses show that, for all observed cases, the product value was the only variable, whereas other indicators (e.g., mass) did not change. Azapagic and Clift (1999, p. 362) support this opinion and argue that an "allocation by financial value can give misleading results and should not be used in systems where physical causality exists". Weidema and Norris (2002), who argue in line with the ISO 14044 guideline that allocation, in general, should be avoided whenever possible, also take a critical position. In their opinion, system extension and substitution methods are more effective than economic and other partitioning approaches. Niederl-Schmidinger and Narodoslawsky (2008, p. 246) declare that "if [it] is not possible or not justifiable [to allocate products according to physical properties], the usual way is to allocate according to the economic value of the products (prices)". In general, the fact that the market price does not always represent the ecological truth (external costs are not considered), and might vary with respect to economic conditions, even in short time periods, summarizes most concerns (Schmidt 2012).

Mainly supporting opinions. However, there are at least as many studies that reinforce the advantages of economic allocation. As a kind of early adopter of the economic principles, Huppes (1993, p. 209, 202) states that “in a social sense, the value created causes the process,” which could be expressed, for example, in the market price. He furthermore concludes that “the value-based method […] may be applied in many situations to which others cannot [...]. However, it cannot be the sole panacea”. Frischknecht (2000, p. 86) argues from a consumer-oriented perspective and says “economic and environmental aspects should influence the determination of allocation factors for consumer goods as well,” since consumer choice is also influenced by these factors and represents the initial reason for production. Even if it is not as generalized as other authors, Azapagic and Clift’s (199, p.106) opinions reflect a similar opinion and state that economic allocation can be used “where physical relationships cannot be used to describe the effects of changing different functional units […]”. Following Clift et al. (1998) the “argument for this is that economic relationships reflect the socio-economic demands that cause the multiple-function systems to exist at all” (Azapagic & Clift 1999, p.106). Peereboom et al. (1999, p. 126) represent the viewpoint that, despite of the viability of other allocation approaches, economic partitioning has essential value. It “better represents the societal cause of […] emissions”. More information on economic allocation (comparisons with other feasible alternatives, hypothetic examples) can be found in Ardente and Cellura (2012)[19].

[19] A general comparison of different allocation methods is given by Hottenroth et al. (2013).

Despite the controversial discussions on the economic allocation within LCA and PCF, the principle represents a solid base to assess the problem of the present study. This thesis not only aims to allocate ecological impacts, but also to allocate impacts from all three dimensions of sustainability to the different supply chain actors, according to the responsibility they have for the initial cause of impacts (in both a positive and negative sense). This is necessary, for example, to distribute compensation payments for sustainability impacts fairly among different stakeholders. A major problem of currently used methods, such as environmental accounting, is that they only consider a small segment (usually in-house) of (environmental) impacts that are caused within a supply chain. This is a major difference compared with LCA (and PCF), which considers the entire product life cycle from cradle-to-grave (Schmidt 2009b). The following section provides a framework to address the stated problem and considers all the important findings from the previous examinations.

For the sake of completeness, the remaining two approaches to allocate ecological impacts within LCA/PCF are briefly introduced. Coming from the social and economic sciences, there are also approaches that are **based on optimization problems** (see Figure 4-5. As a reaction to the argument that overhead allocation by means of the market price principle (in the field of classic cost accounting) is arbitrary, Gümbel (1988) proved that it is not the choice of the allocation principle, but the underlying assumptions and objectives that are arbitrary. The resulting allocation principles, however, are distinctive. His idea is based on the maximization of a utility function and certain constraints, which could include both monetary and non-monetary components. A detailed description of this approach is given by Gümbel (1988). Schmidt (2012) discusses this approach for allocation in LCAs. He furthermore points out that the approach leads to the market price principle if the utility function depends only on market price and sales quantity (Schmidt 2009a). Schmidt (2009b, 2012) additionally analyzes **allocation based on game theory**. This approach is about game wins and losses among players. If certain playing conditions and axioms are assumed, then distinct allocations can be derived. More information on this topic, including different case studies, is provided by Schmidt (2009b, 2012) and Schmidt et al. (2009), but are not of further relevance to this study.

In conclusion, it is striking that experts in the field of sustainability impact allocation hold such varying opinions. Specifically, studies on allocation methodologies based on the market price principle are still rare. Furthermore, it should be noted that a major impulse regarding new developments seems to come from Europe (mainly Germany). Currently, there are only a few English/international studies available for review.

4.1.3 Illustrating the Structure of the Concept

This section illustrates the structure of the developed concept Global-LCIA to assess *Global Product Sustainability* and the allocation of product-specific sustainability impacts reasonable among the different supply chain actors and life cycle stages.

The general structure of the developed framework and its application environment are shown in Figure 4-10. In principle, the framework is designed as a **two-dimensional matrix.** The life cycle (or the supply chain) follows the *x*-axis. The example shows a simplified supply chain from the textile and clothing industry that consists of five different actors/companies *i* (*i* = A…E), which are responsible for raw material extraction (cotton fiber), textile production (spinning, weaving, dyeing, printing), apparel production (cutting, sewing), distribution (packing, transportation), and retailing. The subsequent use and disposal or reuse/recycle phases are not illustrated in the graphic. The *x*-axis, therefore, holds the product view. As shown in Figure 4-10, the output of a supply chain is a specific product that has a certain sustainability impact. This is derived from the hierarchical accumulation of supply chain actor-specific and product-related impacts. Impacts are, thereby, always referred to in all three dimensions of sustainability. The *y*-axis represents the *real net output ratio* (or *vertical range of manufacture*) and describes the fraction of internal production on the total production value of the company. In other words, the *y*-axis represents the structure of companies that are participants in the observed supply chain. It has to be noted that companies can be simultaneous participants in various supply chains (Jentjens & Münchow-Küster 2012). However, since it is impossible to build a model that considers all interconnections between companies and their related supply chains, the system boundaries are given by the analyzed focal company, which triggers the production process to satisfy a certain consumer need. Figure 4-10 indicates this complexity roughly by showing some exemplary processes within companies from the textile chain. As described in Section 4.1.2.2, the production of cotton fiber inevitably leads to the co-product of cottonseeds that can be processed and sold (e.g., as oil) on external and regional markets (bold blue arrow = regional; dotted grey arrow = export). Already at this point, a second supply chain is involved. Additionally cotton fiber might be sourced from different countries (e.g. USA or China), which adds further supply chains and complexity. The cotton fiber is then passed to the next company, which processes it to textiles (following the black arrow). Depending on the company's strategy, different kinds of textiles might be produced here (e.g., textiles for further processing or textiles for immediate use, such as towels). If required, then accessories might be added to the produced textiles. Again, other supply chains are involved in this process. On one hand, (pre-) products can be marketed on regional markets (bold blue arrow) while, on the other hand, the production of accessories is part of another supply chain. The next actor is an apparel company, which uses the textile to produce a garment. The textile could be used to fabricate a defined range of different garments (e.g., t-shirts, pullovers, jeans, etc.). Either they are intended for export (usually requires brand labeling), or distributed on regional markets (compare Section 4.1.2.2). The next steps are necessary to bring the finished product to consumers. Transportation is often executed by independently contracted service companies, who organize distribution for numerous different companies and products. After the products are shipped to the destination country, they are retailed (e.g., through department stores). The dark grey highlighted boxes indicate required steps to produce and retail a classic t-shirt (one product). Each process step has a certain impact on sustainability (small pie chart in the upper corner of each process box). These process-specific impacts can theoretically be summarized to yield a product-specific absolute impact at the end (cradle-to-customer). Furthermore, each company within a supply chain has a product-specific sustainability impact, which represents the sum of a company's process-specific impacts and a fraction of the company's overall impact. Involved in the processes are companies of various sizes in different countries, which leads to further complexity (e.g., regulations, culture, etc.). One major question is illustrated by the grey arrows at the bottom. How should the absolute impacts of a product/company be fairly allocated according to causal responsibility? In environmental law, the "polluter pays" principle (or Extended Producer Responsibility (EPR)) aims to address this question.

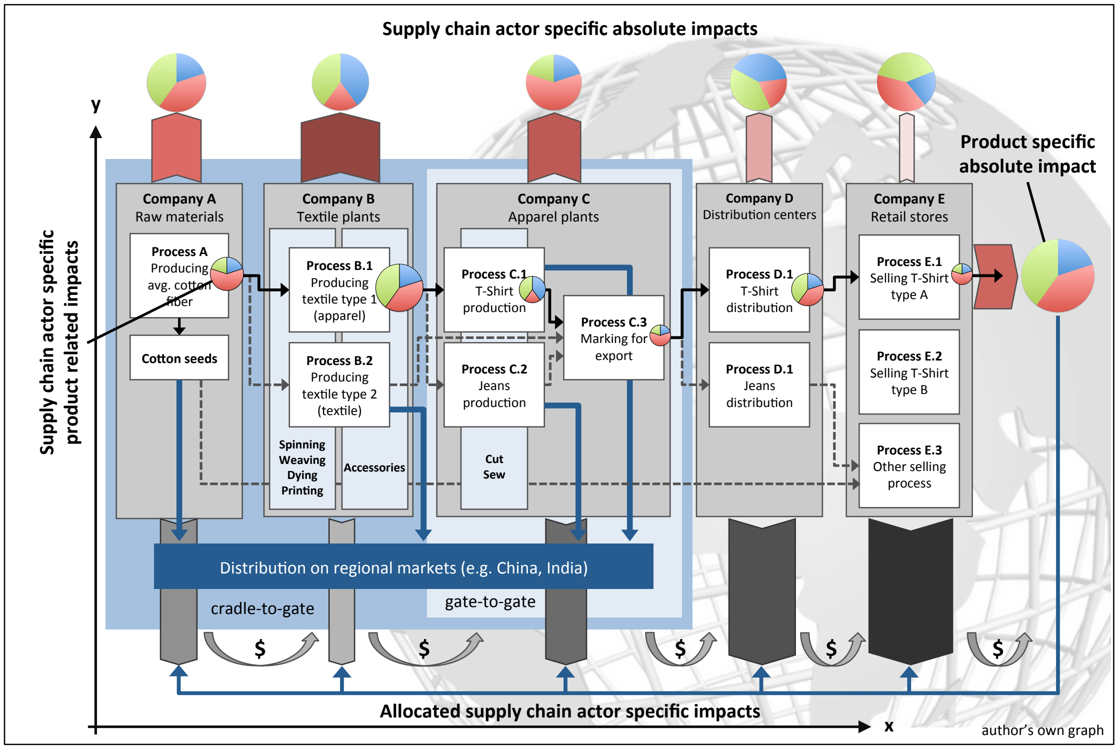

Figure 4-10: Overall structure of the concept Global-LCIA

Two main issues are not distinctively addressed in Figure 4-10. First, the graphical representation does not include the life cycle stages of use and recycling or end-of-life, which are very important, if not the most important stages to be considered. In this context, the consideration of so-called externalities is particularly crucial. Furthermore, one main feature of the concept, namely, to plot the global distribution of the sustainability impacts, is not addressed. However, Figure 4-10 serves to illustrate the complexity in assessing GPS and the number of different fields of research affected. The concept is based on three pillars, which will be explained in the following three sections.

4.1.3.1 Assessing Sustainability Economically (Pillar 1)

In Section 2.2.3, prominent methodologies to assess sustainability were introduced. Section 2.2.3.5 presented product-related approaches that are already well-established in practical use. This thesis does not aim to develop new approaches or methodologies to assess sustainability (integrated or in one of its three dimensions) because currently used frameworks, methodologies, and concepts are broadly discussed and experts and global organizations put their experience in their advancement. Even if numerous different opinions exist within the literature, there is agreement that an integrated assessment of sustainability needs to have a defined spatial reference and the capacity to address environmental, economic, and other flows to assess sustainability holistically. Toman et al. (1998, p. 12) stress that "issues such as spillover effects, distributional issues with regards to spatial externalities, and the appropriate geographic scale of policy responses need to be appropriately addressed". In summary, assessing sustainability remains a challenge—not only regarding products—due to numerous factual issues. Some dimensions of the problem identified and examined in literature were emphasized in the previous sections. A main finding is that there is not one right solution or procedure to assess sustainability that can be proposed by the author. Instead, the present work should give a thought-provoking impulse to start thinking about different possibilities to assess sustainability and to combine different existing approaches in one framework. General questions that should be considered are (besides others):

What is the objective of the assessment (e.g., a region, a company, a product) and what are the system boundaries for balancing impacts (technological, geographical, temporal, etc.)?

Is it meaningful to use a standardized and certified approach (e.g., ISO), or is it more constructive to adapt and customize a company- or branch-specific approach to fit one's personal objective best?

How detailed and comprehensive (scope and depth) must results be? Is assessing in all three dimensions necessary or is a composite indicator, based on individual and subjectively defined normalization and weighting assumptions, the best way to go?

To answer these questions, user-specific information is necessary. Many different factors, such as the industry environment (competitors, legal regulations, etc.), a company's organizational structure (size, available information, communication technology, etc.), and the nature of the analyzed product (type of production process, fraction of externally produced preliminary products), affect the answers to those questions.

Regardless of the chosen methodological approach, a major challenge arises from the **amount of necessary data and its collection**. Data collection may account for a very high proportion of the time and effort required to measure sustainability. At the same time, a majority of the assessment quality as a whole is dependent on the quality of data collected. Issues affecting the amount of data required are, for example, the complexity of the product analyzed (e.g., to assess the sustainability impact of a computer more data is needed than for a plastic bowl) or the chosen system boundaries (e.g., a cradle-to-grave footprint has higher data requirements than a cradle-to-gate analysis) (Hottenroth et al. 2013). As a basis for the identification of data needed, different approaches exist. In the field of ecological assessment, a well-established method employs system flow diagrams that illustrate process modules contained in the production process of a certain product along the chosen system boundaries. These models allow the determination of which internal and external data are necessary and whether primary data are available, or can be collected. Nowadays, these examinations are usually carried out by third-party organizations or the focal companies. In business practice, it is very rare that all production steps necessary to produce a good are conducted within one company (purely internal production). In the garment industry, for example, the entire product, or at least preliminary products (e.g., textiles), are sourced from external suppliers. Additionally, processes are often linked and opaque, which makes it difficult to obtain product-specific data. This hypothesis is supported by a case study carried out by Hottenroth et al. (2013), who analyzed the life cycle of a beer bottle to determine its carbon footprint. A major finding was that more than 30 processes are involved in this seemingly simple production process. According to the procedure of classical sustainability assessment methods (E-LCA, LCC and S-LCA) (see Section 2.2.3), each process has to be analyzed to deduce its metrics, which are then used to assess the impact of the chosen indicators. This procedure is not just time consuming, but it cannot be guaranteed to consider all contingencies arising from process interrelations.

In general, engineering and natural sciences conduct analyses on a highly detailed level to deduce an exhaustive model that encompasses “all” effects and their sources. Such models might be useful to identify concrete measures to improve, for example, processes. However, if the objective is to provide information for continuous reporting and decision-making, then a more social-scientific or economic approach is useful. For this reason, the previously described allocation principles, particularly the economic principle, offer new possibilities to assess product sustainability in a more efficient and less time consuming manner.

The reason why assessing *Global Product Sustainability* is indispensable is that companies bear responsibility not only for their own (direct) sustainability impacts, but also for indirect impacts. These might be caused by suppliers or post-production by consumers. Who for example causes major emissions? - Suppliers in the pre-chain (e.g., due to externally sourced energy or production preliminary products), transportation or consumers during the use of products (e.g., washing of garment)? Figure 4-11 gives an idea how to answer this question and shows how impacts are distributed along the supply chain (here for electronic equipment).

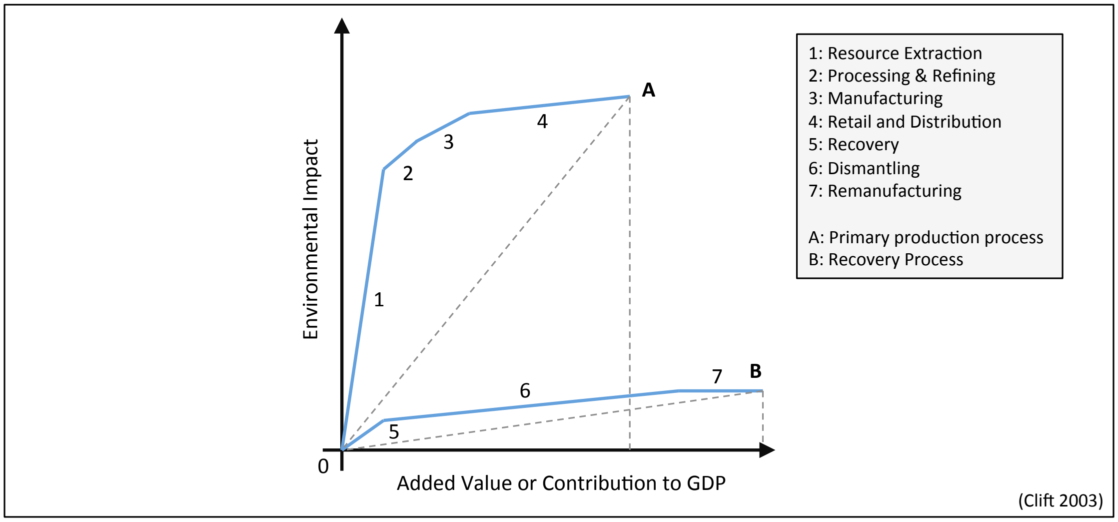

Figure 4-11: Accumulation of economic value and environmental impact along the supply chain

Major impacts are caused in the phases of the PLC, which contribute the least to the value added (or GDP). Such indirect impacts can be influenced by (focal) companies. Therefore, it is necessary to provide enterprises with meaningful benchmarks for comparing their own position, compared with other companies and branches to assess impacts from indirect parties appropriately. Fields of action might be, for example, location decisions, supplier selection, optimization of the delivery chain, or improvements due to product development.

Judging from the overall objective that sustainability impacts should be diminished worldwide, assessing methodologies must not allow pretending ostensible successes due to arbitrarily chosen accounting rules and system boundaries. Currently used approaches may enable companies to cover impacts by means of outsourcing activities (e.g., offshore hazardous processes to countries with less restrictive regulations). This might drop direct emissions at the site, but, from a global perspective, no improvements are achieved: impacts are just conferred to suppliers. This is the reason why only assessing the direct impacts of a company is of little significance. Therefore, the inclusion of indirect emissions caused by suppliers, sub-suppliers, and customers, as well as externalities along the entire supply chain, is of utmost importance. This could easily be elucidated by an example from the automotive industry. The German car manufacturer AUDI is often criticized for its use of aluminum in the construction of their cars, due to the highly energy-consuming aluminum extraction process. However, if considering the entire product life cycle, then the use of aluminum causes fuel savings due to weight efficiency in the use phase and can be reused after a car reaches its end-of-use stage. From an integrated perspective, their products are more sustainable; however, how can these effects be allocated fairly and appropriately communicated?

Lastly, the question of why sustainability impacts should be assessed as product-related remains. On the one hand, consumers are becoming more sensible in terms of affecting sustainability using their own purchasing decisions and, therefore, demand reliable information on the sustainability impacts of products. On the other hand, absolute values regarding the sustainability of a company are not very meaningful. Even if not linearly dependent, there is a significant relationship between the production volume and sustainability impacts (particularly economic and environmental) of a company. Businesses exist to generate economic success. An increase of production volume results in increased impacts. However, this is not implicitly negative. On the contrary, from a social perspective, new employment possibilities might result. Absolute quantities always require suitable reference values on the performance development of a company. This problem does not occur if the assessment is related to single products.

Adaptation of the economic allocation. It is more efficient to obtain a blurry picture of the current situation than no picture at all due to high expenditures in both monetary and temporal terms. As explained before, allocation methods are currently used to distribute the impacts of coupled production processes between product and co-product in the fields of Life Cycle Assessment and Carbon Footprint determination. The author suggests applying this principle in a broader context to simplify the process of measuring sustainability. The basic idea is illustrated in Figure 4-12.

