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# ASSESSING GLOBAL PRODUCT SUSTAINABILITY OF CONSUMER ELECTRONIC PRODUCTS – DEVELOPMENT OF AN INTEGRATED APPROACH

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# ASSESSING GLOBAL PRODUCT SUSTAINABILITY
# OF CONSUMER ELECTRONIC PRODUCTS –
# DEVELOPMENT OF AN INTEGRATED APPROACH

BY

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# ABSTRACT

This Thesis will develop – on the basis of an extensively conducted literature review – a concept with which it shall be possible to better measure, assess and examine sustainability in general and sustainability impacts of (electronic) products.

Against this background, the main goals of this thesis are threefold. The first key objective is to conduct a thorough literature review that will help create a solid foundation to this and all subsequent work dealing with assessing a product's impacts in its various life cycle stages. Light shall be shed to and clarity be achieved in a field of study that teems with papers and information, which have caused it to be rather impenetrable and difficult to access. Based upon this, it is this study's second key objective and primary goal to develop and provide a concept that is capable of addressing one aspect and challenge of assessing sustainability (of products) that has not yet received much attention: The fair allocation of sustainability impacts among the various actors of a supply chain. The literature review will be of help in determining and proposing a method of how to assess sustainability in an integrated fashion, which will then serve as an input for the subsequent allocation. Last but not least and thirdly, it is the goal of this thesis to ideally put this developed concept to use in the consumer electronics sector and assess one majorly significant device of this particular industry for its sustainability impacts.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| CBS | Cost Breakdown Structure |
| CE | Consumer Electronics |
| CEI | Core Environmental Indicators |
| CM | Contract Manufacturers |
| EEE | Electrical and Electronic products |
| e-LCA | environmental Life Cycle Assessment |
| FPSI | Ford Product Sustainability Index |
| GPS | Global Product Sustainability |
| GRI | Global Reporting Initiative |
| GWP | Global Warming Potential |
| LCC | Life Cycle Costing |
| LCI | Life Cycle Inventory |
| OECD | Organization for Economic Cooperation and Development |
| OEM | Original Equipment Manufacturers |
| OBM | Own-Brand Manufacturers |
| PROSA | Product Sustainability Assessment |

| | |
|---|---|
| SME | Small and Medium-sized Companies |
| s-LCA | social Life Cycle Assessment |
| VDR | Value-added Distributors and Retailers |

# LIST OF SYMBOLS

| | |
|---|---|
| $CO_2e$ | carbon dioxide equivalent |
| $x_i$ | (market-)price of the i-th coproduct/coservice |
| $P_i$ | partitioning factor of the i-th coproduct/coservice |
| $n_i$ | quantitiy of the i-th product/service |

# 1 INTRODUCTION

This thesis will develop – on the basis of an extensively conducted literature review – a concept with which it shall be possible to better measure, assess and examine sustainability in general and sustainability impacts of (electronic) products, the drivers of the economy. The first section of this chapter will therefore raise the interested reader’s awareness for the term sustainability and why it has slowly but surely become significant to finally address this global phenomenon and issue. The background of sustainability in manufacturing and the motivation will also be presented. Section 1.2 will then illustrate the objectives that are pursued by this study and how it aims to achieve them. The overall procedure of this thesis will thus be presented at last.

## 1.1 Background and Motivation

The term ‘sustainability’ has reached a state that can be described as almost ubiquitous. In nearly every conceivable part of life, be it watching advertisements on television, looking at a product’s packaging or simply going out for a walk in the woods and running into others, it is very likely to be confronted by some aspect connected to sustainability. It has been the paradigm ever since the start of industrialization that the Earth provides unlimited resources and ever-lasting eco-stability. After 200 and more years of overexerting this planet’s capabilities, however a change has started to unfold. With global warming on the relentless rise, the amount of scholars denying it gradually decreasing in quantity, with ecological catastrophes becoming more and more frequent, the spreading recognition that fossil fuels are on the wane and causing for high pollution etc., mankind has finally begun taking an interest in how the products they buy are made. This interest is rooted in the so-called three main dimensions of sustainability: social, environmental and ecological. Newspaper articles informing the public of horrendous overexploitation of workers and environmental sins committed on a daily basis by manufacturing companies have created an awareness and interest among consumers regarding how companies operate that needs to be spread to all stakeholders. Obviously, manufacturing is and can be a major contributor to both positive and negative sustainability as this sector not only provides countless goods for an ever increasing global population that is about to experience fundamental changes with a number of emerging countries increasingly closing the gap to Western countries, but it also employs a huge amount of people.

The three single key terms of this study – global, product and sustainability – that have been addressed above are therefore, seen individually, relatively straight forward. This becomes an entirely different matter when these items are combined to form compound terminologies. The field of "Global Product Sustainability", in particular, is a research area that has remained largely untouched. This thesis therefore aims to redress this deficiency. Many companies today have already integrated measures and methodologies that seemingly allow them to use their sustainability performance in both their decision-making, manufacturing and marketing. Especially in today's prevalent global supply chains and their almost impenetrable complexity, however, everyone involved – producers and consumers alike – is faced with huge uncertainty regarding the true state of sustainability of suppliers, products and companies as a whole due to the imprecise nature and opaqueness of existing approaches. This is particularly relevant and valid for the consumer electronics industry. This industry's impact on the dimensions of sustainability is enormous and since each one of us likely owns a computer, laptop or smartphone, almost everyone is involved, responsible and capable of exerting influence through decisions of choice. This served as additional motivation to conduct this study. To sum it up, this problem was selected for its base in industrial and systems engineering, its relevance to the increasingly prevalent environmental and social decisions faced by global industry, and in the current context of global operations, it is also an interesting and ethically responsible study. Part of the initial inspiration for this study came when watching Annie Leonard's video "The Story of Stuff". (Leonard 2007) The video shines light on the urgency of systemic industrial, environmental, societal and economic problems for mankind and for the planet as a whole that can be seen growing in the world today.

## 1.2 Objective and Structure

Against this background, the main goals of this thesis are threefold. The first key objective is to conduct a thorough literature review that will help create a solid foundation to this and all subsequent work dealing with assessing a product's impacts in its various life cycle stages. Light shall be shed to and clarity be achieved in a field of study that teems with papers and information, which have caused it to be rather impenetrable and difficult to access. Based upon this, it is this study's second key objective and primary goal to develop and provide a concept that is capable of addressing one aspect and challenge of assessing sustainability (of products) that has not yet received much attention: The fair allocation of sustainability impacts among the various actors of a supply chain. The literature review will be of help in determining and proposing a method of how to assess sustainability in an integrated fashion, which will then serve as an input for the subsequent allocation. Last but not least and thirdly, it is the goal of this thesis to ideally put this developed concept to use in the consumer electronics sector and assess one majorly significant device of this particular industry for its sustainability impacts.

The procedure which will be performed in order to achieve the illustrated objectives is portrayed in the following Figure 1-1.

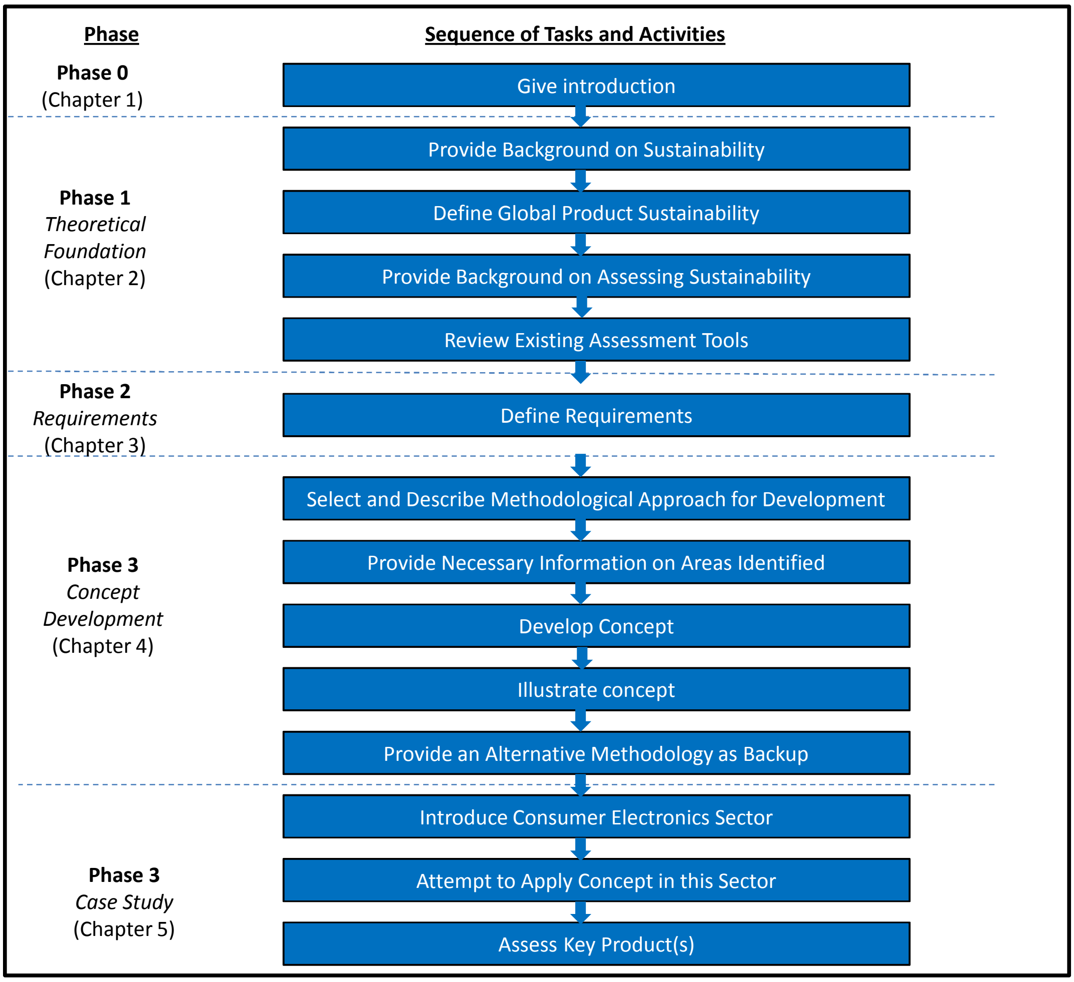



**Figure 1-1: Overall procedure of the study**

# 2 THEORETICAL FOUNDATION: DEFINITIONS & EXPLANATIONS

In order to develop a new sustainability assessment concept, it is pivotal to begin with understanding the background and concept of sustainability. Since this is a highly dynamic field with a considerable amount of research being done, this study will try to trace the evolutionary development of the nowadays commonly used term ‘sustainability’ in section 2.1 and its sub-sections, which culminate in an attempt of a definition for the novel term of Global Product Sustainability (GPS). In the second part of this chapter, the underlying principles and methods of the current state of the art regarding assessment methodologies and tools will be presented. Last but not least, another frequently used term in the realm of sustainability will be explained, namely ‘externality’.

## 2.1 The Concept of Sustainability

Developing sustainable products is one of the key challenges industry faces in the 21st century. For quite some time there has been elevated pressure for companies to broaden their accountability beyond simple economic performance for merely shareholders, to sustainability performance for every single stakeholder. (Visser 2002) What does that – being sustainable or sustainability in general – actually mean, however? “The term ‘sustainability’ is much used, and sometimes [still] misused.” (Feng et al. 2010). Despite the concept of sustainability being understood intuitively, it still is difficult to express in understandable terms. (Briassoulis 2001) Although the words 'sustainability' and its derivations such as 'sustainable development', 'sustained' etc. were already becoming highly popular more than 30 years ago (Brown et al. 1987), even to this day the "definition of sustainability […] is by no means agreed and is subject to value-judgments" (Bond & Morrison-Saunders 2011). (Bell & Morse 2008)

It is therefore this section's and one of this study's key objectives to again examine the concept of sustainability, to review some of the major developments and evolutionary steps undertaken in this field of study – which, though it appears to be quite recent due to it still being largely unresolved, is in fact rather old already – and to condense the manifold pieces of information so that a practical, clear and easily understandable common ground can be established. This culminates in the attempt of this study to define the new and very recently emerged term indeed of 'Global Product Sustainability', which will be of great significance not only for the understanding of the entire thesis, but for the way products will be regarded and looked upon in the future in general.

### 2.1.1 Historical Background of Sustainability

Today the term sustainability is very often used and above all applied in various contexts. To better understand the concept of sustainability and to lay a foundation for the upcoming definitions to be made in this chapter, it is useful to understand the origin of sustainability.

Even as early as the 18th century, 'Nachhaltigkeit' – the German word for sustainability – was mentioned already by Hans-Carl von Carlowitz in "the most influential pioneering book in this field." (Kloepffer 2008) Von Carlowitz – who is consequently considered to be "the father of sustainability in the modern sense of the word" (Kloepffer 2003) – worked in the silver mines business and therefore required a lot of timber. As he was in a leading position including overseeing the acquisition of wood, he noticed that the forests in the area were in poor shape due to the overexploitation at the time. Von Carlowitz was the first one to notice the basic law of sylviculture that one must not harvest more wood from a particular area or forest than can grow back in the long run. Furthermore, he also already acknowledged the relationship of what we call environmental, economic and social factors today. It is because of all this that the early definition of sustainability is still more than relevant for today's discussion.

The origin of the mindset of sustainability and its thinking therefore lies in the 18th and 19th century, a period of time shaped and characterized by thorough industrialization in the first world and a subsequent enormous need of resources of fossil fuels procured worldwide to both operate new machinery and to generate electricity. Especially the time after the Great Depression and World War II saw an unparalleled period of growth in every conceivable area. Approximately linear in its ascent until about the 18th century, the world’s population has grown hyper exponentially over the past 200 years, having doubled since 1960 and to be expected to increase to roughly 9 billion by 2050. (United Nations 2012)

This immense growth of the world’s population, which is partially interconnected with the increasing depletion of Earth’s resources where our environment functions as a sink with all its environmental impacts such as global warming have created an awareness that something must change if the human race is to persist. “The Limits to Growth”, published by the Club of Rome in 1972, is therefore regarded as the first milestone in the evolutionary process of sustainability today as it was the first report to show through simulation the possible consequences of human interaction with his surrounding systems on a global scale. (Meadows et al. 1972; Watson et al. 2005; Loh et al. 2008)

### 2.1.2 Towards Definition: The Term (Global) Sustainability

(Global) sustainability is an idea and concept which is used with growing frequency in today's globalized world (UNEP/SETAC 2011). As has previously been stated, however, there exist many differing definitions and interpretations of the term sustainability. (Feng et al. 2010; Bond & Morrison-Saunders 2011)

This section therefore aims to illustrate some of the tremendous efforts which have been undertaken over the past few decades to move from the state described by Tisdell in 1985 that "sustainability is not defined" (Tisdell 1985) to where we are today.

Moving towards a definition of the term (global) sustainability, it is useful to examine the literal origin and meaning of the word. Sustainability stems from the Latin sub-tenere, assimilated sustinere, which means to hold up. (UNEP/SETAC 2011) It therefore comes as no surprise that the Oxford English Dictionary defines 'sustainable' as "capable of being upheld; maintainable," and 'to sustain' as "to keep a person, community etc. from failing or giving way; to keep in being, to maintain at the proper level; to support life in; to support life, nature etc. with needs." In layman's terms that means that something – a policy, product or process, a technology even etc. – is considered to be sustainable when it is possible to maintain it in a particular state for an (almost) infinite period of time. (Heijungs et al. 2010)

While this gives a first understanding of some of the key terms, it is necessary to go deeper and into more detail in order to really arrive at a robust definition that may stand the test of time and critique of scholars. The term 'sustainability' has always been largely ambiguous with it being used in many different disciplines, there being countless ways of defining it and its meaning being intensely dependent on the context in which it is used, e.g. on the perspective – a social, economic or ecological one – applied. (Brown et al. 1987) In general, even in the 1980s already, many literature reviews were being conducted and attempts made to define the term sustainability. “The academic, scientific, and policy-making communities [were] focusing considerable attention on the concepts of ‘sustainable’ environment and development.” (Liverman et al. 1988) Brown et al. came to the conclusion that a definition that is of good use must specifically contain the context and the temporal and spatial scales to be considered. (Brown et al. 1987) After identifying and analyzing manifold definitions at the time, Liverman et al. (1988) put forward a working definition they had developed: They “mean[t] sustainability to be the indefinite survival of the human species (with a quality of life beyond mere biological survival) through the maintenance of basic life support systems (air, water, land, biota) and the existence of infrastructure and institutions which distribute and protect the components of these systems.” (Liverman et al. 1988)

The above definition was to serve as an example and indication of where the focus of sustainability was at the time, namely predominantly the environmental aspect. This is somewhat mirrored in a list of “[e]ssential [e]lements in [d]efining [s]ustainability” (Brown et al. 1987) Brown et. all compiled following their intensive literature review conducted at the close of the 1980s. The understanding and necessity of a global mindset and scope became apparent already.

- 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

Granted an anthropocentric, global and indefinite view of sustainability, the above condensed list made Brown et. al (1987) deduce three different ways to construct a definition of global sustainability, which marked an important milestone on the path to defining this increasingly important term. One opportunity of a definition “means the indefinite survival of the human species across all regions of the world.” (Brown et al. 1987). Another way of defining the term takes a broader and more thorough view and includes a certain longevity and quality aspect to life of human beings which goes beyond only biological survival. An even broader – the broadest – sense of global sustainability according to Brown et. al (1987) is the durability of the entire biosphere including components that do not have a direct or yet known benefit to mankind.

The 1980s – a period of time characterized by the use of the concept in a sense of human sustainability on this planet – finally culminated in the creation of the internationally most commonly used and frequently quoted definition of sustainability and sustainable development, the one of the World Commission on Environment and Development (WCED, also referred to as the Brundtland Commission). (Ness et al. 2006; Heijungs et al. 2010; Hussey et al. 2001) It was put forward in their report ‘Our

Common Future' which became to be more widely known as the 'Brundlandt Report', named after former Norwegian Prime Minister Gro Harlem Brundtland. Easily put, this at the time new concept of sustainable development describes an approach with which to address challenges such as environmental protection and economic development. It will be defined in more detail in the following section.

The term sustainability has caused many stakeholders – e.g. policy makers, environmentalists and decision makers in industry among many others – 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 as well;
- the realization that every actor is embedded in a chain of activities has led to the development of notions such as supply chains, the life cycle, and extended producer responsibility.

This in turn has yielded many new concepts and approaches such as aforementioned sustainable development, but also life cycle thinking, both of which will be defined and explained in further detail in the following section. As of late and nowadays, 'Sustainability' has become known as a term connected and closely related to global development. (Kloepffer 2008)

### 2.1.3 A new approach: Sustainable Development

"Sustainable development is a broad, complex, controversial and challenging issue." (Richards & Gladwin 1999) It covers society's every aspect and reaches well into the future, oftentimes even decades. (Tibbs 1999). "There is no single, consensus definition of sustainable development." (Hussey et al. 2001)

Even a decade after this publication, this still holds true as the field of sustainability and sustainable development remains a very controversial issue, which is mirrored by the fact that in 2012 alone, roughly 150,000 articles on sustainable development were published by about 40,000 authors from all around the world. (United Nations 2013) And yet, even after all these years and this myriad of publications, the standard definition provided by above mentioned Brundtland Commission in 1987 still "is a starting point for most who set out to define the concept." (Ness et al. 2006) Ever since, sustainable development is consistently defined as

*"a development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (WECD, 1987)

Every individual and institution shall 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)

Although today it is highly unlikely the interested reader has never seen or heard of the Brundtland definition, it is purposely included as it is imperative to the further study. Sustainability – and with this sustainable development as well: they are both referenced in above mentioned Brundtland definition and are not specifically distinguished in the following sections of this thesis (analogous to (UNEP/SETAC 2011)) – was declared the leading principle for the 21st century by the United Nations (UN) in Rio de Janeiro in 1992. It has since been adopted and extended by many governments and countries, the UN and European Union (EU) as a policy principle. (Council of the European Union 2006) A lot of companies, political parties, NGOs etc. have adopted sustainable development as one of their central approaches as well. (Hassini et al. 2012; Heijungs et al. 2010) Changing behavior in terms of consumption and production, changing practices and policies as well as finding new ways to simultaneously improve the environmental performance of processes and products and still be profitable are only a selected few consequences of that.

Essentially and ideally, sustainable development is all about improving every individual's quality of life without overspending the planet's resources past its capacity. For that to be possible, the definition of sustainable development creates many clear connections between issues such as poverty, safety, population control or equity among many others. It is therefore divided up in three areas which must be examined, evaluated and integrated: economic, environmental and social. (Heijungs et al. 2010) Since this is a thesis conducted in the United States, it is sensible to shed some light on the North American stand on this particular issue as well. Analogue and largely agreeing with their European counter parts, the U.S. National Research Council identified three areas which are to be sustained – namely nature, life-support systems and community – and also three areas to be developed, namely people, society and economy. (U.S. National Research Council 1999) This goes hand in hand with the popular so-called 3P or PPP or P3 approach: People, Planet, and Profit. (UNEP/SETAC 2009) People and planet convey a collective interest of mankind as a group on the whole and represent the social and environmental area respectively. Profit – i.e. economic concerns of businesses – is more self-centered and shows a certain self-interest. It was because of this rather negative connotation that in 2002 at the World Summit on Sustainable Development in Johannesburg the 3P approach was officially renamed to "People, Planet, and Prosperity." (UNEP/SETAC 2009) That change of Profit into Prosperity was meant to reflect that more than merely companies' profits are considered and at stake. In the end, however, this is just another way of addressing the three main dimensions or so-called pillars of sustainability. Another widely known and frequently quoted and applied term is "triple bottom line" (TBL) and was coined by Elkington to address and clarify the importance of achieving sustainability through considering all dimensions:

*"Triple Bottom Line accounting attempts to describe the social and environmental impact of an organization's activities, in a measurable way, to its economic performance in order to show improvement or to make evaluation more in-depth."* (Elkington 1998)

These three dimensions – which are commonly depicted by the three overlapping circles and their resulting intersections as shown in figure X – imply that industry must expand and widen their traditional focus on economic issues to environmental and social dimensions as well if they are to establish more sustainable businesses. (Elkington 1998; Heijungs et al. 2010)

### 2.1.4 Criticism of the definition

Not only is the Brundtland definition of sustainable development the most cited definition, it is also oftentimes regarded as being too vague or incomplete. (UNEP/SETAC 2009). In fact, it is widely criticized. (McKenzie, 2004) Some of the more extreme criticism is calling the definition a "smokescreen behind which businesses can continue its operations essentially unhindered by environmental concerns, while paying lip service to the needs of future generations." (McKenzie 2004) It is often argued that the definition was formulated with this sense of vagueness on purpose so that the needs and interests of all stakeholders are met. It is thus possible for businesses and governmental supporters alike to claim they were acting in a way that improves sustainability when in fact they were not. (Jacobs 1999; O'Riordan 1988) Furthermore it is argued that focusing on development where there exists poverty "tends to evade the uncomfortable issue of the need to restrain consumption on the part of the affluent." (Joshi 2002) The notion that sustainable development is always advantageous both for first world and particularly third world countries has also been heavily contested. Banerjee (2003), for instance, 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)

In spite of the all the criticism the Brundtland definition of sustainable development has received, scholars are in agreement at large about the three dimensions of sustainability being interlinked and that progress can only be achieved if they are all taken into consideration simultaneously. (Seliger 2007) There still is widespread disagreement and criticism among scholars and practitioners alike as how to treat the social and ethical dimensions of sustainable development, however. This is due to them not having been dealt with the same care and effort as their benefits are less palpable. (UNEP/SETAC 2007) A trend, however, can be observed that this perception is changing and sub-section 2.2.3.3 will shed more light on this particular issue and go into deeper detail explaining the current state of the art.

### 2.1.5 Towards definition: The term Global Product Sustainability

The three single key terms of this study – global, product and sustainability – are, seen individually, relatively straight forward. This becomes an entirely different matter when these items are combined to form compound terminologies. The term (Global) Sustainability, for instance, has been defined in chapters 2.12. and 2.1.3. However, the field of "Global Product Sustainability", in particular, is a research area that has remained largely untouched. This thesis and this section therefore aim to redress this deficiency.

Because the UN and governments all over the world have the stakeholders pushing sustainable development, the focus of most sustainability frameworks is on national, regional or community level (Veleva & Ellenbecker 2000; Hass et al. 2002; United Nations 2001). There is a huge need to broaden that perspective and include a product view as well. Sustainable production is a key driver to achieving global sustainability as it is the products which are linked to environmental, social and economic impacts that a company exerts. By the same token, however, because of the immense variety of products, it is one of the aspects most complex and challenging to address in a standardized manner. (Vesela Veleva et al. 2001)

Consumers have gradually been becoming more and more interested in the story of the products they buy. New information technologies have allowed consumers to be more demanding. "Apart from price and quality, they want to know how and where and by whom the product has been produced." (Leeuw 2005) It is therefore valid to start the evolutionary process of building the desired definition with a closer and clearer assessment of sustainable production and manufacturing. Not only are they at the base of sustainable development and thus global (product) sustainability in general, they are also the core operation in a product's supply chain.

The Lowell Center for Sustainable Production (LCSP) defines sustainable production as "the creation of goods and services using processes and systems that are non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for employees, communities and consumers; and socially and creatively rewarding for all working people."(V. Veleva et al. 2001) Another well recognized definition was issued by the U.S. Department of Commerce. They define 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." (International Trade Administration 2007) Both of these definitions are very similar and emphasize environmental, social and economic aspects of a business's operations and activities and are thus consistent with today's understanding of sustainable development. (Clift 2003) Furthermore, the National Council for Advanced Manufacturing (NACFAM) argues that sustainable manufacturing means the manufacturing of sustainable products – production of energy efficient, "green" and social equity-related products to name only a few aspects – and the sustainable manufacturing – taking into account the full sustainability and total life-cycle – of all products. (Jayal et al. 2010; National Council for Advanced Manufacturing 2009)

A life cycle approach is very powerful when products and services are being considered from a sustainable development point of view. (UNEP/SETAC 2009) Because of the manifold input and output streams taking place in a product's life cycle, the notion that it is necessary to consider the total product life-cycle in order to assess a product's sustainability score is becoming increasingly popular. (Jayal et al. 2010)

"In order to effectively reduce the sustainability impacts of products, the supply chain aspect of product manufacture needs to be incorporated." (Maxwell & van der Vorst 2003) Today it is thus finally accepted that a product rather than a process oriented view might be more beneficial in order to maximize the potential of cleaner production (Weenen 1995). Hence, it comes as no surprise that NACFAM argues that "sustainable manufacturing of all products [has to take] into account the full sustainability life-cycle issues related to the products manufactured." (NACFAM 2007)

Consequently, for a product oriented view, life cycle thinking (LCT) is of paramount importance just as much as it is to sustainable development at large and to global product sustainability in particular. It means moving beyond the traditional focus of concentrating on manufacture and production processes alone to an inclusion of environmental, social, and economic impacts which a product exerts over its complete life cycle – pre-manufacturing (extraction of raw materials), manufacturing (design and production as well as packaging and distribution), use (and maintenance) and post-use (end of life and disposal). (Barbudeen et al. 2010; UNEP/SETAC 2007) The aim of LCT is to reduce the product's environmental impact – e.g. reduce the resources and emissions a product uses and causes respectively – and to increase its socio-economic performance in all of its major life cycle stages. This is also partly due to modern phenomenon such as the so called Extended Producer Responsibility and Integrated Product Policies, which means that companies may be held responsible for their products from cradle to grave. (business guide to sustainability) A transformation from traditionally open-loop (from cradle to grave) to a theoretically closed-loop (from cradle to cradle) life-cycle paradigm – commonly portrayed in a circle or circular illustration as shown in Figure 2-1 – has taken place. (Joshi et al. 2006)

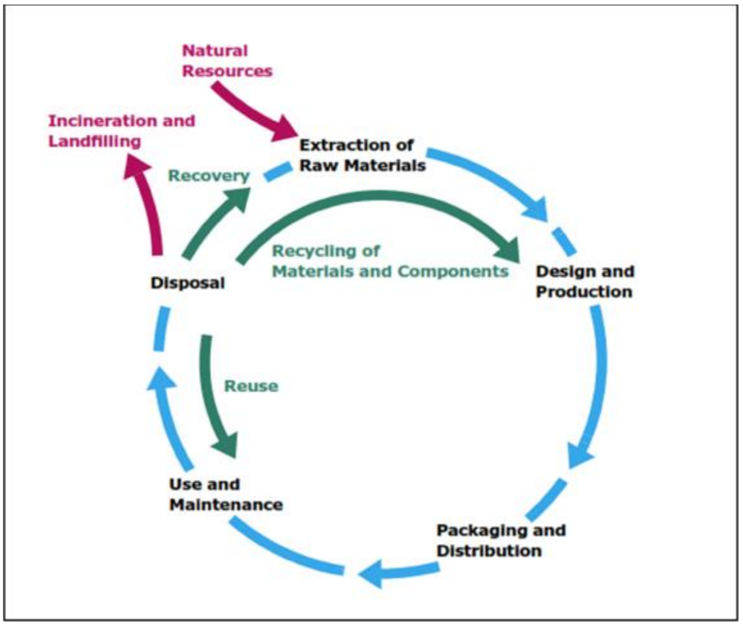



**Figure 2-1: Closed-loop life-cycle paradigm**

This goes along with an extension of the traditional 3RE concept which has promoted green technologies (re-duce, re-use, re-cycle) and sustainability principles to the more recent 6RE concept and “philosophy”, which is illustrated in the following bullet points (Jayal et al. 2010; UNEP/SETAC 2007)

- RE-think the product and its functions, e.g. more efficient usage
- RE-pair – make product easy to repair, e.g. via easily changeable modules
- RE-place harmful substances with safer alternatives
- RE-use – design product for disassembly so that parts can be reused
- RE-duce use of resources and impacts throughout product’s life cycle
- RE-cycle – select materials that can be recycled.