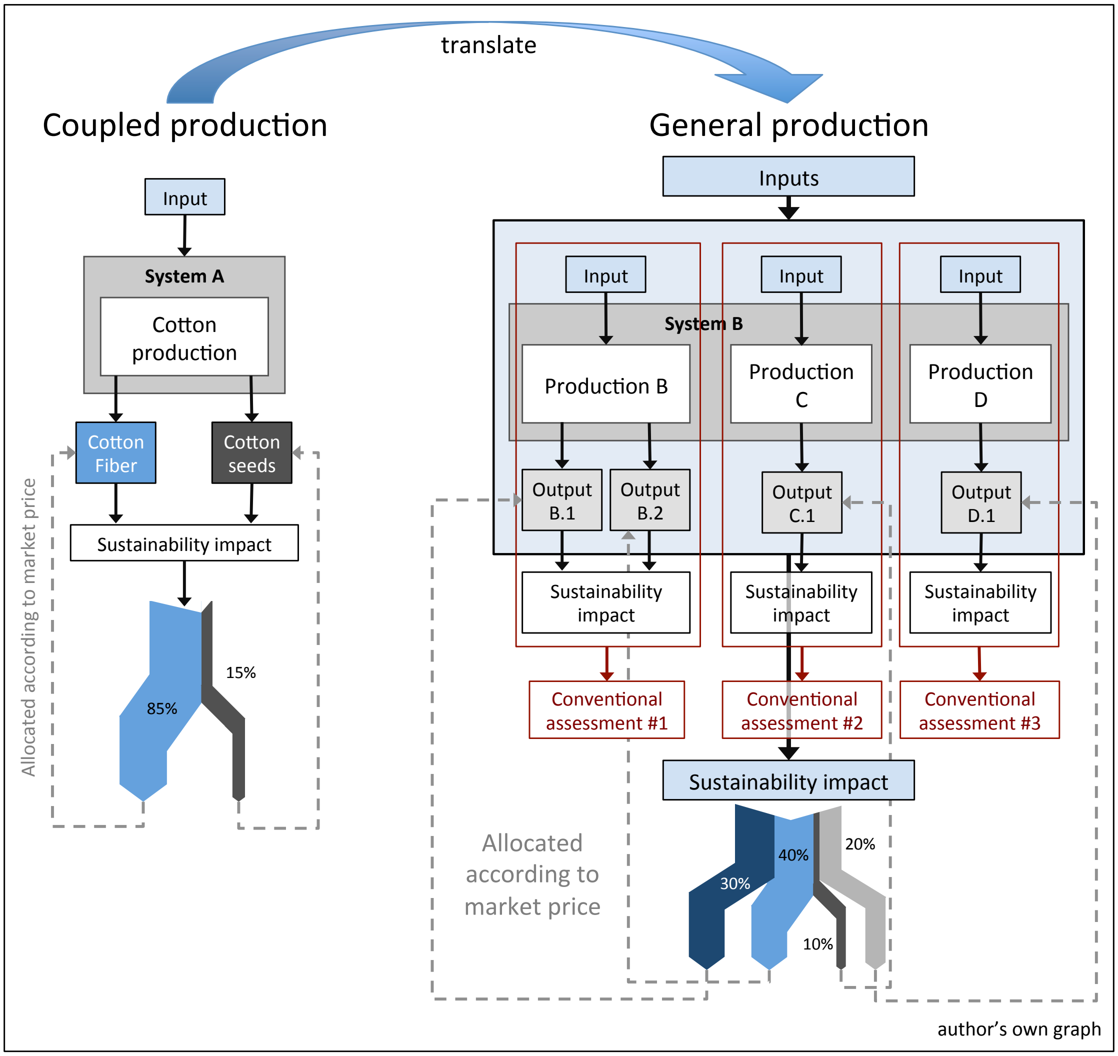

Figure 4-12: Pillar 1 - Application of economic allocation for assessing GPS

Originally, this principle was used to allocate ecological impacts between main product and co-product, with respect to their market prices. This approach has been described previously, based on cotton production (compare Figure 4-9). To assess the sustainability impact of a certain product, specific processes and related inputs and outputs involved in its production are analyzed. If an integrated assessment is required, then, for example, E-LCA, LCC, and S-LCA can be combined (see solid red frames around individual productions in Figure 4-12. As mentioned before, this procedure requires an extensive amount of detailed information on both the technical realization of the production process itself and product-specific data on expenditures and impacts. However, this claim can hardly be met; not only does the continuous updating of data constitute a problem, but it is also difficult to detect the required data. Data gaps are often closed using standard data sets (so-called generic data), which is contradictory to the original idea of providing a detailed model (Schmidt 2010). A fundamental axiom, which may sound philosophical, but was useful analogy to bear in mind during the development of this concept, is that…

…it is better to have a current but blurred picture—taken with a simple camera—than the theoretical possibility to get a sharp picture, for which a camera is required that needs numerous adjustments before being operational and can only be handled by a professional photographer.

Instead of choosing an individual product as the object of assessment, the author suggest, according to Schmidt and Schwelger (2008), to select the entire company for the assessment boundaries. As illustrated in Figure 4-12, the whole system can be viewed as a black box (blue highlighted box). System interactions with its environment and contained elements (cause and effects) are analyzed on a company or site basis. Impacts are then retrospectively allocated to individual products by means of an economic partitioning factor (according to Ardente & Cellura 2012). The share of turnover of one product in the overall turnover of all products proved to be an appropriate factor to allocate sustainable impacts fairly in a social-scientific or economic sense. The fraction is calculated as follows:

$$p_i = \frac{n_i \times x_i}{\sum_i n_i \times x_i} ,$$

where p_i is the share of total turnover of product i, n_i is the quantity of the ith product, and x_i is the market price of the ith product (for i = 1…n). Besides the already-mentioned advantages, this procedure allows the easy validation of data and information, since information provision on a company level is most often subject to legal regulations or management systems. Furthermore, the complexity of the assessment is reduced significantly if an entire business, as opposed to numerous products, is scrutinized.

In this context, the proposed allocation methodology is one of several possibilities and, depending on the objective of the sustainability assessment, other principles might be better-suited (see Section 4.1.2.1).

4.1.3.2 Integrating the Entire Product Life Cycle in the Concept (Pillar 2)

The second pillar of the proposed concept is to perform the sustainability assessment as a cumulative multi-stakeholder process, which is already indicated in Figure 4-10. This approach is particularly necessary to achieve the goal of providing the necessary information continuously, and at reasonable cost, along the entire product life cycle. Thereby, the main problem is to obtain data on indirectly caused impacts and impacts caused in the pre-chain. Assessing GPS should not serve to evaluate individual processes on site; rather, it should support location or supplier decisions and product improvement. To meet these challenges, the assessment procedure is organized in a way, which is, in its basic idea, similar to a KANBAN system. This approach is illustrated in Figure 4-13. A similar system for eco-balancing was developed in a joint project of the TU Braunschweig, the Volkswagen AG, and Systain (Schmidt et al. 2009; Schmidt 2010).

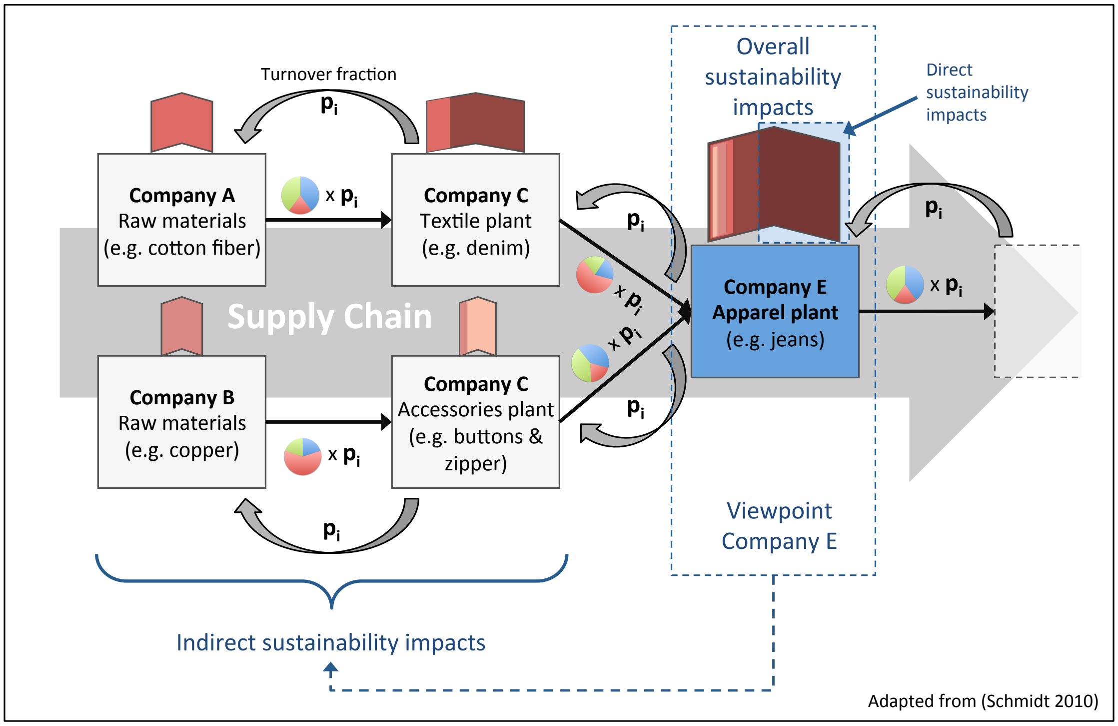

Figure 4-13: Pillar 2 - Passing sustainability impacts upstream along the supply chain

Each company in the supply chain is responsible for the accurate and verifiable reporting of their own sustainability impacts. By applying the partitioning factor, the share of overall impact that is passed to the next link in the supply chain can be determined. Sustainability impacts are considered cumulative, so that each link in the supply chain performs its calculation based on the sum of its own impacts and the attributed impacts from the pre-chain (see dashed-blue frame around company E in Figure 4-13). This design fulfills the requirement that information and data along the entire supply chain can easily be captured and interpreted transparently. This has several advantages, particularly for decision-making. In summary, the procedure can be described as a recursive calculation process along the supply chain.

In this context, to consider the entire product life cycle, special attention has to be placed on externalities. Although this expression has been used before, it should be explained in detail. In the field of economics, an externality (or external effect) describes the uncompensated impact of economic decisions (positive and negative) on uninvolved market participants. In non-technical language, externalities are effects for which no one pays or receives compensation (Buchanan & Stubblebine 1962; Bartling & Luzius 2012). Usually, these effects are not included in the decision-making of the actual causer. In economic sciences, externalities constitute a form of market failure and government intervention might be necessary. Negative externalities are also referred to as external or social costs; positive externalities are often referred to as external benefits, or social returns. The term external, therefore, simply means that the (side) effects of a certain behavior are not (sufficiently) taken into account in the market (i.e., not considered in the price) (Monissen 1980). The questions arising are (a) what are the real life cycle costs of a product? and (b) should and could external effects be measured and allocated to the responsible causer? A recently published article by the *New York Times* takes up this topic and illustrates the described problems using the example of a classic burger. The problem of considering externalities is summarized by means of the following quote:

“What you pay for a cheeseburger is the price, but price isn’t cost. It isn’t the cost to the producers or the marketers and it certainly isn’t the sum of the costs to the world; those true costs are much greater than the price.” (Bittman 2014)

Over nearly a year, these authors tried to identify externalities related to the consumption of hamburgers (as a substitute for fast food in general). The identified effects were mostly environmental and social in nature. For example, the production of meat causes massive carbon dioxide emissions, chemical fertilizers are used to grow corn to feed cattle and pollute drinking water, and the high amount of fat and sugar causes obesity and may increase the risk of cardiovascular diseases, which in turn leads to increased health costs. Even if it is impossible to assign effects distinctly, there is no question that they are related to the consumption of fast foods. Furthermore, more remote effects, like the loss of biodiversity (e.g., due to destruction of rain forests) and human capital effects, like the “cost” of a potentially shorter life, describe externalities that are not considered in the price of a burger. The result: if all externalities were borne by producers, then the entire industry would be unprofitable under current conditions (Bittman 2014).

In the field of sustainable assessment, the problem of including externalities is also presented and discussed. For example, the Society of Environmental Toxicology and Chemistry (SETAC) states that, within LCC, externalities should be anticipated and internalized (complementarity) (Finkbeiner et al. 2010). The same claims are promoted in the Guidelines for S-LCA by UNEP/SETAC: “The internalization of environmental and social externalities must be part of this “New Green Deal” […]”

(UNEP/SETAC 2009, p.13). Kaplinsky and Morris (2000) claim to incorporate externalities within location decisions and highlight the beneficial effect of the presence of firms, or skills, which might aid efficiency for a certain firm unintended. Aiming to establish an efficient use of resources, the Ellen MacArthur foundation asks for “full transparency on materials pricing that reflects the real costs of materials (including externalities) […]” (Ellen MacArthur Foundation 2013, p.70). Huppes (1993) also notes that many environmental effects are not considered in the market price, even if they should be. Loh et al. (2008, p. 29) report pioneering work in the field of managing fisheries and forest products that “has paved the way for a wide range of initiatives to reduce the environmental and social externalities associated with international trade […].”

However, it is conspicuous that concrete measures, suitable for practical usage, on how to incorporate externalities, are nowhere introduced. A first step toward the inclusion of externalities would be to make them apparent; of course, not completely and exactly, but as introduced before, a blurry picture provides more information than no picture at all. This leads to the last pillar of the concept to assess GPS.

4.1.3.3 Graphical Representation of GPS (Pillar 3)

Since a special focus is placed on the term *global*, which indicates that relationships between supply chain actors, life cycle stages and sustainability impacts should be illustrated on a geographic basis, a suitable graphical representation method has to be implemented. Figure 4-14 shows an exemplary case from the clothing industry (production of a t-shirt) to demonstrate how results might be presented.

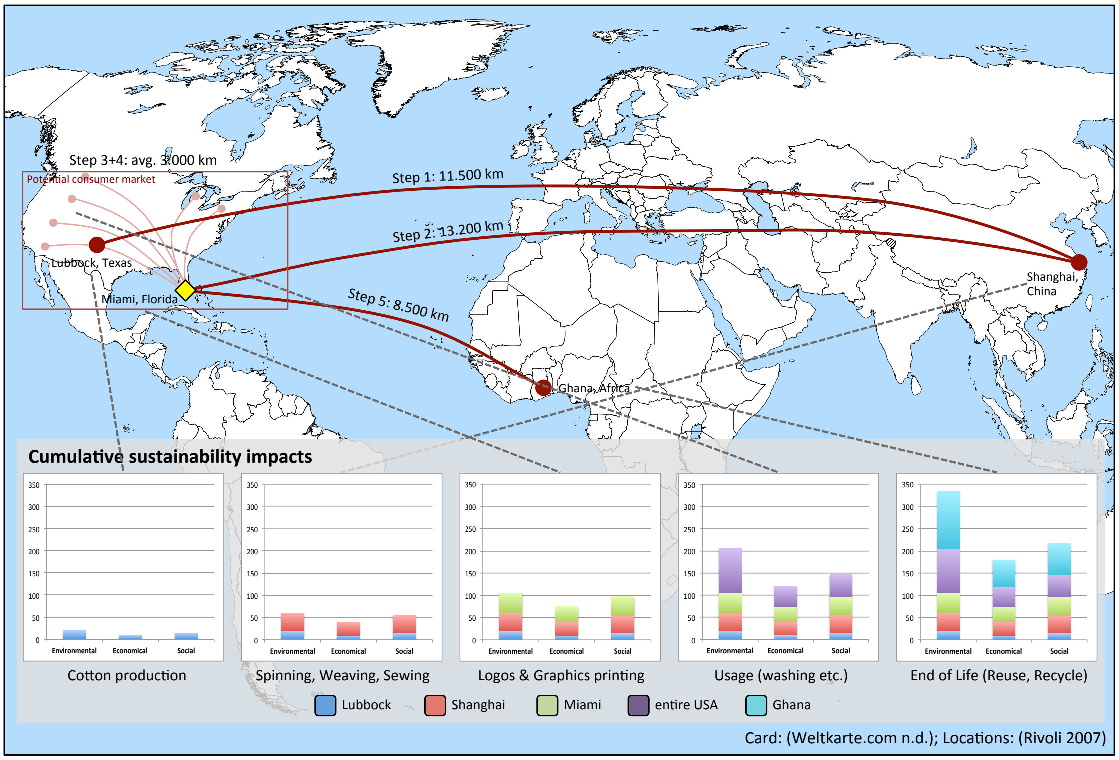

Figure 4-14: Graphical representation of assessment results

Particularly for management decisions, it is important to visualize results in a simple, yet effective manner. To derive location decisions and increase the overall sustainability of a product, it is helpful to see where impacts are bred. The example shown in Figure 4-14 is centered on a study conducted by Rivoli (2007) that examined the markets, power, and politics of world trade, based on the travels of a t-shirt in the global economy. The object of investigation was a classic shirt bought at Walgreen's. The cheap short-fiber cotton was grown and harvested in Lubbock, Texas; spinning, weaving, and sewing took place in Shanghai, China; brand logos were printed on the shirt in Miami, Florida; and its end-of-life was in Africa, where the shirt was resold and reused, or recycled. The presented diagrams are based on assumptions and serve mainly to explain the structure of the concept. For each supply chain participant and/or life cycle phase, a diagram illustrates the impacts for all three dimensions of sustainability. Values are presented cumulatively if moving toward the end-of-life stage. This form of representation captures different information at first glance:

- The overall number of involved countries (= involvements of different regulations, cultures, etc.)
- Potential consumer markets and their sizes
- Necessary transportation distances
- Life cycle stage/supply chain actor-specific information on sustainability impacts (all three dimensions)

Furthermore, different supply chains and/or life cycle scenarios can be displayed in a single figure, which allows making comparisons and, in turn, to identify potential improvements, or areas of further investigation. Thus, the concept can serve to support management-decisions and increase accessibility to this interrelated and opaque field of research (also for end customers). There are no limits set in the scope of adaptation for this analysis. Depending on the objective of the assessment, different aggregation levels can be applied and presented (e.g., data for individual processes within a certain country), since the previously described structure of the concept provides transparency and information on a detailed level (see Sections 4.1.3.1 and 4.1.3.2). The multi-stakeholder structure and, in particular, the style of representation, make it difficult or almost impossible to outsource or disguise sustainability impacts initiated by a focal company (marked with the yellow rhombus).

Thus, a foundation to promote extended producer responsibility[20] (polluter pays principle) and allocate sustainability impacts fairly is established; however, to achieve maximal industrial applicability, an appropriate software implementation is necessary (see Section 4.2.1).

[20] For detailed information on Extended Producer Responsibility (EPR), including definitions, models, practical used systems, etc., see Lindhqvist (2000).

4.2 Challenges in Practical Use

Even if the concept follows a clear theoretical structure, there are many potential challenges arising in practice. Some of these have been discussed in the previous chapters (e.g., potential problems of economic allocation). Especially the tremendous amount of data that needs to be collected for a successful assessment embodies difficulties. Since data is never provided completely, success beyond a broad generalization is unobtainable. Major problems are caused by insufficient software solutions (information and communication technology) and organizational structures (bureaucracy, interfaces). These two areas are discussed briefly in the next two sections.

4.2.1 Data and Software

Some of the challenges of data collection that arise when, for example, conducting a classic E-LCA, can be overcome by the Global-LCIA approach. Originally, data on a functional level are required. The promoted approach, in contrast, leads to meaningful results, even with data on an organizational level. Furthermore, operative personnel do not need to be familiar with the procedures of sustainability assessment; vice versa, an assessment practitioner does not require explicit knowledge on processes for which data has to be compiled. Additionally, fewer methodological assumptions have to be made (which are mostly necessary to allocate impacts to functional units) (Rebitzer et al. 2004). Important is that every link of the supply chain provides data that can be carried forward and, ideally, focus on the same indicators (Schmidt 2010). This requirement is associated with numerous sub-problems; for example, an understanding of highest priority data and key sustainability indicators is vital. Moreover, the fact that there is no standard for assessing sustainability in an integrated manner is problematic. Thus, it is crucial that integrated assessment tools, especially corporate-related ones, are further improved. In general, less effort should be put into refining existing approaches; rather, efforts should be made to develop appropriate structures to overcome weaknesses in data collection and information flow among organizations. Madanchi (2013) introduced an expedient approach using a rapid assessment tool to assess factory sustainability, with a focus on usability. The tool is based on Microsoft Excel and Visual Basic for Applications (VBA), which constitutes a major advantage, since nearly every company, even in developing countries, has access to these software packages. Furthermore, this approach is based on only 20 different key indicators, derived from numerous practically used frameworks comprising global-, country-, sector-, corporate-, and product-related indicators. As shown in Figure 4-15, indicators and sub-categories for each dimension of sustainability, exist. A positive feature is the copious reflection on social indicators.

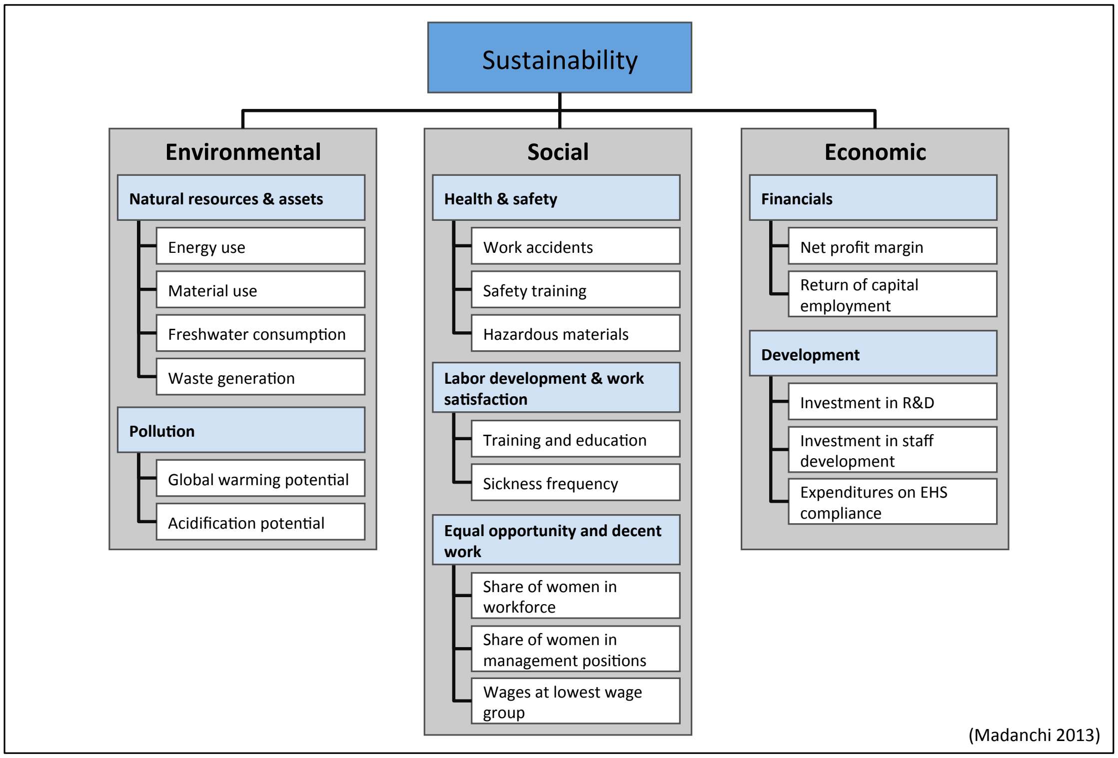

Figure 4-15: Key performance indicators of factory sustainability

Based on specified weightings and normalization methods, the research effort culminates in an Excel input mask, where companies have to enter values for the described indicators. In this way, sustainability can be assessed on a factory level. At the moment, the range of functions just allows comparisons between companies, since no database or standardized scale is available to normalize values and calculate an index for a single factory[21]. However, this problem does not depict an insurmountable obstacle. An exchange of experiences on the implementation of computer-based assessment tools might contribute to ideas to solve this task. The additional functionalities, based on the aforementioned assumptions (e.g.,

[21] For more information, see Madanchi (2013), where more research regarding the refinement of this tool is reported.

partitioning factor) can easily be integrated within Excel. In summary, the foundation to assess GPS in the described way is, hereby, established. The theoretical concept, in combination with more advanced and customizable Excel tools (e.g., specific user manual, greater freedom of choice regarding branch-specific indicators, as per the NIST framework in Section 2.2.2), outlines a powerful approach suitable for decision support and that may pave the way to reducing the global impact of production.

4.2.2 Organizational challenges

An integrated assessment requires communication across several organizational boundaries and, thus, outside the regular business information flow (Rebitzer et al. 2004). Most of the organizational challenges are not sustainability assessment-specific, but rather are rooted in problems occurring in supply chains in general. Strategies for inter-organizational cooperation are necessary for a successful implementation. In practice, efforts are hindered by an incomplete understanding of the value of information sharing (and physical flow coordination). A supply chain consists of various stakeholders with different backgrounds and, most often, conflicting objectives (Sahin & Robinson 2002). Particularly in industries such as textiles and clothing, where companies, which vary greatly in their levels of development, have to cooperate effectively and efficiently, there is a reliance on sufficient structures and organizational relationships for supply chain integration. Relationships exist among companies with an enormous brand awareness and access to the most modern technologies, and SMEs (even family businesses), whose activities are primarily based on manual labor. In addition to these mostly static challenges, the continuously evolving structure of supply chains and their participants causes certain dynamic challenges for effective system integration (Sahin & Robinson 2002). These problems arise mainly due to missing skills, knowledge, and ICT capacity and capabilities, since companies within a supply chain usually do not have access to the same technologies. However, there are certain initiatives, like the Global e-Sustainability Initiative (GeSI) from the UNEP, whose focus is on shaping information and communication technology in the field of sustainability to overcome these gaps (Grießhammer et al. 2007). GeSI is a "leading source of impartial information, resources and best practices for achieving integrated social and environmental sustainability through ICT[22]" (Global e-Sustainability Initiative 2014). Another example is the European Commission, under whose patronage several activities and initiatives focus on the development of ICT networks and infrastructure. The eEurope initiative and the Directorate General Information Society aim to achieve ubiquitous access and opportunity for all by building an appropriate physical and digital infrastructure, as well as activities to raise skills and increase the penetration of ICT. A particular focus, thereby, is on SMEs. National objectives and targets also exist to close regional disparities by means of policies for e-government and e-business development (Millard 2002).

Another key challenge results from inter- and intra-organizational bureaucratic structures and conflicts of interest among stakeholders. There is a lack of interest at a certain level of stakeholders on recording data. One reason for this, especially in developing countries (where most often impacts occur), is insufficient awareness of sustainability impacts; focal companies take advantage of this deficit to offshore their own impacts. Local authorities may find it difficult to prioritize data collection over other, more urgent needs. To assess *Global Product Sustainability* it is necessary to link global value chains and raise awareness. This, however, can only be achieved

[22] For detailed information, see gesi.org.

when focal companies take on their moral responsibility to support lower-level supply chain actors. Despite these inter-organizational challenges, problems also occur within companies. Key stakeholders might not be willing to share data in order to maintain confidentiality. It is an open secret that individual needs and goals are prioritized higher than ethically based goals, like increasing the overall sustainability of a product (production process). In many companies, there is a lack of understanding around the importance of data sharing, publishing, and translating to use internationally. Furthermore, data collection is often associated with financial obstacles. In summary, all existing challenges can be traced back to the problem of providing the necessary data; although this is not a specific problem for the presented approach, it affects sustainability assessment in general.

As shown in Figure 4-16, the concept of Global-LCIA requires more sustainability measurements in total, than a classic assessment, since a product's sustainability impact is based on a cumulative calculation. However, the amount of required data is significantly less and awareness of individual processes is not needed. Additionally, information required for the allocation is available anyway, since information on market prices and sales volumes is required for financial accounting. Losses in accuracy are present in both approaches. In classical assessments, losses are caused by a lack of information (it is impossible that the focal company knows every process required and exact inputs); in Global-LCIA, due to the applied allocation principle. Thus, losses in accuracy might be slightly larger since these assessment results represent more a category of products than an individual product. In the view of the author, the difference is not significant. To derive management decisions, the trend is more important than factitious accuracy. A major advantage of Global-LCIA is that the assessment procedure is less time consuming and more suitable to various kinds of companies, which leads, finally, to increased overall efficiency (see matrix in Figure 4-15).

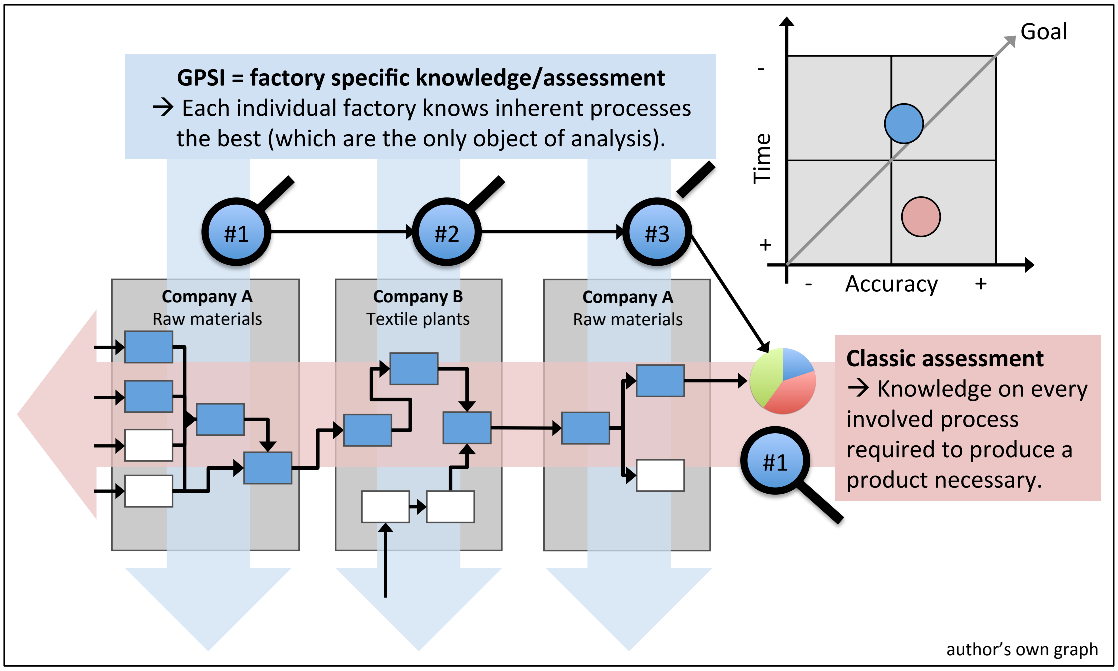

Figure 4-16: Global-LCIA versus conventional assessment: measurement challenges

Summary of main findings from chapter 4: Using *the creativity methodology, synectics-unrelated search fields were connected to the original problem to broaden the scope of a constructive solution to assessing Global Product Sustainability. Imperative specifications are the consideration of all three dimensions of sustainability, the entire product life cycle, and with a focus on products. Furthermore, the concept should be user-friendly and reduce the complexity of existing approaches, thus making it suitable for diverse stakeholder groups. This* *concept draws on the principles of cost accounting. As a pioneering approach to cost allocation, the so-called market price principle is a foundation for GPS, which is based on three pillars. The first pillar encompasses methodological approaches used to assess sustainability. In contrast to existing sustainability tools, the assessment is site-specific for each business involved in a certain supply chain. Each company considers itself as a black box; thus, their entire business process results in sustainability impacts, as well as goods or services (which might be end products or supplies for further business activities). To reduce complexity, individual product impacts are not assessed during product-specific processes, but are allocated afterwards using a partitioning factor based on market prices and sales volumes. The second pillar involves the life cycle perspective. Product impacts are passed up the supply chain, whereby each company then performs similar calculations to allocate impacts, thus leading to a cumulative sustainability impact. Solely the focal company has the additional task to consider the impacts of further life cycle phases; thereby, particularly the consideration of so-called externalities causes problems. The last pillar describes approaches for the graphical representation of impacts, particularly their geographical origins, in a manner that supports management decisions (e.g., location decisions). However, even if the concept were built on logical assumptions, many challenges emerge in practical use. These are particularly rooted in insufficient databases and IT deficits (e.g., software) that disrupt accessibility to all stakeholders. Additional organizational challenges are present that hinder data gathering (e.g., defensive attitudes by suppliers)*

5 CASE STUDY: GPS IN THE TEXTILE AND CLOTHING SECTOR

Following Chapter 4, which serves to illustrate the development of the assessment concept Global-LCIA and describe its fundamental principles, Chapter 5 aims to investigate whether the concept, or at least some of its ideas, can be practically applied. The object of investigation is the textile and clothing (T&C) sector. The general structure of Chapter 5 is outlined in Figure 5-1. As an introduction, a brief description of the current structure of the T&C sector is given in Section 5.1. This is followed by the description of the textile and clothes making process and how a usual supply chain is built. In Section 5.3, the developed concept is analyzed with regard to its application to the T&C sector under current circumstances. To give the reader an understanding of the sustainability impacts in this industry, selected case studies are presented in Section 5.4. For the sake of completeness, Section 5.5 closes with an excursus on location decisions in the T&C sector.

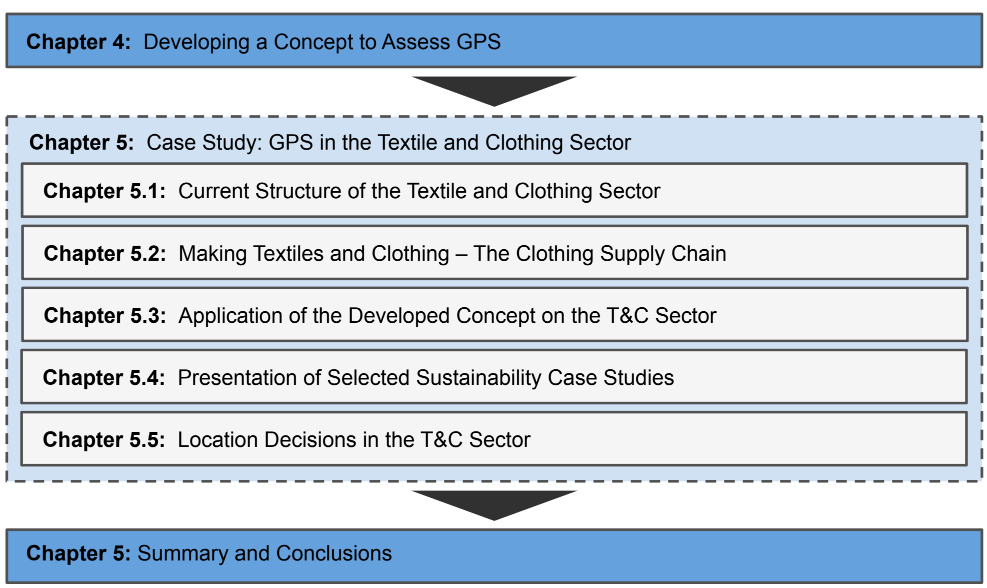

Figure 5-1: Structure of Chapter 5

5.1 Current Structure of the Textile and Clothing Sector

This chapter provides an overview of the current structure of the textile and clothing sector. Since there are no institutions or organizations that provide summarized and objective data on sector characteristics, different data sources are used. For this reason, the currency of these data varies.

Position in world trade. The market for textiles and apparel plays a significant role in the world's economy. Textiles, apparel, and apparel retailing generate annually around US$2 trillion globally. In 2000, consumers spent around US$1 trillion on apparel. Western Europe and North America are the biggest spenders and together spend roughly one-third of the total (Allwood et al. 2006). Apparel and footwear sales contribute US$350 billion to the US economy, which makes the industry more meaningful than the sale of cars (US$175 billion) and the fast food industry (US$75 billion) (WTO statistics 2012). According to the statistics database of the WTO, the proportion of textiles and clothing to total world merchandise exports in 2012 is around four percent (WTO statistics 2012). Figure 5-2 illustrates qualitatively the world exports of clothing and textiles by country in the year 2012 (WTO statistics 2012).

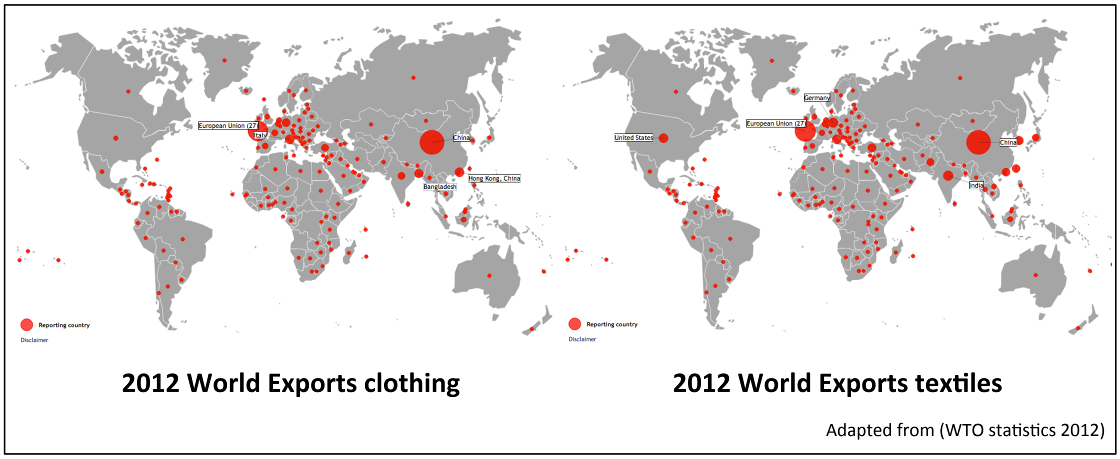

Figure 5-2: Comparison of world exports in clothing and textiles

As can been seen, a significant portion of this sector is dominated by developing countries, particularly Africa, Asia and led by China. However, industrialized countries are still important exporters of textiles and apparel; in particular, European countries like Germany and Italy, and the United States contribute in this regard. While the export of apparel and textiles is clearly dominated by developing countries, other countries have important roles, particularly in terms of exporting raw material. For instance, the USA remains as it has for decades as the world's largest exporter of cotton (Rivoli 2009) while Australia and New Zealand are main suppliers of wool and carpets (Allwood et al. 2006). Also in the field of high-value added segments, developed countries are still in the position of market leaders (Nordas 2004). A high level of research and development, modern technology, well-paid workers and designers, and a high degree of flexibility characterize these countries.

Acting in the environment of rapid changing markets. The apparel and textile industry is spread all over the world and includes economies with different levels of development in various fields. As mentioned before, it depends on the focused market segments, which can vary from low-wage and labor-intensive segments to highly engineered ones. However, due to the size of the sector, and its historically related dependence on cheap labor, the textile and apparel industry is subject to political interest and has been significantly shaped by international trading agreements. The sector has changed within the last years, especially due to the removal of several restrictions. To protect their own manufacturing interest from competition of developing countries with advantageously low wage rates (e.g., China), numerous developed countries imposed quotas and tariffs on exports to protect their own jobs and industry (Allwood et al. 2006). Regulation of national trade by quantitative restrictions has existed for a long time in several markets, but in no industry have they been more broadly applied and common as in the textile and clothing sector, which has had substantial consequences on the development of the sector. Some of the consequences have been indented and some of them not (Naumann 2006). On January 1, 2005, all existing quotas expired when the Agreement on Textiles and Clothing (ATC), the successor of the Multi-Fiber Arrangement (MFA), was removed. The ATC regulated the gradual transition of the previously protected industry to a free trade industry. The industry is now regulated by the general rules and disciplines embodied in the multilateral trading system and no longer subject to special quotas outside normal WTO/GATT[23] rules (WTO 1995; Brambilla et al. 2010; Naumann 2006). Nevertheless, in spite of these developments,

[23] General Agreement on Tariffs and Trade (GATT): Multilateral agreement regulating international trade.

unrestrained free trade does not exist yet. On the one hand, new “anti-dumping” and safeguard measures were introduced and, for example, China’s admission to the WTO was only agreed by accepting an extension of quotas (Allwood et al. 2006). On the other hand, there are still import tariffs (average 12% on garment import prices) and subsidies to control trade. However, it is given that trade in the clothing and textile sector since 2005 is less restricted than ever before. This liberation of international trade is one of the main influencers on the dynamics in the T&C sector (EMCC 2008) and sets the stage for the substantial reallocation and diffusion of exports and production all over the world (Brambilla et al. 2010). Particularly noticeable were the rapid increase of exports from countries like China, and a decrease of prices for textiles and apparel in developed countries (Allwood et al. 2006). Besides the main reason—the removal of restrictions—the clothing sector is a sector where relatively modern technology can be adopted even in poor countries at relatively low investment costs. These technological characteristics of the industry have made it possible for poor countries to profit from the industrialization and experience a very high output growth rate in the sector (e.g., Bangladesh, Vietnam, and Sri Lanka). Exactly those features “made [the textile and clothing sector] a footloose industry that is able to adjust to changing market conditions quickly”(Nordas 2004, p.1).

Subsidies still distort fair competition. Besides the aforementioned protection from low wage countries by quotas and import tariffs, exporting countries like the USA have supported their industry through massive government subsidies (Watkins 2002; Rivoli 2009). Figure 5-3 illustrates the extent of those subsidies.

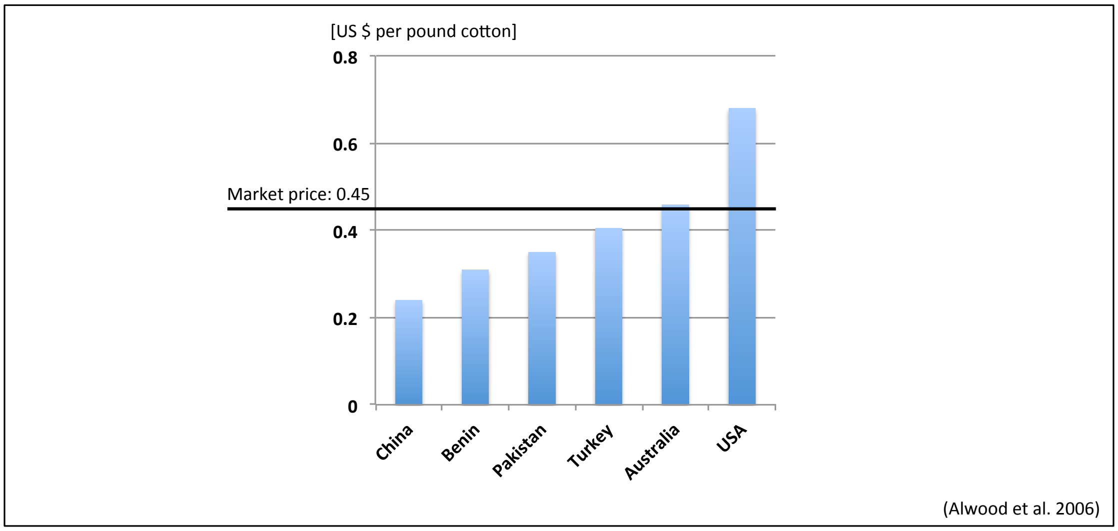

Figure 5-3: Market and producer prices for cotton per pound) 2000/01

The diagram compares the true cost (estimate for 2001) for producing one pound of cotton and its market price in different countries. In 2001, the market price was around US$0.45 per pound. Due to subsidies, the by far highest price for cotton produced in the USA was reduced artificially by the US government (Allwood et al. 2006). On the one hand, these circumstances create difficulties for developed countries to gain market share and on the other hand are a main factor in why the US is still the second largest producer of cotton in the world and the largest exporter (Watkins 2002). In summary, cotton subsidies have a big impact on poor countries because cotton is a critical crop for some of the world's poorest countries, for whom cotton could be a significant fraction of their exports (e.g., the "Cotton 4" countries of Benin, Burkina Faso, Chad, and Mali) (Cheng & Kuyvenhoven 2007). Furthermore emerging nations such as Brazil, and middle-income countries like China, could gain much through the elimination and reform of US cotton subsidies (Cheng & Kuyvenhoven 2007). This provides a good example of how immense the impact of government decisions can be in terms of (social) sustainability.