Last but not least, one final puzzle piece and area needs to be introduced and discussed for the subsequent definition of GPS - the term sustainable supply chain (management). A supply chain generally describes all parties involved in fulfilling a customer order. This is to serve as an indication that there usually are a number of decision makers involved, some or many of which can be beyond the control of a particular company in question. Furthermore, life cycle management can be defined as the control of the supply chain to maximize the focal company’s profit whilst satisfying the customer’s order. (Chopra & Meindl 2007) Sustainable supply chain management, on the other hand, is in research among scholars closely linked to establishing life-cycle management. (Seuring 2004) A thorough literature review of 191 papers published between 1994 and 2007 on this very topic conducted by Seuring and Müller produced a number of lessons learnt. For instance, research in this particular field is also still predominantly concerned with environmental issues. As is the case with sustainable development in general too, the integration of a social dimension as well as simultaneously considering all three major dimensions is basically just as rare. (Seuring & Mu 2008) Furthermore, another result of their literature review which is of particular interest to this thesis is the fact that focal companies – a focal company means a company that is of key importance in a supply chain and is the initial point, regularly by offering a product or service to the customer, of the supply and value chain – must pay more attention to sourcing minor components in order to reduce their own risk following an increased responsibility to which companies are accounted for these days. The need for cooperation among different stakeholders of a (sustainable) supply chain is greatly increased. (Seuring & Mu 2008)

Taking all aforementioned pieces of information, explanations and definitions of all previous sections into consideration, the term Global Product Sustainability could be defined as follows:

> *Global Product Sustainability is a state that could be 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. During all phases of their product life cycle the interrelation between those three dimensions is considered in every kind of decision making so 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*

*products life cycle 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 quoted as saying. The contrary is actually the case, though: He stated that running a company on visible figures (alone) is one of the biggest diseases of management. However, even if the statement may sound like an old management adage, it still holds true. In layman terms one cannot know whether an activity is successful or not unless there are defined and traceable indicators, indicating the high significance metrics have.

There is no dearth of literature of how to measure and assess sustainability in its various forms. On the contrary, papers upon papers dealing with this very sensitive and essential topic have been published with there being no end in sight. Searching for some of the respective keywords (sustainability AND assess OR assessing OR measure OR measurement OR metric OR indicator OR index) via SCOPUS in June 2014 illustrates this remarkably. Considering the period of time from 1990 until today, an almost exponential increase in the number of publications can be observed as is to be seen in Figure 2-2 .

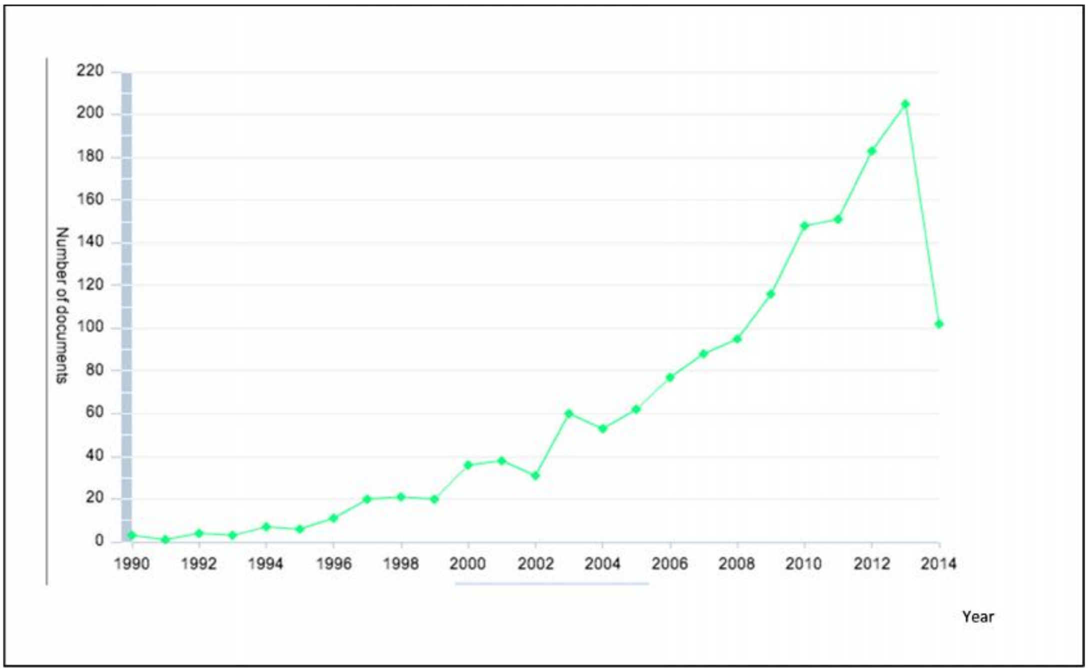



**Figure 2-2: Number of publications according to SCOPUS**

A total of 1541 publications in all different fields of study – e.g. environmental-, social-, agricultural- and biological sciences as well as engineering to only name the most frequently found ones – could be traced.

Consequently, confusion among scholars, practitioners and people who are generally interested in the topic has steadily increased over the past few decades. One of this literature review's and thesis's main contribution will therefore be to provide some much needed clarity and structure and to sensibly condense the countless pieces of information that have accumulated in the process of this ever-increasingly important matter. Similarly to the issue of a photo camera which is perfectly capable of capturing images of great quality, but which cannot easily or not at all be used by its user due to the myriad of options and settings, a camera of less sophisticated quality but which is easy to use, thus enabling photos to be taken in the first place, may actually very well be the better option and more valuable. The authors thus believe the reasonable combination and simplification of the various existing concepts and pieces of information alone to be sufficient justification for conducting this study, let alone their slight alteration and expansion so as to better meet today's global challenges.

The reasons for the great availability of literature concerning the assessment and measurement of sustainability are manifold. A lot of customers nowadays want the products they buy to be designed and manufactured  in a sustainable manner and thus be able to choose their items accordingly(MIT Sloan Management Review 2011)(MIT Sloan Management Review 2011)(MIT Sloan Management Review 2011)(MIT Sloan Management Review 2011)(MIT Sloan Management Review 2011). Hence, a method and way are required to portray a product's sustainability performance. Furthermore, in today's increasingly global world, companies are embedded in a market environment which sees them facing competition worldwide and a progressing obligation to compel to and to report on the overall sustainability performance of their actions. (Labuschagne et al. 2005)

It is because of this that manufacturers have begun to look for sustainability measurement solutions. In spite of all publications, however, there are only very few effective measurement methods which allow the assessment of manufacturing's impacts on society and environment. In fact, due to there having been developed such a great number of various indicator sets, confusion is high among producers and many others alike. Companies, particularly in the field of manufacturing, have had to deal with the still not trivial task of choosing what indicators to use with which to assess their processes and products. Interpreting these indicators to make their businesses more sustainable has yet been another, additional challenge. A great many papers and authors, for instance Sikdar (2003) and Gaurav et al (2009) to name only a few, expose that there is no consensus understanding of sustainability-related metrics and that major sustainability metrics are not only dependent on the businesses they are employed in but they are also inconsistently defined (Sikdar 2003; Gaurav et al. 2009). Even to this day and despite all the effort and attention that this particular field of interest has received "no one set of metrics is recognized universally" (Hussey et al. 2001). A consensus definition of a standardized set of indicators is of utmost important, however, as it – among others – allows a number of things (Hussey et al. 2001):

- Comparison of similar products of different companies
- Comparison of different processes regarding the same product
- Benchmarking of units
- Rating of companies against competitors
- Assessing the progress toward achieving sustainability (Azapagic & Perdan 2000)

Ultimately, for a company to successfully and effectively strive towards sustainability, it is of paramount importance that its goals are assessed. Ever since this connection was made, it has thus been a significant task and challenge for scientists to provide efficient and reliable tools, which can be used by the companies themselves. This has been accompanied by a huge and quick development of the area. (Ness et al. 2007) Essentially, assessing sustainability is all about assisting and directing decision-makers in determining what kind of actions should be taken or should be refrained from in order to make their own businesses and ultimately society more sustainable by providing them with both a short and long term perspective, with a local to global dimension. (Bond & Morrison-saunders 2011; Hacking & Guthrie 2008; Kates 2001) Most indicator frameworks, which are available today, however, address the topic of sustainability inadequately, more often than not neglecting certain aspects of it. Social criteria, in particular, are still considered insufficiently (Labuschagne et al. 2005).

### 2.2.1 Defining major terms in the field of sustainability assessment

A number of terms have been used in the above paragraphs the interested reader may not be familiar with yet. The following paragraphs will therefore provide some much-needed definitions in order to establish a common base and understanding.

**Sustainable assessment:** As Bond and Morrison-Saunders point out sustainability assessment "is commonly associated with the derivation of indicators which can be used as measures of the state of the socio-economic and biophysical environment and therefore used as the basis for predictions where there is a development intervention" (Bond & Morrison-Saunders 2011). (Donnelly et al. 2007; Bockstaller & Girardin 2003). A key term to comprehend is therefore the term 'indicator'.

**Indicators and metrics:** These are terms which are not easy to be explained due to their being countless approaches attempting to deliver the one and only solution. In fact, indicators in the field of sustainable development were first discussed in literature as early as the 1970s, (United Nations 2009) and consequently, quite a wealth of definitions has accumulated since which are partially of very contrary nature. This thesis is reluctant to repeat the great many options to distinguish indicators – integrated versus nonintegrated, core versus additional, content versus performance indicators among many others – all over again and therefore only defines what indicators generally are in terms easy to understand. Indicators are usually quantitative pieces of information that are increasingly recognized and used to report on the performance of certain stakeholders, such as countries or companies for instance, in areas like environment, economy or society. (Ness et al. 2006) They help to explain how things alter over time and make certain, possibly rather minor, changes and trends easier to spot, more visible and understandable. (Zhou, Tokos & Krajnc 2012) Not only can indicators thus be used to estimate the current state, but also to evaluate the distance to a certain target and the direction of development. They will provide dependable and repeatable means for manufacturers when evaluating their level of sustainability and allow comparisons to be made between products, countries etc. Furthermore, a good indicator – which in addition to having the previously mentioned characteristics Harger and Meyer (1996) also state to be simple in application and providing (a wide) scope (Harger & Meyer 1996) – can be used as a problem alert (SIP 2014) due to it being reasonably sensitive, thus allowing timely identification of change. Indicators can have many functions and are widely used for decision-making as they summarize, stress and focus as well as condense the great complexity of the dynamic environment they are employed in to a more easily controllable amount of sensible information, (Godfrey & Todd 2001) thereby simplifying, analyzing and communicating information which is otherwise complex and difficult in its nature. (Warhurst 2002)

In literature there is also great confusion with the terms “indicators” and “metrics”. Conducting this thorough literature review, however, it can be concluded that very frequently they are used synonymously with “indicators” usually having a broader scope than metrics, also encompassing narrative descriptions on top of their quantitative measurements (Tanzil & Beloff 2006). It is because of this that the author of this thesis has chosen to solely use the term indicators rather than metrics.

However, “a given indicator does not say anything about sustainability, unless a reference value such as thresholds is given to it.” (Lancker & Nijkamp 2000)

More precisely, indicators, in particular environmental ones and those dealing with and being embedded in the large area of sustainability, have undergone an evolution and followed – what Veleva and Ellenbecker describe – a learning curve (Veleva & Ellenbecker 2001). Nowadays they not only reflect impacts within the entire life-cycle and along the supply-chain of products, they also have a much bigger scope than previously in order to deal with long-term problems, for instance material depletion (Tanzil & Beloff 2006). And yet, however, it must be stated that even as recent as 2009, a group of scholars still claimed that the development of indicators especially for sustainable processes and products had not been fully addressed yet (Feng et al. 2010), indicating further research requirements. It is therefore even more important to finally establish common ground which can be built upon in the present and future.

In particular those indicators dealing with eco-efficiency can differ comprehensively from company to company because of the various cause-and-effect relationships that exist in each entity (Tanzil & Beloff 2006).

There is, however, a great need in general for more standardized processing of information. One way that has been proposed to remedy this are indicator sets.

***Indicator sets:*** An indicator set usually consists of a certain number of indicators which make up for a more holistic view of sustainability as indicators from all three dimensions are combined and evaluated in a joint manner (Joung et al. 2013).

Sustainability can hence be measured on a much bigger scale than would be possible with individual indicators. Due to the highly complex interrelationships between the single indicators, many contradicting conclusions about both the state of sustainability and possible improvements may be drawn (Kibira et al. 2009; Ueda et al. 2009). An almost overwhelming amount of stand-alone indicator sets has been proposed, the most important of which for the field of GPS this thesis will briefly introduce later.

**Index / indices / composite indicators**: Indices, contrary to indicator sets, are much more straightforward since they merely aggregate a number of indicators to only a single score via a specific mathematical scheme. An example is the Environmental Vulnerability Index, which combines indicators of hazards, resistance and damage in one single value (Joung et al. 2013). After reviewing a great many deal of literature, this thesis understands composite indicators to be synonymous to indices (Singh et al. 2009). Composite indicators thus provide thorough and broad information. Their results are dependent on a variety of choices, such as the normalization method and weighting scheme used as well as the selected aggregation method of the sub-indicators. This is exactly why it is argued by many they are not objective enough, giving too much room for bias (Zhou, Tokos & Krajnc 2012). This is supported by a number of authors, such as Spangenberg (2005), who claims that "from a scientific point of view, there cannot be such a thing as one comprehensive measure or index of sustainability."(Spangenberg 2005) Due to the fact that managers and public alike usually crave for a single number when assessing and contemplating sustainability the popularity and use of composite indicators has been increasing. Yet, they remain highly controversial as they generally cause too much disagreement among experts in terms of the stated choices that are to be made. (Zhou, Tokos & Krajnc 2012).

It is because of this and due to the plentiful research and work which has been done in the field of measurement systems for sustainable development and manufacturing, that there is a lot of confusion. Not only are indicators, which define the framework and function as feedback loops, instead of directly helping to achieve the sustainability goal, still frequently mixed up with tools and concepts (Singh et al. 2009). The multitudinous number of indicator sets has also caused a lot of complications regarding the understanding of interrelated terminology and choosing the right indicators for different areas of sustainability. (Joung et al. 2013)

**Tools:** Tools are used to measure and assess sustainability. According to Devuyst et al. sustainability assessment is defined 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." (Devuyst 2000)

**Framework:** Frameworks can be used in order to establish a categorization of these assessment tools. This categorization can be and is based upon a number of factors and/or dimensions, which has frequently and successfully been demonstrated. (H. Baumann 1999; Moberg 1999; N Wrisberg et al. 2002; G Finnveden et al. 2009; Finnveden & Moberg 2005). Sometimes being used synonymously, the term framework can also be used to describe a certain tool and the way it is constructed. In such cases frameworks usually address the three main dimensions of sustainability and describe what criteria belong to which dimension (economic, environmental, and social). Such frameworks are also referred to as indicator frameworks since they include sets of indicators. (Labuschagne et al. 2005) ) The United Nations Commission on Sustainable Development Framework, the Sustainability Metrics of the Institution of Chemical Engineers and the Global Reporting Initiative (GRI) – which will be explained later in further detail – are popular examples of this very approach.

**Data:** Independently of what methodology or approach to assess sustainability is selected, data always builds the foundation for a successful measurement. Data may be obtained from different sources such as organizations, initiatives or companies themselves. A schematic overview of how some of the above described terms are interconnected to one another is to be seen in Figure 2-3.

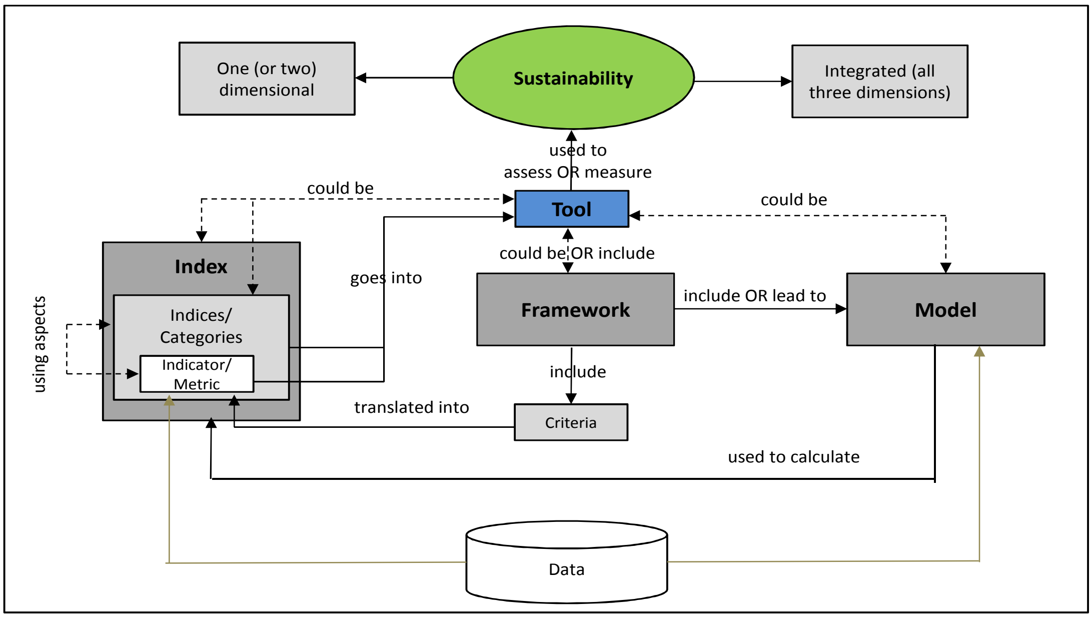



**Figure 2-3: Relationship between key terms in the realm of sustainability assessment**

### 2.2.2 A progressive framework to structure sustainability assessment

To assist in this regard and to address the challenge of the existence of a myriad of indicators and indices and disintegrated indicator sets – which are oftentimes business specific and thus not generally applicable (Ameta et al. 2009) –, the US-American based National Institute of Standards and Technology (NIST) has established a means to categorize sustainability indicators which in a clear and lucid manner attributes a big amount of indictors into their respective and fitting categories and subcategories. The purpose of this categorization is to serve as both an organizational as well as an educational tool. Thereby, a sensible and centralized structure is provided which companies are able to select from. This so-called "Sustainable (Manufacturing) Indicators Repository" (SMIR) contains more than 200 indicators and allows to assess both companies' processes and products in terms of sustainability. (Joung et al. 2013; Sikdar 2003) That this is helpful the quantitative comparison of two popularly and commonly used indicator sets illustrates. In order to assess the degree to which the environment is impaired by human and industrial activities, the Organization for Economic Cooperation and Development (OECD) propose to use 46 Core Environmental Indicators (CEI) (OECD CEI 2003). The United Nations (UN) Commission on Sustainable Development (CSD), on the other hand, promotes the utilization of a total of 96 indicators for assessing the exact same topic (United Nations 2007), showing the very different stands that can be taken.

Before introducing as announced earlier some of the more relevant and popular indicator sets, the categorization structure as proposed by NIST is presented in Figure

2-4 to ease the transition for the interested reader and to give her a better idea of what sub-categories appertain to what broader categories, how important certain indicators are and what to expect in general.

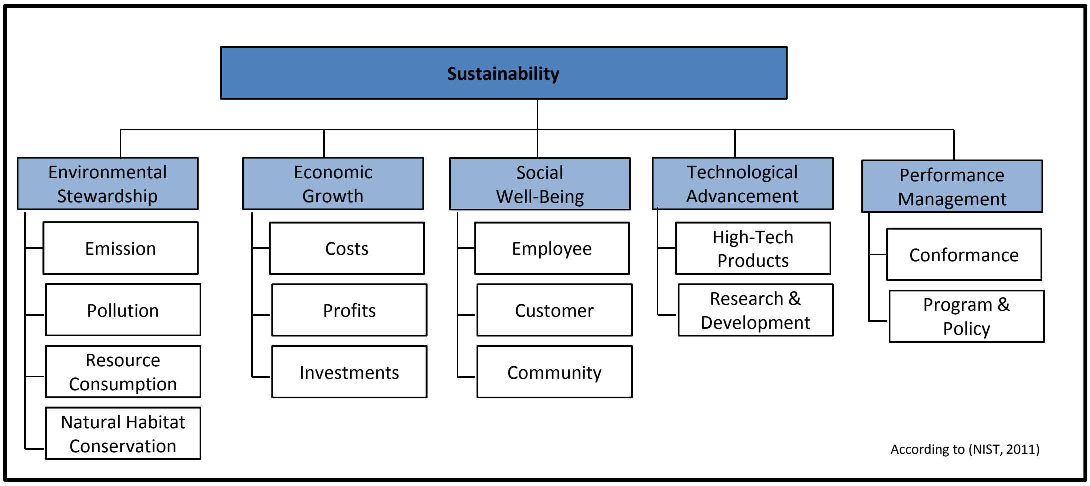



**Figure 2-4: Categorization structure as proposed by NIST**

One must always keep in mind that there exist many different ways to conduct such a categorization and the one done by NIST is one of many.

The method NIST applied to achieve and realize their goal of easing sustainability measurement was to come up with a categorization structure that is based upon an analysis of a total of 13 publicly available indicator sets such as provided by the Global Reporting Initiative (GRI), the Dow Jones Sustainability Index (DJSI), the OECD and many more. Critical in their decisions were similarity and the application of indicator (NIST 2012; Joung et al. 2013)

In addition to the previously mentioned, well-known and often quoted Triple Bottom Line introduced by Eltington as early as 1999 and its three main sustainability dimensions environmental, economic and social the NIST indicator categorization is furthermore based upon the two dimensions technological advancement and performance measurement and thus on a total of five dimensions. (Joung et al. 2013)

Environmental impact caused by emissions, harm done to ecosystems from manufacturing processes and products and resource use are all covered within the environmental stewardship. Economic growth, on the other hand, stresses costs, profits and benefits from investments made by the particular organization. (Joung et al. 2013) The dimension social well-being deals with the impacts health and safety programs have on employees, customers and the community alike. Additionally, career and educational development options and satisfaction assessments are considered. (Mihelic et al. 2003) Out of the unconventional dimensions, performance management is concerned with deploying sustainability programs and policies and whether they confirm to regulations. An important part of sustainability is also technological advancement with which this planet can still be saved and future generations still live a rather unrestrained life. (Joung et al. 2013)

NIST's achievement has not only been to provide that useful categorization, but also the quantitative analysis of all the evaluated indicator sets. All indicators used are stored in and can be found in the NIST's Sustainable Manufacturing Indicator Repository (SMIR) website. (NIST 2012)

In order to give an obvious indication as to the importance of the single indicator categories as well as their sub-categories, Joung et al. (2013) analyzed NIST's indicator repository, which contained 212 indicators at the time (Joung et al. 2013), the result of which can be seen in Figure 2-5.

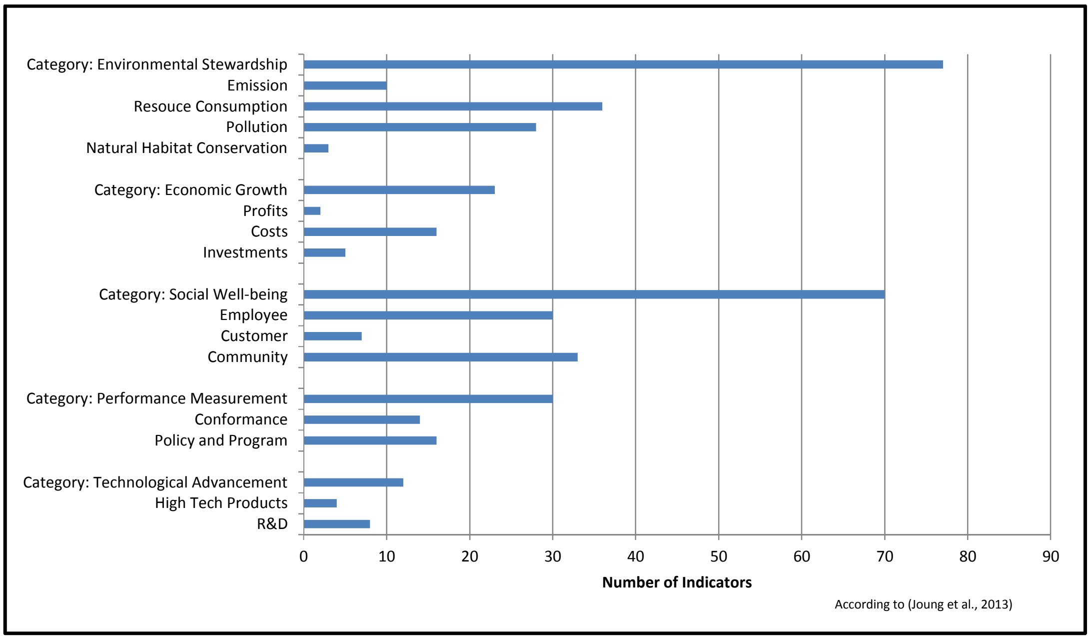



**Figure 2-5: Number of indicators in main- and sub-categories of NIST's indicator repository**

With established tools like Life-Cycle Assessment (LCA), which will be explained in more detail in section 2.2.3.1 that focus primarily on environmental aspects of sustainability, it comes as no surprise that with 77 indicators (36% of SMIR) the dimension and category of environmental stewardship contains most indicators. This area is based upon a rather established foundation, which is why future work should focus on existing indicators and how data collection for them may be eased and made more reliable (Joung et al. 2013).

The economic growth category accounts for only 10% of the SMIR indicators, which is somewhat surprising given that a lot of its indicators belong to long established methodologies such as life-cycle costing (LCC) which have been extensively used for many years and accepted by many organizations. (Joung et al. 2013) LCC will also be further explained in section 2.2.3.2.

Social well-being – in spite of its measuring methodologies still being in their infancy (Kloepffer 2008) – quite surprisingly contains the second largest quantity of indicators (33 % of SMIR). (Joung et al. 2013; Dreyer et al. 2006; Visser & Sunter 2002) This is a reflection of the fast development the social dimension has undergone. This in turn casts doubt on the stability of its current indicators, however. Currently available indicators are still strongly organization-based. Social Life-Cycle Assessment (SLCA), which is still a rather new tool, may potentially and successfully add the process and product-based component to it.