A critical role in creating jobs, promoting economic development, enhancing human development, and reducing poverty. There is no question that the textile and clothing sector employs many people. Due to the high number of small firms and sub-contractors, it is difficult to estimate a number of people working in this industry with any certainty. Global estimates vary from more than 120 million people (Keane & Willem 2008) to 30 million people (ILO 2000). Main differences occur due to the underlying scope. Whereas the first number includes all people directly employed in the clothing and textile sector, the second number concentrates only on people employed in manufacturing (not retail, services, etc.). China, with 7.5 million employees, is clearly dominant, followed by the EU, Pakistan, Bangladesh, India, and Indonesia. In general, countries with higher labor costs have more employment in the area of textiles than in clothing that relies more on (simple) manual labor (Keane & Willem 2008; Nordas 2004). Therefore, former ATC countries' employment has been sustained up much better in the textiles sector than in the clothing sector. Another reported trend is a loss of employment in the overall sector of T&C. However, this reduction is unevenly distributed. In particular, the US and EU textile and apparel industries report declines while some Asian countries have experienced employment growth in this sector (data between 1990 and 2002).

Another characteristic of the T&C sector is the high proportion of women working in this field. Between 70 and 80 percent of the workers in poor countries are women; labor intensive working processes like sewing, finishing, and packing clothes are conducted by female workers[24]. It should be noted that many of them would not have had an income in the absence of the textile and clothing sector (Nordas 2004). Men usually tend to earn more, and are employed in positions like supervisors, machine operators, and technicians (Allwood et al. 2006). These conditions proof inequalities and social injustice.

[24] For a detailed description of the manufacturing process of clothes (and textiles), see Section 5.2.

5.2 Making Textiles and Clothing - The Clothing Supply Chain

The following paragraph demonstrates an exemplary supply chain within the textile and clothing sector. This will also include a description of a characteristic production process of textiles and clothing. The supply chain is considered embedded into the whole life cycle of textiles and clothing. Since textiles are a necessary input for clothes, and their production processes are basically the same, the focus will be on a clothing/apparel/garment supply chain.

A common supply chain is assembled as a linear sequence of numerous discrete events. Everything starts with the **sourcing of raw materials**. Raw materials for clothes can typically be divided into three different categories. First, they can be derived from living creatures (e.g., wool and silk); second, raw materials can be plant-based (e.g., cotton and linen); and, importantly, synthetic fibers (e.g., nylon, polyester) (WG 2014). Another common classification for fibers is either natural (e.g., cotton, silk, wool), man-made (does not exclude natural) from cellulosic (e.g., rayan), or synthetic. As an input raw material for synthetic fibers, oil serves to create polymers (e.g., nylon, polyester). In summary, every textile and clothing product begins as a fiber (Allwood et al. 2006). In parallel to the raw material extraction, the **design process** can take place since these two activities are not linked (but not independent) to each other, and serve as an input for the following activity of fabric manufacturing. The **fabric manufacturing** process consists of different successive activities. It begins with the spinning of the original fibers, which are thin and might be of different length, into yarns. These yarns are processed into fabrics, in most cases in the form of flat sheets. To achieve this product state, two different processes can be used: weaving or knitting (depending on the desired function and design). The following described activities differ and depend on whether the end-product is a garment or textile. The main difference is that, for a garment, the “flat” fabric sheets have to be formed into a three-dimensional shell. Processes required for both product types are, for example, dyeing, printing and finishing. These production steps are usually carried out in textile plants. However, depending on the end-product, dyeing might take place at the yarn or fabric stage. Processes that are only required for clothes, and carried out in apparel plants, are pattern making, grading, nesting and marking, cutting, and sewing. Depending on the end-product, accessories like buttons or patches will be added here too. Each of these processes has different requirements regarding necessary capital, technology, and labor. Interesting in this connection is that continuous technological developments have been made for all of the listed processes to reduce labor intensity and achieve quicker delivery; however, still no technology is available to substitute the sewing process. Due to complex patterns and different kinds of raw materials, manual labor is still most used in this process and is often conducted by women with no other job opportunities. In contrast, knitwear is nowadays increasingly (but not mostly) made my machines, which are able to produce seamless whole garments. Finally, the garment goes through the finishing process, which includes quality inspection, pressing, and ticketing before it will be folded and packed to be ready to leave the apparel plant (Allwood et al. 2006; Nordas 2004; Cotton Incorporated and PE International 2012;

Textile/Clothing Corp. 1994). The next steps in the T&C supply chain are the transport to **distribution** centers and in a final step the shipping to retail stores where the garment will be displayed and distributed to the customers (Textile/Clothing Corp. 1994). All mentioned steps could be categorized into three basic operations: pre-assembly (design, grading, marking, and cutting), assembly (sewing), and post-assembly (distribution, marketing, and retail). Pre-assembly represents the most capital-intensive stage in the whole process because quality and precision are very important here (EMCC 2008). The whole supply chain is therefore organized as an integrated production network. The production process is divided into specialized activities where each of them is located where it can contribute the most to the value of the product and the goals of the focal company (Nordas 2004). It thus becomes clear that location decisions are influenced by many different variables, for instance costs, quality, reliability of delivery, flexibility, infrastructure, and technology. An interesting question, stated at the beginning of this thesis, is whether those location decisions can be influenced using new ways of measuring sustainability. The described structure of the supply chain is summarized in Figure 5-4.

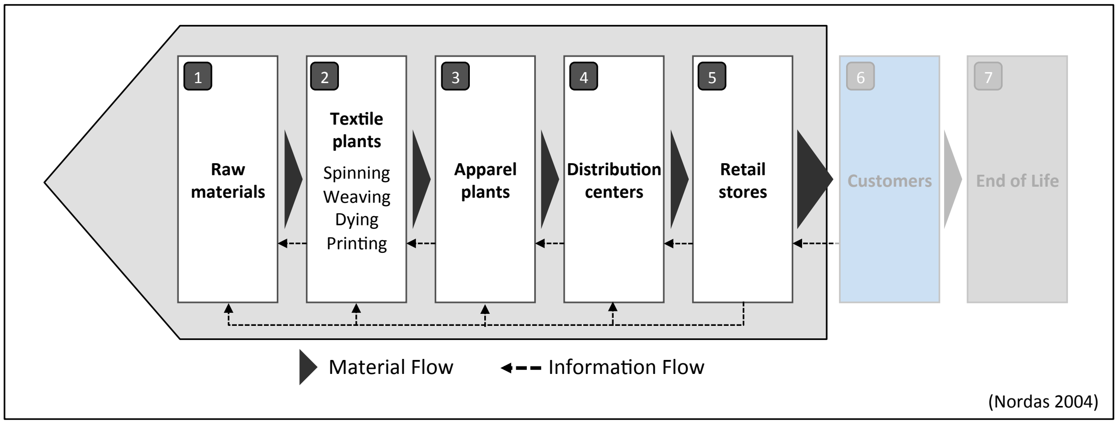

Figure 5-4: Common linear supply chain within the textile sector

Both the flow of goods (solid triangles) and the flow of information (dotted lines) are illustrated. The direction of the arrows from the customer to lower levels in the supply chain indicates a demand-pull-driven system, where the customer "decides" what is being produced and when (Nordas 2004). It is worth noticing that the textile and clothing industry is characterized by a relatively direct information flow. For example, information flows from retailers to textile plants with no detours because they produce for the clothing sector and for household use and have to guarantee a high degree of flexibility. Since there are usually more than one firm involved at each production step, business services and logistics play a big role in this industry. The flow of goods, payments, and information has to be organized in a sophisticated manner and is highly dependent on the size and development of the host economy. According to the current situation, those services are either provided by the lead firm in the supply chain or independent service providers in developed countries (Nordas 2004). Like introduced before these factors also have a high influence on assessing sustainability since the directly affect the process of data gathering.

Because garments have become fashion-oriented, they are increasingly challenged by short product life cycles (Allwood et al. 2006). Therefore a brief discourse on how an exemplary supply chain in the T&C sector operates should be given. Retailers that are responsible for replenishing their stores (usually on a weekly basis) extract and analyze sales data to place replenishment orders with the manufacturer. This should be able to fill the retailer's inventory within about a week after placing the order. Therefore, large inventories of finished products have to be held to accommodate the lead time of the manufacturer and demand volatility. The larger the product varieties (e.g., different fits, colors, and sizes), and the larger the fluctuations in demand, the larger the inventories have to be. Reduced inventory levels relative to sales are possible if short lead times, reliable demand forecasts, and large markets (less variation in aggregated demand) are given. Depending on the gap between the remaining inventory and the size of the replenishment order, the manufacturer will make production orders to the production plants, which might be located in different countries. Since retailers want to ensure a consistent level of quality even if they spread large orders of a product over several producers in different low-wage countries, it is common practice that buyers provide suppliers with input material. This material could be, for example, yarn, fabric, or accessories (Kelegama & Foley 1999; Abernathy et al. 1999; Nordas 2004). The described procedure is mainly for fashion products. Commodity items (e.g. socks) would be supplied continuously.

This supply chain is embedded as part of a whole product life cycle. The sale of garments or textiles to customers indicates the starting point of the use phase, which can have different lengths, depending on the purpose of the product. In reaching the end-of-life stage, four different options for the textile products are usually available: 1. send them to landfills; 2. incineration; 3. export used textiles to second-hand markets; or 4. recycle the used material to make new textiles (Allwood et al. 2008). Options one and two represent the final state of a classic product life (see Figure 5-4) while options three and four present opportunities to extend the product's life cycle. If products are reentering the supply chain in any manner, then the supply chain becomes a "closed loop" supply chain.

This case is illustrated in Figure 5-5. Both the individual supply chain links and resultant impacts are shown. Within each phase of the life cycle, various sustainability impacts might occur. Within this graphical representation, the impacts are categorized into four main groups and eight different impacts. The first category (what we take) comprises resources that are taken from nature (virgin materials (R), water (W), fossil fuels (F), electrical energy (E)); the second category (what we make) includes toxic and harmful (man-made) substances (T) that are used or created within processes and have a negative impact on the environment. Organic pollutants and solid scrap (P), which could only slowly be degraded by nature, as well as "waste" that could be used for another innocuous purpose (compost, used textiles) (R), are grouped together under the third category (what we break). Impacts on humans (H) are represented by the last group, Human needs. The interested reader may wish to take a closer look at the individual processing steps and their specific impacts shown in the figure (Maki 2006). Conspicuous is that the focal company, whose focus is usually only on distribution and retail (sometimes labeling), does not affect the nature due to taking or releasing substances and resources. Impacts are mainly of social nature or due to the use of electricity. This demonstrates again the problem of pseudo-sustainability (see Section 4.1.3.3), which may be significantly reduced due to assessment, according to the developed Global-LCIA.

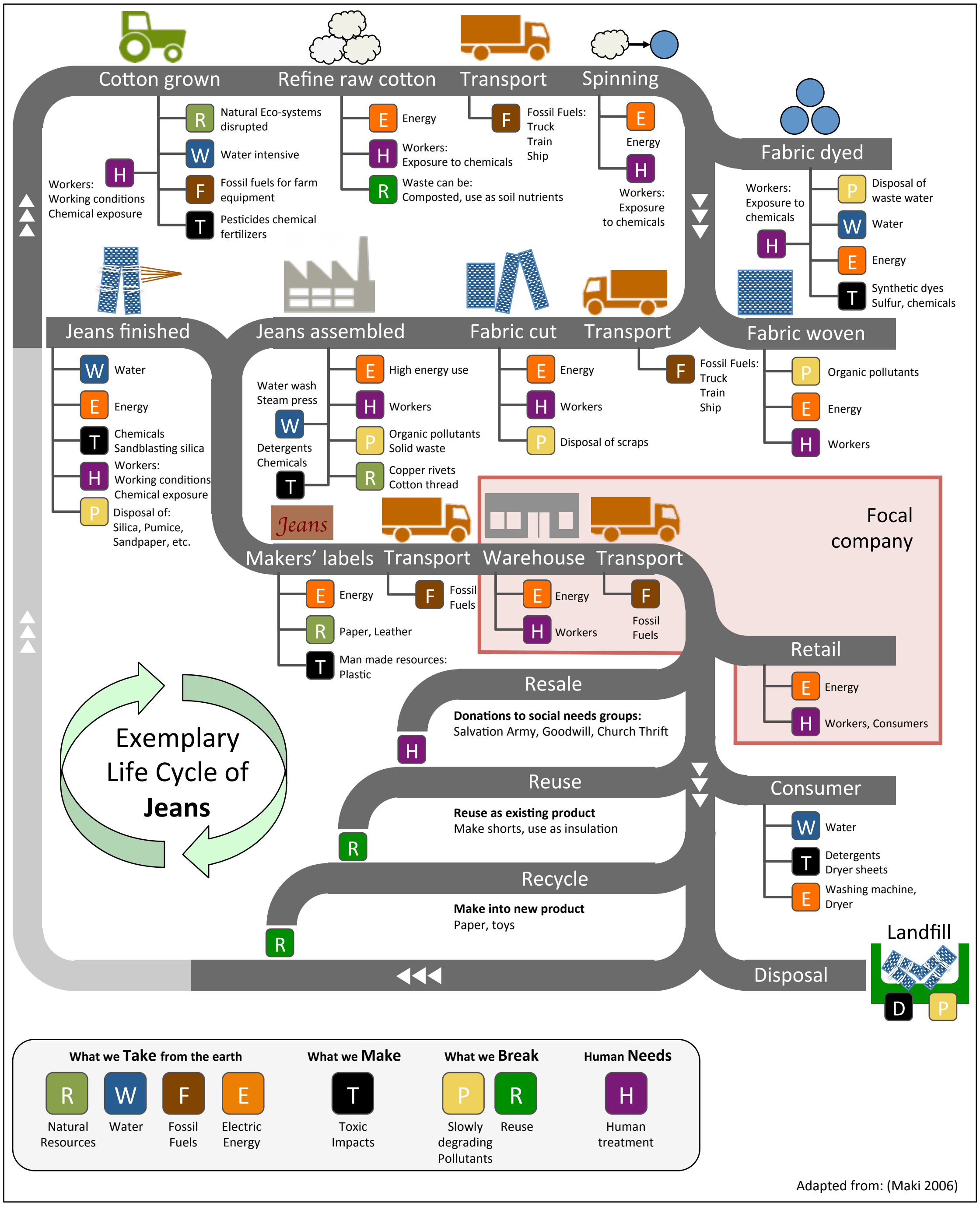

Figure 5-5: Closed loop supply chain within the T&C sector (including impacts)

5.3 Application of the Developed Concept on the T&C Sector

Sections 5.1 and 5.2 served to provide an overview on the branch and its constitutional characteristics to create a framework for the exemplary application of the concept. A crucial basis for the assessment of GPS is the availability of data. To identify possible data sources, the author examined various papers, homepages (initiatives, organizations, and governmental), and sustainability databases (GaBi, SimaPro).

The availability of specific data for the textile and clothing sector represents exactly the picture provided in Section 2.2.3, that methods and data for environmental Life Cycle Assessment are prevalent. There is lots of research done to assess the environmental impacts of certain products or processes within the textile supply chain. Results present actual values for the typical E-LCA impact categories (e.g., global warming potential, ozone layer depletion, etc.). A certain proportion of the research conducted is in the field of social sustainability. However, the availability of actual data is only very limited. The same holds true for Life Cycle Costing approaches and composite indicators for this particular branch.

There is no publicly or general accessible data available that could serve as an input for the intended practical capability analysis of the developed concept. Large gaps are present primarily in two fields:

- On-site data regarding sustainability impacts (all three dimensions), which is necessary for impact assessment

- Publicly accessible data on the product portfolio, turnovers, and sales volumes, especially of SMEs (necessary for impact allocation)

However, this is expected, since there are no legal regulations and, in many cases, no need to assess sustainability impacts on a factory level. Particularly within the considered T&C industry, companies at the lower end of the supply chain do not currently collect the necessary information. General reasons for that have been discussed in Section 4.2.2 (e.g., missing skills and financial and technical resources). The data transfer required for a successful assessment is based on inter-firm cooperation. A study conducted by Arretz et al. (2009), with a focus on greenhouse gas emissions within the textile pre-chain (outside the company's own corporate boundaries), leads to the result that there are currently massive reservations regarding the collection of data from supplying companies. Most (small) textile producers have no experience with the systematic collection and bundling of data (e.g., regarding energy consumption). The quality of existing data, particularly regarding environmental issues (e.g., for the determination of a PCF), varies between examined countries (e.g., good in Greece and Turkey; only rudimentary in Bangladesh and India). Analog problems were obtained in terms of the availability of resilient economic data. Economic indices were deliberately obfuscated to prevent third parties accessing commercially sensitive information, such as sales, profit, existing business relationships, or other activities. The major reason for this behavior is the fear that sales figures may provide evidence of profit margins, which in turn could be used by buyers to put downward pressure on prices during negotiations. However, even if this fear is unfounded, the disclosure of such data is precarious for certain textile suppliers since it allows inferences to be drawn regarding (illegal) subcontracting to third party suppliers. These “outsourcing activities” not only hinder the determination of key figures, they also constitute a very sensitive issue in the enforcement and monitoring of social standards in the textile industry. The conducted study, however, demonstrated that an increased awareness of sustainability issues (climate protection and energy efficiency) as well as facilitated data collection can be achieved through the implementation of cooperative projects (Arretz et al. 2009).

In conclusion, further research is necessary to evaluate the concept. Conceivable also are collaborative projects or workshops conducted by focal companies to increase the awareness and advantages of appropriate approaches to assess sustainability. A first step of gathering information on the current situation can be achieved using a survey instrument. Within the scope of this study, the presented situation might be disillusioning; however, it is precisely these aspects explained previously (e.g., fear of losing competitive advantage, missing sustainability awareness) that proves the necessity of implementing an approach like the one presented. Lasting changes, which have a significant impact on global sustainability, can only be accomplished with intrinsic motivation from all suppliers. There is no question that governments and focal companies have to initiate and force the implementation of sustainability measures; nevertheless, the long-term motivation should be recognition of the importance of assessing sustainability. Particularly for SMEs, the linkage to global value chains in a cooperative and open manner (open exchange of information) provides access to markets and knowledge of leading players. Although small- and medium-sized textile and clothing manufacturers are already integrated into global supply chains, participation in sustainability assessment initiatives is voluntary; however, these may serve as a steppingstone to firms entering global value chains in a way that allows rapid innovation and learning on a trustful basis ("fast track" strategy)[25] (UNIDO 2004).

Nevertheless, to provide an overview on sustainability impacts of the clothing and textile industry some assessment results from literature will be shown in the following Section.

[25] Extensive information on how local industries can be integrated into global value chains is provided by UNIDO (2004).

5.4 Presentation of Selected Sustainability Case Studies

Table 5-1 is an overview of some selected case studies carried out in the sector of clothing and textiles and that were reviewed by the author. The presented articles present only a small fraction of all reviewed articles. A major selection criteria was if the results contain numerical data (numbers and values). The table contains information on the source, the year of publication, a short statement of the addressed topic (and, if available, system boundaries), a short description of the major results, and a subjective rating of the relevance for this study (5 = very relevant; 1 = less relevant).