Performance management is one of the two categories that are not part of the traditional dimensions of sustainability. In essence, however, performance measurement indicators do measure all of them as well in a joint manner. Various authors point out the need for a further decomposition of the indicators so that they can also be used on a product and process level. Additionally, it still needs to be determined whether they really are relevant and sensible for sustainable manufacturing. This is – in spite of this very category containing 30 indicators, which accounts for 14% of the SMIR, – an indication for its current relatively underdeveloped state. (Joung et al. 2013)

Technological advancement indicators assess and value the new technology used and the R&D capability in organizations, particularly manufacturing ones. Ultimate goal is to promote advancement in the technological field. It is the category that contains the fewest – 12 or 6 % out of all 212 – indicators. Similarly, to the former category of performance management, its indicators also still require a lot of development and assurance, mirroring their relatively novel state. (Joung et al. 2013)

Last but not least and before moving on, many authors feel it to be necessary to create awareness of an ongoing debate as to what extent sustainability assessment and the use of respective indicators should be holistic and/or reductionist. (Bell & Morse 2008) Essentially, sustainability measurement is all about trying to analyze complicated systems into a more easily manageable amount of component parts. Reductionism is understood as just that, the breaking down of complex structures to simple terms and/or parts. The varying degree to which reductionism is applied can range from always decreasing measures to the extreme of using only one single value as is done with composite indicators. By using a selected number of indicators, the sustainability of a whole system is meant to be explained. Holism, on the other hand, recognizes systems as possessing complex and difficult interactions that oftentimes cannot (currently) be explained in its entirety. Relationships between certain variables are analyzed. (Bond & Morrison-saunders 2011)

Research conducted by Bond & Morrison-Saunders (2011) shows there is great variation among different stakeholders regarding the number of indicators used, varying from 24 to 151, which was and is to be expected among different contexts (Bond & Morrison-saunders 2011). Both the country of England (Office of the Deputy Prime Minister, 2005) and the Australian state Western Australia (Government of Western Australia, 2003) recommend the use of disaggregated indicators. While this is in itself an act of holism, it is still a form of reductionism despite not using the extreme of composite indicators. (Bond & Morrison-saunders 2011)

### 2.2.3 Popular methods to assess the three main dimensions of sustainability

As has been evaluated in the previous section 2.2.1, most indicator sets focus on the traditional environmental, economic and social dimensions. At the same time, its most popular and influential measure- and assessment methodologies LCA, LCC and SLCA have been mentioned and brought to attention as well. Since not only currently available indicator sets, but also sustainable development tools in general which are used to assess the sustainability of, for instance, products with, are partially to greatly dependent on these methodologies, the following sub-sections will go into some detail explaining them. As indicators alone are unable to measure sustainability, these most commonly used methodologies in the field of sustainability assessment provide the necessary and rational basis for sustainability related decisions and arguments. (Heijungs et al. 2010)

A product-related assessment which is the focus of this thesis concentrates on flows of differing nature in connection with production and consumption of goods and services. Tools assessing products and processes have traditionally evaluated resource use and environmental aspects along the product's life cycle. Until quite recently, they have not integrated nature-society systems.

Nowadays, however, consumers are additionally interested in the economic and social circumstances in which a particular product was made. They do not want to support corruption or child labor by potentially buying unsustainably made products.

Companies are intent on not following the example infamously set by sports apparel company Nike whose products were boycotted after it had been found out their items were made employing a number of questionable practices. They are thus determined to inform the public as well as current and potential customers that the goods are produced in a sustainable way.

Applying a life cycle perspective is a valuable approach as it provides elevated insight on the three traditional dimensions of sustainability. In literature, the single life cycle stages usually span from raw material extraction, to production and distribution till consumption and disposal, also nowadays more commonly called end of life.

This framework is applied to enable more comprehensive decision-making. Furthermore, life cycle thinking should be performed in all countries as it is instrumental in avoiding shifts of burdens to occur between countries and products alike (GRI 2013). A number of tools has been developed to assess parts of the framework, the most famous of which will now be presented. Their most important common feature is that they really do perform an analysis from cradle to grave.

LCA "is the only internationally standardized environmental assessment method." (Kloepffer 2008). This makes it in combination with it having been used over the past 40 years the most established and well-developed tool there is (Ness et al. 2006).

It is quite possible to make progress towards humankind's ultimate and pressing goal of sustainability without direct political influence, but not without the economy. It is the companies that manufacture and sell products whose impacts are subsequently felt locally and globally and thus exert an absolutely vital and comprehensive influence due to the astounding consumerism of mankind. This is only to increase in the decades to come with emerging countries further developing and closing the gap to industrialized nations. Therefore, LCC should be included in the assessment of sustainability. LCC provides valuable insights for a company and is thus a significant addition to LCA since a company can only stay in business and influence the world in a positive way, if its products are perceived to be economically sound and thus accepted and bought. (Kloepffer 2008)

For development to be stable, sustainable and of a certain long duration, social justice must be in place as well. This is particularly an issue of great concern and interest for consumers and management alike. It may not be easy to imagine the potential impact of a slight increase in acidification potential, but most can show compassion for children forced to hard and oftentimes (relatively) inhumane labor so that the products bought in the first world can be produced in a cheap, profitable fashion. Sustainable products still need to be profitable and not unreasonably expensive as the market does not accept them otherwise. This is a strong argument for SLCA to be considered and included in any life cycle assessment. Though it is still too early for a certain degree of standardization to be reached and SLCA still being in the stage of infancy, some harmonization could already be realized, also largely thanks to the astounding surge in papers. (Kloepffer 2008)

The next paragraphs will therefore explain in more detail the characteristics, unique elements and the steps to be performed of the individual assessment tools. Since there is no dearth of literature comprehensively describing how to fully perform and apply the introduced methodologies, it is this paper's aim – following its aspiration to give a broad and yet thorough overview – to educate the interested reader and give him a better understanding about what is essentially the foundation of so many indicator sets and sustainability assessment tools. This knowledge will be helpful when introducing this paper's conceptual approach to GPS.

#### 2.2.3.1 (Environmental) Life Cycle Assessment

What has been known under the simple and not very specific term Life Cycle Assessment (LCA) is now with the increasing use of different methodologies to also assess the social and economic dimensions often called Environmental Life Cycle Assessment (E-LCA), e.g. (UNEP/SETAC 2011) It was first developed in the late 1960s and early 1970s following the wish to be able to understand the environmental impacts of several packaging options (Oberfacher et al. 1996). LCA addresses issues such as global warming, acidification caused by combustion processes, photochemical ozone formation which is largely due to fugitive emissions from the transport and energy sector and what effects they have on the environment and its inhabitants including human beings. LCA attempts to quantify these aspects from a product point of view and the potential environmental impacts a product has throughout its entire life cycle, from raw material extraction to end of life, i.e. from cradle to grave. To consolidate the many LCA methodologies that had come into existence, four ISO (International Standards Organization) standards (ISO 14040-14043) on environmental management were developed and published at the turn of the millennium. They were recently replaced by two new standards, ISO 14040 and ISO 14044, which describe the elements of E-LCA. (Finkbeiner et al. 2006)

According to the ISO standards, there are four steps to be performed when conducting a life cycle assessment, which are illustrated in Figure 2-6 and are now briefly explained.

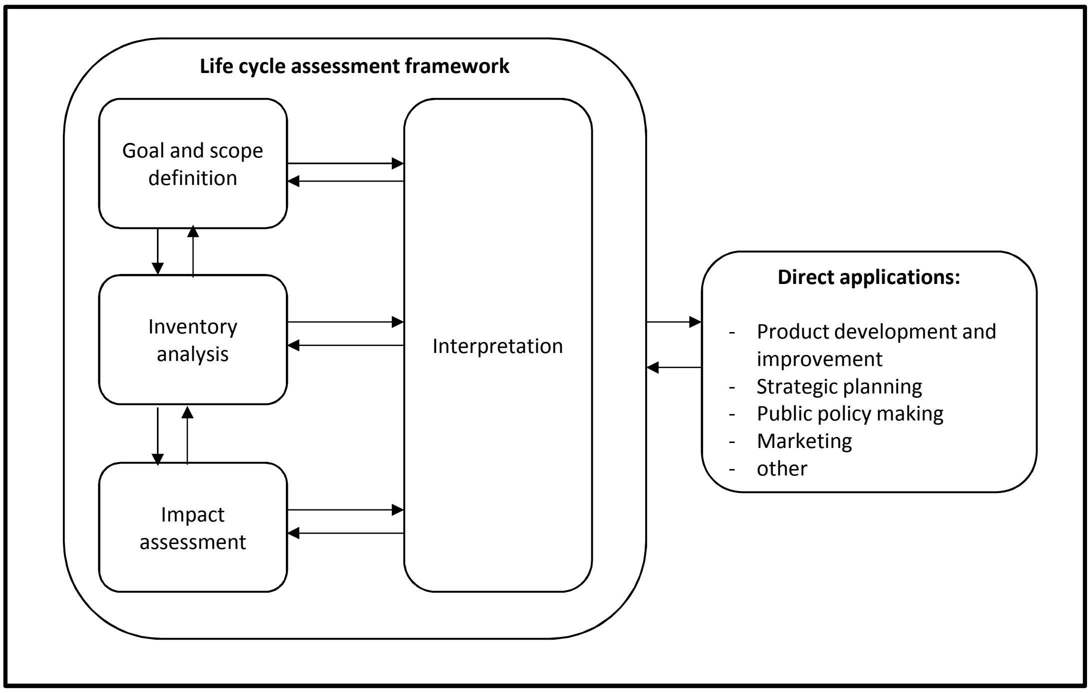



**Figure 2-6: The LCA-framework according to ISO 14040**

1. **Goal and scope definition**: Here, the object of evaluation and the reasons and goal of conducting the assessment are defined. System boundaries and the approach taken are explained and the functional unit which all calculations and the assessment of potential impacts are based upon is specified. Furthermore, assumptions made, limitations of the study and considered impact categories are stated. (UNEP/SETAC 2011)

2. **Inventory analysis:** In a second step, the product system and its component unit processes are described and its exchanges with the environment are quantified and evaluated. These so called elementary flows include both inputs – resources extracted from the environment – and outputs which are emissions released into nature. They are grouped in an inventory. This takes place in an exclusively scientific-technological manner and is the foundation of and for the next phase. Over the years much data has been collected and gathered in a number of libraries (e.g. EcoInvent, NERL, GaBi). They include a wealth of generic life cycle data about processes and resources, trying to capture and make available life cycle data as broad and thorough as possible.
3. **Impact Assessment:** Based upon the data from step 2, here the magnitude and significance of the environmental impacts – both at midpoint and endpoint level – are analyzed. First, in the classification step, the available and gathered data – elementary flows, i.e. environmental interventions – is assigned according to the apparent and thus to be selected midpoint environmental impact categories, for instance climate change or human toxicity. Here, the magnitude of aggregation is still very low. Second, the so called characterization is performed, which essentially converts all elementary flows within each category to a single and common unit via characterization factors. This way a category indicator result is determined, showing the contributions of the single categories. At this so called endpoint level, emissions and resource demands are linked with damages to human health, ecosystem quality

and resource base. Figure 2-7 illustrates the UNEP/SETAC scheme of this procedure in its entirety. ISO 14040 and ISO 14044 allow the optional steps normalization, aggregation and weighting to be taken. Normalization means the conversion of units with different dimensions into a dimensionless value in order to show the contribution of each impact category in comparison to a reference. Aggregation and weighting mean the conversion and aggregation of indicator results across impact categories through the use of numerical factors. An example of such a weighted and aggregated impact category is Global Warming Potential (GWP), which is a commonly accepted aggregation method to determine the environmental impact of atmospheric gases. Key to this aggregation method is the amount of CO2 that has the exact same effect on greenhouse effect as 1 kg of a specific gas. (UNEP/SETAC 2011)

4. **Interpretation:** In this very last step all previous findings are analyzed, compared and assessed in light of the initially defined goal and scope. By means of a clear, lucid and logical way of presenting the results, conclusions and recommendations are meant to be drawn. Oftentimes a sensitivity analysis is performed in order to evaluate the results regarding the impact of certain assumptions, aggregation methods, conditions etc.

Summing up, the LCA method has come a long way and matured over the past decades. There is a growing confidence in using LCA, which is to be observed in different parts of society. Because of the ever-growing spread of life cycle thinking and related environmental information in the last years, sales of software dealing with

LCA have risen steeply (Göran Finnveden et al. 2009). Though many limitations have been addressed by scholars, its biggest ones are still that it is very data intensive, that data collection remains the most time-consuming process as so many different pieces of information must be collected (Zhou, Tokos, Krajnc, et al. 2012), and lastly that a lack of data can largely restrict the conclusions to be drawn from a specific study. (Zhou et al. 2012)

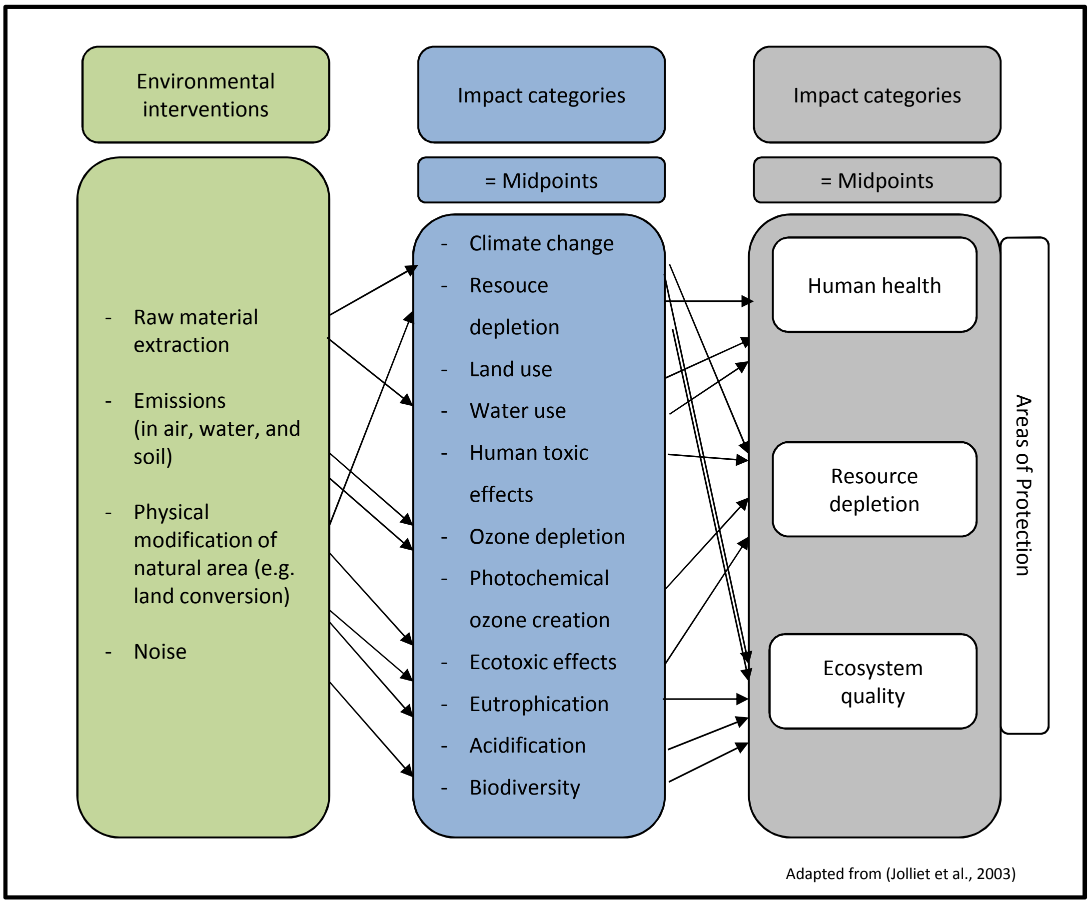



**Figure 2-7: Overall UNEP/SETAC scheme of the environmental LCA framework, linking midpoint to damage categories**

#### 2.2.3.2 Life Cycle Costing (LCC)

LCC is an assessment tool considering all costs related to a product which are incurred over its entire life cycle, encompassing all phases. This is very important as even today it still is quite common to only take into account acquisition cost, even though life cycle cost is often a multiple thereof. Hence, performing an LCC is essential to make substantiated decisions. Contrary to its subdued use particularly in comparison to LCA, it is actually the life cycle methodology which was conceived the first. As early as in 1933, the costs of tractors employing a life cycle perspective were officially assessed following a request by the United States of America General Accounting Office, thereby representing the origins of this methodology. Later it became more sophisticated and rose to some more wide-spread relevance and popularity when in the 1960s as a means of US military to assess the costs of goods deemed to be long living such as tanks, LCC was (further) refined. (UNEP/SETAC 2011; UNEP/SETAC 2009)

And yet, only since quite recently, LCC has been gaining in significance again. Unlike for LCA, an ISO standard does not yet exist in spite of the fact that quite an amount of industry guidelines and references have been developed. However, a number of essential elements can be traced in any LCC. These elements are first the definition of cost categories and cost "measurement procedures" and second modeling decisions. These decisions may be, among others, implementing a discount rate and setting of system boundaries, which need to be equivalent to LCA. Even though this would be ideal, that does not mean they need to be identical, which is oftentimes impossible to ensure. Although there is still a lot of research and validation – to be achieved via further case studies, for instance – to be done, in the earlier 2000s scholars of and in SETAC first specified an LCC methodology capable of assessing the costs of a product incurred over its entire life cycle which is additionally consistent to an E-LCA. The single steps to be performed are now presented in an identical fashion to how it has previously been done for LCA earlier in this section. (UNEP/SETAC 2011)

1. **Goal and scope definition**: Very similar to what needs to be done in an E-LCA, implementing a discount rate and cost breakdown structure (CBS) are the major differences. The advantage of developing a CBS is a consistent and easier collection of data of the life cycle phases. (UNEP/SETAC 2011)
2. **Inventory analysis:** Here, costs are inventoried based on a unit process level. Due to the fact that many companies most often produce more than one product, it is sensible and necessary to allocate the cost to each product. Suggested ways by UNEP to perform such an allocation is to proportionally apply the income a certain product generates or the working hours it takes to manufacture it.
3. **Impact Assessment:** Also very similarly to E-LCA, in this step the results – here being obtained costs - are aggregated by cost categories.
4. **Interpretation:** Interpreting the resulting costs is the last step of an LCC and may sometimes be followed by a review. At this stage, three different structures or dimensions of costs are distinguished: The life cycle stage (e.g. design and development) and the cost category (e.g. labor costs).

The following Table 1 exemplarily illustrates life cycle costs of three different, competing products. Figure 2-8 graphically plots them in a bar chart, giving a quick and clear overview of "total" life cycle costs per year.

| | Opel Corsa 1.0 | Fiat Punto 1.2 | Citroen C2 1.1 |
|---|---|---|---|
| Acquisition cost | 10,945 € | 10,890 € | 10,990 € |
| Life cycle cost (p.a.) | | | |
| Acquisition cost | 1,977 € | 2,164 € | 1,936 € |
| Tax, insurance etc. | 1,753 € | 1,911 € | 1,527 € |
| Operating costs | 909 € | 964 € | 998 € |
| Maintenance/repair | 352 € | 490 € | 318 € |
| **Yearly total cost** | **4,991 €** | **5,529 €** | **4,779 €** |

**Table 1: Life cycle cost of (operating) a motor vehicle**

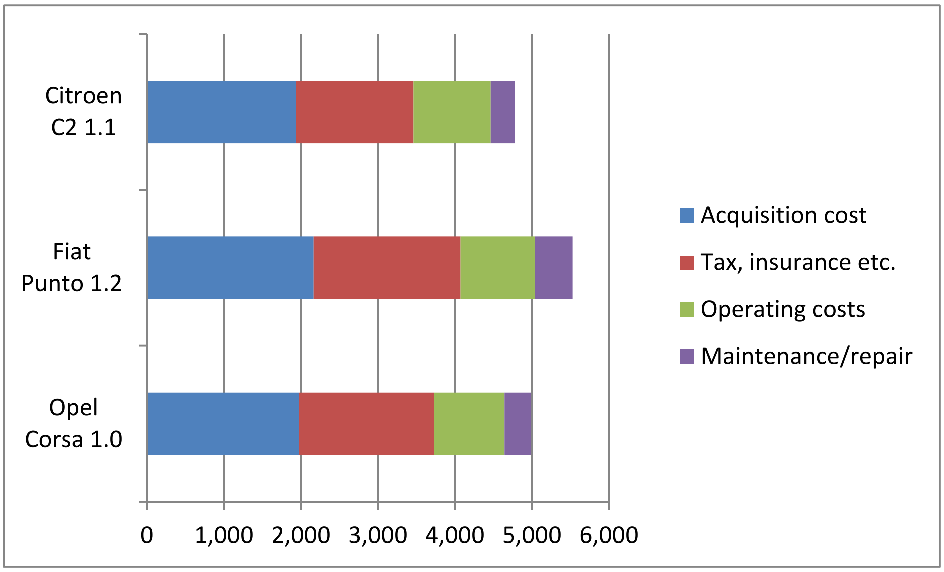



**Figure 2-8: Breakdown of total cost of operating motor vehicle on a yearly basis**

Because LCC and E-LCA are rather similar as in that they are both based upon interconnected material flows over the single life cycle phases, it is very tempting and also quite possible for LCC to address the economic impact of a product that is being assessed for its environmental impacts in an E-LCA. However, this proves to be very complex and difficult as there are many modeling pitfalls to attain a reasonable and consistent assessment.

#### 2.2.3.3 Social-Life Cycle Assessment

S-LCA is the last pillar of measuring the impacts in all three major sustainability dimensions and is considered to still be in its infancy (Kloepffer 2008). The three-dimensional view on sustainability lastly found its way into business and public attention through Elkington's definition of the Triple Bottom Line, which has been mentioned before. Elkington himself acknowledged that social justice was often overlooked in the business world in light of the company's ardent focus on economic prosperity and environmental quality. (Elkington 1998) Since social and socio-economic assessment methodologies have been largely neglected until quite recently and still are to some extent, the next paragraphs will go into slightly more detail in order to introduce this rather new technique not an abundance of literature has yet been published about. Social Life Cycle Assessment (S-LCA) is seen as the reference method at the moment. (Ciroth & Franze 2011a)

S-LCA evaluates and determines social and socio-economic impacts of a product and its impacts – both positive and negative – along its life cycle. For that reason, generic and site specific data are used. This is exactly where and how S-LCA majorly differs to longer existing techniques. Although a certain amount of frameworks in the field of social impact assessment has been published over the years, they hardly ever focused on a product-, let alone life cycle view. Consequently, the various stakeholders – supply chain actors, consumers, the public etc. – play a vital role in S-LCA as they are the ones who do affect and are affected by a product during its transition through the individual life cycle stages.

S-LCA does not aim to assist decision-makers in their choice of whether a product is to be produced or not. Instead, it is only meant to document the utility of the product and thus still provide useful information for decision-making (UNEP/SETAC 2009). It is also a useful means to investigate and analyze claims made about products. It helps companies improve their products' social performance and assists to eradicate wrong public perceptions. (Ciroth & Franze 2011a) It may thus also initiate the dialogue between subjects on relevant social aspects of production and consumption, consequently potentially providing the stepping stone to improve the sustainability efficiency and well-being of organizations and stakeholders respectively. (UNEP/SETAC 2011)

There are quite a few similarities between LCA and S-LCA as the latter "draws largely on the E-LCA methodology." (UNEP/SETAC 2009) Just as is the case with LCA, S-LCA requires a large set of data, is an iterative procedure and conducts hotspots assessments among many others. S-LCA differs in that regard that it provides a broader and more thorough picture of the products' life cycle impacts. It also follows the ISO 14044 framework of E-LCA with there being many common elements. For instance, the functional unit is just as fundamental in S-LCA as it is in E-LCA. However, a few aspects do differ of which the most significant ones are now presented according to the single steps in which they occur. This makes elaborating on S-LCA so important for this study which aims to assess sustainability on all three dimensions.

Since conducting a S-LCA is expensive, time consuming and possibly delivering an abundance of data, prioritization is frequently required. Oftentimes it is not necessary to get data on site at every organization that is part of the product's life cycle. It may thus be beneficial to set priorities according to the sphere of influence of the companies involved in the study and the relative importance of the specific life cycle phases of the product being evaluated. There are a couple of options to specify the latter. Determining the added value of each of the processes along the supply chain and life cycle or quantifying the worker hours are two examples out of many.

The following paragraphs will explain the differences of S-LCA as well as in some more elaborate detail what each phase consists of. An S-LCA framework will be presented as it is illustrated in the Guidelines for Social Life Cycle Assessment of Products by UNEP/SETAC (UNEP/SETAC 2009) and the report Towards a Life Cycle Sustainability Assessment, which was also drafted by UNEP/SETAC. (UNEP/SETAC 2011) The following paragraphs are almost exclusively based upon these two sources by the very influential institution that is UNEP/SETAC as they are one of the first to have composed such a delicate and applicable framework for social LCA which has been a field of interest largely neglected.

1. ***Goal and scope definition:*** On top of the necessary steps and requirements of an E-LCA as has been pointed out previously, an S-LCA additionally requires practitioners to consider the social impacts of the product's use phase. S-LCA

also encourages external stakeholders to provide input on impacts. A major difference is that there are also stakeholder categories on top of impact categories. Subcategories are classified accordingly. S-LCA is much more site-specific than E-LCA still currently is – even though awareness of the need of the latter being more site-specific has increased lately as the impact of e.g. emissions is often dependent on the local ecosystem affected – in that in some cases it may require information about politics in their varying degrees from country to country and its specific laws.

The framework that is presented here understands social impacts to be the consequences of social interactions in the context of e.g. production and actions induced by stakeholders. They are a result of relationships and therefore depend on politic, economic, ethical, psychological, cultural etc. aspects, making them very complex in nature. They also give feedback to the production system itself and society on the whole. This way, they also induce other and further social and environmental impacts.

Subcategories are the foundation of any S-LCA assessment as their inclusion or exclusion is to be justified. They are evaluated using a number of inventory indicators and classified regarding to stakeholder and impact categories. Subcategories are important themes of social concern.

In Figure 2-9, the assessment reference framework for S-LCA developed by UNEP/SETAC is presented.

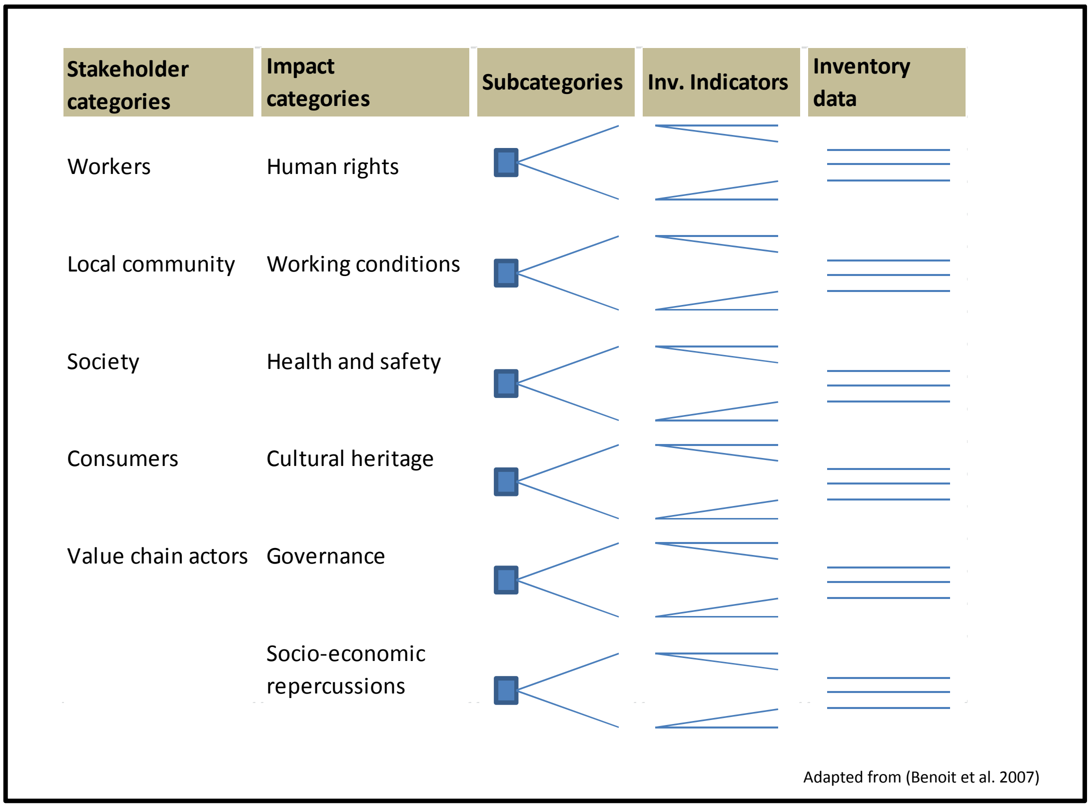



**Figure 2-9: Assessment system from categories to unit of measurement**

To ease operationalization, classification into impact categories is useful in order to determine and identify the necessary and particular stakeholders involved. It is expedient and generally assists acceptance when impact categories reflect standards that are recognized internationally, such as the UN declaration of economic, social and cultural rights. Social subcategories can then subsequently be classified by their respective stakeholder categories. This in turn eases the classification of subcategory indicators which have the same impacts in groups.

The stakeholder categories reflect the entire life cycle of a product and are clusters of stakeholders which are assumed to have common interests thanks to their insinuated comparable relationship to the product system in evaluation.

Social and socio-economic subcategories are all defined in accordance to international agreements and presented in the following Figure 2-10.

| Stakeholder categories | Subcategories |
|---|---|
| Stakeholder "worker" | Freedom of Association and Collective Bargaining<br>Child Labor<br>Fair Salary<br>Working Hours<br>Forced Labor<br>Equal opportunities/Discrimination<br>Health and Safety<br>Social Benefits/Social Security |
| Stakeholder "consumer" | Health and Safety<br>Feedback Mechanism<br>Consumer Privacy<br>Transparency<br>End of life responsibility |
| Stakeholder "local community" | Access to material resources<br>Access to immaterial resources<br>Delocalization and Migration<br>Cultural Heritage<br>Safe and healthy living conditions<br>Respect of indigenous rights<br>Community engagement<br>Local employment<br>Secure living conditions |
| Stakeholder "society" | Public commitments to sustainability issues<br>Contribution to economic development<br>Prevention and mitigation of armed conflicts<br>Technology development<br>Corruption |
| Value chain actors not including consumers | Fair competition<br>Promoting social responsability<br>Supplier relationships<br>Respect of intellectual property rights |

**Figure 2-10: Stakeholder categories and subcategories**

The proposed best example of a universally applicable set of social criteria are the international conventions on Human Rights and Workers Rights. They are the result of negotiations between countries and thus neglect personal and cultural subjectivity let alone political orientation.

2. ***Inventory analysis:*** Here, the differences are mostly in the realm of data. Data sources are obviously not the same as much more data is supplied by stakeholders whose involvement and participation is generally very much emphasized. Their collection and extraction steps and methods are different as well. Another striking dissimilarity is that for S-LCA a lot more so called activity variables data, for instance the amount of working hours to be able to estimate the share of every process in the product system, is used than in E-LCA. It must be noted, however, that with S-LCA data that is subjective in nature may often actually render and mirror a more realistic and accurate image of the working situation. Examples for such subjective and yet rather objective data are the perceived level by workers of their environment they work in or the control they have over their schedules. If one was to include the variability of the arrival times of the employees, for instance, the obtained results may cause for there to be more uncertainty than without.

Here in this step, the most time-consuming activity is to gather the required data in order to be able to determine how the single organizations involved in the value chain perform on social and socio-economic aspects. As has been mentioned earlier, conducing a S-LCA needs to be reasonably inexpensive and time-efficient for it to be applied and thus to be of value. Hence, not every single stakeholder involved in the product's life cycle can be taken into consideration and assessed. Instead, above mentioned prioritization comes into play, culminating in hotspot assessments – the provision of extra information on areas that may be of most important concern in the life cycle of a product – and a small number of on-the-spot visits to name only a few methods. Random checks would incur the risk of possibly neglecting meaningful problems.

3. ***Impact assessment:*** First, the characterization models vary and second, the use of performance reference points is specific to S-LCA. A major difference to E-LCA is the fact that with S-LCA there can be positive impacts that a product has on or in its various life cycle stages. In E-LCA there is only negative impacts. To also include positive beneficial impacts comes in useful as they are more often than not quite important and keeping track of them also serves as an incentive for companies to perform to a level beyond mere compliance.

Here, impact categories (e.g. working conditions of workers) and its subcategories (e.g. fair income, working hours etc.) are selected. The next steps are very similar to the ones also performed with E-LCA. A classification process – i.e. the assignment of inventory data to the single subcategories and inventory categories – is followed by a last step, the characterization. This means an aggregation of inventory data within the previously selected subcategories and categories in order to determine the results for the subcategory indicators.

Impact categories are a logical way to group the S-LCA findings and results. Two types of impact categories are distinguished: type 1 impact categories accumulate and summarize the various subcategories' results that are in the same cluster of interest to the stakeholder. Human Rights is an example for that. Type 2 categories, on the other hand, are concerned with the results of the subcategories which are causally related to each other based on the criteria, autonomy for instance. These type 1 and 2 results are the last values to be calculated before moving on to the interpretation step.

It is quite possible that more than one subcategory can be used to describe an impact category. The aim of subcategories, in general, is to characterize the impacts in an impact category. To state the just mentioned example above, working hours and a fair salary may be used to describe the impact category of working conditions of workers.

4. **Interpretation:** Here, additionally information on the level of engagement of stakeholders is assessed.

### 2.2.3.4 Concluding remarks

With the assessment tools just presented, one must always consider the substantial question of whether the tools used fulfill the objectives? Moreover, according to Ness et. al (2006) the following questions need to be posed to evaluate the usefulness and robustness of the tools employed: (Ness et al. 2007)

Is the tool employed capable of…

- … integrating nature-society systems?

- … assessing different scales or spatial levels?
- … addressing short-to long-term perspectives?

Particularly in the realm of product-related assessment tools, however, environmental parameters are still the ones that are majorly focused on. Reviews of common practice and literature which have been conducted in the course of this study come to the conclusion that other than LCC, the tools frequently and overwhelmingly still do not pay much or any attention to social or economic aspects. Although there have been developments towards more integrated approaches, they are not widely used yet. Furthermore, research has taken on a different and additional path of combining a number of tools for a wider scope of analysis. (N. Wrisberg et al. 2002)

In this particular regard of combining several tools, there exist two different opinions on which scholars are strongly divided upon. (Kloepffer 2008)

***Option 1:*** One option is to separately conduct E-LCA, LCC and S-LCA using – if not identical at least – consistent system boundaries. Although there still is further research to be conducted, a certain level of standardization and harmonization (thanks to the guidelines of UNEP / SETAC, for instance) has been achieved with it now being possible, among others, to follow the same step routine with all of the three methodologies.

This option's key advantage is the transparency it provides. No weighting scheme is applied between the three dimensions of sustainability so that there cannot be any compensation between them. Advantages and disadvantages of the single assessments can be clearly, individually and meaningfully illustrated.

$$LCSA = LCA + LCC + SLCA$$

***Option 2:*** With the other option – which Koepffer (2008) points out is not compatible with ISO 14040 as a "proper" LCA only addressed environmental aspects and potential impacts etc. and is therefore not be favored – up to three impact assessments (= step 3 of all proposed methodologies) may follow one Life Cycle Inventory (= step 2). This gives it the advantage of it needing to only define one Life Cycle Inventory model within the first Goal and Scope step. Another benefit of this approach is that only one final and clear score is reached, compressing all sustainability assessments. This simultaneous approach of all three tools is particularly interesting for management and public alike as they often neither have the time nor the necessary knowledge to comprehend and retrace the single steps conducted. However, the overall results of such an approach are currently not integrated in any manner. (Ness et al. 2007)

*LCSA = LCA new (including LCC and S-LCA as additional impact categories in Life Cycle Impact Assessment)*

Further research and implementation in industry and management will show which of the two options will prevail.

### 2.2.3.5 Snapshot of industrially used concepts

Having introduced the three most commonly and established tools or methodologies to assess the impacts of products across their life cycle stages, it is now time to move from the rather theoretical background to the more hands-on and applicable part of this this very section. We will now introduce a small number of the most frequently applied approaches and key tools that all take use of aspects and methodologies that have already been brought to attention. They are the foundation upon which the recommended and developed approach to assess GPS of this thesis are based.

**Global Reporting Initiative (GRI).** As has been mentioned at numerous occasions already, it cannot be stressed enough what a great wealth of literature has been published concerning the field of sustainability development and assessment. Consequently, a large number of parameter sets and methods to report on sustainability has been devised and proposed over the years, many authors and scholars wanting to make a valuable contribution. This, however, has caused quite some confusion, which – again – this study aims to resolve.

It is due to these countless philosophies that exist in the area of sustainability and the subsequent countless reporting practices that the Coalition for Environmental Responsible Economics (CERES) and the United Nations Environment Programme (UNEP) created the GRI in 1997 with the aim of "enhancing the quality, rigor and utility of sustainability reporting" (Global Reporting Initiative 2002). Despite it not particularly focusing on products alone, it is still included in this study for a couple of reasons. Not only has the GRI initiative made a key contribution to the field of sustainability assessment in general and in terms of its global scale as well, but it is also the only internationally recognized initiative the focus of which is with the reporting of sustainability of the entire company. (Global Reporting Initiative 2002)

CERES and UNEP have achieved to launch a single and global framework, which even as early as in the year 2000 had plentiful and ardent followers (Birchard 2000). The GRI Sustainability Reporting Guidelines are a framework that provides companies a means to voluntarily report on the performance of their activities, products and services in the three sustainability dimensions. They are designed to be long term, universally applicable to all organizations across the world, involving all relevant stakeholders and to be suitable and used for comparisons of companies regarding their sustainability efforts. (Hussey et al. 2001) They introduce a standardized, transparent and consistent approach that enables the information given to markets and society to be more useful and credible. (Global Reporting Initiative 2013)

Other reasons for the decision to include GRI in this study about GPS are among others, the fact that GRI contributed the most indicators to the previously introduced classification done by NIST and that in the past other authors also determined the GRI guidelines to be the most comprehensive. (Joung et al. 2013; Hussey et al. 2001) Furthermore, it is the companies that manufacture the products which is why it always comes in helpful to be able to assess the sustainability at corporate level as well. One could then use the overall impact of the entire organization at all dimensional levels and allocate it to the individual product categories and products themselves via certain methodologies, e.g. a value added or revenue ratio approach.

As the GRI are periodically reviewed and updated, it is subject to changes. It currently contains 93 indicators spanning all three major dimensions of sustainability. Figure 2-11displays the dimensions and the hierarchical structure of the GRI. (Global Reporting Initiative 2014; Labuschagne et al. 2005)

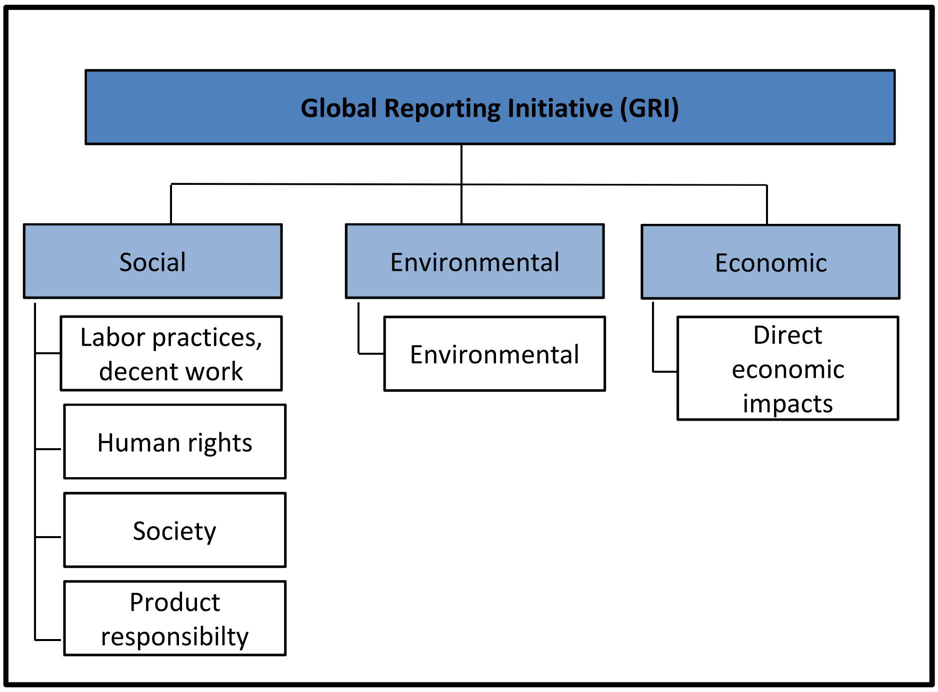



**Figure 2-11: The hierarchical structure of the Global Reporting Initiative (GRI) framework**

**Ford Product Sustainability Index (FPSI).** Among the wealth of literature and indicator set reviews, the FPSI would often be mentioned as a tool focusing primarily on the process and product level for sustainable manufacturing. It considers indicators of all three main sustainability dimensions in the manufacturing of their products – automobiles – and services. Due to the specific and rather narrow approach in terms of products evaluated, this approaches suffices with eight indicators only (Joung et al.

2013), which reflect major impacts of subjects in question. Figure 2-12 illustrates these dimensions and themes.

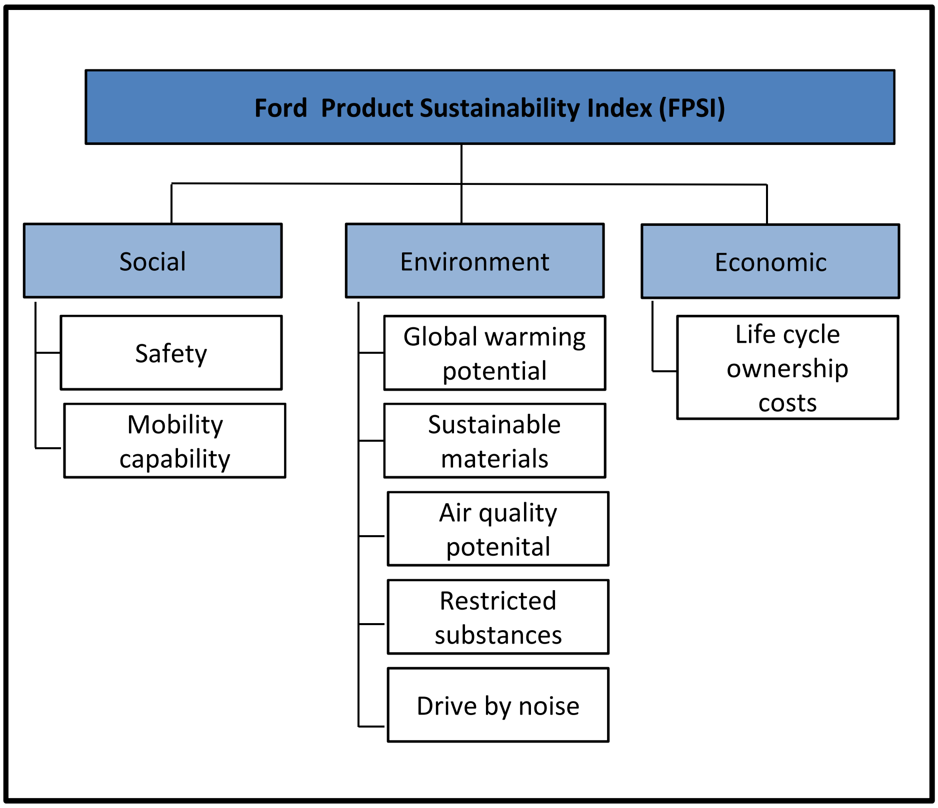



**Figure 2-12: Hierarchical structure of the Ford Product Sustainability Index (FPSI)**

Although the FPSI was introduced slightly over a decade ago, it still even to this day is one of the very few sustainability assessment tools on the micro product level and was therefore of particular interest to this study. The Ford Galaxy and Ford S-MAX were the first cars to be developed employing this framework, with all other vehicles since to keep the PSI in mind (Ford 2007).

The specialists at Ford invented a conclusive and broad and yet rather easy to use spreadsheet file which enables everyone to track PSI progress without long training sessions and to keep the administrative burden to a minimum.

A major shortcoming of this methodology, which is why it can only be regarding as a starting point and stepping stone on the way to a truly comprehensive product assessment tool, is that although it follows the four main steps of an LCA, it does not cover a range of topics. Service aspects, legal compliance issues, information on toxicity etc. are only a few issues that do not find appliance.

What served as great inspiration for the development of the tool and approach which is later presented is Ford's usage of a spider chart to present the assessment's results in a clear and lucid way that is easy to get an overview of as is presented in Figure 2-13.

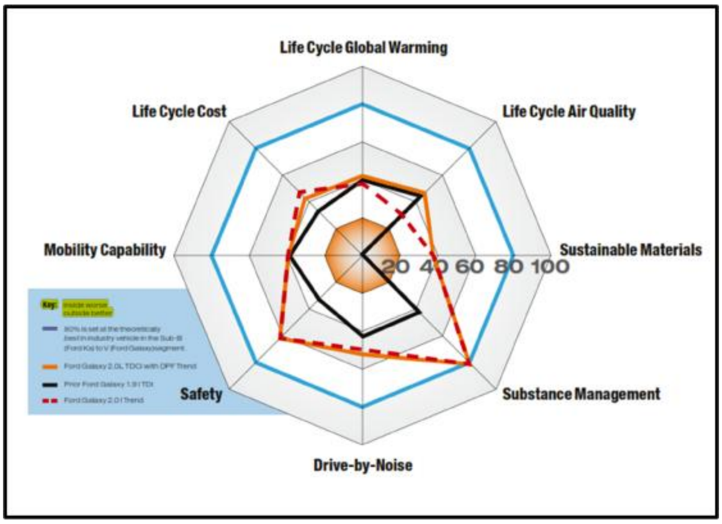



**Figure 2-13: Example of application of Ford Product Sustainability Index of Ford Galaxy**

In the above figure, three different models of the Ford Galaxy are portrayed. Around the spider chart the indicators and their dimensions are plotted. The further away the differently colored lines – each one representing one of the models – are from the center the better it performs in that particular area.

**BASF SEEBALANCE.** Firms operating in the chemical business have always been pioneers in the usage of any form of life cycle assessment. In particular, BASF as the world's largest chemical company, has proven to be a trendsetter. Their invented approach called SEEBALANCE is a frequently quoted example of a product assessment tool in literature. (Grießhammer et al. 2007; Saling et al. 2002)

The foundation of this very approach is an eco-efficiency analysis which covers the two sustainability dimensions of economy and environment in a simultaneous fashion. (Saling 2002) It serves to quantify the sustainability of several products and allows comparisons between them to be made This way, ecological impacts and total costs of the products and their main drivers are assessed. Eco-efficiency analysis by BASF compresses these key pieces of information and presents them in a clear and easily understandable form. No absolute values but exclusively relative comparisons are used. The way this is done is shown in the following Figure 2-14. BASF employs a spider chart as well, which – with their relative values – is then plotted on a vertical line. The differently colored lines represent different alternatives.

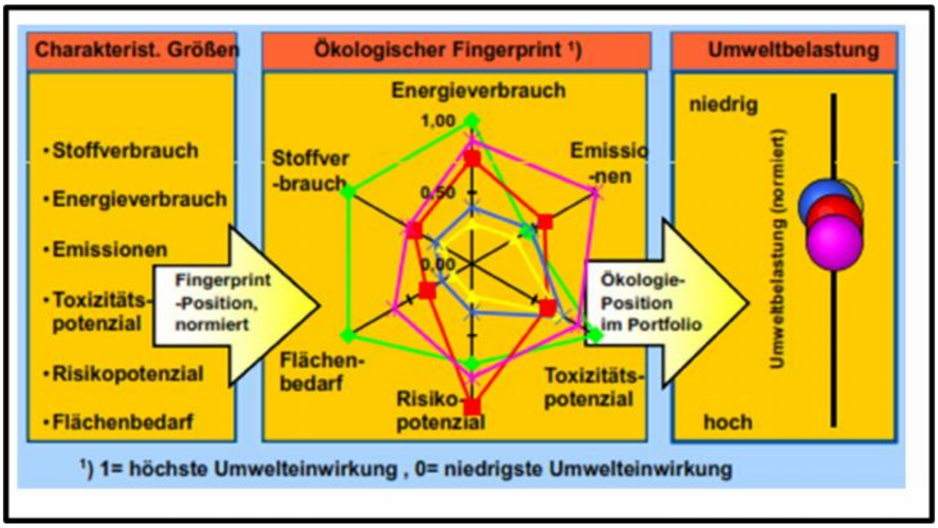



**Figure 2-14: Relative comparison of environmental costs in SEEBALANCE method**

In a second step, total costs are then plotted on a vertical line, with the alternatives incurring higher cost plotted to the left of the line. This is illustrated in Figure 2-15.

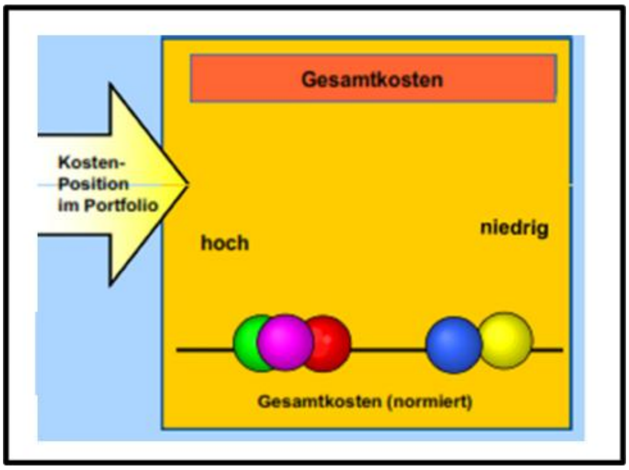



**Figure 2-15: Illustration of next explained step in SEEBALANCE method**

In a last and final step of the first part – the eco-efficiency analysis part – of the SEEBALANCE method is a synthesis of the assessment of total costs and environmental impacts. This is achieved via a normalization as shown in Figure 2-16.

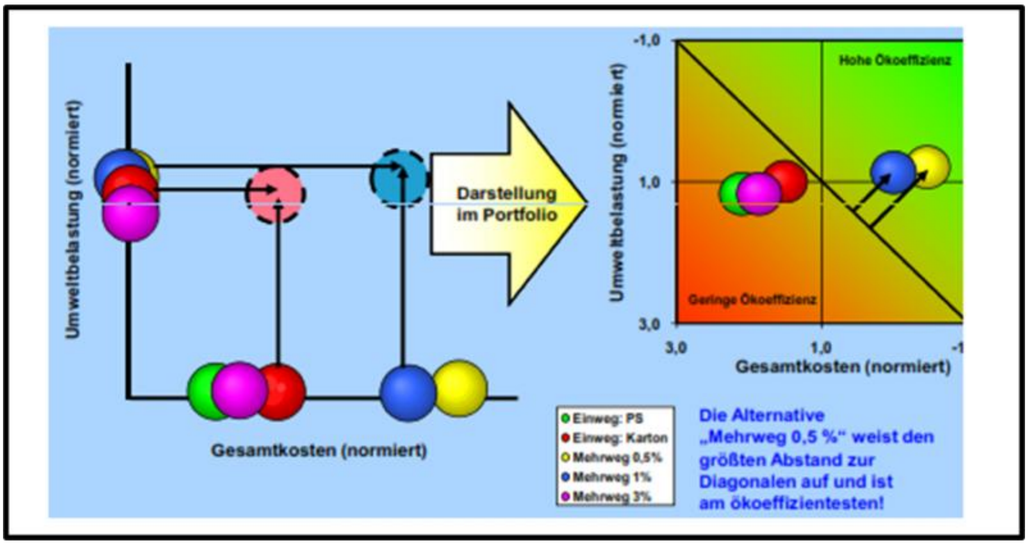



**Figure 2-16: Synthesis of assessed total costs and environmental impacts in SEEBALANCE**

BASF employs a rather concise yet expedient way for this. By laying the one dimensional representations on top of each other, the economic and environmental results are shown in a two dimensional grid, allowing for a readily intelligible and easily readable form, which is useable by LCA-experts and people without any experience in this field alike. The alternative represented with the yellow circle is the farthest away from the diagonal line, thus  making up for the most eco-efficient line.

With the second and last key step of the SEEBALANCE analysis, the third pillar of society is added to the eco-efficiency analysis, thus making it a comprehensive tool covering all dimensions of sustainability. This is achieved by an integrated assessment of ecological, environmental and social quantifiable factors for products and processes. (Saling 2002) The social indicators used are classified according to five stakeholder categories, which is a very similar approach to the one advocated by

UNEP / SETAC in their contribution to S-LCA as is shown in section 2.2.3.3. For the sake of completeness, the social indicators are shown in the following Figure 2-17.

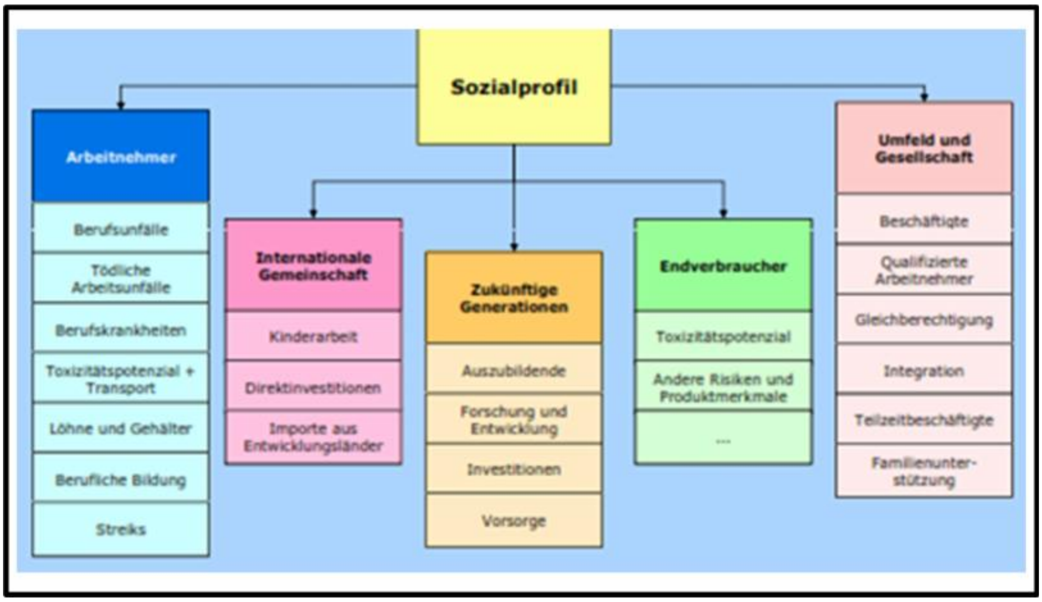



**Figure 2-17: Social indicators employed in SEEBALANCE method**

The social impacts in and of every category are first assessed and then plotted in their respective bar charts which can be seen in Figure 2-18.

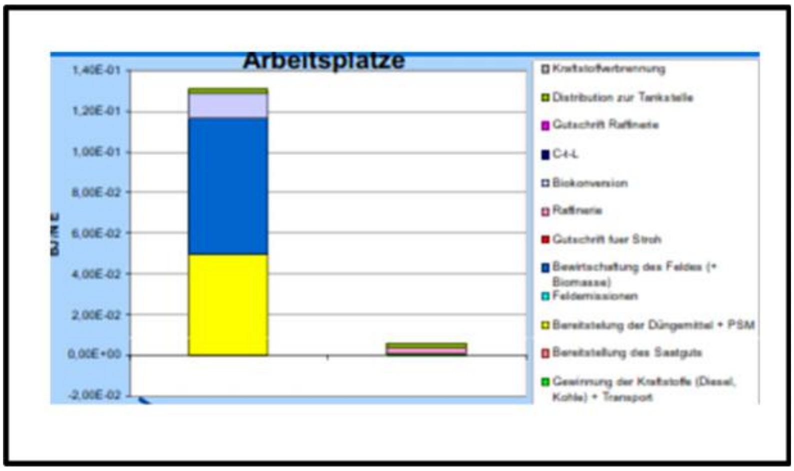



**Figure 2-18: Plotted social impacts**

Next, the results of all bar charts are weighted and transferred in a so called “social footprint” spider chart, where it is again beneficial to be as close to the center as possible with the value 1 symbolizing the highest impact. This is illustrated in Figure 2-19.

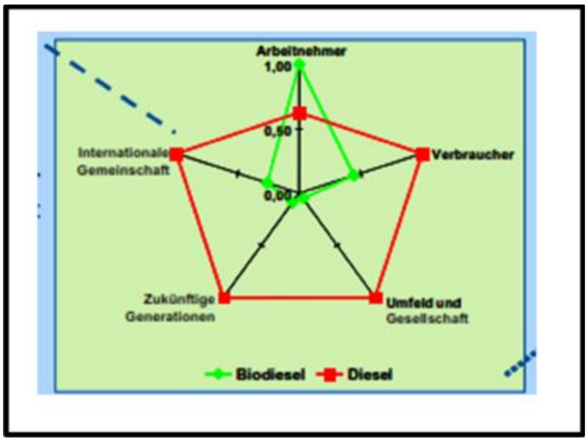



**Figure 2-19: “Social footprint” spider chart as it is used in SEEBALANCE method**

These results are then in a final step to the other two dimensions, making up for a three dimensional graph which BASF calls the SEE Cube. This is illustrated in Figure 2-20.

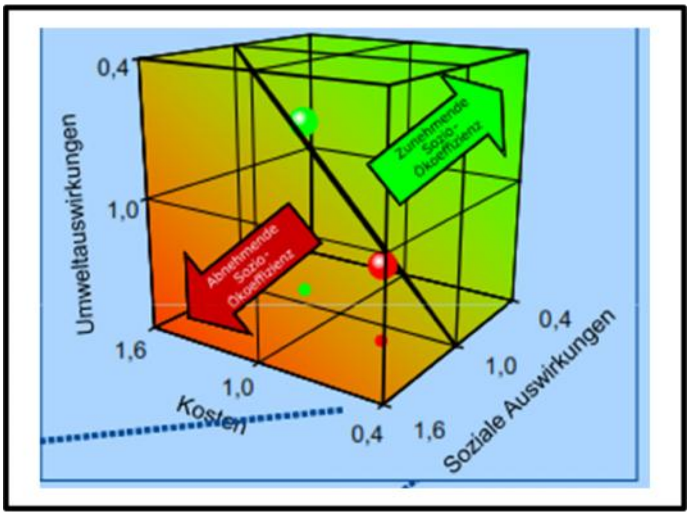



**Figure 2-20: Final result including all three dimensions of sustainability in so-called SEECube**

The further a sphere representing an alternative is to the green far right top corner, the better its social-eco-efficiency is.