Table 5-1: Selected literature on assessing sustainability in the T&C sector

No.	Source	Year	Topic	System Boundaries	Results	Rating
1	Cotton Incorporated and PE International: The Life Cycle Inventory & Life Cycle Assessment of Cotton Fiber & Fabric Executive Summary	2012	Life Cycle Assessment Cotton Fiber and Fabric (including an detailed description of the methological approach and the execution of the LCA) Different scenarios considered for the consumer use phase	Software used: GaBi 4 and 5 Based on primary and secondary data Data are representative of the crop years 2005 through 2009 and textile manufacturing in 2009–2010 Analyzed products (consideration of 6 production processes for each type) Batch-Dyed Knit Fabric, Yarn Dyed Knit, Woven Fabric	Detailed figures for each product and necessary production processes Summarized presentation of impacts for a Woven Pant (Average U.S. Consumer) LCA categories: (1) Acidification, (2) Eutrophication, (3) Global Warming, (4) Ozone layer depletion, (5) Smog Creation, (6) Energy Demand, (7) Water Consumption, (8) Water Use Analysed phases: Agricultural Production, Textile Manuufacturing, Consumer Use, Total	5
2	Martinuzzi, A. et al.: CSR Activities and Impacts of the Textile Sector	2011	Collecting literature to determine trends in the EU textile industry.		General figures on the EU textile sector Listing of pubilshed literature in the field of: Future Trends (4 papers) CSR issues (6 papers) Quality of Work (13 papers) Environmental issues (5 papers) critical success factors (16 papers)	2
3	Sule, A.: Life Cycle Assessment of Clothing Process	2010	LCA for the clothing process, which is a part of the textile manufacturing process, comprising usually cutting, sewing and ironing and packagin.	Exclude: raw material, yarn and cloth production, dyeing and finishing; Include: cutting, sewing, packaging Functional unit: Cotton t-shirt (170 gram)	Absolute values and relative contribution to included processes regarding: (1) Abiotic depletion, (2) Acidification, (3) Eutrophication, (4) Global Warming (GWP100), (5) Ozone layer depletion, (6) Human toxicity, (7) Fresh water aquatic ecotox, (8) Marine aquatic ecotox, (9) Terrestrial ecotox, (10) Photochemical oxidation Information on energy consumption	3
4	Chapman, A., Oakdene Hollins Research & Consulting: Mistra Future Fashion – Review of Life Cycle Assessments of Clothing	2010	Comparison of different conducted LCAs Goal: Assessing current extent of information and uncover gaps in knowlwedge in the area of T&C LCA		Comparison of 11 diffrent LCAs from various institutions (retailer, producer, organizations) Focusing diffrent functional units	3
5	Agbonkhese, S.E.: Measuring Environmental and Social Sustainability in the Apparel Supply Chain	2010	Estimation of a comapny's sustainability based on initiatives (categorized by supply chain stage and sustainability dimension); Classification is based on type of initiative and number of initiatives.	Sustainability score calculation based on a formula that considers number of initiatives and subjective weights that describe the quality of initiatives carried out within a company.	Matrix with certain sustainability scores. Subcategories are the Supply Chain Stage (Raw material, Production, Distribution, Transportation, Use, Disposal and total) and the sustainability dimension (Energy/Emissions, Water, Waste, Materials, Social Responsibility and total)	4
6	Jungmichel, N., Systain Consulting, 2009: Der Carbon Footprint von Bekleidung	2009	Determination of the Carbon Footprint of a cotton longshirt (detailed) Additional examination of sweat-jacket and acrylic children's jacket	Material: 100% cotton, Size 40-42 Net weight: 222 gram Cotton grown in the USA, longshirt manufactured in Bangladesh, sold in Germany	Options for reducing carbon emissions Product Carbon footprint for all three products Values provided for the following phases: Disposal, Use Phase, Packaging, Catalogue, Distribution, Transportation, Manufacture, Raw Materials	4
7	Pan, J. et al.: Global Cotton and Textile Product Chains	2008	Social and environmental impacts of globalization in the cotton/textile supply chain (Including a scenario analysis).	Focus on Africa and China Data provided is basically on environmental toxication.	Comparison of environmental impacts between 2005 and 2020 (for each of four scenarios) Absolute values for Water demand, Power demand, Coal demand, Waste water, COD (summarized for entire production in a country) Discussion of social impacts (no concrete values) Policy recommendations in the cotton/textile sector from a sustainable development perspective	2
8	Allwood, J.M. et al: An approach to scenario analysis of the sustainability of an industrial sector applied to clothing and textiles in the UK	2008	Integrating the triple bottom line approach of sustainability into scenario planning exercises (focusing on large changes with relevance for the entire sector)	Considering a Basecase and three Scenarios Focus of analysis: Cotton t-shirt	Quantitative results for the considered scenarios (for USA, UK and China, Global Total) Consideration of all three sustainability dimensions Environment (Climate change, Waste, Environmental impact) Social (Employment) Economic (GNI, Balance of trade, Operating surplus)	4
9	Eurostat: Sectoral analysis of EU manufacturing activities - Textiles, Clothing, Leather and Footwear (Chapter 3)	2006	Sectoral analysis of EU textiles, clothing, leather and footwear manufacturing Particularly social and economic data provided	Data used from 2000, mainly 2003, 2004 and 2005 Categories analyzed chosen with respect to the NACE guidelines	Information and figures on value added processes Employment statistics	2
10	Allwood, J.M. et al.: Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom	2006	Extensive report for a broad range of interested groups aiming to provide as balanced evidence as possible about the present and future impacts of the clothing and textile sector.	Focus: textile industry within the UK	Information on: The structure of the industry, Mass balance, Scenario analysis (examining the effects of location decisions, consumer behavior, new products and materials, government decisions)	5
11	Nadvi, K. et al.: Vietnam in the global garment and textile value chain: impacts on firms and workers	2004	Examination of impacts on firms and workers in Vietnam	Information gathered based on interviews with firms and buyers, and analysis of data	Employment and output per worker (focus on differential gains for state owned and private enterprises)	2
12	Tobler-Rohr, M.: Life Cycle Assessment of a cotton fabric in textile finishing	2000	Life Cycle Assessment for the finishing process	LCA according to SETAC methodology Software used: GaBi and öBeB.Pro Two studies carried out in Swiss finishing companies (each having different processes): A: Woven: Cotton 57%, Viscose 43% B: Knit ware:Cotton 96%, Lycra 4%	Recommendation for future research: Striving for improvement of processes and products (instead of improvements made on plant level). LCA categories: (1) Acidification, (2) Eutrophication, (3) Global Warming (4) Ozone layer depletion, (5) Human toxicity, (6) Terrestrial ecotox, (7) Energy Demand, (8) Smog Creation Analysed processes: Flaming, Desizing, Bleaching, Mercerizing, Dyeing, Printing, Finishing	2

The idea is to derive data from these examinations that could serve as input into the evaluation of the tool's practical suitability. Site-specific data, which is originally required for the developed concept, is provided by none of the listed articles. However, some data is presented in a way that allows illustrating the functionality of Global-LCIA after conducting small adaptions and conversions.

Study 1: Particularly the grey highlighted article at the bottom of table 5-1, with the title "well dressed", includes useful data. It was published in 2006 by the Institute for Manufacturing of the University of Cambridge and aims to investigate present and future trends for the clothing and textile industry in the United Kingdom (UK) (Alwood et al, 2006).

Results from this exemplary study will be used in the following to give an idea on how sustainability impacts in the textile and clothing industry are distributed on a global scale. The object of investigation is a standard cotton T-Shirt. Figure 5-6 illustrates the global price structure of such a t-shirt. The depicted prices are the intermediate prices paid by one company/business to another at the different stages of production. It is interesting to see that the prices approximately double at each progressive stage. Additionally the difference between a certain selling price and a certain buying price is an estimate of the gross profit of a particular business.

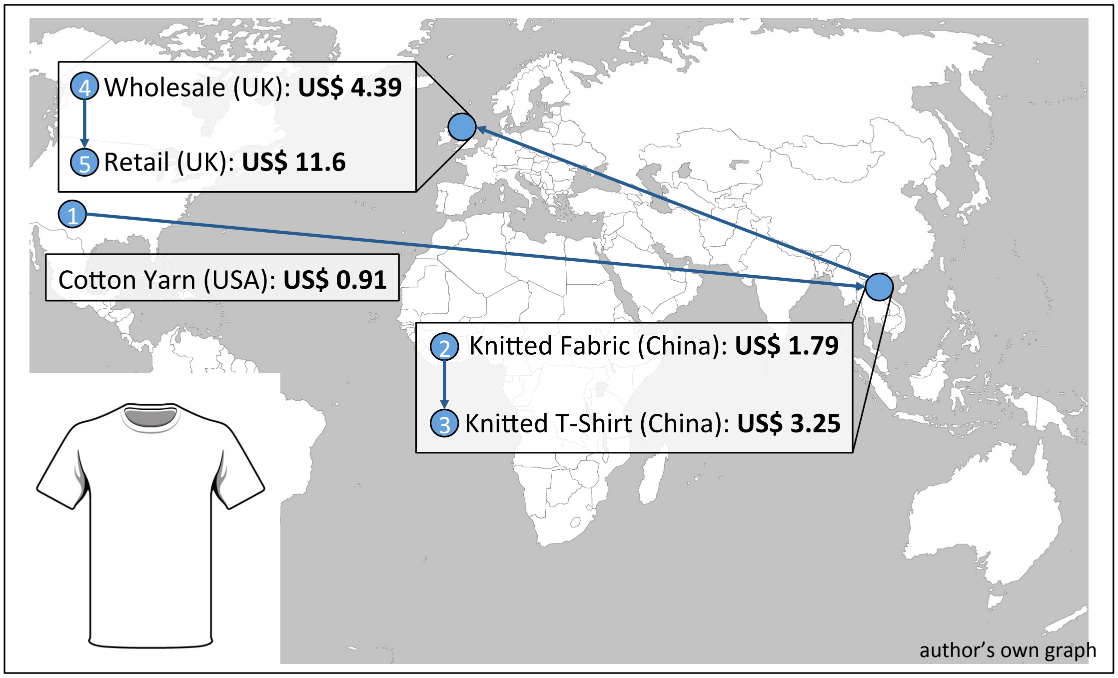

Figure 5-6: Global price structure of a cotton t-shirt

The used cotton is harvested, ginned and spun into yarn in the United States. In the next step the yarn is shipped about 11,500 km to China, where knitting, dyeing, cutting and sewing takes place. Afterwards the t-shirt is shipped nearly the same distance (about 9,200 km) to the United Kingdom where retailing, using and finally the disposal of the shirt occurs. Like stated in Section 5.1 the USA is the largest cotton producer in the world. In 2006 more than 5 million tons of cotton were harvested and then spun into 1.4 million tons of yarn. General data on productivity and employment are summarized in Table 5-2.

Table 5-2: General numbers on the production of cotton and t-shirts

USA	Cotton harvested	5.2 million tons
	Number of people employed in cotton farming	174,000
	Kilograms of cotton fibre per employee per year	30,000
	Spun cotton yarn	1.4 million tons
	Number of people employed in fibre, yarn and thread mills	54,000
	Kilograms of spun yarn per employee per year*	25,000

* assuming the yarns produced were all spun cotton yarns

China	Number of T-shirts*	460 million
	Productivity per employee per day (number of T-shirts)	15
	Productivity per employee per year†	4,500

* Based on UK imports in 2004

† Based on 50 working weeks per year, six days per week

Adapted from (Alwood et al., 2006)

Working steps in China are mainly conducted by young women, which are often migrants. For them the prospect of a job in a textile or clothing factory is more attractive than arranged marriage and living close to the subsistence minimum. In many cases the entire live takes place in the company, since most often working places are coupled with factory dormitories. The government officially restricts labor-working hours to eight hours per day and a weekly average of 44 hours. However, these rules are not strictly enforced and may be overlooked and working conditions can be poor. Shifts up to 12 hours a day, seven days a week, are not unusual in this industry.

Consumers in the UK demand for 460 million t-shirts, which corresponds to a weight of 115,000 tons. The weight structure of a cotton t-shirt is illustrated in Figure 5-7. To produce a classic shirt with a weight of 250 grams, 273 grams of knitted fabric are needed, which are produced from 326 grams of cotton fibers. Therefore about 25% of cotton waste arises in the production of a t-shirt.

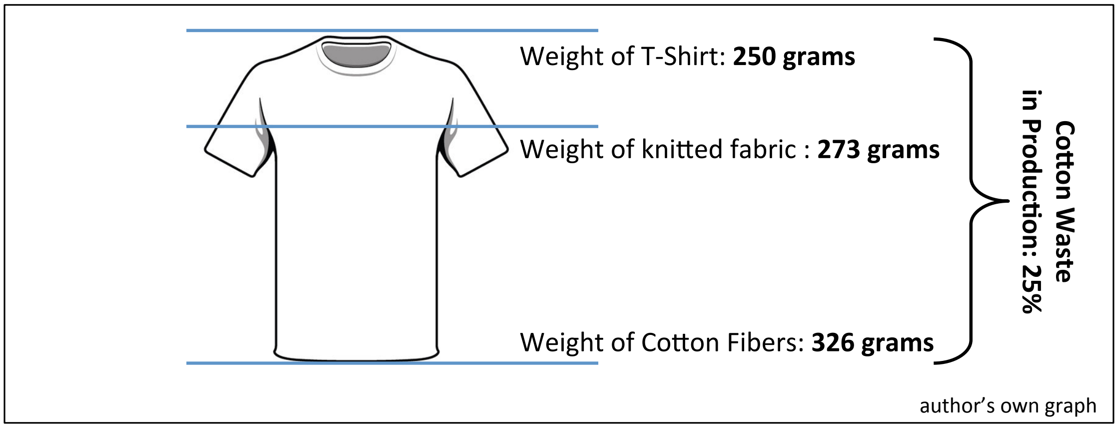

Figure 5-7: Weight structure of a cotton t-shirt

According to the proposed graphical representation in section 4.1.3.3 the following part will present an example with actual data from the case study "well dressed". It has to be noted that the used data was not provided by the involved companies themselves (like proposed from the author), but rather gathered from databases like provided by GaBi (Alwood et al. in 2006). However, the example gives an overview on how certain sustainability relevant factors are distributed globally. Following the previous made examination the presented numbers relate to a classic cotton t-shirt (250 grams). The graphical representation of the results is shown in Figure 5-8.

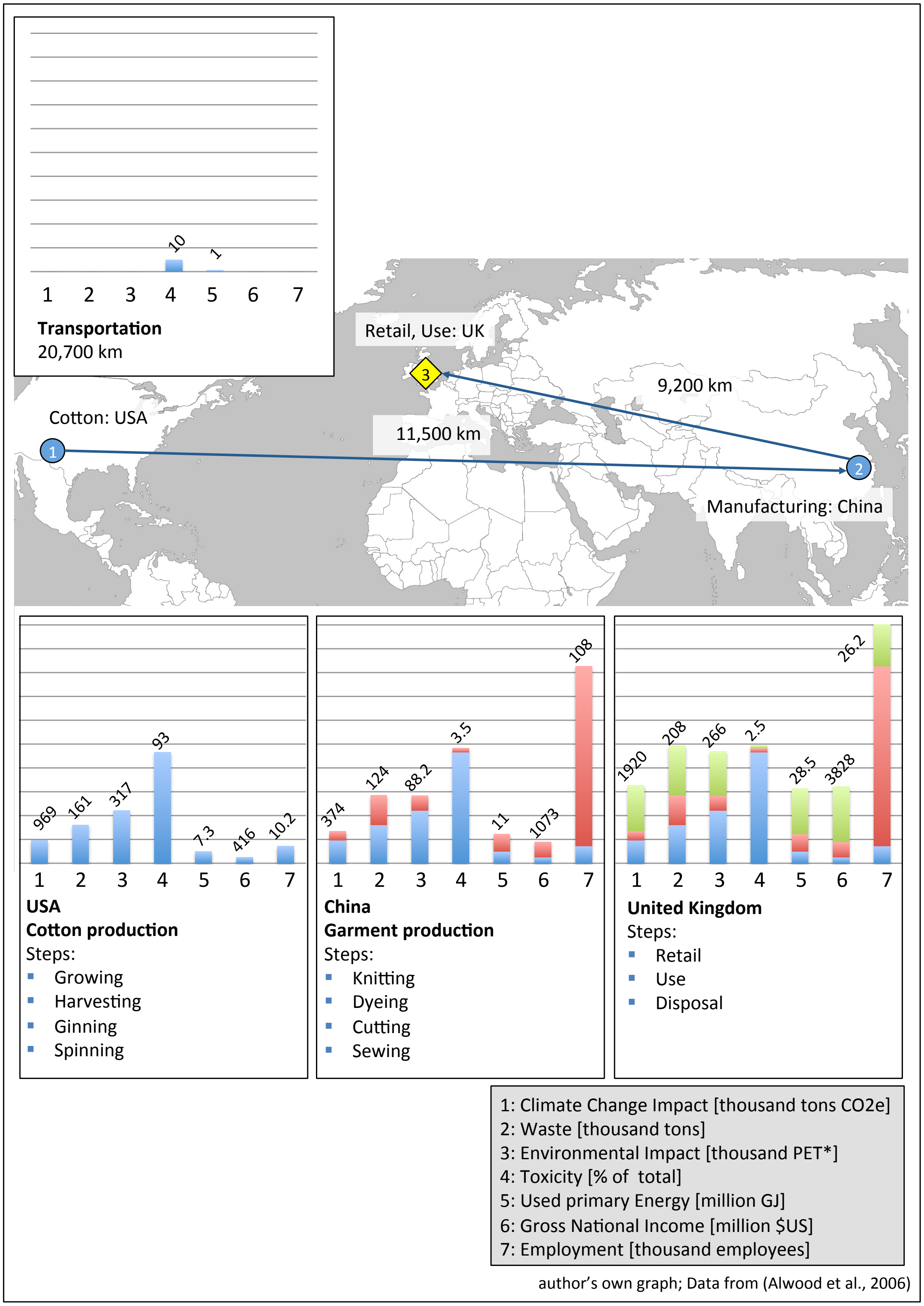

Figure 5-8: Graphical Representation Global LCIA for a cotton t-shirt

As described several times within this study the life cycle of textiles spans over the entire world. The production of cotton fibers takes place in the USA, the actual garment production is located in China, and the final product is sold, used and disposed in the United Kingdom. For each of these three locations several indicators are plotted in Figure 5-8, which are:

- Climate Change Impact [thousand tons CO_2 equivalent]
- Waste [thousand tons]
- Environmental Impact [thousand PET*]
- Toxicity [% of total]
- Used primary Energy [MJ]
- Gross National Income [million US$]
- Employment [thousand employees]

The first three indicators are used to predict the environmental impact. The provided values have been calculated by means of detailed life cycle analyses that are based on the internationally recognized Danish methodology EDIP (Environmental Design of Industrial Products). The climate change impact is measured using CO_2 equivalent, which is a common procedure according to the ISO guidelines (see Section 2.2.3.1). The waste is measured in thousand tons. Results for these two indicators refer to the entire import volume, of 460 million shirts into the UK, as the functional unit. The third indicator "Environmental Impact" is an aggregated environmental index. It represents the combined effect of ozone depletion, nutrient enrichment (e.g. growth of algae that might cause fish dead), acidification (acid rain) and photochemical ozone formation (smog) in one composite index. The considered effects are again commonly used indicators known from the ISO 14040 guidelines. The numbers unit is “Person Equivalent Targeted’ (PET). This means that impacts are normalized to one persons share and then weighted according to certain political reduction targets. For the calculation of the values the software GaBi was used, which encompasses extensive database that provides information on in- and outputs for nearly all processes involved in the life cycle of textile products. To estimate the given environmental impacts the software uses several internationally recognized life cycle assessment methodologies. The fourth indicator considered in Figure 5-8 is “Toxicity”. The data used for the underlying case study includes major chemicals that are used in the different life cycle stages of a t-shirt at different locations. In the cotton production phase (USA) five major chemical groups are used: insecticides, herbicides, fungicides, growth regulators and defoliants. In the manufacturing process of a cotton t-shirt (China) mainly dyestuffs and chemical auxiliaries are used. For the use phase (UK) for example washing powder represents a chemical with toxic characteristics. Since no absolute values were available the percentage share of the total toxicity value is illustrated in the graphical representation. The fifth indicator is “consumption of primary energy”. Again the functional unit is the entire import volume of t-shirts in the UK. For the use phase it is assumed that a t-shirt is washed 25 times at 60°C and afterwards tumble dried and ironed. The value is given in million Giga Joule.

As a representative of the economic dimension serves the indicator "Gross National Income". The underlying study calculates this value by simplified set of national accounts. Like shown in Figure 5-6 the cost structure for the analyzed t-shirt was determined that shows prices for each stage. In a next step the product costs are converted to national accounts for every involved country. Therefore the total output and intermediate consumption of the businesses that operate within each participating country were calculated. Finally a Gross National Income was derived for every country.

The social impact is also assessed by means of only one indicator, namely the number of people employed in the industry and country examined. In the opinion of the author this indicator alone is not very meaningful to predict social sustainability impacts since it does not allow drawing interferences regarding for example working conditions. However, since numbers on the employment within a certain industry sector and country are not accessible for every involved country and business, published figures on productivity and working hours were used to predict a quantitative value.

After all the graphical representation according to the developed concept Global-LCIA gives various key insights into the global distribution of sustainability impacts of the life cycle of a cotton t-shirt. It is interesting to see that all three environmental measures are high (two of them highest) at the place of distribution and usage. As a major driver for environmental impacts the required electricity for washing and drying can be called. This explains furthermore the great amount of used primary energy in the UK. Environmental impacts in the USA are mostly caused by the use of diesel in agricultural machinery and electricity to power machines.

For the sake of completeness the main contributions of the discussed article will be summarized in the following. The report focuses on the use phase of textiles, since it is recognized as the major contributor to the sustainability (environmental) impacts of T&C. The report is written not for an expert audience, but rather for a wide range of interested groups. It was found that major environmental impacts are due to energy consumption and toxic chemicals. Additionally, the problem of increasing waste volumes is addressed. In the UK, an average consumer sends 30 kg of clothing and textiles to landfills per year. The reason for that is that garments have come to represent "fast-fashion" and are only worn for a relatively short period of time, until new trends are released. Particularly the different composition of textiles (varying fractions of natural and man-made fibers) leads to challenges for waste treatment facilities (Allwood et al. 2006).

Besides environmental issues, the report examines social impacts from the sector. General information on campaigns for improvement of social conditions, and some data on the composition of the labor market (legal minimum wage levels, skill levels, fraction of men and women), is provided in this section. Focal companies and UK-based retailers are increasingly releasing codes of good practice and guidelines to suppliers. However, the problem addressed in the previous section, that throughout the supply chain (particularly at the lower end) many difficulties sill exist, is prevalent. On the one hand, it is challenging to impose such codes and guidelines and verify their compliance due to opaque structures (e.g., due to sub-contracting to third-party suppliers). On the other hand, resistance from suppliers due to a lack of integration and information poses difficulties. Unregulated working hours, missing safety standards, and child and women labor are still current issues in the textile and clothing sector. Additionally, minimum wage levels, if the exist, most often do not represent a minimum living wage, which makes it difficult to escape from the circle of poverty for some workers (Allwood et al. 2006).

The reviewed report includes a detailed clothing and textiles mass balance calculated for the UK that depicts major mass flows and their directions. The results are helpful to illustrate volume ratios and relationships (Allwood et al. 2006).

The largest part of the report is a wide-ranging scenario analysis. Different scenarios, with varying underlying assumptions regarding changes in production structure, consumer behavior, material and process innovations, and government influence, were applied to predict possible future developments and environmental, social, and economic consequences. The major finding was that changes in the sector to reduce sustainability impacts require an intrinsic consumer motivation. Both social and environmental impacts are reduced if consumers demand products that are produced under sustainable circumstances. Additionally, consumer behavior has a significant impact in the use phase. Buying second-hand clothing and more durable products, as well as changes in washing behavior (less often, low temperature, using eco-detergents, hang dry) can substantially decrease environmental impacts (Allwood et al. 2006). However, motivation for companies to use and develop more sophisticated materials that require less maintenance can only be increased if the impacts of these care related effects are attributed to the focal company. This is currently not the case.

To achieve this goal, consumer and producer education is necessary, as well as new business models (maintenance, e.g., repairing clothes), technological development (e.g., new means to freshen clothes), and more regulatory involvement by governments. Detailed results are provided by Alwood et al. (2006).

Study 2: A comprehensive study is provided by the French Bio Intelligence Service, which is a member of Deloitte Touche Tohmatsu Limited. The report is only available in French language. On behalf of the ADEME Bio Intelligence Service the institute conducted a life cycle analysis of a pair of jeans according to the ISO 14040 standard to analyze the results of consumer decisions. The higher-level objective was to determine a magnitude of the environmental impacts that are related to the production of jeans. The reason why jeans were picked as a representative of classic consumer goods is that it is a product that is used by a very broad mass. Additionally the accessibility of data for this product type was a major reason, since the study was conducted in a close cooperation with the French based company *Lafuma*, particularly with its jeans brand *Ober*. The company provided data on both, technical processes needed to produce jeans as well as figures from marketing and on consumer behavior. The study results have been verified by from the French Institute for Textiles and Clothing (Institut Français du Textile et de l'Habillement (ITFH)) and the National Union of Family Associations (Union Nationale des Associations Familiales (UNAF)). The conducted LCA aims to identify and quantify the use of natural resources, energy and environmental impacts (e.g., emissions into air, water, soil and waste). In a first step the observed system has to be analyzed in detail to build up the life cycle inventory for each input-output process involved in the system, to further quantify indicators for the environmental impact. Within this study a focus will be on the global distribution of such impacts to detect the movement of environmental pollution from one process step to another. The following part will specify the system boundaries and describe the underlying system characteristics.

The studied system is decomposed according to the following steps, validated by IFTH:

- Cotton production (Harvesting)
- Cotton spinning
- Cotton Weaving
- Finishing
- Manufacturing of denim pants
- Special Treatment of denim pants
- Use
- End of Life (Incineration or Reuse)

The stage of distribution has not been analyzed individually, since it was assumed that the impacts associated with it could be neglected. However, the detailed steps are summarized in Figure 5-9 and 5-10, whereas the structure is validated by the IFTH. It has to be noted that the production of denim is a very specific process in which the sequence of production steps differs significantly from a conventional process for producing a cotton product (e.g., t-shirt).

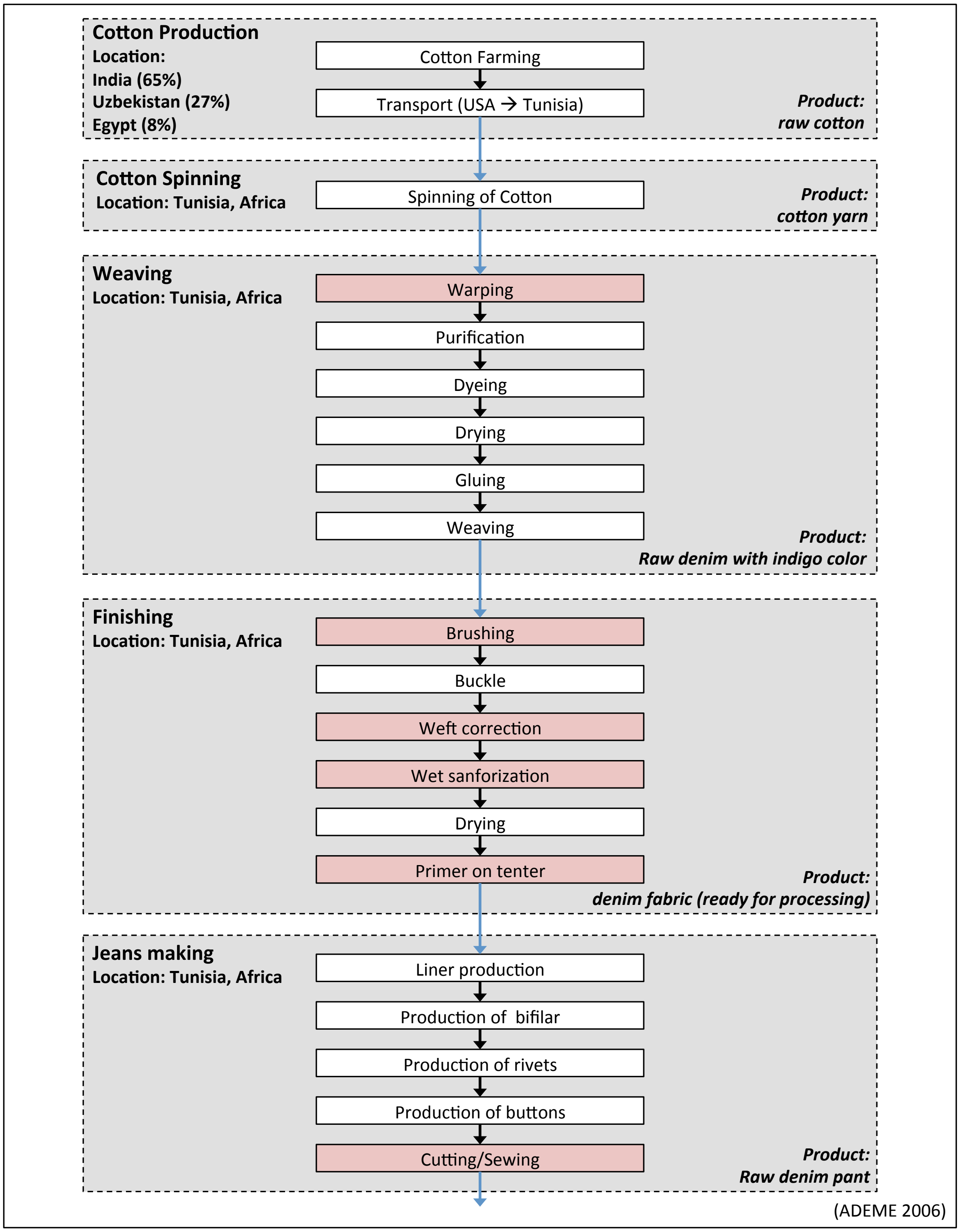

Figure 5-9: Life Cycle of a denim pant (part 1)

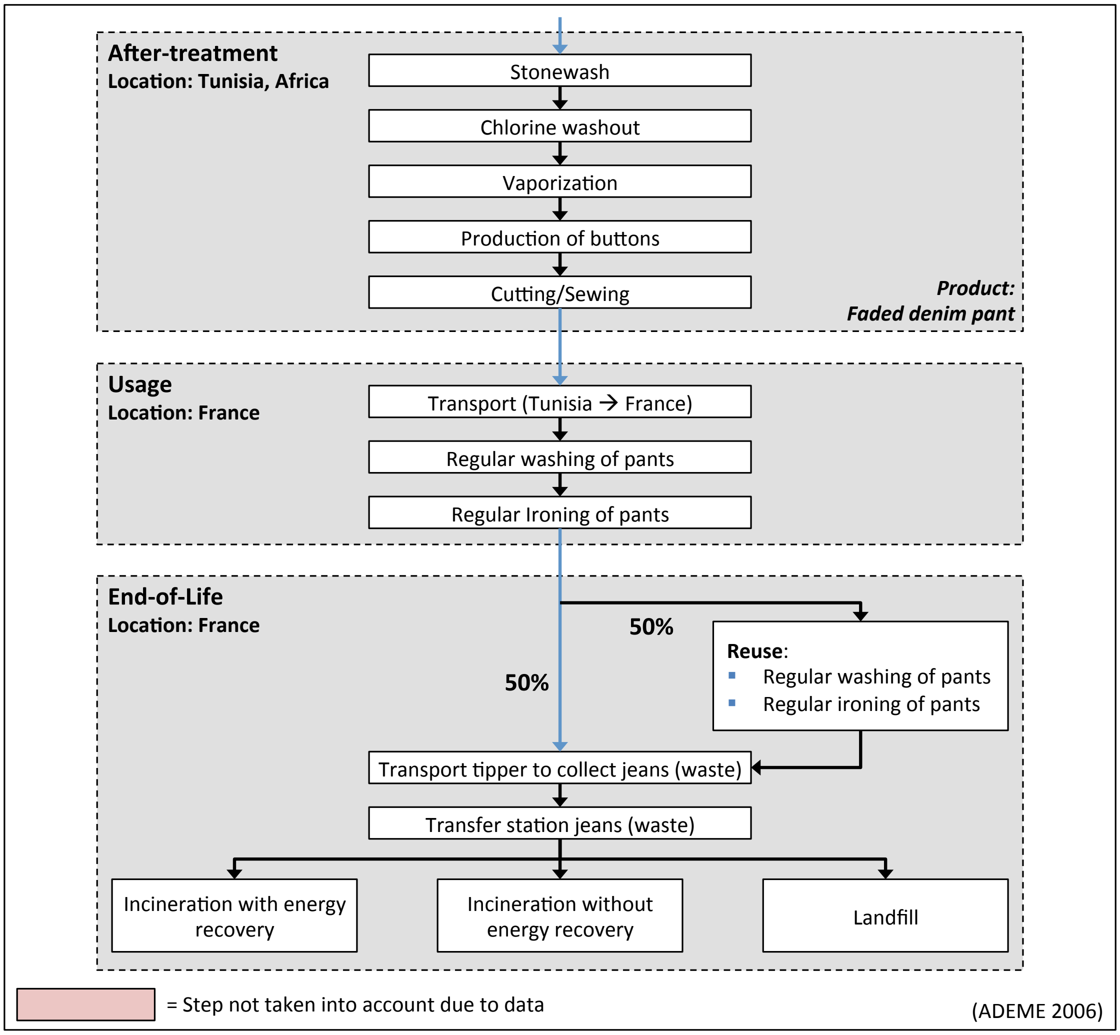

Figure 5-10: Life Cycle of a denim pant (part 2)

After the production process has been described comprehensively, the following part will help to describe the functional unit chosen for the assessment and to give a closer description of the examined product. Like introduced in previous sections of this study a functional unit has to be defined to facilitate comparisons between for example different product types (here denim pants) or different modes of use. It introduces a common reference for expressing the materials and energy life cycle assessment system. This functional unit (FU) of environmental performance chosen for this study is:

"Wearing a pair of jeans for one day."

The intention of this reference value is to illustrate and if possible reduce the potential impacts generated throughout the life cycle of a pair of jeans worn for one day.

The product selected for the LCA is a pair of jeans, which was denoted as "standard" pair of jeans by the marketing experts of the company Ober. It is produced from blue denim and was treated post-production to achieve a certain fading: stonewash and chlorine washout. The pants weight is 665.5 grams, broken down into the following: 600 grams of denim, 10.4 grams of bifilar, 37.5 grams of lining, 3.6 grams of rivets (6 rivets) and 14 grams of buttons (4 buttons). Like can be seen from Figure 5-9 and 5-10 the jeans is manufactured in Tunisia and sold in France. The scenario applied for the use phase is the following (according to the marketing experts of Ober):

- Life of denim pants: 4 years of primary use
  4 years of second use (only 50%), eq. 2 years
- Frequency of use: 1 day a week
- Frequency of cleaning: every 3 uses
- Washing instructions: washable at 40°c
- Ironing
- End of Life: 50% of household waste, 50% in industry for reuse

By means of this information the mass of the product can be broken down according to the functional unit. By means of the following equation the mass of the product can be converted according to the functional unit.

$$\frac{product\ weight}{frequency\ of\ use \times weaks\ per\ year \times years\ of\ use} \rightarrow \frac{665.5\ g}{1 \times 52 \times 6} = 2.1\ g$$

This value is representative for the mass of product that is considered for the stages of production and end-of-life. For the phase of usage the quantities of supplies (detergent, water, electricity, etc.) have been reduced to the functional unit by multiplying them with the total number of washes over the entire lifetime divided by the total number of days worn.

$$\frac{quantities\ of\ supplies \times total\ number\ of\ washes}{number\ of\ days\ worn}$$

Due to the comprehensive approach of the LCA different assumptions were considered to model the life cycle of a pair of jeans as close to reality as possible. For example different sources of energy have been integrated as well as the chemical composition of used chemicals (e.g., detergents or fertilizer) to determine their environmental impact. These assumptions should not be explained in detail within the scope of this study. For more information see ADEME (2006). However, of greater interest for the scope of this study, is the exact modeling of necessary logistic operations within the reviewed study. Particularly the global distribution of raw cotton suppliers serves as a good example to illustrate how diversified production networks are set up nowadays. Figure 5-11 compares the transport routes from different locations of cotton sourcing to the location of manufacturing in Tunisia. To determine the environmental impacts from these operations, data from the Ecoinvent (v1.2) database[26] was used.

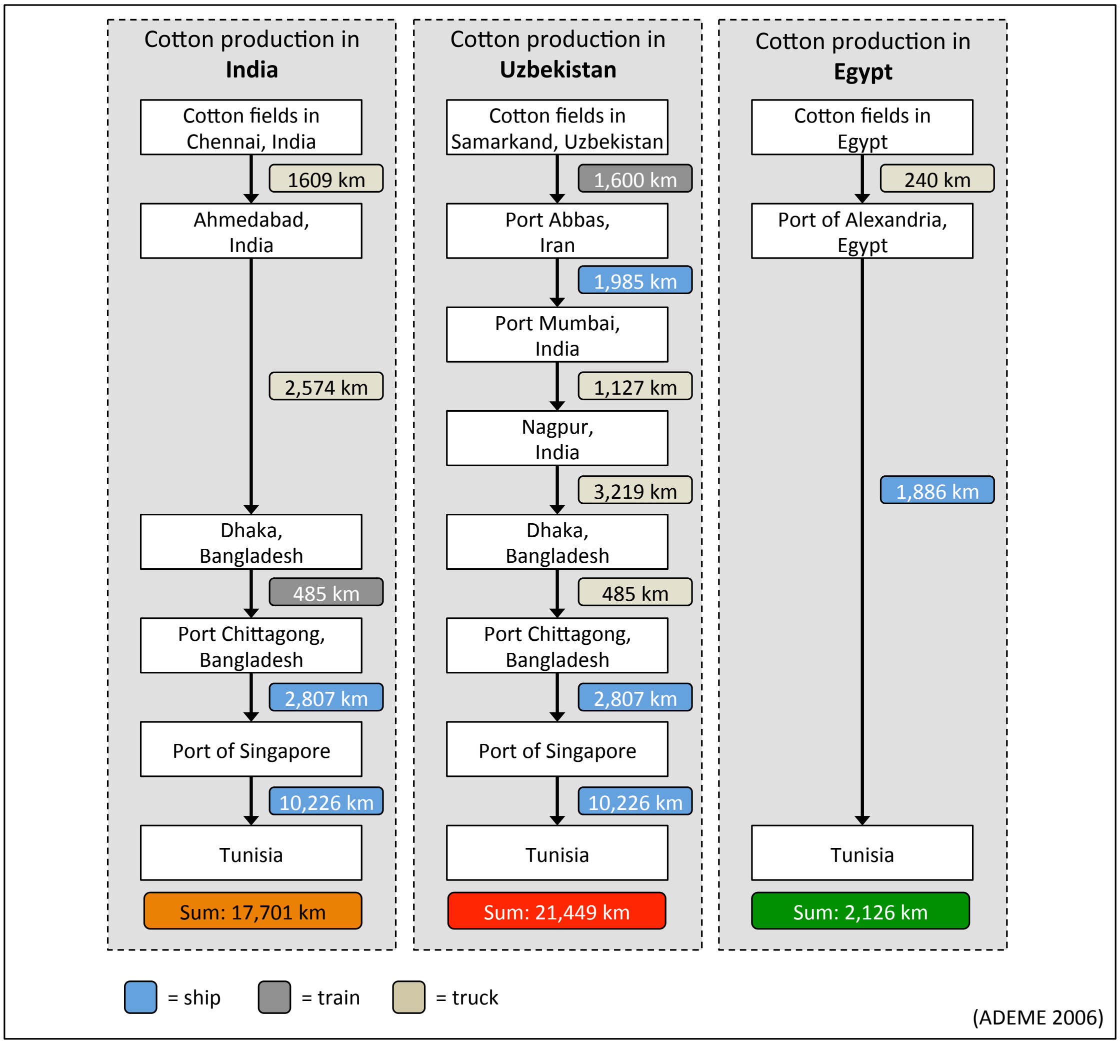

Figure 5-11: Transport of cotton from field to Tunisia

It should be noted that only 8% of the raw cotton are sourced from Egypt even if the distance to Tunisia is by far the smallest (2,126 km). The major part (65%) of the

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[26] The ecoinvent Centre hosts the world's leading database of consistent, transparent, and up-to-date Life Cycle Inventory (LCI) data.

cotton is sourced from India. This due to the fact that sourcing decisions are price driven and the difference between the effects of lower raw material prices outstrips costs for transportation. The same holds true for the environmental impact. Overall the impacts caused by transportation are small compared to other effects, which will be shown in the following. Figure 5-12 illustrates how environmental effects are globally distributed. Additionally impacts related to each production step/life cycle phase are presented. Figure 5-12 uses data shown in Table 5-3 and Table 5-4. Besides the listing of environmental indicators, units are described and values provided.

Table 5-3: Results of the LCA for each step of the life cycle (steps 1-4)

Indicator	Unit	Cotton Production	Cotton Spinning	Weaving	Finishing
Depletion of natural resources	kg Sb eq.	3,95E-05	3,63E-05	8,02E-05	3,06E-05
Water consumption	m3	1,52E-02	0,00E+00	1,89E-04	0,00E+00
Primary energy consumption	MJ primary	8,95E-02	8,08E-02	1,79E-01	6,67E-02
Global Warming Potential (GWP100)	kg CO2 eq.	6,62E-03	3,99E-03	9,83E-03	3,74E-03
Air acidification	kg SO2 eq.	4,16E-05	1,07E-05	2,38E-05	7,92E-06
Photochemical Ozone Creation Potential	kg C2H4 eq.	4,63E-05	6,84E-06	1,51E-05	5,15E-06
Ozone Depletion Potential	kg CFC-11 eq.	6,90E-10	5,51E-10	1,19E-09	4,62E-10
Eutrophication Potential	kg PO4 eq.	1,05E-05	1,02E-06	3,07E-06	8,67E-06
Human Toxicity	kg 1.4-DB eq.	2,68E-03	8,82E-04	1,97E-03	7,35E-04
Aquatic Ecotoxicity (freshwater)	kg 1.4-DB eq.	4,57E-02	6,81E-05	4,81E-04	2,23E-04
Sediment Ecotoxicity (freshwater)	kg 1.4-DB eq.	6,24E-03	2,02E-04	5,02E-04	6,02E-04
Terrestrial Ecotoxicity	kg 1.4-DB eq.	3,11E-05	9,22E-06	3,34E-05	6,40E-06
Solid Waste	kg	0,00E+00	2,14E-04	0,00E+00	0,00E+00

(ADEME 2006)

Table 5-4: Results of the LCA for each step of the life cycle (steps 5-8)

Indicator	Unit	Jeans Making	After-Treatment	Usage	End-of-Life
Depletion of natural resources	kg Sb eq.	6,97E-06	1,11E-05	1,25E-04	2,28E-08
Water consumption	m3	0,00E+00	1,61E-04	1,99E-03	0,00E+00
Primary energy consumption	MJ primary	1,65E-02	2,42E-02	1,04E+00	-8,82E-03
Global Warming Potential (GWP100)	kg CO2 eq.	6,97E-04	1,35E-03	1,76E-02	2,89E-04
Air acidification	kg SO2 eq.	7,81E-06	2,96E-06	1,00E-04	7,71E-07
Photochemical Ozone Creation Potential	kg C2H4 eq.	3,30E-06	1,96E-06	5,44E-05	3,88E-06
Ozone Depletion Potential	kg CFC-11 eq.	5,12E-11	1,88E-10	1,15E-09	-8,11E-11
Eutrophication Potential	kg PO4 eq.	8,37E-07	2,64E-07	1,83E-05	5,38E-07
Human Toxicity	kg 1.4-DB eq.	5,64E-03	2,52E-04	1,89E-02	1,38E-04
Aquatic Ecotoxicity (freshwater)	kg 1.4-DB eq.	3,86E-04	1,31E-05	3,83E-03	-6,16E-06
Sediment Ecotoxicity (freshwater)	kg 1.4-DB eq.	1,19E-03	4,60E-05	1,04E-02	1,31E-06
Terrestrial Ecotoxicity	kg 1.4-DB eq.	2,00E-05	2,28E-06	6,25E-04	2,16E-05
Solid Waste	kg	0,00E+00	0,00E+00	3,71E-03	2,13E-03

(ADEME 2006)

The graphical representation of the Global-LCIA shows that major environmental impacts within the life cycle of a pair of jeans occur in the production stage. The lowest environmental impacts are caused in the agricultural production of the cotton. However, the illustration of the global distribution of impacts shows that major impacts do not occur in the country, where the focal company is located. This is pretty normal for supply chains from the T&C industry, but brings up the question who should be held responsible for the impacts caused in the country of production (Tunisia). For the sake of completeness Figure 5-13 shows, which processes in the manufacturing stage cause the greatest environmental impacts.