This method's most significant shortcoming is that it only allows for relative comparisons. Although this certainly has the potential to aid any company to select the most eco-efficient and social alternative, thus contributing to a more sustainable world, it is of limited use in terms of GPS. However, many ideas could be drawn from BASF SEEBALANCE, which made it worth exploring in more detail.

For a more in depth description of the method, the interested reader is asked to read the full document which can be found at the BASF website.

**PROSA.** PROSA, which is short for "Product Sustainability Assessment", is a guideline developed by the Öko-Institut e. V. – Institute for Applied Ecology. It is a method which greatly inspired this study as it combines quite a number of frequently used and established individual tools (such as LCA, LCC etc.) in one framework. It is a method to strategically analyze and assess products and services with the goal to identify system-innovations and options with which to achieve a development towards more sustainability.

One of the main contributions of PROSA is to structure the necessary decision processes and to reduce complexity to a minimum. This is achieved via several tools PROSA offers. One of which is the pathfinder, which structures the execution of PROSA in a clear way, showing the specific phases, its individual tasks and the desired outcomes as well as the tools and aids used to achieve them. Additional tools which help the user are checklists making sure nothing is forgotten, indicator overview lists, example extracts of the single tools used within PROSA and in general extra tools such as ProfitS, which is an interpretation framework.

The basic structure of PROSA can be seen in Figure 2-21.

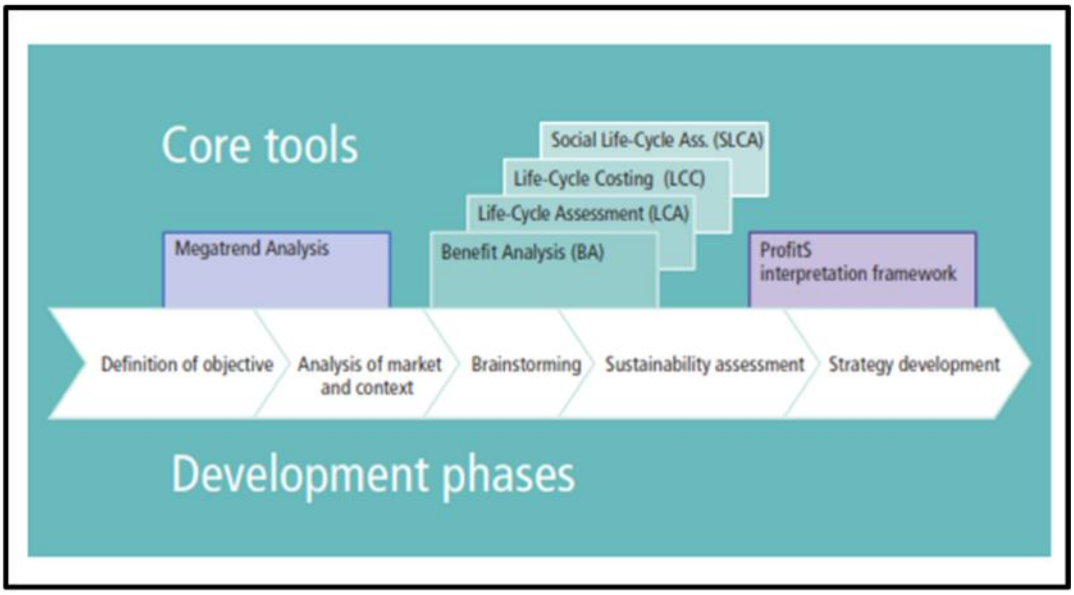



**Figure 2-21: Basic structure of PROSA**

It is the integrated assessment model ProfitS, which stands for Products-fit-to-Sustainability, that combines all assessment tools and thereby assesses the product in all three sustainability dimensions, giving an overall impact. This can be done with the ProfitS Excel tool which takes the average value – which ranges from 1 = very good to 10 = very poor – of each separate tool and thus dimension, aggregates these and lastly weights these as well. A standard ratio of 1:1:1 is used, which can be adjusted as is wished. The overall evaluation can then be presented either via a bar or spider chart, which can be exemplary seen in Figure 2-22.

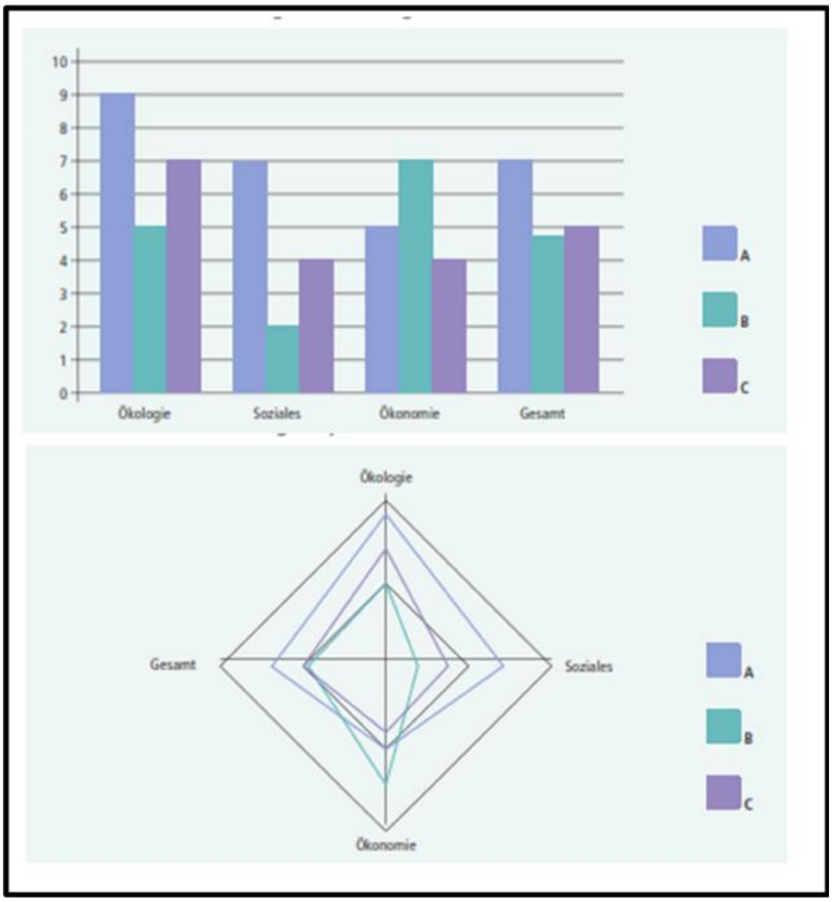



**Figure 2-22: Bar and spider chart representation of overall evaluation in PROSA**

As is the case with BASF SEEBALANCE, it is not the goal of PROSA to assess products in absolute terms. Instead, strategic decisions are to be prepared and opportunities and risks regarding sustainability to be identified.

## 2.3 Explaining Externalities

In the following, a term shall be explained that was of substantial inspiration to the author to conduct this study. In one of her very informative and highly provocative videos called "The Story of Electronics" Annie Leonard defines the term "designed for the dump", a strategy supposedly employed by companies to manufacture goods to be thrown away quickly. (Leonard 2009) She states that today's electronics are hard to upgrade, easy to break and impractical to repair. Leonard goes on and tries to explain that through the act of externalizing the cost of production, i.e. the real cost of production is not captured in the price – manufacturers make everyone pay their prize along the entire supply chain, from a loss of natural resources to severe health issues. (Leonard 2009) As this study will in later stages move towards consumer electronics, this video thus provided particular motivation to deal with the almost impenetrable field of sustainability.

The term externality is originally rooted in economics and is also frequently referred to as external costs. Some costs of a product are borne by producers such as salary expenditures or material costs, which are then paid for by the consumers. Other costs, however, are not covered. External costs describe these kinds of costs that are not represented in the price of a product or a service etc and mean the uncompensated effects – which can be beneficial, but are more often than not harmful – of economic decisions on stakeholders that did not choose to be affected, neither positively nor negatively, in the first place. (Mankiw & Taylor 2012) Bittman (2014) argues that almost everything produced had externalities and provides the simple example of wind turbines, which kill birds and are noisy, which is not factored in in their price. (Bittman 2014) He then goes on to make the comprehensive case of evaluating the true cost – a term often used in this context – of a burger, which is much higher than the actual price people pay at the respective fast food chains or food stores. The major externalities connected to burgers are carbon generation due to the large herds of cows that need to be maintained to obtain the masses of meat as well as obesity and the subsequent substantial amount necessary to treat the negative health effects. None of this is captured in the retail price, however. Although this is directly connected to sustainability as well, the following example given by Leonard (2007) is meant to sensitize the interested reader concerning the topic of sustainability and serve as motivation and an incentive for continued interest in both sustainability at large and this study in particular.

In her highly popular video "The Story of Stuff" with which she managed to acquire acclaim and popularity all over the world she gives a very illustrative and thoroughly researched account of externalized costs with the example of a small radio anyone can buy at the retailer Radio Shack in the United States. The video provides an overview of the necessary steps in the manufacturing and distribution life cycle stages as they appear all over the world – mining of metals in South Africa, drilling for petroleum in Iraq, production of plastics in China, final assembly in Mexico, distributing it in the US – and concludes with the question how all this was possible for only 4.99 USD. Leonard recites that none of the true costs, which include the loss of clean air for factory workers, higher cancer rates among the employees, young children dropping out of school so that they can work etc, are accounted for in the account books of companies, which are all about externalizing the true costs of production. (Leonard 2007)

This provocative and generally thought provoking example represents the end of the theoretical foundation of this study, which will now move on to the development of the proposed concept and its requirements.

# 3 REQUIREMENTS TO ASSESS GPS

Before moving on to chapter 4 and the development of a concept to assess Global Product Sustainability, here in this chapter the foundation which the concept will be based upon will be laid out. Certain requirements the concept must ideally if not necessarily have and satisfy will be presented. The suggestions and solutions proposed are taken from both the findings of the literature review that was conducted and from what the authors feel are the most important elements. Figure 3-1gives an overview of these findings.

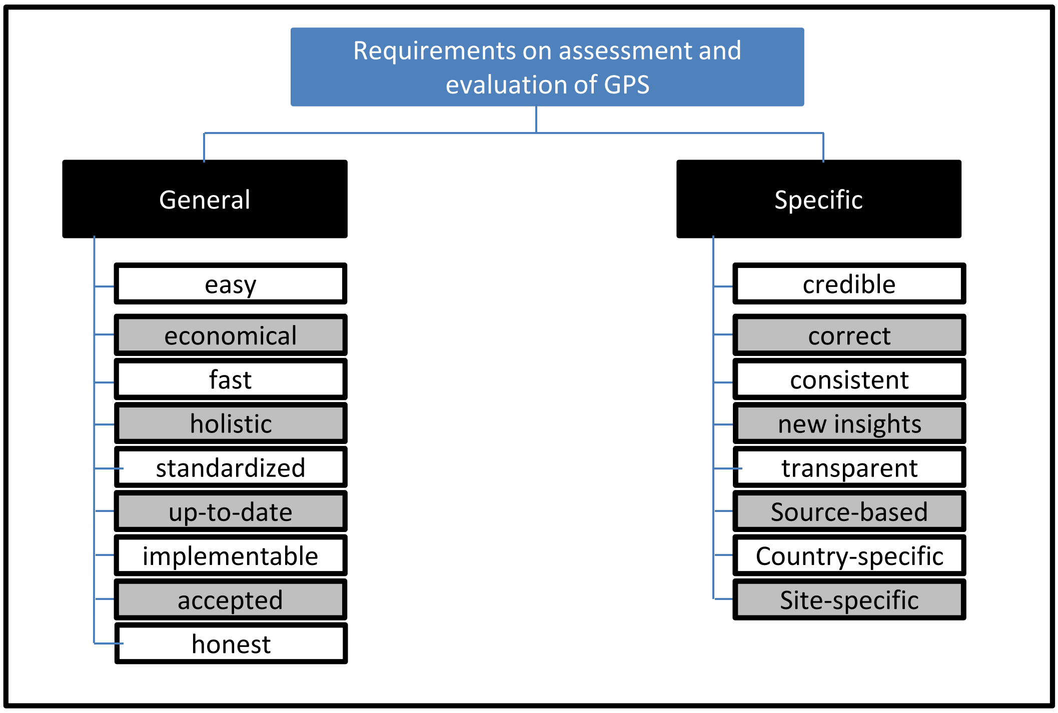



**Figure 3-1: Requirements on assessment and evaluation of GPS**

For the sake of clarity, the somewhat large number of requirements that assessing and evaluating Global Product Sustainability pose is structured in two different blocks, general and specific requirements. Even though such a classification is always bound to be regarded critically due to its apparent and logical subjectivity, this arrangement and representation has been selected deliberately with the global context fully in mind. As could be and was illustrated in chapter 2, assessing sustainability at large has been done for decades already. This calls for a range of general requirements, which will be introduced in section 3.1. Due to the novelty character of assessing sustainability in all of its three major dimensions in an integrated manner and even more innovatively and startlingly, on a global scale as well, it calls for specific requirements. Looking in a dictionary gives a better understanding of the term. Here, specific means particularly distinctive and characteristic, typical and peculiar. Section 3.2 will thus attempt to capture what novel aspects and needs the newly introduced global scale stipulates. At times, one requirement or the other might as well fit in the other category and a clear assignment was impossible. This is a logical consequence of the classification scheme chosen, which is due to mentioned subjectivity not the most selective of them all. It will, however, give the reader a good idea and understanding what is to be expected of the concept that will be introduced in later stages of this study.

## 3.1 General Requirements

For indicators to be well defined and to be of valuable quality when being applied in the assessment of sustainability, they should possess the following SMART-characteristic (Feng et al. 2010; U.S. Department of Energy 1995)

- **S** = Specific and simple: Indicators must not be cause for misinterpretation. They should therefore include and state assumptions and definitions and thus be easily interpreted.
- **M** = Measurable and manageable: It must be possible to measure the indicator quantitatively in an area which is of a sustainability nature, e.g. social well-being. The indicators are also to meet the purpose of measurement while trying to keep their number to a minimum without too much redundancy.
- **A** = Attainable: Information provided must be achievable and reasonable and credible.
- **R** = Realistic, reliable and reproducible: Indicator fits in the given company's constraints and is cost-effective in terms of data collection. Information provided must be trustworthy and consistent in comparing different time periods
- **T** = Timely: Measurement must enable timely, informative decision-making.

This SMART-characteristic already covers quite a number of requirements proposed in Figure 3-1 and its application is therefore crucial in attaining a successful assessment and evaluation of GPS. A meaningful indicator, for instance, would be valuable to management. Striving for better sustainability would thus become an inter-corporate incentive, with management being able to initiate a continuous improvement process. What is additionally of utmost importance is the establishment of a common database foundation. The situation and issue today is that there are manifold life cycle databases and there number is still gradually growing. (Dresen & Herzog 2009; Ciroth et al. 2013) Although a certain standardization could be achieved in the wide area of assessing sustainability, especially in the field of E-LCA and LCC, the elaborations in chapter 2.2 regarding S-LCA showed a relatively big need for catching-up to be done. A commonly accessible database, which for instance stores emissions values of most relevant production processes, would be of enormous help for companies. (Dresen & Herzog 2009) Currently, there is no interaction and no fluent exchange, usually causing businesses to decide for one system and database, thus hugely limiting the availability of data. (Ciroth et al. 2013)

Comprehensive, easily and economically accessible as well as up-to-date (generic) databases which are capable of providing a holistic view is extremely important as in particular most small and medium sized enterprises (SME) are not able to bear the expenditures and the time demands required to conduct a thorough life cycle assessment, which would involve the immaculate tracking of every single process and product. (Dresen & Herzog 2009; Manhart & Grießhammer 2006) It appears as though global guidance is the basis for improved interconnectivity of databases worldwide (Ciroth & Valdivia 2011). Although establishing such a widely accepted database would be a huge step towards a sensible simplification, other aspects are of great significance, too. A widespread and above-average standardization must be achieved so that products of different companies can be, e.g., compared to one another in a fair and concise method. Companies need to use the same system boundaries, among many others, for there to be any chance of meaningful comparisons. This includes a required level of honesty across all companies world-wide. For instance, a company should fairly and honestly state the average estimated consumption and subsequent sustainability impacts of its product during use-phase. If this cannot be warranted, then independent experts should be employed to verify and authenticate a company's claims. Standardization also means identical, i.e. standardized, balancing regulations and identical time periods, for instance GWP100a, meaning that the Global Warming Potential is estimated for the next 100 years by all companies and not for 25 years by one business and 50 years by another. (Schmidt & Walter 2009) As becomes apparent, many requirements deal with achieving a certain level of comparability. In the end, however, none of what is and will be demanded of the single supply chain actors must overburden them. As has previously been illustrated with the example of taking a picture with a camera, a potentially imprecise assessment is much better than no assessment at all. By and large, a method and way of assessing GPS must be put in place that is easily implementable and accepted across industry.

## 3.2 Specific Requirements

Contemplating some of the proposed specific requirements must always be done with the global context in mind. It is of no use when a company only assesses the sustainability impacts of its very own factory where its products are produced without taking into account the preceding and succeeding supply chain actors. Therefore, and this will be discussed in thorough detail in the next chapter, sustainability impacts must be viewed along the entire supply chain, across all life cycle stages of a product, beginning with raw material extraction till recycling and possibly re-use. A fair so-called allocation of the impacts sustained must be insured so that every stakeholder involved receives its respective share of the burden. Such a method as will be introduced and explained further along the line of this study must be credible, correct and consistent. (Ciroth 2013) This goes hand in hand with the crucial requirement of it having to be valid. Companies will only comply and follow certain directives and proposed methodologies – even if it is for the greater good of mankind – if they do not put themselves at a disadvantage because of it. When everyone applies the same principles, however, incurred disadvantages due to its application are out of the question. Furthermore, the proposed methodology and concept in chapter 4 must be able to create new insights in order to be accepted in the first place. It will have to show, for instance, where exactly in a supply chain the biggest costs – both financial and sustainability wise – are incurred so that the biggest potential for improvement can subsequently be deducted. The notion of creating new insights also calls for a certain modifiability of the concept so that it can be adjusted to whatever changes occur in a rather simple fashion. The soon to be established concept needs to be transparent as well (Arretz et al. 2009), which is essentially very closely connected to the requirement of being able to create new insights. Only if the concept is able to create transparency, (new) insights can be realized. This will enable, for instance, hot spots to be spotted and what really is and lies within the area of responsibility of a particular company among many other things. Being connected to the aspect of responsibility is the demand to be source-based. Only those stakeholders who actually cause particular sustainability impacts should be held accountable for those, not enabling them to pass it on to others. (Arretz et al. 2009) Last but not least, the concept should be both country- and site-specific. Certain prevalent circumstances, e.g. different cultures and customs, should be taken into consideration. (Arretz et al. 2009) For instance, experience seemingly proves that one must be cautious with inaccuracies such as double-entry bookkeeping in some emerging markets. Additionally, the existence of different climates and certain types of economic activities which differ from region to region should be taken into account. (Arretz et al. 2009)

A number of what the authors feel to be the most important requirements for the process of assessing and evaluating sustainability on all three dimensions has been compiled and put forward. These were incorporated when developing the concept, which was the next step of this study and which will be illustrated in the next chapter.

# 4 DEVELOPING A CONCEPT TO ASSESS GLOBAL PRODUCT SUSTAINABILITY

Following the previously stated and described issues, requirements and challenges, it is the authors' goal to develop and provide a concept that is capable of addressing one aspect and challenge of assessing GPS that has not received much attention. Rather than providing an applicable tool, it is this chapter's aim to initiate and support scientific discussion as how to deal with it.

Section 4.1 largely deals with the development and composition of the concept. For this, a methodological approach has been used which will be described in section 4.1.1 after which the solution of an additional literature review will be outlined in 4.1.2. Section 4.1 concludes with the description and illustration of the new concept. Several different sources of challenges that may lay and occur within the concept and thus limit its practicality will be introduced in section 4.2. Last but not least section 4.3 closes the entire chapter by providing a discussion of whether or not and to what extent the developed approach is capable of satisfying the requirements which have been posed earlier.

As chapter 4 is all about developing a concept, it appears useful to first define what a concept actually and really is. The origin of the term is with the Latin word 'concipiere' which goes along the lines of 'to capture'. Today, its meaning is to draft or design a temporary, not yet final and very detailed plan. For a concept to be of any use, its goal must be defined and clarified. In practice, concepts are applied very frequently. With the current topic in sight, changes in environmental conditions or internal structure may call for, for instance, a conceptual approach or a change of an existing concept. Essentially, when developing a concept, it is critical to adhere to a structured procedure for it to be of assistance. (AD HOC 2014) That is why one possible option of a clear and lucid proceeding will be introduced in the following section.

One such option is the application of a tool called the problem-solving cycle. Its methodology is presented in Figure 4-1.

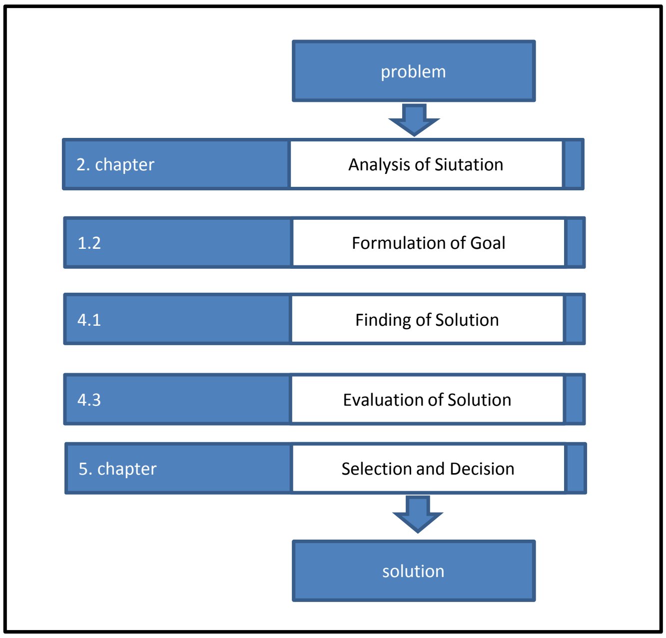



**Figure 4-1: Applied methodology of problem-solving cycle**

As can be seen in the above illustration, the process of developing a concept is always initiated by a posed problem, which is then to be analyzed in a first step. The goal of this study's critical assessment of the situation was to find answers to the questions posted in the summarizing box in Figure 4-2. These findings are then to be synthesised with the formuluation of objectives in the problem statement (see chapter 1.2) so that a solution can be found. Finding and evaluating a solution is this chapter's aim.

| | Questions | Description |
|---|---|---|
| Situation Analysis | What is currently going on? | Look at the problem from different angles |
| | What is the problem? | Analyse possible stakeholder groups |
| | What do we want to change? | Determine the most influential factors and the |
| | What is preventing us from reaching the desired state? | context of the problem |
| | What is it that we need to change? | Define weaknesses |
| | How is the issue currently being dealt with? | Uncover potential risks |
| | What will happen if we do not do anything? | **In short:** Conduct a **diagnosis** |
| | Social Benefits/Social Security | |
| | Used sources | |
| | Extensive literature review | |
| | Brainstorming | |
| | Expert interviews | |

**Figure 4-2: Summary of questions asked and description of steps in situation analysis**

## 4.1 Methodological approach applied for the development

Due to the ever-expanding complexity of the view we have of the world and life in general as well as of the problems we are faced with, the time of universal geniuses such as Leibniz is long gone and not conceivable anymore today. Instead, the ability to recognize and identify problems and needs and devise creative solutions for them are crucial for being successful today. (Vollmer 2012) The authors have therefore availed themselves of the methodology of synectics, a methodology suitable for the generation of new thoughts and ideas that come in helpful when addressing the challenges of developing a concept to assess GPS. The term ‘synectics’ is derived from the Greek and means “the joining together of different and apparently irrelevant elements.” (Gordon 1961) The problem solving methodology of synectics is all about not only attempting to prompt thought processes in the subconsciousness, but also enabling the applicant to understand them in the first place and to then put them to use. New thought patterns shall be derived through reorganizing seemingly discontiguous and distinct knowledge.  (Biermann & Dehr 1997) Applying the methodology of synectics follows ten distinct steps, which are typically performed in small groups and illustrated in the following Figure 4-3.

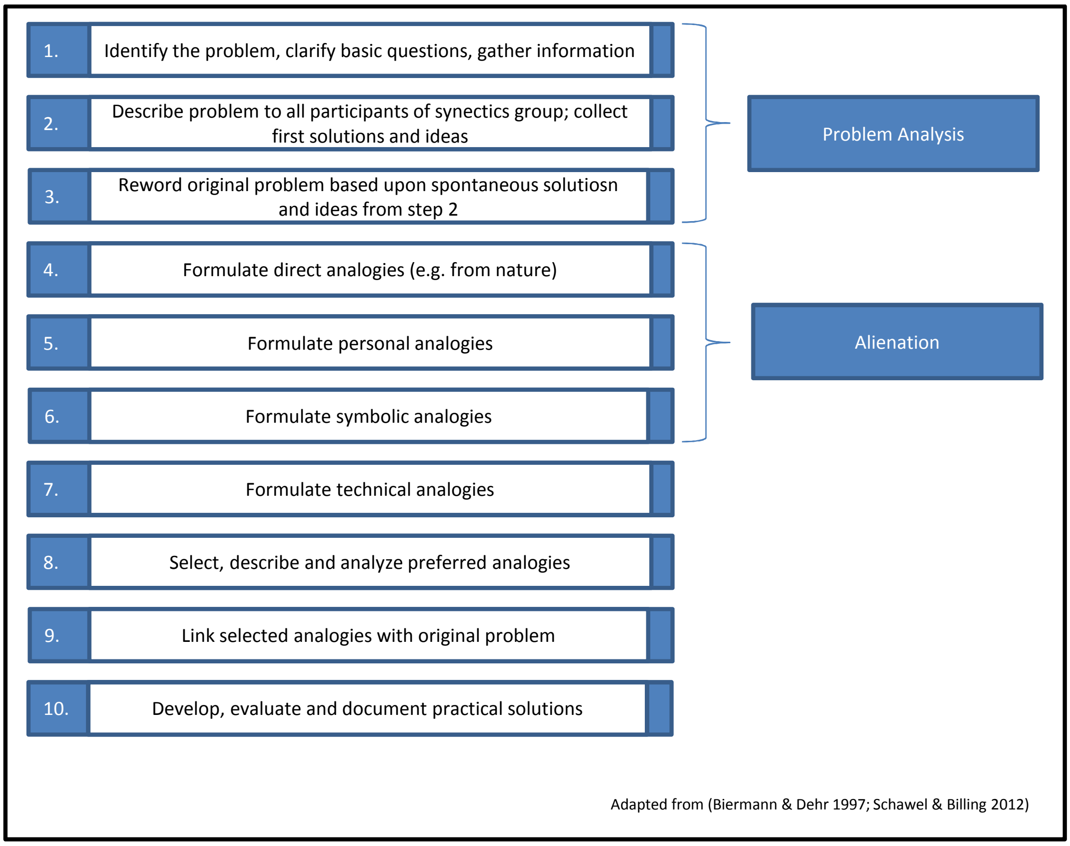



**Figure 4-3: Methodology of synectics approach**

Through this illustrated repeated alienation of the original problem, new and yet still somewhat connected aspects and topics can be derived and linked to the initial issue. Thus the area of knowledge is majorly enlarged. The process of rewording the original problem allows for more distance to the explored issue and hence less restriction in terms of finding new solutions. All this gives this particular methodology an edge over other problem solving techniques. (Biermann & Dehr 1997)

This study's main goal of assessing global product sustainability is very broad in scope and consists of a number of sub-problems, which in turn define sub-objectives. Figure 4-4 illustrates the principle sub-objectives which are aligned with the requirements introduced and explained in section 3. The three columns to the right – depicted in light grey: considering all three main dimensions of sustainability, bearing in mind the entire product-life cycle and evaluating individual products respectively – have already been addressed largely successfully. The sub-objectives illustrated in the right two columns colored in red, however, have not yet been addressed. It is because of this that the problem solving methodology of synectics is mainly focused on finding a solution to the fair accountability of sustainability impacts to all stakeholders of a supply chain and to finding a way to provide better transparency and usability for companies when calculating and accounting for their actual impacts.

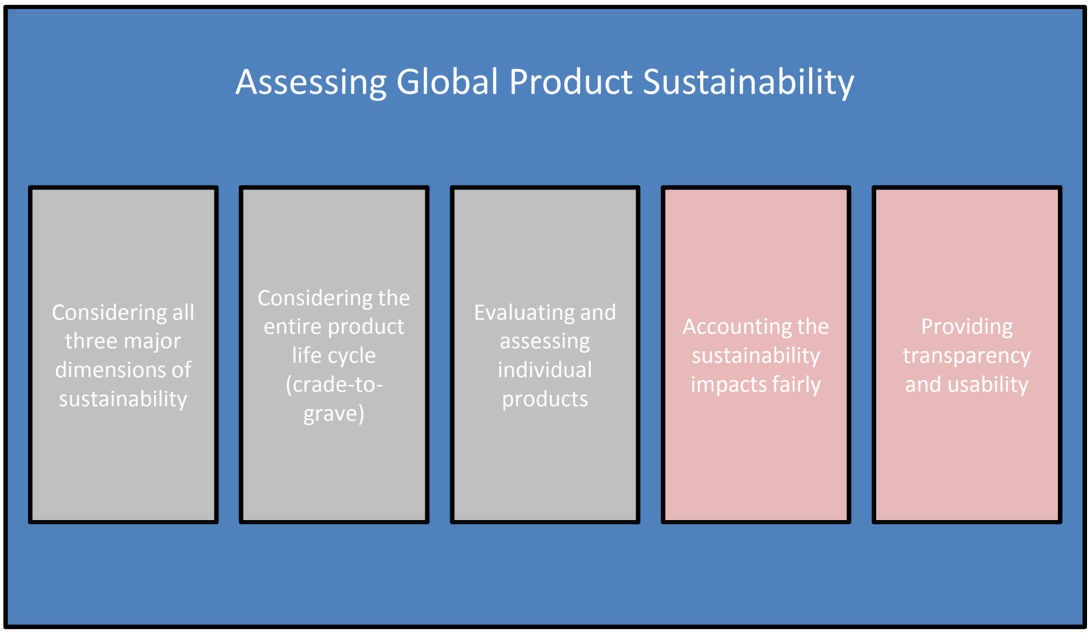



**Figure 4-4: Overall objective and major sub-objectives**

Breaking down the original main objective of assessing Global Product Sustainability yields a reworded problem and thus restructured and reworded goal as well. This new very goal is the foundation of the subsequent alienation phase performed in steps 4 to 7 of the synectics procedure.

*Account process consequences fairly, objectively and transparently between the involved stakeholders.*

The results the authors obtained when performing process steps 4 to 7 of the synectics methodology are illustrated in Table 2.

| **Goal:** Account process consequences fairly, objectively and transparently between stakeholders of a supply chain | | |
|---|---|---|
| | Process Step | Results from alienation |
| 4. | 1. analogies: direct | food chain, fishbone |
| 5. | 2. analogies: personal | trial, cause-effect diagramm |
| 6. | 3. analogies: symbolic | adding by subtracting, miss the forest for the trees, Darwin's rule |
| 7. | 4. analogies: technical | cost causing principle, overhead allocation |

**Table 2:Results of alienation phase**

Evaluating and deciding what the most suitable and best fitting analogies are among the traditional wealth of analogies that can be found is the next step in the synectics methodology. Some of the analogies can be dismissed straight away, for instance the direct analogy food chain and the symbolic one of Darwin's rule (survival of the fittest). What may be correct and fitting in nature, letting "the strongest survive" simply cannot be regarded as fair when considering supply chains. The cause-effect diagram which is also often called a fishbone diagram due to the way it is structured is an example of a personal analogy. It is employed to clearly illustrate the causes of a certain effect, where the causes are associated to the five main categories of people, machines, methods, materials, measurements and environment. It is because of this easily accessible nature that this kind of diagram is frequently used in quality management, particularly in the field of defect prevention. Symbolic analogies, on the other hand, are generally very abstract. Therefore, the adages “sometimes less is more” and “miss the forest for the tress” may seem ridiculous at first, but at second thought it will become obvious what a fitting analogy they represent: They are symbolic for the thorough lack of clarity observed in the literature review conducted for chapter 2 regarding the application of the manifold indicators, indicator sets and tools that exist to assess sustainability. Technical analogies are often the best fitting as is the case here. The cost-by-cause principle essentially assumes a cause-and-effect relationship linking the source and origin of the cost  - the initiating cause – with the cost itself. Consequently, only those costs can be accounted for and allocated that would not exist without the presence of the originating cause, often called a reference value. These so called direct or variable costs can be dealt with directly and in a number of ways . Many different approaches exist. A different approach is overhead allocation which is used to attribute certain overhead costs to manufactured products or services. Overheads or fixed costs as they are often called are the result of operating a business and include rent, gas, electricity and many more. Independently of the output quantity produced, these kind of costs are accrued, which is why it is impossible to directly relate them to a company’s output. It is not only a question of quantity, however, but also one of quality as it is often very difficult to tell exactly how to split these costs among a number of subjects and objects. Hence, here also different methods exist to allocate them preferably precisely and fairly.

The next step in the chosen synectics approach is to link the found and selected analogies to the original problem in question. As is almost always the case with such approaches, some analogies fare better and turn out to be more helpful than others, which is why only the best fitting ones are focused upon. This is why the cost-by-cause principle could be quickly dismissed as it cannot appropriately address fixed costs. Sustainability impacts, which can be considered as sustainability costs (e.g. emissions have a proven negative effect on environment, somewhat damaging it in the process and thus symbolizing a cost), resemble overhead costs much more than direct variable costs. Although it is possible to attribute – to stick to above example – emissions to certain products via the methodologies introduced in chapter 2, there will always be emissions – for instance those accrued by heating the factory halls via the company's own coal power station – which cannot. Hence, in the process of conducting the synectics approach, overhead allocation of sustainability impacts proved to be the authors' most promising finding and preferred solution to the problem considered. Therefore, traditional methods of allocating overheads – which is originally a field of research in cost accounting and business administration – will be introduced in the next section. Additionally, another result of conducting this problem-solving technique was the symbolic analogy "sometimes less is more" which has been found in regard to the goal of providing more transparency and better usability for the applicant when assessing sustainability. As was shown in chapter 2, there are manifold frameworks, tools, indicator sets and indicators which are all discussed in literature and applied in practice. On top of that, many methodological guidelines circulate the world of sustainability. This disunity and information overload have led to great confusion, especially among small and medium sized enterprises, which additionally often lack expertise and resources to properly apply these methods in the first place. This study has underlined the importance to concentrate on well-established frameworks and to possibly lower the amount of indicators used to a reasonable minimum. It is the authors' conviction that there should not be any more research into new indicators or methodologies, but to instead reuse and focus on as many standardized, accepted and well-known approaches (e.g. E-LCA, LCC, S-LCA) as possible in a new solution to assess Global Product Sustainability.

To put it all in a nutshell, Figure 4-5 provides the solution of the synectics approach performed and illustrated in this very chapter.

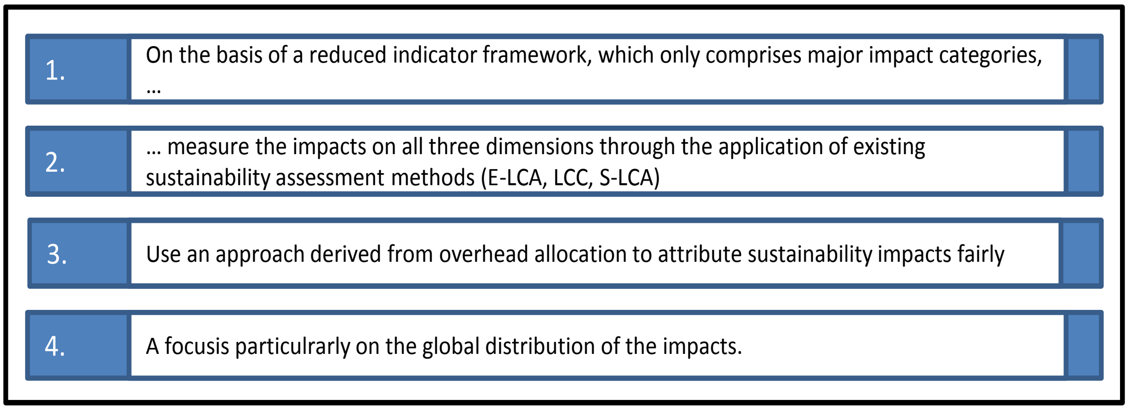



**Figure 4-5: Solution of synectics approach**

This concept of globally allocating sustainability impacts will in the following be named **Global Product Sustainability Impact Allocation (GPSIA).**

## 4.2 The Basic Concept: Characteristics Inherited from Overhead Allocation

Part of the proposed definition of GPS in section 2.1.5 is the following:

> *Impacts causing both advantages and disadvantages for every country and region affected in the products life cycle have to be attributed transparently to the element in charge to ensure comprehensive global objectivity.*

After measuring a product's impacts on all three main dimensions, i. e. after assessing a product's (global) sustainability score – some methodological approaches of which as well as this study's illustrated and favored approaches have been presented in previous sections – the definition at last calls for a transparent and fair attribution of the sustained impacts of mainly products but also companies – which is not of immediate and ostensible interest – to whichever stakeholders are responsible for them in the first place.

Although it is one of the present's and future's great priorities to first and foremost provide ideally all companies throughout the world with a methodology and means to assess their product's sustainability and thereby exhausting all possibilities of the ideally holistic view taken, the authors of this study have gone a step further and addressed an additional dimension of GPS, the allocation of the environmental, social and economic burdens to the stakeholders involved of the particular supply chain and life cycle.

In spite of this notion likely still being decades away from taking of and being implemented, the authors hope to assist and advance the scientific argument and discussion by introducing the ideas and concept regarding a transparent allocation of the environmental and social burdens sustained along the life cycle of a product and its supply chain.

This section and its following paragraphs will therefore shed light on the topic of allocation. The process of allocation becomes necessary in many situations, such as transport and joint production processes as well as recycling among many others. There exists quite a number of different principles of allocation, which will be briefly explained. The goal is to be able to determine the products' and involved companies' share of bearing the impacts and thus burdens.

An easy and very simplifying example (thus not mirroring actual circumstances) shall illustrate the significance of that and why it has been dealt with, thus maintaining if not raising the reader's motivation and interest to continue with the lecture of this study. Computer company Dell globally sources all its components that will end up going into their desktop and laptop computers they sell worldwide. The mining company, for instance, that is responsible for the extraction of gold, which is an important conducting material built into almost all electronic devices, has a huge environmental impact due to the heavy machinery and subsequent emissions required to salvage that valuable resource. With the company being at the very beginning of the supply chain and with the companies further up the value chain being able to somewhat dictate prices, the mining company's profits are generally rather slim. Dell, on the other hand, being the focal company having initiated the entire supply chain, has – compared to all the assisting and preceding companies – a relatively high margin, making a good profit just by assembling the single items. Dell's environmental and social impact should thus be rather limited. The majority of the impacts and thus burdens therefore traditionally occur in Asia, where the items Dell will eventually merely assemble are actually and almost always manufactured. Dell thus needs to be allocated a certain portion of responsibility too as they are the ones who initiated the entire production process in the first place and since they must not be able to off-shore and outsource their responsibility beyond the grasp of their customers. Since Dell bears the majority of the profits accrued along the value and life cycle chain, they should ideally help other companies become more sustainable, with the goal of finally making the world a better place.. It is a very idealistic idea, but it may be a vision that is worth working for and towards. It will be explained in some more detail in a later section.

Allocation is essentially meant to address the question of how to divide things into shares or portions, how to attribute certain things to a certain number of subjects, which can be companies, products, co-products etc. It is a concept primarily borrowed from business studies and administration. In the context of LCA, however, allocation means "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 2006a)

"Science does not dictate a method of coproduct allocation." (Boguski et al. 1996) The issue of allocation has been a very controversial and fiercely debated topic right from the beginning of the introduction of LCA and its beginning application (Boustead & Hancock 1979; Projektgemeinschaft "Lebenswegbilanzen" 1992; Huppes & Schneider 1994). In the realm of LCA and sustainability in general, the attempt is to allocate environmental (and social) impacts to products according to their actual causes. (Schmidt 2012) This study goes one step further still and additionally attempts to allocate a certain imaginary financial burden to assist the entire supply chain in becoming more sustainable. Very similarly to the research field of indicators and life cycle assessment on the whole, there is a great wealth of publications dealing with methodological approaches of how to actually perform an allocation (Frischknecht 2000). This is partly due to the fact that the choice of an allocation method is of great importance and that allocation is still considered to be an unresolved issue in the LCA methodology (De Haes & De Snoo 1996)

As has previously been mentioned, allocation is traditionally rooted in (cost) accounting. The next sections will thus introduce classic cost allocation principals as well as economic allocation and establish a foundation for further elaboration, which will then be applied in life cycle assessment consideration. There allocation principles also play a key role when questions of how to allocate environmental burdens to business activities and products.

**Classic cost accounting**. Classic cost accounting deals with balancing principles of how to allocate certain expenditures or costs to revenues or yields. One distinguishes between direct and indirect costs. While the former are rather easy to allocate, the latter pose more difficulties. This differentiation is crucial and is thus illustrated in Figure 4-6to underline the issue.

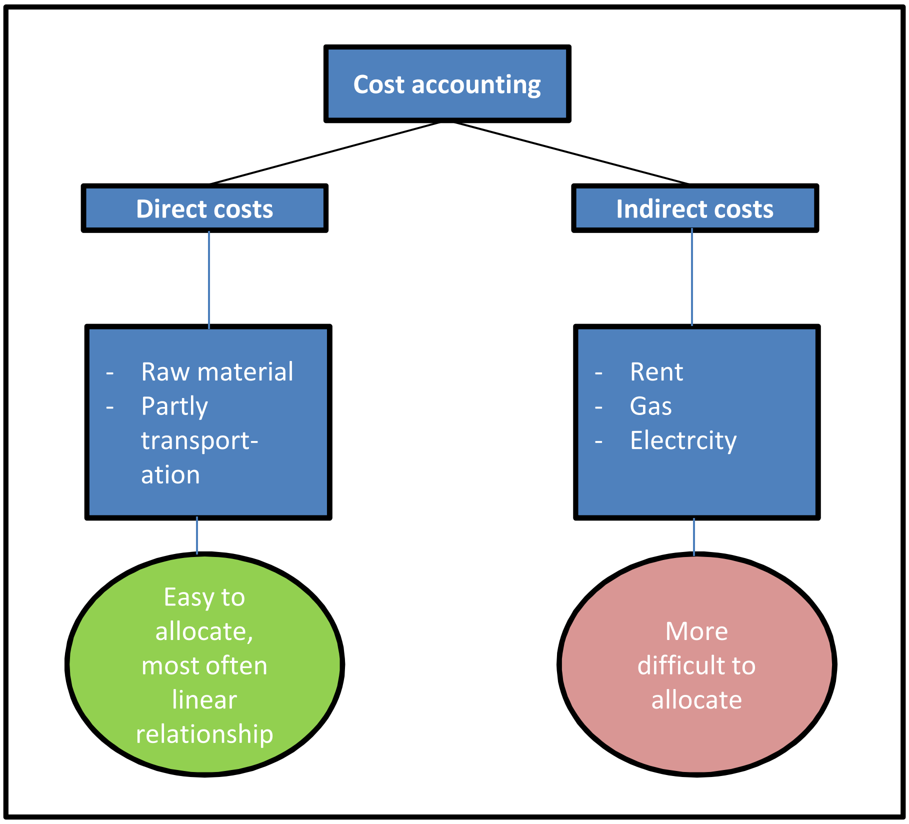



**Figure 4-6: General differentiation of costs in cost accounting**

Direct costs – such as the cost for a certain quantity of raw material required for the production of one additional unit – can be rather easily allocated in line with causality. This so-called principle of causality presupposes that costs are the direct consequences of producing a certain yield, a product for instance. Therefore, it is automatically assumed that the lower the output – i.e. the yield, for instance a product – that is produced, the lower the cost and vice versa. Direct costs are dependent on the output volume. According to Schmalenbach and Rummel, however, the principle of causality cannot be applied for fixed costs or overheads. (Kilger 1976) Fixed costs can be maintenance costs of machines, heating costs of offices and buildings, certain procurement expenses, quality and production control costs and many more. The question may be asked, for instance, of how the cost of lightening the factory hall is supposed to be attributed or allocated to the individual units of a possible range of products that are manufactured, which is neither a trivial nor an easy task. It therefore comes as no surprise that there is a heated debate in literature regarding how to allocate these overheads. They are incurred most often completely, only sometimes partially independent of the volume output. This is why they are called fixed costs as their magnitude cannot easily be influenced. Traditionally, indirect or overhead costs have been tried to allocate via machine hours and direct labor costs. Due to the changing nature of the manufacturing business and industry in general, particularly regarding global competition and environmental concerns, today companies are forced to determine their accrued costs more precisely to make for better decision making.

**Allocating environmental burdens.** There are great similarities between (financial) costs or monetary expenditures for certain economic actions in classic accounting on the one hand and environmental burdens – which can be expressed in e.g. physical quantities (e. g. 100 tons of CO2 emissions or waste) and other accumulated quantities – on the other hand. There is a clear analogy between the discipline of cost accounting and environmental accounting (Möller et al. 1998) Despite the difference in nature, the revenue of an economic activity – e.g. the production of a product – leads to both an economic and ecological expenditure which are both to be measured and allocated. The necessity to deal with allocation in the field of (environmental) impact assessment has long been recognized as the previously mentioned ISO standard and heated discussion among scholars indicate. The problem of allocation typically arises with joint production, which describes production/manufacturing processes which yield the actual desired product(s) as well as one or more byproducts. Not only for decision making, but also for life cycle assessment, here it becomes crucial to allocate the different inputs – e.g. energy flows – and outputs – e.g. emission flows – to the products produced. Hottenroth et al. therefore pointed out the need to fairly allocate the inputs and outputs. (Hottenroth et al. 2013)

In line with the results of the synectics approach performed in section 4.1, a second literature review was consequently conducted to find out what principles are already currently in use for allocating ecological impacts and which ones this study can possibly built upon.

#### 4.2.1.1 Currently discussed principles to allocate ecological impacts

Conducting this second literature review, it was quickly realized that allocating sustainability impact is not yet done in an integrated manner, i.e. the three dimensions of sustainability still do not find simultaneous consideration. Allocation principles are currently only applied in Life Cycle Assessment and the Production Carbon Footprint (PCF) (Huppes & Schneider 1994; Möller et al. 1998; Schmidt 2012; Schmidt 2009b; Schmidt 2009a), which will be explained at a later stage of this study. An overview of the currently used principles in allocating sustainability and particularly environmental impacts is given in Figure 4-7. They will be introduced in this very section.

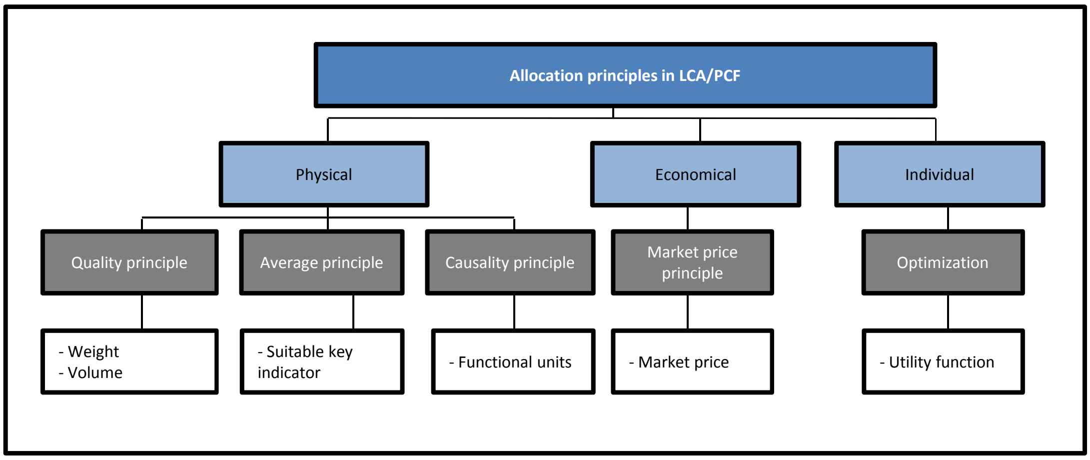



**Figure 4-7: Overview of allocation principles**

There is a large number of methodologies and approaches to allocate environmental burdens with (Frischknecht 2000). Generally, three different types of allocation principles in the field of LCA and PCF are distinguished. Physical principles, economic principles and individual principles. Scientific and physical  based allocation principles are still predominant. Although “[a]llocation on the basis of economic value is generally discouraged because the Life Cycle Inventory (LCI) methodology is based on the measurement of physical parameters, and economic value is not a physical parameter” (Boguski et al. 1996) – a view upheld and shared by the guideline ISO 14044 and supported among scholars  (Schmidt 2012) – here, the environmental area could very well benefit from the methods of cost accounting. And this is in spite of the environmental area’s bias and base in technology and science. (Schmidt 2009b)

In the following, some vital principles of allocation will finally be briefly presented, one of which is then selected for further elaboration.

The **quality principle**, a representative of the most commonly used physical allocation methodologies, is typically used. (Pfleger 1991) This can be attributed to the fact that (environmental) engineers and scientists alike are keen to use principles possibly free of arbitrariness in order to achieve a maximum of objectivity. Therefore, technical quality quantities of all produced products and byproducts are used, such as weight or volume etc., thus establishing a level playing field to then allocate costs and ecological expenditures correspondingly. An important example taken out of the area of LCA is supposed to better illustrate this very principle and its shortcomings as well.

At a waste incineration plant, usually several types of waste are incinerated together and simultaneously which causes for environmental impacts. For the sake of simplicity, it shall be assumed that only emissions will be considered. The question now is how to allocate these accruing emissions to the different input materials. The quality principle provides a rather easy methodology as it suggests that environmental impacts should be distributed in line with, e.g. the quality or quantity of materials put into the incineration plant. For instance, if two waste products A and B were to weigh 100 lbs and 50 lbs respectively, two thirds of the emissions would be allocated to product A, the rest of which to product B. This corresponds to the ratio of input weights. Continuing with this example, however, this mode of allocating impacts and thus the quality principle are only sensible if the inputs used are rather homogenous, i.e. leading to the same kind of emissions. If, for instance, one of the waste inputs contained heavy metals, this would result in specific emissions. It would be wrong and unfair to allocate them evenly across all other inputs, some of which may not contain that kind of material.

A better way to allocate those impacts is provided by the **principle of causality**, which is very frequently used especially among engineers who call it causal principle (Riebel 1994a). It assumes a cause-effect relationship – usually of either physical, chemical or biological nature – between the produced output (e.g. a product) and ecological expenditures. In the above example, for instance, the specific emissions would only be allocated to the very product that actually caused them in the first place. It is furthermore presupposed that a higher production quantity of the desired products results in higher ecological expenditures. It is worth nothing that there is somewhat of a debate among environmental engineers regarding the terminology. (Riebel 1994b) The principle of causality typically defines that an effect is provoked by a cause, that the effect would not be apparent or existent if it was no for the cause. Looking at the manufacturing context, however, the creation of products can be considered the cause for environmental pollution to occur, which is both the effect of the production and an ecological expenditure. Since these emissions are accrued along production before a certain product is even completed, the effect takes place before the cause. Since this cannot confidently be called as a principle of causality, the so called means-purpose relation has become rather common. Production with its incurred cost for e.g. machinery and raw material and its environmental impacts are the means to deliver a certain output to the customer. (Schmidt 2009b) A major pitfall of the principle of causality the high demand of specific data, which is scarcely available. More specifically, when dealing with overheads, the principle of causality is very difficult if not impossible to apply, which basically rules out its usage.

The **principle of averages** borrows from both the principle of causality and the quality principle, drawing from their advantages and thus being simpler and more frequently used in practice (Schmidt 2009b). So-called genuine ecological overheads are costs which still exist even when the production of a certain output ceases. These overhead costs must thus allocated and distributed accordingly, which this particular principle does via suitable key indicators.

#### 4.2.1.2 The pioneering approach: Principle of market prices

Previously described principles do have their limitations, however. Although it is not part of this particular study's scope, the easy example derived from the clothing sector of growing and harvesting cotton is used to illustrate some of those principles' major shortcomings and why the principle of market prices – despite it being partially heavily contested among scholars (Boguski et al. 1996; ISO 2006a) – has its clear advantages. (Schmidt 2009a; Jungmichel 2009)

When cotton is harvested, two products are obtained. First the actual raw cotton which is the desired product of the initial cultivation and second the cotton seeds which can also further be processed. It would be possible to allocate costs and especially environmental expenditures according to their weight which is 40% and 60% respectively, attributing more of the overhead and sustainability impacts to the cotton seeds. A different allocation methodology is much more sensible here, though. Raw cotton is the a lot more valuable as well as the actually intended product at 87% of the joint value. An allocation according to the **principle of market price** thus captures this notion more appropriately. This very principle states that expenditures are attributed with regards to the benefit of the output products. The quantification of which and thus allocation of (environmental / sustainability) overheads is determined by the market. This way, dependently on the allocation method chosen, entirely different results can be obtained, which is illustrated for the above explained example in Figure 4-8.

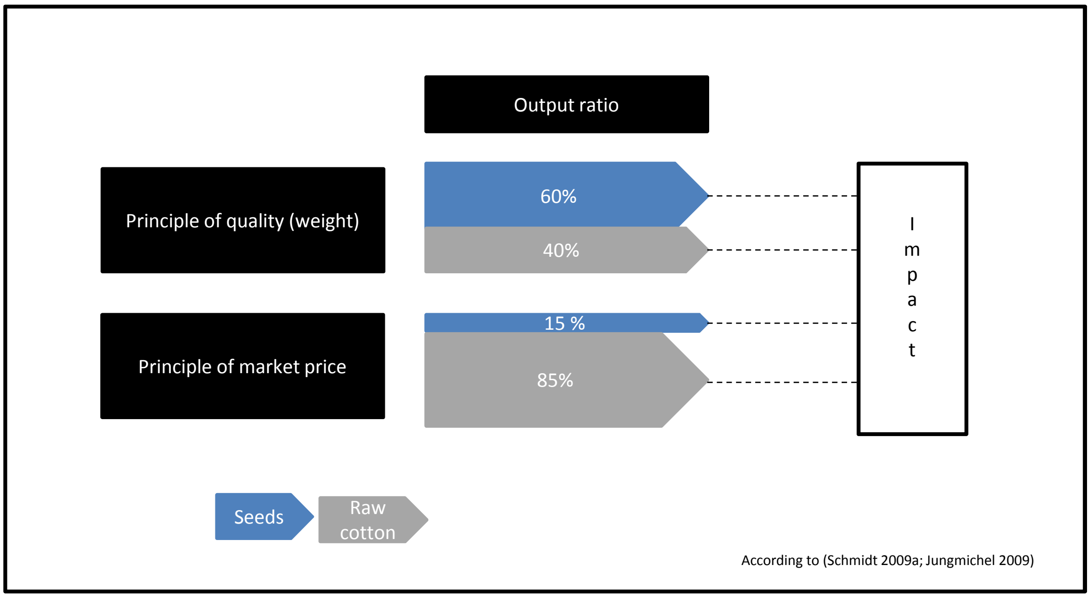



**Figure 4-8: Comparison of allocation principles of market price and quality**

Going along with the market price principle is a certain criterion some scholars call “ability to bear” (Frischknecht 2000). It describes the products’ ability and capacity to bear and shoulder production costs as well as environmental costs. More impacts could be allocated to a co-product that is capable of generating a profit in such a way that they could be used to initiate changes, e.g. lower pollution or expenditures in general.

Despite its clear and many advantages, there are still many scholars who object to the application of economic allocation principles. Probably most prominently, the International Organization for Standardization (ISO) states in their ISO 14.044 guideline that economic allocation is to only be used as a last resort and that other methods should be attempted to exploited first. (ISO 2006b) The European Commission also considers the application of the market price principle as problematic as their research let them conclude that "a frequent error for this type of allocation is to apply the allocation at the wrong point [which] is most often related to the use of the market price as criterion." (European Commission 2010) The clear preference of the ISO standards for physical allocation still appears to be a widespread paradigm among scholars and is further underlined and expressed by Boustead et. al who state that physical allocation is to always preferably used over other approaches. (Boustead et al. 1999) Although Azapagic and Clift could see the limitations of applying an allocation purely based on physical relationships, they also concluded that in the case of their existence, they should be used instead of economic allocation. (Azapagic & Clift 1999) The biggest critique usually concerns the variability of prices, making the allocation very volatile, unstable and imprecise. Arbitrariness is more often than not the consequence, they argue.