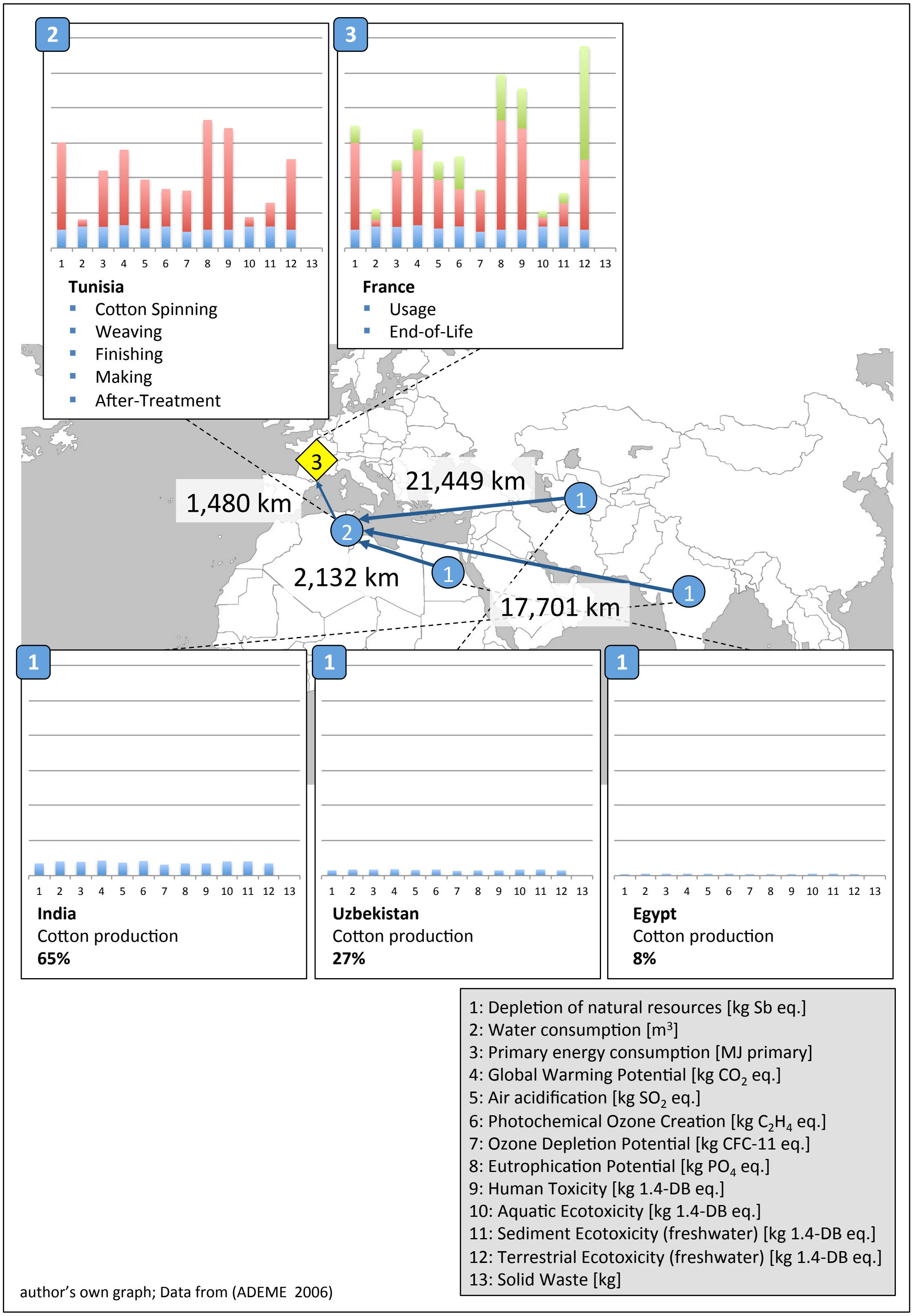


Figure 5-12: Graphical Representation Global LCIA for a pair of jeans

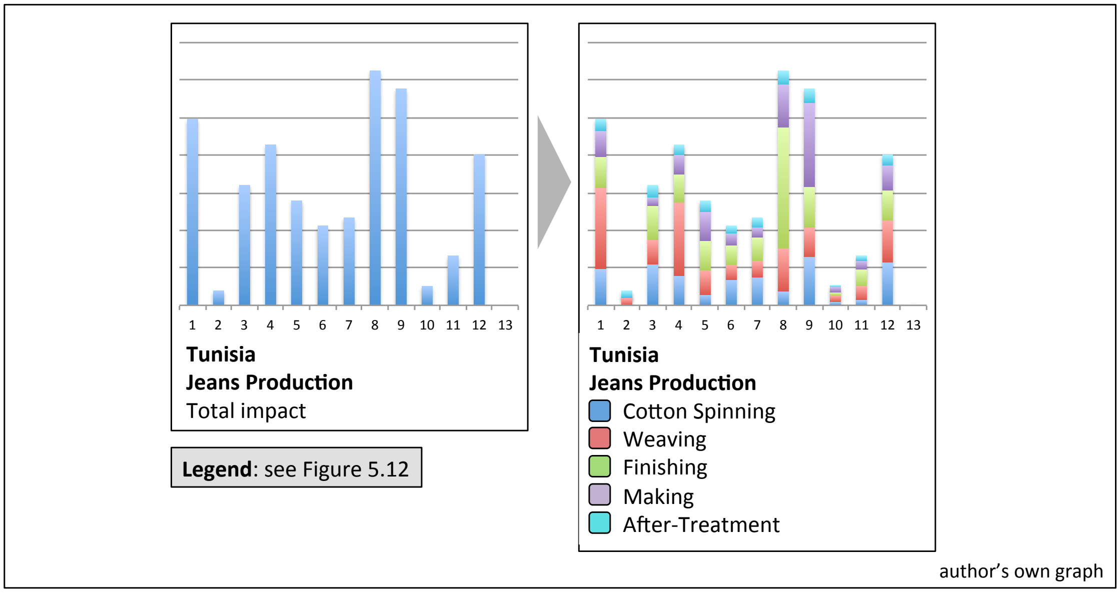


Figure 5-13: Distribution of impacts among production steps carried out in Tunisia

In summary the results proof that the graphical representation from Global-LCIA allows identifying the global distribution of impacts from the entire product life cycle. The individual results of each life cycle phase should not be discussed within the scope of this study. However, the interested reader may take a closer look at the provided tables to get a more specific view on the environmental impacts occurring n the life cycle of a "standard" pair of jeans. Besides the provided data on the 13 impact categories the original study provides detailed sensitivity analysis as well as a comprehensive appendix that includes information on used characterization factors for the indicator determination.

Study 3: Another comprehensive study on the life cycle inventory and life cycle assessment of cotton fiber and fabric was published recently by Cotton Incorporated (2012). Cotton Incorporated is a trade organization founded in 1970 by cotton growers in the United States. Driven by the economic objective to increase the demand for cotton, the organization conducts various research activities in the field of technical assistance and training, consumer trends, and sustainability. Due to its international orientation with offices in the US, Canada, Latin America, East Asia, Southeast Asia, China, and Europe, the organization has central access to a huge pool of data, which has consequential meaning for LCA (Cotton Incorporated 2014). The Life Cycle inventory consists of both primary and secondary data. Partnerships with researchers, the industry, and co-operators served as major sources of primary data and were supplemented with data from the literature and from industry averages; major sources for this were GaBi 4 and GaBi 5 databases. The functional unit chosen was 1,000 kg of investigated product (fiber, woven fabric, knit fabric). Calculations lead to the result that 1,000 kg of knit fabric yields 2,780 shirts and 1,000 kg of woven fabric yields 1,764 casual pants. The considered life cycle stages (system boundaries) comprise raw material extraction (average cotton fiber from cultivation in the US, China, and India), fabric manufacturing (knit and woven fabric), garment use, and disposal (cradle-to-grave) (Cotton Incorporated and PE International 2012). Stage 3 of a LCA (see Section 2.2.3.1) is the LCIA where individual emissions are assigned to impact categories. To provide a clearer picture, the examined categories are described in Table 5-5.

Table 5-5: Environmental impact categories

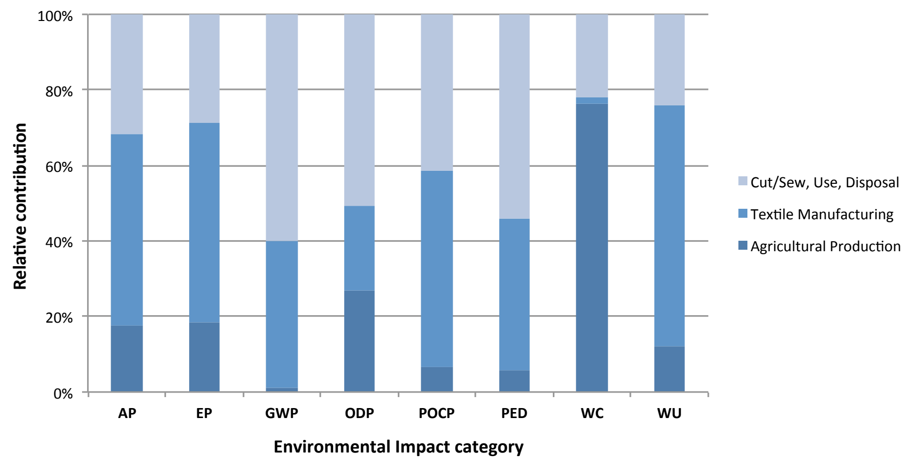
Abbrevation	Techincal Term	Unit	Example
AP	Acidification Potential	kg SO2-Equiv.	Acid rain
EP	Eutrophication Potential	kg phosphate-Equiv.	Water pollution
GWP	Global Warming Potential	kg CO2-Equiv.	Greenhouse gas emitted
ODP	Ozone Depletion Potential	kg R11-Equiv.	Ozone hole over polar ice caps
POCP	Photochemical Ozone Creation Potential	kg Ethene-Equiv.	Smog
PED	Primary Energy Demand	MJ	Electricity and fuel needed
WU	Water Used (Gross volume)	M3	Water used in washing machine
WC	Water Consumed (Net volume)	M3	Water evaporated in dryer
ETP	Ecotoxicity Potential	not included in assessment	Animal health
HTP	Human Toxicity Potential	not included in assessment	Human health

(Cotton Incorporated and PE International 2012)

The report provides detailed figures and data for the following sub-themes:

- Contribution of the life cycle phases to each impact category for batch-dyed knit fabric and woven fabric
- Contribution of specific agricultural process steps to each impact category
- Contribution of specific manufacturing process steps (batch- and yarn-dyed knit and woven fabrics) to each impact category
- Contribution to energy demand for each life cycle phase under consideration of three different use scenarios (best, average, worst)

Figure 5-14 shows the relative contribution of the three life cycle phases to each impact category. It is built based on the values provided in table 5-6. It can be seen that manufacturing and use contribute the greatest overall impact. However, the interpretation of these results requires attention since not all impact categories are equally detrimental (Cotton Incorporated and PE International 2012). Furthermore the data is not suitable to be represented by means of the graphical representation that is proposed within the Global LCIA concept since the data is not given country specific. In contrary the study aims to provide average values. For example the impacts from the agricultural production represent averages from production in the USA, India and China.



(Cotton Incorporated and PE International 2012)

Figure 5-14: Relative contribution of life cycle phases to environmental impacts

Table 5-6: Impact Total per Life Cycle Phase for a Knit Shirt (Average U.S. Consumer)

Abbrevation	Measure*	Agricultural Production	Textile Manufacturing	Consumer Use
AP	Acidification Potential	21.3	61.4	38.3
EP	Eutrophication Potential	4.4	12.6	6.8
GWP	Global Warming Potential	305	9070	14025
ODP	Ozone Depletion Potential	0.021465994	0.017922939	0.040477562
POCP	Photochemical Ozone Creation Potential	0.46	3.6	2.85
PED	Primary Energy Demand	17000	114000	155000
WU	Water Used (Gross volume)	2410	49.4	694
WC	Water Consumed (Net volume)	3120	16141	6150

*functional unit: 1000 kg fabric, (Cotton Incorporated and PE International 2012)

The report closes with conclusions and recommendations. A major finding is that further research is necessary. The application of sustainability assessment methodologies includes multiple possibilities for variability, which leads to inconsistent results and makes comparison between similar studies difficult. Numerous existing studies rely on different sources. The data of these sources might be not up-to-date. Furthermore, studies are often based on similar types of garment (material) and different impact categories might be chosen for the assessment. This confirms the hypothesis discussed in Sections 4.2 and 5.3, that data collection and missing guidelines on the standardization of metrics and methodologies pose the greatest challenges for sustainability assessment. Results should always be interpreted with caution and not before system boundaries and assumptions are clarified. For more information, see Cotton Incorporated and PE International (2012) and Cotton Incorporated (2014).

In summary and critical appraisal of the goal of Chapter 5 (test the practical suitability of the developed Global LCIA approach by means of a case study within the textile and clothing sector) could be achieved partly. Its basic functionalities were shown even if no site-specific data was available. However, the analysis of existing sustainability studies offers interesting insights in the industry sector and provides distinct and logical reasons why application of the approach is not possible under current circumstances. On the one hand, a lack of capacity to conduct deeper investigations (e.g., expert interviews) of the author impedes data collection. The primary challenge is caused in the structure of the textile and clothing supply chain. The high variance in the development levels of supply chain actors and the required levels of sustainability awareness make it almost impossible to gather site-specific data. If data gaps are closed in the future, which is an already ongoing process (e.g., due to collaborative initiatives and projects), then the developed concept provides a powerful tool to increase the overall life cycle sustainability of products by means of its decision-supporting characteristics.

5.5 Location Decisions in the T&C Sector

As mentioned several times in the course of this study, one hypothesis was that the effective assessment of *Global Product Sustainability* might affect future location decisions. This was already discussed in general and in Section 2.3, which came to the result that an effective measuring of GPS might replace the additional examination of sustainability factors within location decision-making. The present section should serve to answer this particular question for the clothing and textile sector; thus, current location decision-making within this sector was analyzed.

As already explained in Section 5.1, the textile and clothing sector has changed within the last few years, especially due to the removal of several restrictions (MFA and ATC). Moreover, developments in transport and communication infrastructure technology have provided increased access to emerging markets. These global developments have resulted in challenges as well as opportunities. For example, new strategic options emerge since companies are now able to locate their activities in countries that offer the best chance to achieve their targets (EMCC 2008). It is often observed that, within the last two decades, many textile and clothing companies have moved their manufacturing activities to low-wage countries in Eastern Europe or to Asian countries (e.g., China, India, Vietnam, Indonesia) (Allwood et al. 2006; EMCC 2008; BCI 2013). To understand and describe those changes, the European Monitoring Centre on Change developed a framework that links a geographical dimension with an organizational dimension. The resulting matrix is shown in Figure 5-15

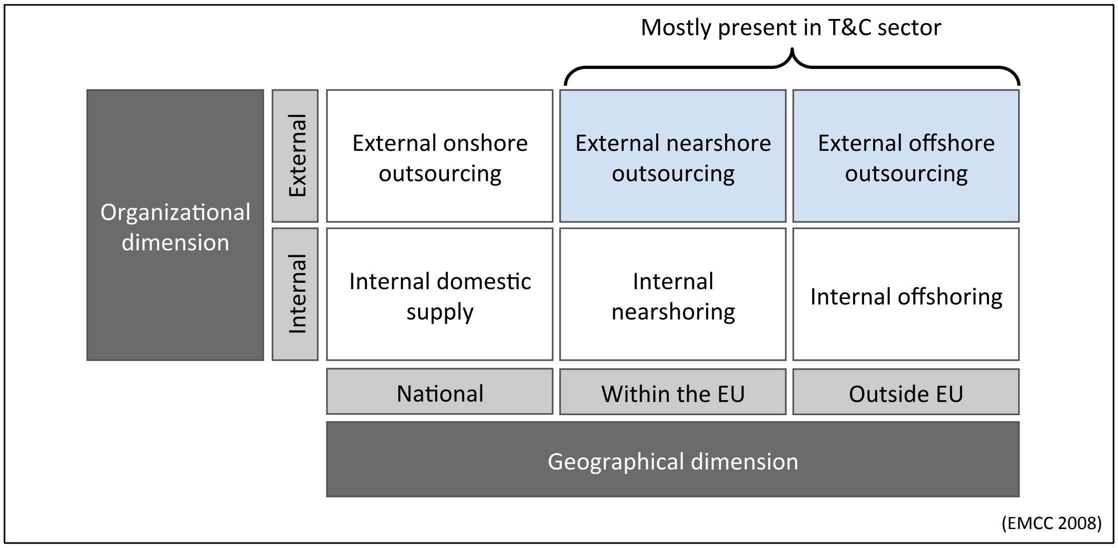


Figure 5-15: Geographical and organizational dimensions of location of activities

The geographical dimension is used to identify whether the outsourced good or service is supplied within the same country or from abroad. On the other hand, the organizational dimension takes into account whether the good or service is supplied from an affiliated company (or branch) or from external suppliers (a different company). In general, both nearshore and offshore outsourcing to independent companies outside the country involve multinational companies (EMCC 2008). Decisions could be far-reaching since SMEs that don't have activities abroad could be affected due to sub-contracting or partnerships (OECD 2007). Especially the European textile and clothing industry, which is still one of the largest high-quality and fashion industries, has experienced a high degree of outsourcing within the last decades. This involves both nearshore outsourcing within the European Union (EU) and offshore outsourcing to non-EU countries, especially in Asia (see blue highlighted boxes). Competition from low-wage countries forces textile and clothing companies in developed countries to respond, which they do by mainly focusing on two business strategies (Abecassis-Moedas 2007; Lane & Probert 2004; Eurostat 2006):

1. Relocate production and certain other activities to low-wage countries;
2. Advance development and value-added (smart functions) in the higher end of the value chain.

These strategies are not mutually exclusive, but rather complementary (Abecassis-Moedas 2007), as will be clarified toward the end of the chapter. Location decisions are complex and dependent on numerous competitive factors. These include labor costs, productivity, capital costs, necessary investment, infrastructure (transport), and insurance. Furthermore, access to markets and the availability of its inputs (workers, suppliers, etc.) are, besides political stability and security, exchange rates, taxation, quotas and tariffs, and other important external variables that have to be taken into account when deciding where to locate facilities (EMCC 2008; Abernathy et al. 1999). It is important to acknowledge that sustainability-related factors are only mentioned in very few papers that examine location decisions in the T&C sector. As explained in Section 5.2, the supply chain of the textiles and clothing sector is increasingly organized as an integrated production network, with different specialized activities located where they can contribute the greatest end-product value. Therefore, the aforementioned decision variables have to be considered. To get a basic understanding of a company's location decisions and strategies, a value chain perspective is expedient. The value chain illustrates the stages of production as an ordered sequence of activities. These activities create value, consume resources, and are linked through their processes (Kaplinsky & Morris 2000). This concept was first introduced by Michael Porter in his book *Competitive Advantage* (1985). which is a subject of numerous publications in the fields of economics and management (Mills et al. 2004). The underlying idea of using the value chain concept is that a company's location decisions are essentially affected by the level of value added and the tacit knowledge of the activity. In simple terms: the lower the ratio of value added and tacit knowledge, the more likely an activity will be outsourced (Millard 2002). To assess this phenomenon, it is helpful to differentiate between three types of innovation and competition: cost-driven, research and development- (R&D) driven, and user-driven (EMCC 2008).

1. The function of **cost-driven innovation and competition** is profitability improvement, which is achieved through increasing sales and market share of existing goods and services while reducing production costs per unit, delivery costs, labor costs, and other necessary inputs in parallel. Drivers for such innovation are, for example, price differentiation, which grasps the maximum consumers are willing to pay in every segment, or the maximization of the supply chain efficiency, especially in the areas of logistics and delivery. Increasing the degree of automation due to the application of information and communication technology (ICT) could also have great relevance on profitability maximization. Usually, this kind of innovation depends on highly explicit, or codified, knowledge, which is not bound to a certain location. This

added value is mostly embedded in technology and the (existing) system itself, and could be geographically dispersed.

2. **Research and development-driven innovation and competition** is based on added value achieved through the identification and (commercial) utilization of R&D activities within a business. This process could involve different companies or institutions and result in product, process, or organizational innovation[27]. Such kinds of innovation are associated with activities that require highly tacit knowledge and result in a unique selling proposition (USP). Usually required are face-to-face interaction and a high level of experience. This type of added value is mainly embedded in people and organizations; therefore, it is not suited to be outsourced. R&D activities cannot easily be geographically moved around and, thus, are tied to a particular location.

3. **User-driven innovation and competition** refers to innovation by intermediate users (e.g., user firms) or consumer users (individual end-users or user communities), rather than by suppliers (producers or manufacturers) (Bogers et al. 2010). The goal is to differentiate a product or service due to intelligently bundled products, personalized options, marketing activities, and good customer relationship management (CSR). A main driver for this type of

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[27] Product innovation: developing new products that could either be new for the market or the company; Process innovation: implementation of a new or significantly improved production or delivery method (including significant changes in techniques, equipment, and/or software). Organizational innovation: implementation of a new organizational method in business practices, workplace organization, or external relations.

innovation is customer or employee input that can be translated into strategic knowledge and then used for future market and product development. Customer intelligence and knowledge are important variables to generate this type of added value. The most efficient way to absorb strategic knowledge is to operate close to the different consumer markets.

Since the textile and clothing industry is both a labor intensive and low-wage industry, as well as a fast changing and innovative industry with different market segments, all three approaches to generating value-added products are prevalent. Therefore, according to a company's strategic market position or product segment, location decisions could also differ. In summary, only activities at the lower end of the supply chain (e.g., manufacturing) that are not bound to a particular location are suited for outsourcing. Thus, it could be observed that, for example, in the European textile and clothing industry, many companies sub-contract labor-intensive work and relocate production facilities to low-wage regions, especially to eastern Europe and the Pan-Euro-Mediterranean zone (Eurostat 2006).

Common Drivers and Determinants of Location Decisions in the T&C sector. Mainly textiles or clothing products that are more standardized or non-replenishment goods (garments that will not be restocked when sold out) are qualified for outsourcing activities. In literature certain drivers and determinants that affect outsourcing decisions have been identified. A widespread opinion is that wage levels are still the main reason for outsourcing activities (EMCC 2008). However, "the climate in which low income countries can drive development from a manufacturing base created by the T&C sector is now framed by the presence of extremely large supplying countries in the global market" (Keane & Willem 2008, p.12). The fact that start-up costs and important economies of scale are comparatively low favors production in developing countries; however, changes in the global market for textiles and clothing may impact the development of the sector differently than during previous episodes of industrialization (Brenton & Hoppe 2007). Although advanced T&C producers like China and India can still derive scale economies, it can be observed that domestic pressure influences the cost competiveness of certain countries and regions. For example, southern China is faced by the challenge of wage and land rental increases. These will not only increase competition due to other T&C exporters taking their opportunities to gain a foothold in newly developed niche markets, it will also force firms to reconsider their investment strategies and explore other possible (low-wage) production locations, such as South East Asia (Keane & Willem 2008). Even successful companies have difficulties sustaining their competitiveness due to changing market conditions and increasing wages in their countries (UNIDO 2004). Suppliers and countries are forced to find other ways to differentiate themselves from the large number of competitors. Conversely, T&C companies at the upper end of the supply chain will consider additional factors when making outsourcing decisions. Examples include the physical distance to market, reliability, flexibility, volume of series, range of garment size, and the availability of suppliers and customers (Abecassis-Moedas 2007). Many of these factors are derived from the same root cause, which is the increasingly important factor of time. Especially in the segment of specialized fashion-oriented products, time is a major decision factor. As in other manufacturing industries, concepts and terms like just-in-time, quick market response, and short lead-time are becoming more important, particularly for European clothing companies that still dominate the fashion segment (Evans & Smith 2004; Abecassis-Moedas 2007). In this market, the ability to change production (assembly) processes quickly is a basic requirement to adapt rapidly to different designs and changing fashion trends. Product life cycles are getting shorter in the T&C, as well as most industries. The fact that clothing has become a commodity good causes disadvantages to producers located at a distance from consumer markets, where trends are set that demand a short time-to-market (Eurostat 2006). Summarizing these results at a higher level, under the present circumstances, leads to two conclusions. First, if servicing the fashion market, which requires a high degree of flexibility and responsiveness, central and eastern European countries are still leading suppliers. The advantages gained by shorter distances to main fashion markets in Europe and the US mean that Asian competitors cannot, at present, meet the required timeframes (clothes are usually shipped by sea) (Heymann 2005). Within the European market, companies favor central and eastern European countries compared with western European countries, due to their lower wage levels (EMCC 2008). Second, if not focusing the fashion segment, then the aforementioned advantages become less significant, since flexibility and time are relative to the retail price and not considered that important. However, a closer look at the statistics and future trends shows that this competitive advantage is shrinking as the gap in wage levels between Europe and Asia is enormous. Furthermore, production locations in eastern Europe have low productivity compared with the former EU15 countries (only about 20%–40%) and compared with the productivity levels of, for example, China (Heymann 2005).

Another important factor currently influencing outsourcing activities besides production costs and time is the availability of human capital. This factor is strongly linked to R&D and user-driven innovation. To develop and produce textiles and clothing with high fashion content, niche products, and product innovations, value-added activities are necessary. As a fundament for those activities serve established markets and adequate skilled people. One objective of competitive advantage might be, for example, to capture the tastes and preferences of consumers or, even better, to influence them. Especially functions like marketing and design in the high-end fashion industry require human capital. Human skills in the research and development are needed, for example, in the sportswear industry, where both design and material technology are important. Human capital is even more important for novel areas of application of textiles, like for example in the automotive industry (e.g., materials for air bags) (Heymann 2005; EMCC 2008). These kinds of processes are mainly located in developed countries. Companies have always evaluated the trade-offs between the expected advantages and possible risks and additional costs resulting from strategic decisions.

All the aforementioned explanations can be summarized in four factors that mainly influence strategic location decisions and the outsourcing of textile and clothing processes.

- **Cost levels**, particularly wage levels (due to the labor intensity of the industry) still play an important – if not the most important – role.
- The **availability and the access to input factors**, like human capital and suppliers, is an important factor. It determines outsource decisions as well as the strategic focus on value-added activities.
- **Time and flexibility** (particularly in the fashion segment of the industry) are factors that are becoming more important. Fashion cycles are getting shorter and designs and consumer tastes are changing faster, which requires shorter production and delivery times. This factor focuses on technical prerequisites.
- The **distance to (main) market(s)** should be considered for two main reasons: To achieve shorter turnaround times (linked with Time and Flexibility) and to be able to identify current trends and policy proceeding in the main market segments (consumer markets).

A study conducted by Bain & Company in 2005 summarizes the key to success regarding location decisions in answering three critical questions: what, where and how to migrate (Vestring et al. 2005). A basic need is furthermore to balance lowering cost with accelerating time to market and mitigating risk. A major finding was that the need to move to low-cost countries varies dramatically depending on the industry and product segment observed. The best indicators demonstrating the need to move to low-cost countries are labor and transportation cost. “Where labor accounts for a high percentage of total costs, and transportation costs are relatively low, most firms will need to migrate to low- cost countries to remain competitive.” (Vestring et al. 2005, p.2) If outsourcing is an option it is important to understand that it is not necessary to move factories to low cost countries but functions. That provide massive chances since shut-down and start-up costs could be saved. Including the constraint “availability of skilled labor” into the goal function offers additional chances. “Low wage no longer translates as low skill.” (Vestring et al. 2005, p.4) For example China and India offer an attractive combination of low costs, developed capabilities, investor-friendly governments and a large domestic market. Figure 5-16 provides an overview that tries to capture the relationship between wage rates and value added of different countries adequate for outsourcing.

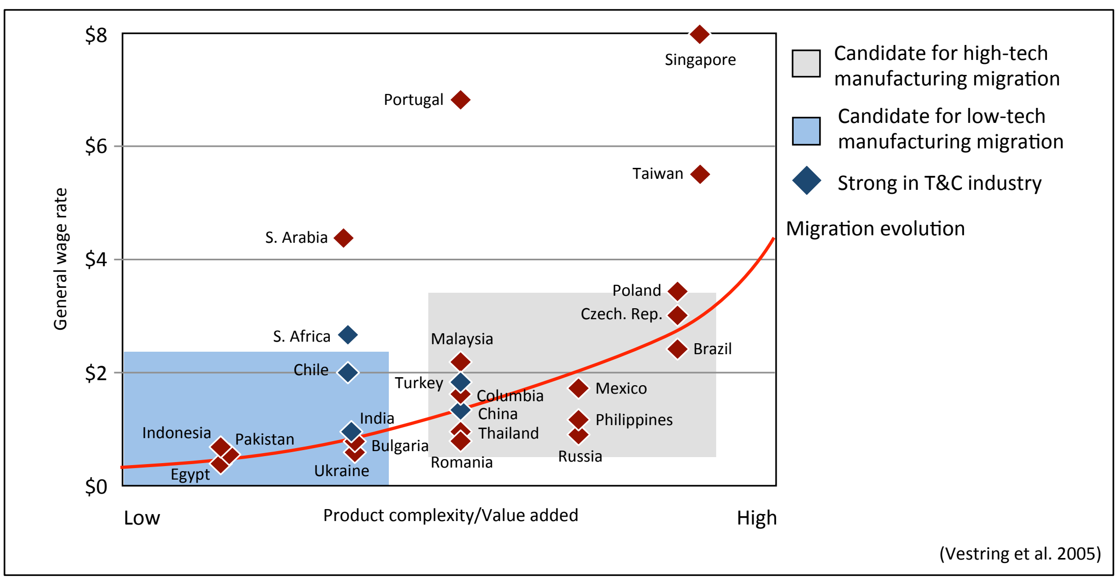

Figure 5-16: Assessment of opportunities to migrate manufacturing costs

In summary, it can be seen that location decisions in the T&C sector are mainly driven by factors other than sustainability. Particularly cost issues are still mainly responsible for offshoring decisions. In accordance with Section 2.3, which showed that in general location decision-making sustainability issues (should) play an important role, their importance should be increased within the T&C sector too. Only if companies put more attention on sustainability, for example due to the consideration of sustainability in location decisions, progress in improving the overall supply chain sustainability could me made. A concept like Global-LCIA could play a relevant role in this process.

Summary of main findings from chapter 5: *To evaluate the applicability of the developed concept in practice, a case study in the T&C sector was conducted. The basis of any assessment is data; therefore, the author reviewed literature, databases, and websites for relevant data. Both data on on-site sustainability impacts from all three dimensions, as well as general figures, e.g., on product-specific sales volumes and market prices are indispensable. At an early stage, it became apparent that this goal could not be achieved under the present circumstances. Various authors who conducted, for example, LCAs in the T&C sector, supported this finding. This industry is characterized by a high proportion of manual labor that is mostly carried out in low-wage countries. On the one hand, the use of appropriate information and communication technology is poorly developed, on the other hand, suppliers are resistant to sharing data in a transparent manner. Fear of losing negotiating power and concerns that providing data might allow inferences to be drawn regarding* *(illegal) sub-contracting are present. This illustrates the need for an approach like Global-LCIA. LCAs and general sector analyses from recent years show that the sector is still dominated by poor working conditions, e.g., a high proportion of female and child laborers and wages that are lower than the required living wage. Particularly, the use phase of textiles (e.g., washing and drying) and manufacturing steps at the lower end of the supply chain are harmful for the environment and humans. There is no question that more research needs to be conducted to assess sustainability appropriately. The examination of how location decisions are currently made in the T&C sector showed that sustainability issues are not addressed properly in location decision-making. However, an effective assessment approach, such as Global-LCIA, can support management and affect future (location) decisions. This would influence companies along the entire supply chain to act in a more sustainable manner.*

6 SUMMARY AND CONCLUSIONS

If it is agreed that the overriding objective of sustainability is to reduce the impacts of products and their manufacturing processes globally (excluding partial or ostensible successes), then the assessment of global product sustainability has to be established. By means of this thesis, a solid cornerstone has been laid to achieve this ambitious objective.

There is no doubt that, even after reading this thesis, sustainability is still a vague concept. Sustainability cannot be grasped or measured accurately—it is a concept. The first part of this study, however, accomplishes the task of equipping the reader with the knowledge required to address systematically problems in the field of sustainability, particularly in the context of products with a global product life cycle.

The study starts with a brief historical background of the term. Already in the first half of the twentieth century, sustainability was recognized as a concept that promoted environmental rethinking by industries. Nowadays, the scope of (product) sustainability is broader. Sustainability has to be established at all levels, including the three dimensions of society, economy, and environment, as well as consideration of the entire product life cycle, including external effects. The consideration of critical opinions in the literature-based examinations of this study calls for personal reflection and does not pretend accuracy of the final stated definition.

Besides the aspects of sustainability, the study provides a considerable literature review of sustainability assessment methodologies and examines the state-of-the art in this research field. The literature review comprised a multitude of related and not directly related research fields. Correlating with the increased perception of sustainability by consumers, companies, governments, and society in general, the number of published research articles in the field of assessing sustainability has increased exponentially in recent years. For this reason, the author cannot claim the literature review to be exhaustive. The conducted illustration of interrelationships and dependencies among commonly used terms in this field resolves uncertainties and forms a foundation for subsequent examinations. Setting limitations to product-related approaches that aim to consider the entire product life cycle, further restricted the search field. Monitoring and assessment are usually based on indicators. In the field of sustainability, a vast number of indicator frameworks exist. The indicator framework proposed by the NIST turned out to be valid and "complete." It thus provides a suitable basis for future standardization attempts. There are more than enough metrics to capture influencing factors related to major and minor impacts on sustainability. Future research, therefore, should concentrate on areas with more deficits than trying to improve indicator frameworks, which most often only adds additional complexity.

Another focus of the literature review was on tools that "measure" sustainability using specific indicators and methods. The most commonly used assessment methodology is the Environmental Life Cycle Assessment (LCA), which has matured over several decades of use. This instrument provides a comprehensive assessment of environmental product impacts across all life cycle stages. LCA is the most developed approach and is standardized within the ISO guidelines. Nonetheless, challenges arise from the handling of uncertainties (lack of knowledge of the system), and methodological choices that have to be made (e.g., system boundaries, functional unit, weighting, and normalization methods). Current research activities focus on data gathering (databases), quality assurance, consistency, and harmonization with other assessment methods to provide integrated results. The economic dimension is most commonly assessed using Life Cycle Costing (LCC), which is one of the oldest assessment methods. The idea is to summarize all costs incurred during a product's life cycle and allocate them appropriately. The literature review confirmed that Social-LCA is the least developed assessment tool. Capturing social impacts in the product chain of businesses is necessary to promote economic and social welfare. A major difference to E-LCA and LCC, is that S-LCA not only focuses on damages, but also is capable of considering beneficial sides of economic development. Opposing opinions exist regarding the system boundaries; most often, social impacts are translated to social issues on workers. However, in the opinion of the author all stakeholders, including consumers and other value chain actors, have to be considered, since products have impacts far exceeding their production process phase (e.g., health detriment in the use phase). In general, S-LCA presents the biggest challenges, mostly due to different social/cultural contexts, time scales, and insufficient experience with necessary indicators. Nevertheless, only if sustainability is assessed in all three dimensions can meaningful information be derived. There is no question that economic development causes negative impacts, e.g., environmental degradation. However, consideration of this result alone may lead to incorrect conclusions. Environmental impacts might be small relative to gained social benefits (e.g., improvement of living conditions and health). To assess impacts in an integrated manner, researchers currently discuss new frameworks that integrate all three named methods into one model: Life Cycle Sustainability Assessment (LCSA). This assessment method has been shown to increase organizational interest in developing guidelines that focus on integrated assessment. A major challenge is to provide compatibility and reliability. In particular, inconsistencies due to an ill-defined functional unit (constituting a reference value), deviating system boundaries, or the use of generic data and its time-sensitivity cause problems.

The first section of the thesis concludes with an overview of integrated assessment approaches in current use. Innovative examples are provided by the chemical company, BASF, and the automobile manufacturer, Ford Motor Company. Both approaches represent a lean approach to assessing sustainability, with a focus on the graphical visualization of results.

In conclusion, the first part of this work is not necessarily related to the second part; indeed, it represents a comprehensive summary of the topic of sustainability and state-of-the-art sustainability assessment that enables anyone to gain fundamental knowledge in this field of research, including links to further literature.

Based on that summary, a concept for assessing *Global Product Sustainability* was developed in this research, called the Global Product Sustainability Impact Allocation

(Global-LCIA). A first step in the development was the definition of (compulsory) requirements based on the previous literature review that highlighted shortcomings of existing approaches; in particular, gathering reliable data at reasonable expense and the representation of the actual global distribution of impacts emerged as major problems, and thus development priorities. Using synectics, the author developed a concept, whereby the fundamental principle is deduced from the overhead allocation, borrowed from the field of financial accounting. In simple terms, this concept translocates the strategic steering mechanism; like in modern supply chains, the concept is figuratively switched to a push instead of a pull system. Sustainability assessments are no longer conducted by one focal company or third-party organization, but are built on the cooperative passing on of supply chain actor-specific impacts that finally culminate in an overall product impact. Therefore, companies consider themselves as stand-alone black boxes whose activities lead to certain sustainability impacts. Instead of allocating these impacts to products by means of super-detailed process analyses and specific effects, a partitioning factor is used based on sales volume and market price. This idea contains major advantages. The aggregated view on impacts allows even companies with no specific knowledge regarding the sustainability effects of certain processes to determine those impacts. In particular, SMEs in developing countries can benefit from this idea. Information and data are only required at a high (strategic) level and impacts are allocated afterwards with the aid of available data. At first glance, this might seem inaccurate; however, the author highlight that no current assessment approaches guarantee accuracy and completeness due to subjective assumptions and data gaps. The advantages of reduced complexity far exceed the disadvantages due to losses in accuracy. Partial impacts are then passed up the supply chain, where each consecutive actor performs similar calculations, which ultimately culminate in a product-specific overall impact. The graphical representation of the global distribution of impacts and user-specific aggregation levels makes the approach suitable to support decision-making in a way that leads to improved global product sustainability. The representation of impacts and where they actually occur allows for future discussion on how impacts should be allocated fairly relative to their positive and negative effects.

Finally, the developed concept was applied to the textiles and clothing (T&C) sector, which represents a major industrial branch of consumer goods. Its contribution to the US economy is twice that of the automotive industry and more than four times larger than the fast food industry. Additionally, the supply chains are relatively short and clear. Numerous sustainability studies have been conducted for textile products, which is why the sector was chosen as an object of examination. It quickly became apparent that current structures do not allow applying the concept under the present circumstances: there are no publicly accessible data available. Large data gaps exist in on-site data as well as product portfolio, turnover, and sales volume data of the SMEs in this sector. Particularly within the T&C industry, which is characterized by a high proportion of manual laborers and mostly carried out in low-wage countries, there is resistance to sharing information transparently: suppliers are afraid of losing negotiating power or are concerned that providing data might allow others to draw inferences regarding (illegal) sub-contracting. However, even if the current situation hinders practical capability analysis, it demonstrates the necessity of an approach like the one developed in this study. The commercial defensiveness shows that sensitive issues (e.g., social standards and working conditions) are touched.

Nevertheless, to provide an overview of current sustainability development in the T&C sector, selected studies were presented in the last part of this work. A key finding was that the major share of environmental impacts is caused in the use phase of textiles, due to the use of chemical detergents, high washing temperatures, and machine drying. Besides that, insufficient water treatment and the use of toxic chemicals lead to environmental depletion in the manufacturing phase. Social problems are mainly unregulated working hours, missing safety standards, and child and female labor practices.

Finally, it can be concluded that all the research objectives of this study were achieved. The first part of the study provided an extensive insight into the field of sustainability and sustainability assessment. Furthermore, the definition of the novel term *global product sustainability* condensed evolving issues in one definition. The second part provided a concept that can meet emerging challenges, and therefore a framework with which to assess global product sustainability. Even if the application trial in the T&C sector showed that a practical implementation is not yet possible, it demonstrated the necessity of such an assessment approach.

However, the developed concept requires more research to verify its suitability for practical application. Various critiques and ideas for improvement and extensions have been mentioned throughout this study; the most important ones are summarized here. As is inherent in the term *concept*, the developed approach is not methodologically sophisticated and ready to be implemented. Case studies and cooperative projects are necessary to evaluate whether the suggested allocation method is suitable. Depending on the sector being examined, different requirements regarding the choice of functional units, the level of data detail and timeliness, as well as its verifiability, have to be posed. Major challenges arise from data gathering. On the one hand, companies at the lower end of the supply chain have to be equipped with the necessary tools and knowledge to assess sustainability. Effective changes can only be achieved if focal companies and consumers support SMEs and demand product sustainability. On the other hand, appropriate software has to be developed and implemented that harmonizes and communicates the data so as to promote interaction among all stakeholders along the entire supply chain. A web-based or open source approach would present a possible IT solution. Existing sustainability software is often expensive and requires a high degree of expertise; thus, the many small companies that contribute most to sustainability impacts are the least likely to possess these tools. Transparency and data sharing are inevitable; however, these challenges affect the whole field of sustainability assessment. Sustainability is a wide-ranging and complex concept that affects different parties in various manifestations. Further research is necessary to identify and capture key impacts. However, generating assessments that pretend pseudo-accuracy is nothing more than a waste of resources.

A fundamental axiom, which may sound philosophical but should always be borne in mind when assessing sustainability, is that…

…it is better to have a current but blurred picture—taken with a simple and cheap camera—than have the theoretical possibility to get a sharp picture, for which a camera is required that needs numerous adjustments before being operational and can only be handled by a professional photographer.

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