However, economic allocation has come a long way and found many supporters in literature. A number of examples are reported when economic allocation should be used, even when other allocation procedures are quite possibly applicable as well. (Ardente & Cellura 2012) Huppes, for instance, concluded his study by stating that "the value-based method […] may be applied in many situations to which others cannot […]. However, it cannot be the sole panacea." (Huppes 1993) Similarly, Frischknecht is a huge proponent of economic allocation, arguing that "if economic and environmental aspects influence consumer choices, economic and environmental aspects should influence the determination of allocation factors for consumer goods as well." (Frischknecht 2000). Not only since "[…] economic allocation better represents the societal cause of the emissions" (Peereboom et al. 1999), there are quite a number of authors who use economic allocation, for example Althaus and Classen when they determined the environmental impacts of metals and related co-products. (Althaus & Classen 2005)

Taking everything into consideration, it could be shown that the market price principle supplies a very sensible foundation for the allocation of environmental impacts. Since it is the focus of this study to assess all three dimensions of sustainability and distribute them accordingly among a product's supply and life cycle chain, the principle of market price allocation should be extended to also consider the other two dimensions rather than only the environmental one. For reasons having to do with the requirements posed in the previous chapters, a slight modification or, to be more precise, expansion of this very principle will provide the key in this study's concept which will be illustrated in the next section.

Concluding this chapter, the notion of arbitrariness shall once again be reviewed and highlighted. The literature review has proven that most application methods are judged against objectivity and whether or not they can provide a minimum of arbitrariness. It turns out, however, that the assumptions and objectives applied cause for arbitrariness rather than the allocation methods themselves (Schmidt 2012), where the latter are dependent on the former. And where there are objectives of certain stakeholders, for instance human beings, involved, it is more of an issue for social- and business studies rather than natural sciences. When attempting to conceive a method that is not arbitrary, economist Gümbel therefore proposed the optimization of a utility function. Whilst maximizing the utility, i.e. profit, function, certain both monetary and non-monetary constraints need to be satisfied. Since this approach basically culminates in the market price principle again, this study merely likes to point to the work of Gümbel for more in depth information. (Gümbel 1988)

## 4.3 Introducing the Concept

This section now aims to illustrate and explain the concept the authors have conceived in light of the proposed requirements and issues to assess Global Product Sustainability. Sub-section 4.3.1 will establish the framework and setting in which the concept is built around and into. It is meant to collect the reader and make the process of understanding easier as an visual aid will be of assistance when following the explanations. Sub-section 4.3.2 will then continue with remarks about how GPS actually can be and is assessed in all of its three dimensions, after which in sub-section 4.3.3 the actual concept will be illustrated, based upon the framework and setting that will be given in 4.3.1. As will be seen, this very sub-section is all about allocating impacts, the paradigm of which was introduced in 4.2. This last sub-section 4.3.4 will at last introduce a different possibility of assessing sustainability (impacts) and may prove out to be a sensible alternative for the time being.

### 4.3.1 Framework and structure of concept

This very section will try to illustrate the framework and structure of the developed concept for assessing Global Product Sustainability and, as is proposed to be an integral part of this process, allocating the incurred sustainability impacts on all three dimensions in a fair, transparent and source-dependent manner across the evaluated product's entire life cycle and among the actors involved in that particular supply- and value chain.

The general structure and framework of the concept is illustrated in Figure 4-9:

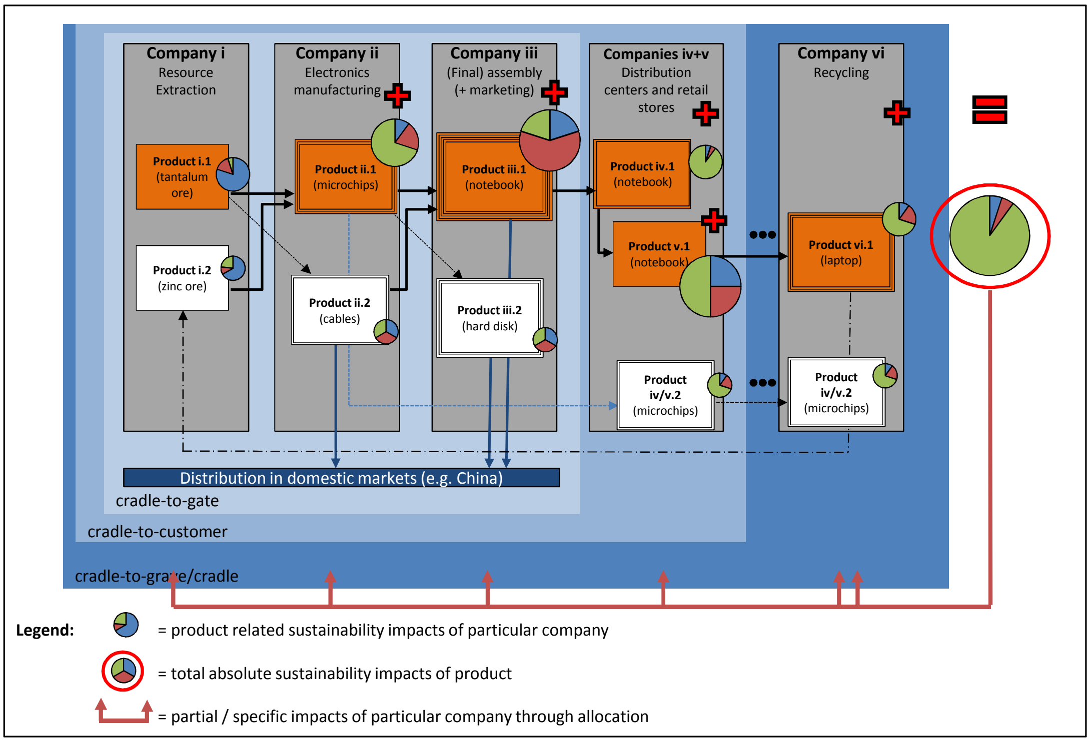



**Figure 4-9: General structure and framework of the proposed concept**

Above figure shows a very simplified supply chain as can be found in the consumer electronics industry. Looking at it horizontally from left to right, different actors of that very supply chain can be identified with companies i to vi being responsible for raw material extraction, electronics manufacturing, distributing, retailing and recycling respectively. Not only does the horizontal display thus illustrate the singly actors involved in that particular and observed supply chain, it also represents the life cycle view of the evaluated product. The illustration does not aspire to be complete, but to give an easy to understand excerpt of reality and example. Therefore, for instance, the significant use phase which in most cases occupies the longest period of time and therefore does not have an unsubstantial effect on the sustainability impacts incurred, is merely hinted at by the three horizontal dots in between the two last grey boxes representing companies. The life cycle view of products is depicted and can be identified with the orange and white boxes within the involved companies' grey boxes. The illustrated example and structure aims to exemplarily follow a certain focal company's particular lead output, in this case a laptop over its entire life cycle. This is represented via the orange boxes. Looking at observed Figure 4-9 vertically from top to bottom, an internal company view can bet obtained. Because only a very limited amount of firms worldwide still produce one product only, the companies' vertical representation depicts their array of products. White colored boxes therefore symbolize either co- or byproducts and/or other products which are not or only indirectly related to the focal company under consideration. These products are then further processed , sold and transferred as part of other supply lines other than the one at focus here. It is an extremely difficult and unrewarding endeavor to be aiming at the depiction of all subjects, objects and flows involved. For the sake of somewhat illustrating the many interlinkages between different companies and the supply chains they are involved in, the path some of these white-colored products may potentially take are further illustrated. For instance, when company i with their heavy machinery extracts the raw materials necessary for the manufacturing processes of company ii, it may automatically obtain zink ore as a byproduct as part of the extraction. This zink ore, additionally, may be needed as a virgin material in the manufacturing of microchips in the second company, too, though. Similarly, not all of the extracted tantalum ore may be needed for microchips, but also for the production of other products, such as cables. Let alone selling these materials to different companies, too. Since companies can be entities in a number of supply chains (Jentjens & Münchow-Küster 2012), this is a very complex affair. This complexity is further increased with the illustrated possibility of the involved stakeholders' opportunity to sell their products and materials where they are actually manufactured, namely in their respective domestic markets. Since the majority of (consumer) electronic products is manufactured in Asia, in particular China and Taiwan, nowadays, especially the Republic of China as the world's biggest and striving developing market is a huge market for the manufactured products. This will be addressed in further detail in chapter 5 as well. These purchases which are not part of the exemplarily evaluated supply chain of the observed focal company's end product of a laptop computer are illustrated via drawn through blue arrows. Likewise, the dotted blue arrows, for instance the one going from Product ii.1 (microchips) to Product iv/v.2 represents the second company's sale of part of their lot of microchips to an external distributor and/or retailer. The number of lines around the products' boxes vaguely represent an assumed exemplary complexity and quantity of the necessary processes and steps to obtain and manufacture this very part of the final end product. Additionally, each process step has certain sustainability impacts on all three dimensions, in turn giving each of the illustrated products their very own burden on the main dimensions. This is illustrated via the pie chart in the right of each product box. They are tripartite due to the three dimensions of sustainability. Naturally, different companies and different processes and steps can have and have different effects and affect the world we live in differently. The differently sized pie charts are meant to convey the notion that the different components and (sub)products going into the final product sold to the customer carry differently large sustainability burdens, sometimes correlating with the amount of production steps. In company iii, where, for instance, microchips of all different sorts and other components are manufactured and mounted, so that hard disks, optical drives, motherboards and many other devices are obtained, oftentimes also final assembly takes place. Hence, in this illustrative example, Product iii. has been attributed the most production steps and quite significant sustainability impacts. In the case of well-known US-American company Dell they partially assemble many of the sub-products and components they have outsourced and do their own marketing and subsequent selling, this way circumventing retailers among others. The products are either intended for export or distributed on regional markets. Distribution, i.e. transportation is frequently executed by independent service companies which are oftentimes responsible for the distribution of products of quite a number of companies.

As has been indicated above, the use phase is not distinctly addressed due to reasons of simplicity and clarity. However, the use phase is a very important, if not the most important life cycle stage to be considered. Especially the in section 2.3 introduced externalities play a major role in this very phase. Attributing the product in the retailing company (e.g. department store) an at first glimpse disproportionately large impact on sustainability tries to compensate for the omission of the use phase by indicating that retailers should put the company's label on the packaging illustrating the average impacts that occur during the product's use phase. Threats to data security and the danger of becoming lost in a virtual world can be stated as examples of social impacts of owning and operating a laptop device. This study will go into further detail regarding this issue later on. The recycling phase is, however, included again as its recognition has become increasingly important, especially in the field of electronic products. Commonly used and described system boundaries are also part of the illustration and are cradle-to-gate, cradle-to-customer and cradle-to-grave/cradle. The culminated process impacts of each product and thus making up for the specific products' impacts can theoretically be summed up along the single life cycle stages. This way, the total absolute sustainability impacts of the product in question could be obtained. A major question to be asked here is how to potentially and fairly allocate these impacts across the different actors of the supply chain, which will be dealt with in the next sub-sections. This section was meant to convey the idea and feeling of how complex the challenge to assess GPS really is and how many different fields of research are affected.

### 4.3.2 Assessing the three main dimensions of sustainability

A number of popular and frequently used methodologies and concepts to assess sustainability have already been introduced in previous chapters and sections of this study. It is not the objective of the authors to extend stated confusion in science and praxis alike by the introduction of yet other new tools. Instead, some major questions and challenges concerning a company's product assessment shall be introduced and discussed. Despite all the controversies among scientists, it has become common understanding that a holistic picture must be created either through an integrated method or one that measures all three dimensions separately. Nowadays it is essential that all major dimensions are addressed appropriately. Additionally, scholars agree on the need of a defined spatial reference, appropriate geographic scales of policy responses and considering spillover effects (Toman 1998). What can surely be deducted from this is the fact that assessing sustainability in general has been and still is a highly controversial and challenging topic due to a number of reasons. Quite a few issues have been addressed and dealt with in literature, some of which and others have been put forward in previous chapters of this study as well. Having intensely dealt with the area of sustainability assessment, the authors have come to the conclusion that there currently is and may very well never be the one method or procedure to assess sustainability with. Instead, this study aims to give thought-provoking impetus to begin playing with the idea of utilizing different possibilities of how to assess sustainability and how to combine different, already existing approaches. The authors have thus come up with a list of general concerns, which they feel should be taken into consideration. Among others, the list includes:

- What is the scope and objective of the assessment? (Is it a region, country, company or product etc.?)
- What are the system boundaries needed for balancing? (Are they of a technological nature, geographical or temporal etc.?)
- Is it really sensible to dictate standardized and certified approaches such as the ISO one? Or may it be more reasonable and supportive if, for instance, a company uses its own methodology which can potentially be very specific to its needs and objectives? A lot of experience may come into play as well, possibly outweighing a mandatory set of procedures? How does this agree with the requirements to have a consistent and thus comparable method?
- May a composite indicator based on individual and subjective normalization methods and weighting assumptions be more beneficial?

There is not one right solution to any of these questions. Instead, the answer is dependent on user specific data and is thus influenced by a number of things, such as a company's environment (its competitors, legal regulations among many others) and its structure (size, information and communication technology used etc.) or the nature of the analyzed product (complexity, type of production process etc.).

Independently of the approach chosen for the assessment, **data collection remains a major challenge.** The large amount of necessary data as well as its collection are still significant pitfalls that need to be addressed accordingly. The issue is that an adequate data collection for assessing sustainability impacts requires a lot of time and is quite difficult as it is very complex. At the same token, high quality data is required for the assessment to be meaningful, thus only adding up to the challenge and time needed. The amount of data that is necessary is also dependent on, for instance, the complexity of the product evaluated – e.g. assessing a laptop computer in terms of its sustainability impacts necessitates much more data than say a pair of gloves – or the selected system boundaries. A cradle-to-gate assessment will require considerably less data than a cradle-to-cradle evaluation. (Hottenroth et al. 2013). Different approaches exist for identifying the data that is needed to conduct a proper life cycle assessment. It needs to be determined, for example, what internal and external data is necessary and if primary data is available and if it can be collected. Today, these examinations are more often than not done by either third party organizations or the focal companies themselves. This has become customary over the past few decades as a consequence of the widespread outsourcing process – which will be shed further light on in chapter 5. Nowadays hardly ever, one will find a company which conducts all production steps by itself. To add to the difficulty and complexity, production processes are often connected and not easy to fathom. Hottenroth et al., for instance, analyzed the life cycle of a beer bottle and realized that in what is clearly a rather simple production process there are already more than 30 processes and production steps involved. (Hottenroth et al. 2013) According to the procedure of classical sustainability assessment methods (E-LCA, LCC and S-LCA) these processes are analyzed to infer indicators. These can then be used to assess the relevant and respective impacts. Not only is this procedure time consuming, it also cannot be guaranteed that all contingencies from process interrelations are considered adequately.

In fact, right now a top-down approach is being applied in most industry. What this actually means is explained in the next few lines. The focal company which is originally responsible for the production or at least initiation of production of a certain product that is to finally be sold to the consumer to consequently satisfy his or her needs, is responsible for the sustainability assessment of its manufactured goods. These manufactured goods are in fact the most interesting ones in the particular supply chains as they are the goods that are essentially sold to the customer. To the customer, for instance, it is not important what the sustainability impact of the extraction of gold is as he does not actually get to hold the gold in his hands. It is merely a byproduct of the final end product. Hence, as has been mentioned above, the focal company either assesses the sustainability impacts of its supplier itself or appoints third party organizations. Either way, however, it is unlikely to be able to obtain very precise let alone up-to-date data due to the large distance and missing insights in that particular supply chain company. They have an interest to keep certain practices a secret as they more often than not also supply other companies and are logically afraid to lose their contract or lose out to competition. This is partially why those generic data bases exist to make up for data that is either non-existing or extremely difficult to acquire. Independently of the method applied, the data used is often inadequate and insufficiently precise, usually resulting in only rather vague assessments in spite of the huge effort both in terms of time, hardship and expenditures. Measuring all three dimensions in contrast to only the single environmental one as has been the case for quite some time merely adds to the challenge. These inaccuracies are further increased when the focal company or third party organization sums up the incurred sustainability impacts along the individual supply chain stakeholders, thus obtaining the total absolute sustainability impact of the evaluated product.

However, the previously described allocation principles, especially the economic principle, offer new possibilities and opportunities to assess product sustainability if adjusted to this purpose. As has been explained above, allocation is currently used to distribute and attribute the impacts of joint production processes between product and co-product. The authors therefore suggest to transform and extend the idea of allocation and apply it for a new and additional usage within the field of product sustainability assessment. This new paradigm will be discussed and introduced in the following section and was interestingly conceived by the authors of this study, at first not being aware of the fact that German scholars Schmidt and Schwegler first introduced it in 2008. (Schmidt & Schwegler 2008)

Instead of focusing only on joint production, allocation will be extended to the entire production process of a company. Companies will therefore subsequently be considered as black boxes which can also be viewed as a factory illustration very similar to the approach introduced by Nadine Madanchi (Madanchi 2013). Of particular importance are leading indicators, which can be used to provide clues as to what important changes are likely to take place in the future. The range of practical leading indicators of sustainability is limited by cost, data availability and reliability, and the level of social consensus about the interpretation and significance of what is being measured. Essentially, following discussions with experts and taking into account their verdict she was able to come up with a very manageable number of reliable and important key indicators of all three dimensions, thus generating an assessment tool that is quick, simple and yet holistic, robust and capable of providing new insights. A methodology like the one she has proposed may very well be a reasonable prerequisite and base for the application of the allocation principle that is to be introduced in the next paragraphs.

### 4.3.3 Allocating the impact throughout the entire supply chain

In the following, the major element of the developed concept will be illustrated, the use of economic allocation to distribute sustainability impacts accordingly. Although independently conceived by this study's authors, it must be conceded it is essentially adopted and derived from allocation applications in the field of carbon accounting and the Product Carbon Footprint (PCF), which will be explained in further detail in section 4.3.4, since German scientist Schmidt was the pioneer who must rightfully be acclaimed for his idea he already had many years ago. (Schmidt & Schwegler 2008; Ardente & Cellura 2012) His framework has consequently been adapted to better suit the assessment of Global Product Sustainability, i.e. it has been extended to also consider the other two main dimensions of sustainability, as is required in this study today.

As has been addressed at various spots all over this study already, it is once again brought to attention to underline the significance of this very development. It is becoming increasingly important for companies to scientifically and comprehensively state how much and what kind of an impact a company regarded as a total entity as well as all of its products and services have. These are pieces of information stakeholders – customers, business partners, investors and the public – are gradually more interested in. To be environmentally and socially friendly is progressively becoming a significant competitive factor. Hence, it is pivotal for companies to assess their products' impacts adequately, fairly, transparently and precisely as well as in an accepted fashion.

**Various and significant shortcomings of the classic assessment methodologies** of E-LCA and LCC as well as of the rather newly developed S-LCA have ultimately triggered the establishment of the subsequently proposed framework. Potential repetition is deliberate in order to underline the aspects brought forward. A major challenge for any type of LCA, particularly E-LCA however, has to do with the inclusion and handling of the entire supply chain. As has previously been pointed out, significant impacts can occur in “pre-chains” of the manufacturers, which is why LCA is a balancing method which cannot solely be based on in-house figures. (Schmidt 2009b) This is why companies all over the world currently access manifold data sets and bases, which is both a blessing due to somewhat of a swiftness it allows and a curse due to the vagueness of the data they contain. These databases merely contain average, so-called generic, values. When several datasets are linked with one another, the result is potentially even more generic. Thus, “the LCA of a product then only maps the average situation, in other words an average or generic product.” (Schmidt 2009b) This is what scholars call fuzziness of generic data. Another shortcoming classic assessment methodologies bring with them is the time of updating. The assessment of a product largely neglects variability over time and is therefore merely a “snapshot[] in which production and delivery conditions are frozen.” (Schmidt 2009b) Hence it is not easy to say if the assessment conducted is valid or not, seeing that since the actual assessment many aspects such as suppliers or transport distances may have changed. It is because of all these limitations that neither of the classic sustainability assessment methodologies are perfectly capable of giving a true and precise account of the impacts a product has as only a generic product can be and is analyzed. Schmidt therefore argues that "[s]uch analyses can only provide indications for the typical weaknesses in production, design, use etc. of a product [but] are not very useful for comparing two concrete products." (Schmidt 2009b) Consequently, he and other scholars alike question the suitability of such accounting methods for supporting consumer's decision making, but also the decision making of companies regarding their supplier selection. As is still the case today, it is very difficult to make sure and be certain of the validity of the data provided by the suppliers, let alone the validity and the state of being up-to-date of their respective suppliers. Especially in the global context, it is an "extremely complex affair" (Schmidt 2009b) to allocate environmental pollutions and other sustainability impacts to various products alone as well as their pre-products of the suppliers.

It has thus been proposed by the authors to broaden the scope of the assessment and to leave the dimension of particular products for now – future and further advancement of common assessment methodologies which are already in use today and more precise and easier to extract databases will all likely provide a remedy – and to instead use companies as the balancing entities. Despite the many decades of research, human understanding and the capability to adequately map all impacts is still limited, which is why a certain simplification seems advisable for the time being. As other authors have previously proposed as well, turning towards companies as a stepping stone for a potentially more appropriate measurement and assessment of sustainability impacts on all three dimensions combined with economic allocation provides many advantages.

Section 4.2.1.2 delivered a description of economic allocation and LCA literature explicitly issues a variety of examples of and for its use. This is generally quite sensible due to and partly motivated by “its simplicity and […] its ability to illustrate the properties of complex systems.” (Ardente & Cellura 2012)

The two important corner stones of the proposed concept thus are: (see Figure 4-10)

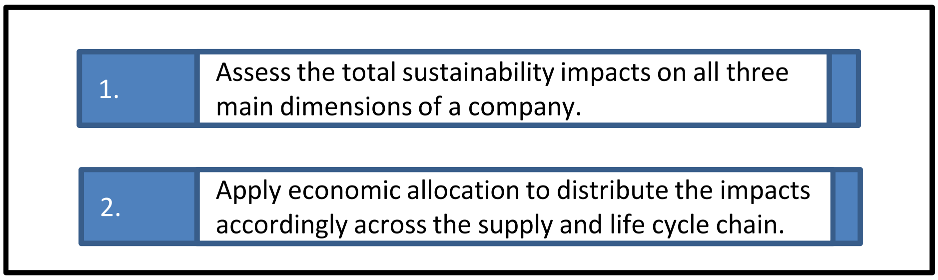



**Figure 4-10: Important corner stones of the proposed concept**

**Step one.** Schmidt as the true pioneer of this idea calls it “cumulative emission intensities” (Schmidt 2009b), which has been extended to cover all three dimensions of sustainability. Globally assessing the total impacts caused by a company and all of its processes and products has quite a number of advantages. First, it is less complex – it is very difficult, for example, to appropriately assign three exemplary injuries sustained by personal responsible for the company’s controlling to a certain product or process used for manufacturing a certain product. Second, it also is easier as many impacts, such as particularly emissions, but also with other sustainability impacts as well, are usually measured on a site or company basis and are thus and can be validated at this level, too. Furthermore, they are often subject to legal regulations. (Schmidt 2009).

What Schmidt and Schwegler (2008) and also similarly Arretz et al. – German authors surprisingly currently seem to be in the lead in this particular field of interest – proposed regarding cumulative emissions intensities and quantities can and should be extended as part of this study to all three dimensions. (Schmidt & Schwegler 2008; Arretz et al. 2009) Madanchi's Factory Sustainability Assessment Tool as proposed in her study (Madanchi 2013) is an approach that could very well be applied for this purpose. With 20 key performance indicators portraying all three dimensions relatively evenly, she provided a comprehensive, functional, capable, effective and useable indicator set and tool to assess the sustainability performance and impacts of a factory with. Her assessment tool can rather easily be extended to an entire company also if it is considered as a black box with certain quantities and qualities going in – i.e. certain inputs – and going out – i.e. certain outputs. This is further illustrated in Figure 4-11.

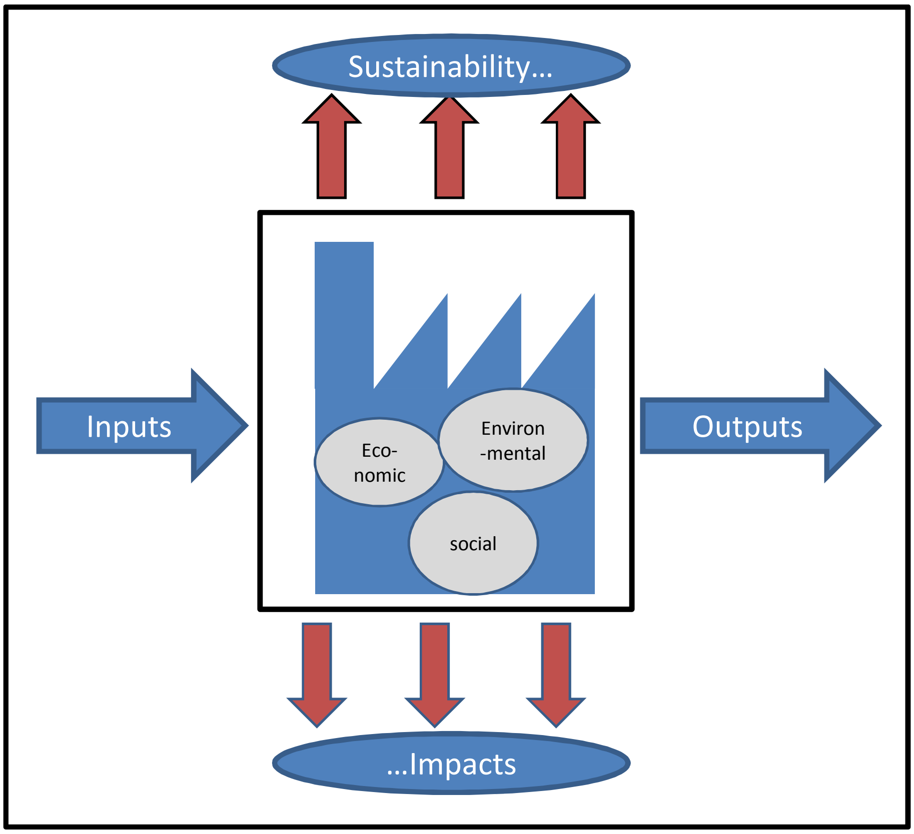



**Figure 4-11: Black box measurement of sustainability impacts on factory floor level**

Additionally, Figure 4-12 serves to give a quick confirmation of the validity of the possibility to extend Madanchi's assessment tool to measure the total sustainability impact of an entire company as all derived indicators can rather effortlessly be obtained for any company, e.g. by looking at the annual balance report.

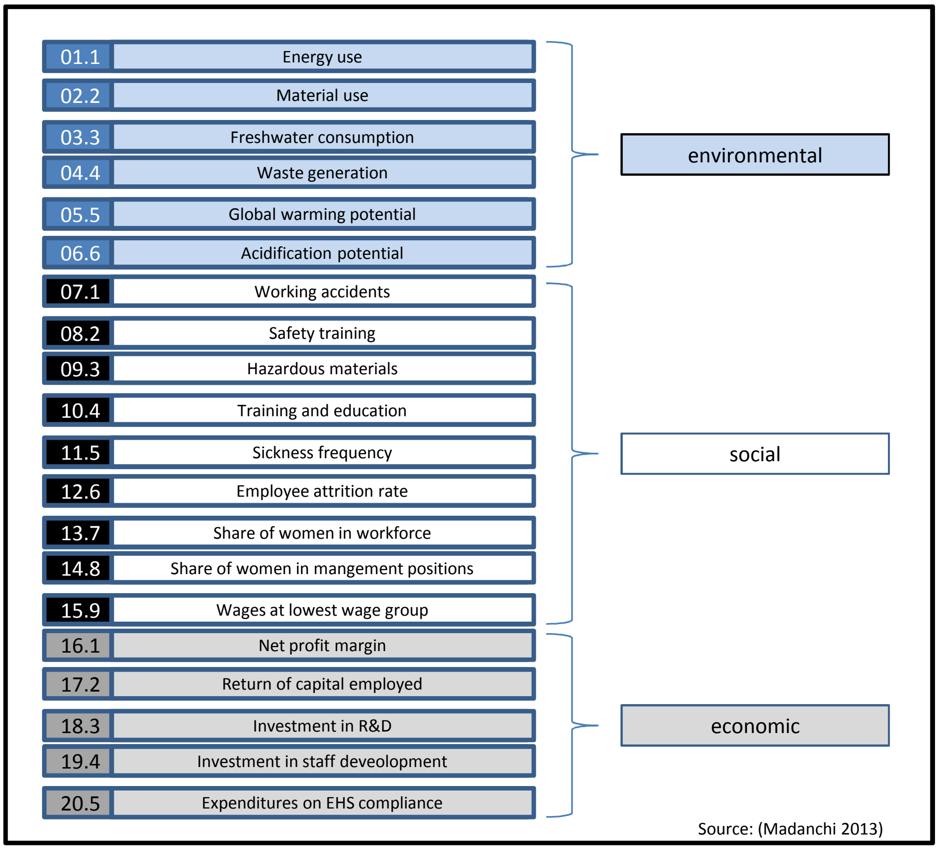



**Figure 4-12: Indicator set as proposed by Madanchi (2013)**

This way, what is called total sustainability impact of company i in Figure 4-9 is determined, which is essentially an accumulation of the impacts of all processes and steps performed within a company. In the particular example illustrated in Figure 4-9 the total amount of work accidents from both the extraction of tantalum and zink ore are taken into consideration, thus making up for a complete and thorough picture of the company. As desirable as the product-related approach is in order to, for instance, give the customer valuable decision support at the point of sale when comparing different products, the effort required to adequately provide sensible pieces of information is tremendous and unrealistically feasible. (Schmidt 2010)

**Step 2.** This is the second step of the concept. After having successfully determined the total sustainability impact of a company, it is now necessary to allocate a respective share of that total impact to the particular (pre-)product in question. This procedure is based on the price and quantity of products and economic partitioning. Based upon Schmidt's approach, a recursive method is applied, meaning that each company states its cumulative sustainability impacts, which it obtains via the following formula, which is taken from Ardente and Cellura (Ardente & Cellura 2012) (economic allocation in LCA):

$$P_i = \frac{n_i x_i}{\sum_i n_i x_i}$$

where $P_i$ is the partitioning factor of the i-th coproduct/coservice, $n_i$ is the quantitiy of the i-th product/service, and $x_i$ is the(market-)price of the i-th coproduct/coservice. Essentially, to stay with the example illustrated in Figure 4-9 and which has previously been addressed, that particular mining company – in order to find out the sustainability impacts of its tantalum ore – would multiply its extracted and forwarded quantity by the current market price of it and divide it by all products it obtains and generates by their respective market values. This way, the so-called portioning factor is obtained, which is essentially the portion of this particular product or service of the total profit obtained by the examined company. This calculated percentage is then multiplied by the total sustainability impact score, which can for instance be obtained by Madanchi's tool. Preferably, additionally this partitioning factor is also multiplied with the individual scores of the single dimensions in order to provide even more insight into the matter and give clues as to where sustainability impact hotspots might occur. Only this – though different in nature, yet the authors have adopted the name of it – performance figure, which is the product of the particular portioning factor and the total sustainability impacts, has to be passed on from supply chain actor to supply chain actor and eventually to the customer as additional information. This is portrayed in the illustration of Figure 4-13 through the little boxes with “$ %” written in them in the top left corner of the orange boxes. Accumulating these specific impacts will result in obtaining the total absolute sustainability impacts of the end product. Essentially, each company in the supply chain is responsible to ascertain its sustainability impacts in a way that is precise and controllable. This is then passed onto the next company, making up for a recursive system, in which sustainability impacts are included in calculations of the supply chain actors from processing stage to processing stage.

This method follows the market price principle. The expenditure, i.e. the accumulated impacts, are not allocated among the products based upon causal relationships but instead according to the market value, market price times quantity, and its share of the respective company’s total impacts. Consequently, when, for instance, selecting a supplier of a certain good, it is not possible to differ between individual products anymore, but only between manufacturers of various products. (Schmidt 2009b) The market price principle is deliberately applied to the entire sustainability expenditures of a firm in light of the poor data situation that has been mentioned. Basically, the supplier and not the individual product is assessed. Here, the ability to bear principle also comes into play, meaning that a product with a high market price generally bears a higher share of the impacts of its manufacturer than a product with a slower score. Accumulating these impacts over all products of the particular manufacturer, however, one obtains the total impacts, so nothing is lost. The focal company which is more often than not the company selling the end product to the customer then in a last step only has to accumulate all forwarded impacts of the individual supply chain actors and can then attribute their certain share of the entire impact, indicated by the green lines in Figure 4-13. The entire concept is illustrated in Figure 4-13.

**This concept finally brings quite a number of advantages and fulfills many of the posed requirements.** By decreasing the complexity of the examined system, i.e. by ceasing to assess products and its processes individually and instead moving up to a company level, sustainability impacts can be mapped much more easily, adequately and precisely. This is due to the fact that easily obtainable and accepted numbers just like they appear in annual balance sheets and report as well as sustainability reports of companies are the foundation for the assessment. These numbers additionally much better mirror the true circumstances as most of them are regularly and annually updated and moreover under rather strict scrutiny by official organizations, whereas with classic life cycle assessments there is quite a large grey area. Not actual, but value-related structures of the supply chain are of pivotal importance (Schmidt 2009b; Schmidt 2010) This objective scheme essentially provides a much more transparent allocation as is possible with LCA and other approaches as it is all based on current market prices and the true sustainability impacts of a particular company. This is also why this concept is satisfactorily site- and country specific as those impacts will also contribute to the total sustainability score of a company and thus not rendered irrelevant. It also provides for more credibility as the companies – when passing on the specific performance measures – have fewer opportunities to cheat as almost all data can be reviewed in official documents and, particularly market prices, can be observed almost everywhere.

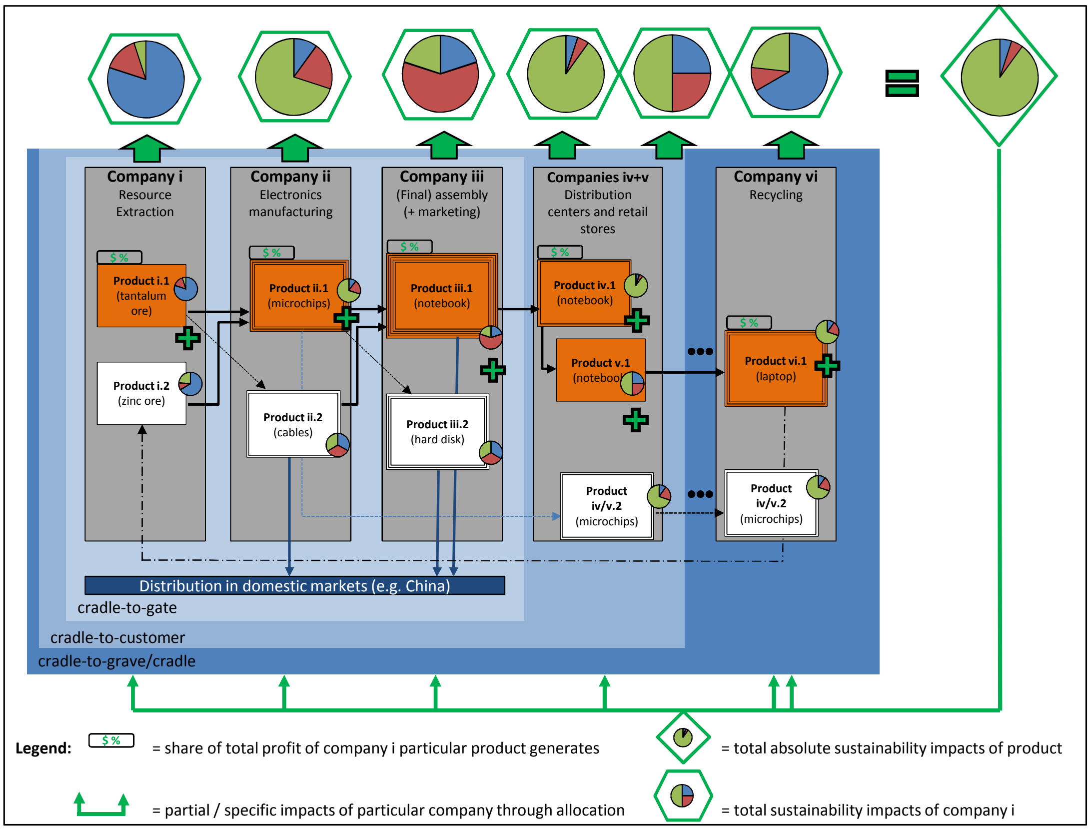



**Figure 4-13: Structure and framework of the entire developed concept**

Further consideration may in future studies be given to a notion which will be explained in the next paragraph.

With the world in rather desperate need for a change of the way mankind maladministers, considerably over-extending the Earth's capacity with unhalted consumption and production, the paradigm of sustainability might require some further impetus and aid. As unlikely as this may appear today, the authors consider a financial levy to be issued by each company involved in the provision of a product to the customer a possibility in the future. This monetary obligation is indicated by the grey dollar signs on top of the arrows in Figure 4-13. The idea is that each supply chain actor commits to be using a certain percentage of its profit – and this percentage would likely have to be set by global, widely accepted organizations such as the United Nations and possibly governments also – to contribute to the improvement of the sustainability performance of all stakeholders involved. As this is not the focus of this study, however, the authors here merely wanted to show a possible future research topic that may be worth investing.

### 4.3.4 Alternative approach to assess sustainability

**Carbon footprint – a catalyst for life cycle assessment** (Weidema et al. 2008). Various challenges and difficulties have been demonstrated in laying out the concept. One possibility to alternatively approach the issue of assessing sustainability may for the time being actually be using the carbon footprint, which has the potential of serving as a catalyst for life cycle assessment at large. The term 'carbon footprint' is a new catchphrase that has gained increasingly significant popularity over the past few years. Unlike LCA and the other classic methodologies, the development of carbon footprinting (CFP) and CFP itself have been driven by nongovernmental organizations (NGOs), retail chains and proactive companies. The wealth of organizations and initiatives – the World Business Council for Sustainable Development (WBCSD), the Japanese Ministry of Economy, Trade and Industry (METI) and the UNEP/SETAC Life Cycle Initiative to only name a few among many others (Finkbeiner 2009) – dealing with it, have had the effect that there are now many definitions and suggestions regarding the calculation of the carbon footprint. (Weidema et al. 2008) A study by Wiedmann and Minx (2007) shows, however, that most approaches have in common that they use both carbon emissions as well as equivalent indicators to also map non carbon emissions, which is essentially very similar to the Global Warming Potential in classic LCA. (Wiedmann & Minx 2008) The great appeal of CFP – especially in comparison to traditional life cycle assessment tools – is that it is very simple. Only emissions are sketched and its calculation is very easy to do online. Additionally, the calculated value is better and more easily imaginable compared to, for instance, the deduced conclusion of something to have an effect of shorting one's life expectancy by 3.5 years. What is also so very appealing about the CFP is that "[g]lobal warming and reductions of carbon emissions are at the top of the environmental policy agenda today." (Weidema et al. 2008) Though it greatly simplifies the sustainability assessment by omitting two dimensions altogether, by focusing on the environmental dimension alone, particularly emissions, it is publicly considered to map the most important sphere. It is because of this, that CPF, more than any other method, has managed to catch public's attention. (Weidema et al. 2008)

Accounting for (product) carbon footprints is about quantifying and presenting the entire greenhouse gas emissions (GHG) for the entire life cycle of products in a consistent manner (Finkbeiner 2009). Consequently, it is often considered to be "slimlined" (Weidema et al. 2008) or "kind of simplified" (Schmidt 2009b) LCA. The British Standard and its Public Available Specification 2050 (PAS 2050) document was published in 2008 and has become a highly popular standard at that matter. (Sinden 2009) In fact, it is a method that for the very first time is "an internationally consulted, standardized [one] for the assessment of GHG emissions from the life cycle of goods and services." (Sinden 2009) It attempts to provide a rigorous and simple in praxis application and includes guidelines on how to handle system boundaries etc. (Weidema et al. 2008) PAS 2050 is founded upon existing LCA approaches and by adopting them in a simplified and clarifying way it sets out to determine the carbon footprint of products (Sinden 2009). The PAS 2050 has ardent followers with WBCSD and ISO, showing its significance in the field of product carbon footprinting.

The scope is rather limited and can result in oversimplification as focusing on GWP alone can result in a misleading picture. PCF may play an important role, however, in assisting the LCA community. They have shunned giving clarification on important issues such as system definitions, how to deal with certain data etc. On top of the advantages PCF already provides, it also therefore has the potential to renew and strengthen the attention to open elements in LCA that have been left unattended and insufficiently addressed. (Finkbeiner 2009)

Finkbeiner nicely sums up PCF: "[W]e cannot allow all the other environmental interventions to be brushed under the carpet. However, among the blind the one-eyed is king. […] CFP is too bad to love it, but too good to leave it." (Finkbeiner 2009) It may therefore really serve as a catalyst for a gradual implementation of life cycle and sustainability thinking and assessments across the globe by further successfully raising attention. To measure incurred emissions is a rather easy and quick task to do for which a certain degree of standardization can be and has been achieved, thus providing a level playing field. It is also conceivable to measure CHG for the entire company, again viewed as black box, and to subsequently allocate the emissions and impacts using the economic allocation method and general methodology described in the previous section.

# 5 CASE STUDY: THE CONSUMER ELECTRONICS (CE) SECTOR

After explaining and illustrating the developed concept in the previous chapter – which included introducing the underlying principles of allocation and shedding light on a number of limitations of classic assessment tools as well as showing some alternatives – chapter 5 now attempts to investigate to what extent or what parts of the proposed concept may already be applied in praxis. For this reason, this study took a closer look at the consumer electronics industry.

This last main chapter of the thesis is structured as follows: Section 5.1 will serve as an introduction to the consumer electronics industry, its structure and some key products it encompasses. Next, in section 5.2, on the basis of a particularly selected, major CE product, an exemplary transition through the single stages of both the life cycle and value chain are demonstrated. A supply chain as it can often be found in the CE sector will be introduced. In section 5.3 it will be tested whether the developed concept can or may even already be applied in the particular industry. The next section will then review and present some key papers having dealt with the CE sector and its products. Social and environmental impacts they have will be discussed. Section 5.5 will then give a brief overview of location decisions that have played a substantial role in the development of the CE industry.

## 5.1 An introduction to consumer electronics and the particular industry

This section will now give an overview of the consumer electronics sector and industry and the products its manufactures – including definitions of what they actually are as there are many terms floating around describing more or less the same items. Since no summarized data and objective statistics could be obtained free of charge, a large number of papers were used to create as thorough and yet as holistic a picture as possible.

**General information and definitions.** Information Technology (IT) which essentially is provided and made possible by electronic products – also called e-products – is often referred to as a revolution that is just as significant as the invention of the combustion engine and electricity were due to the way it has changed our everyday lives, starting from doing business to how we socialize. (Williams 2004) The growing convergence of information, communication and entertainment is very likely to herald the start of a new era of consumer electronics all over the globe if it is not doing just that already. (Report Buyer 2013) An article published in 2004 stated that even back then in a lot of rich countries, it was quite common to have two or more computers and that the quick advancement in technological change implicated that computers, among other electronically run items, were bought much more regularly than many other durable goods. (Williams 2004) Now, 10 years later and with the rapid ascent of laptop computers, this has become normality with a large number of people owning at least a desktop computer and a laptop, which is backed up by empirical studies. Due to increasingly very short product life cycles, the high speed in innovation and ever decreasing prices, the lifespan and useful life of a notebook computer has shrunk to three years (Deng et al. 2011) and even to two years whilst still decreasing, according to other studies (Widmer et al. 2005), further contributing to the growth of the entire industry.

The electrical and electronic product (EEE) industry is considered to be one of the biggest, most swiftly growing, most dynamic and most complex sectors in the global economy of today. (Eugster et al. 2008) In 2006, total revenue through sales of e-products accounted for 640 billion USD alone in China (Eugster et al. 2008), which is currently leading in most segments of the consumer electronics industry worldwide. (Report Buyer 2013) According to Report Buyer, a market research company, China and the United States – being the two biggest consumer electronic markets – together make up for more than 37 % of the global industry. (Report Buyer 2013) It is estimated, that although revenues for consumer electronics will likely be at a new record high of 208 billion USD in the US in 2014 (CEA 2014), China is to surpass the United States in total market size by the same year. (Report Buyer 2013) This comes as no surprise given that in 2006 already, China alone was responsible for 75 %, 39 % and 48% of the global output of laptop computers, desktop computers and CRT (cathode ray televisions) televisions respectively (Eugster et al. 2008; NBSC 2006), most of which is imported. Other major consumer electronics markets are Japan, India, Germany, South Korea and Taiwan. (Report Buyer 2013)

At the same time, the above mentioned rapid development and advancement in the field of consumer electronics causes a swift obsolescence of many consumer electronics, which is to a somewhat artificial extent amplified due to the oftentimes non-existent opportunity to upgrade the particular devices (Prakash et al. 2012), coupled with the continuous replacement of millions of analogue devices through new technologies, handling electrical and electronic waste (e-waste) has become one of the most significant issues worldwide. In fact, e-waste is and has been for a number of years the most quickly and biggest growing waste stream worldwide. (Lundgren 2012)

Many terms to describe the output of this particular industry have been used in an intermixed fashion. This paragraph will therefore deal with the question of what kind of items are actually considered to be consumer electronics. The general term e-products describes any manufactured good that uses electricity for its functioning or use. Products termed to be 'electrical and electronic products' also include large household appliances, which in turn are composed of e.g. washing machines, refrigerators and air conditioners. Consumer goods and information technology and communications equipment, on the other hand, mean any CRT and LCD televisions as well as personal computers (PC), laptops, mobile and smart phones respectively. E-waste is classified as any e-product and thus consumer electronic device that does not serve and satisfies its original purpose any longer. The definition includes all of the e-product's components, sub-assemblies and consumables seen individually. (Eugster et al. 2008)

As with any terminology, different definitions and understanding may exist. It is because of this that this study defines the term consumer electronics to consist of items that are intended for everyday use  and designed for the purpose of entertainment, communications and office productivity. According to worldwide research and surveys on consumer electronics conducted by renowned consulting company Accenture, the world's most sought after consumer electronic products include smartphones, laptop computers, tablets, TVs, digital photo and video cameras, Blu-ray DVD players, eBook readers, game consoles, portable music players and gaming devices. (Accenture 2013) The same study also coined the term the "Big 4" – comprising PCs, HDTVs (High Definition TVs), smart phones and tablets, which Accenture – based on their findings – considers to be the dominant consumer electronic devices with double-digit climbing rates. (Accenture 2013)

**Overview of the industry's structure.** As is intended in this very section, the following paragraphs will merely give a short overview of the industry's structure and deal with key terms. A more thorough reflection of the structure will be given in section 5.5, where some location decision having played a role in the evolution of the market will be illustrated. Outsourcing of manufacturing processes to emerging countries has been a key characteristic of globalization. The (consumer) electronics industry is no exception. On the contrary, while in the past developing countries were mostly responsible for resource extraction, some of these countries – first and foremost China – have successfully established manufacturing industries themselves. (Manhart & Grießhammer 2006) Manufacturing is now organized across many international borders, in which emerging countries have been playing a gradually increasingly important part in. To be competitive in the electronics industry, three must-have elements have been identified: innovation, price and organizational flexibility (Eugster et al. 2008). The control of so called brand manufactures – which are also frequently referred to as original equipment manufacturers – of research and development investment has established them as the genuine leaders in international e-product supply chains, even though they are mostly located outside of China and other manufacturing countries and their real net output ratio has decreased considerably. Many world-renowned companies such as, for instance, Dell, Apple or Hewlett-Packard do not have any manufacturing operation of their own anymore. (Manhart & Grießhammer 2006) Price does remain a very critical component in determining market share,  which is why "China's importance as […] a supplier […] of electronic goods or e-products has grown at an unprecedented pace over the course of the past decade." (Duan et al. 2009; Wong & El-abd 2003) China has been able to combine a low-wage and highly efficient labor force (Eugster et al. 2008), which will be further sketched in section 5.5. However, the increasing complexity of consumer electronics has resulted in the necessity of more investments at the level of production, which has in turn led to a consolidation process among producers of electronic items in order to take advantage of economies of scale. These larger entities are posing a progressively influential challenge to brand manufacturer leadership in the supply chain (Eugster et al. 2008). This increased competition as well as the previously mentioned high paced innovation and advancement in e-products, has resulted in the need for more adaptable and responsive production systems. Only those systems that are very flexible and capable of producing the right product at the right time to the most promising segment of the market have the ability to stay in business. Therefore, companies are faced by the need to both outsource in order to distribute risk and responsibility alike and to work more closely with other supply chain stakeholders. (Eugster et al. 2008)

Again, a number of terms characteristic to the industry have been used, which will in the following be briefly explained to increase understanding and to serve as a basis for the next section. This is of particular importance to the electronics industry since there is much confusion regarding the different terminology. (Sturgeon 2001)The definition given by Eugster et al. (2008) will therefore be used to lay out a foundation for further discussion of the production process and its supply chain in section 5.2. (Eugster et al. 2008) Original equipment manufacturers (OEMs) are also called Own-Brand Manufacturers (OBMs) and deal with the development of both the product concept and market. OEMs have for quite some time been outsourcing the tasks that are to a lesser extent linked to the specific objectives of the products themselves. Contract manufacturers (CM) – or electronic manufacturing service providers – produce the desired e-products according to specifications set by OEMs. CMs either perform the manufacturing tasks on their own or hire other third party companies, so called sub-contractors. CMs are gaining in significance. Not only is there a growing previously mentioned consolidation trend among CMs to be observed, they are also expending their responsibility by offering additional tasks having to do with product servicing and take-back. The spectrum of tasks of original design manufacturers (ODMs), on the other hand, includes production and basic product design. They allow OEMs to focus on their tasks and yet pose a threat as they can turn into direct competitors by entering the OEM markets. Last but not least, sub-contractors and component manufacturers – typically SMEs – also play a substantial role and have to therefore be mentioned as well as ODMs and CMs more and more depend on them due the growing demands.

**Brief overview of trends.** To create a holistic picture of the industry and market, a brief overview of the observed trends must not be excluded. Data suggests that “China’s role in the global e-product supply chain is growing faster than market growth itself” (Eugster et al. 2008), which is quite comprehensive already. China has become the world’s largest manufacturer and sourcing point for PCs, televisions and mobile phones alike with the United States, Japan and the EU being the major export markets (Eugster et al. 2008), usually accounting for more than 50 % of all e-product exports (Eugster et al. 2008). China also exerts a unique role in terms of it having considerably grown in significance as a market on its own. Coupled with China’s economic success, millions upon millions of Chinese have ascended in the middle-class, which has led to a substantial increase in buying power. In combination with the low market saturation and the huge market size, China is poised to have a considerable growth potential in the domestic markets. The domestic market of China will become a progressively significant driver over time, for both new and mature markets. (Eugster et al. 2008) This is definitely already the case in the e-waste production and trade. China has for years been the undisputed world leader of foreign e-waste (Eugster et al. 2008). As the physical volume of e-waste that is being created is a function of consumption, product useful life and material volume per unit, it comes as no surprise that e-waste has as aforementioned become one of the major and fastest growing waste streams of the planet. (Hischier et al. 2005) Actual numbers are very difficult to obtain as large parts of the e-waste recycling process are, following its informal character, quite undocumented. It is documented, however, that e-waste volume placed on the market has increased from 19.5 million tons in 1990 to 57.4 million tons in 2010, which is believed to more than triple to roughly 75 million tons by 2015. (Step Initiative 2014; Huisman et al. 2004) Furthermore, it is estimated that a significant majority of roughly 80 % of all the developed countries' e-waste that is sent for recycling is eventually shipped – rarely legally – to emerging countries such as China, India or Nigeria (Lundgren 2012; Kiddee et al. 2013). While African recipients of e-waste generally reuse e-products that have been disposed of, Asian countries commonly dismantle the shipped products, using hazardous methods. (Wong et al. 2006) This is where the main problem of e-waste is and where the biggest environmental impacts come into play, which is different to most other types of waste. (Osibanjo & Nnorom 2007) Figures 5-1 and 5-2 attempt to capture the major global e-waste streams and the e-waste generated respectively.

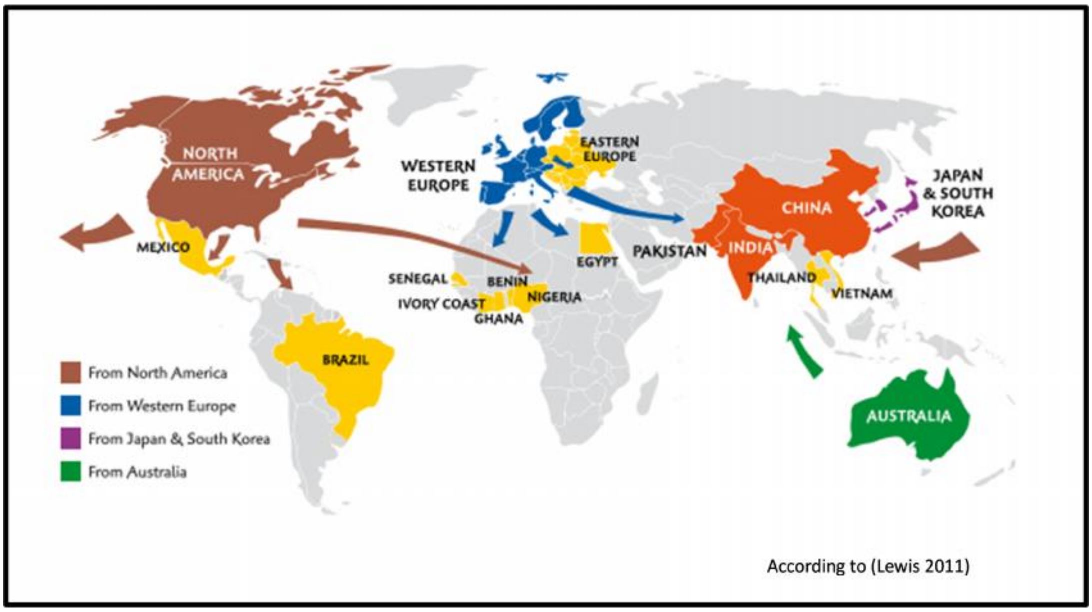



**Figure 5-1: Major global e-waste streams**

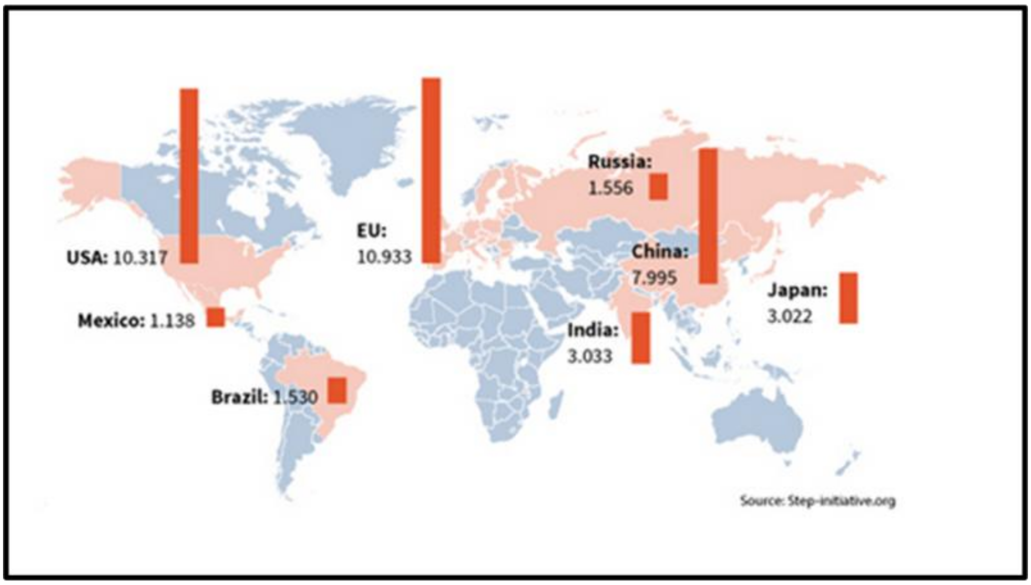



**Figure 5-2: E-waste generated by country (2012 total, in millions of tons)**

**Significance of chosen case study.** Although the extraordinary amount of e-waste poses a major issue for mankind in general and for developing countries in particular, which are shouldering an excessive extent of the burden of this very global phenomenon in nature, it is only a fraction of an extract of the situation and issues at hand. Also, many articles circulate the media, reporting of inhuman working standards and conditions in so called “sweatshops”. Though engaging in the e-product sector has provided major economic benefits to some developing countries at national and community levels alike, it has caused increasing pressure on the local and global environment as well. (Widmer et al. 2005; Puckett et al. 2002) The huge extent of the impacts sustained may be less difficult to imagine when looking at the following impressive numbers: Over the period 2004 through 2009, an annual average 26 million notebooks were sold in the United states with the estimated lifespan having decreased to two to three years. (DesAutels & Berthon 2011) The enormity of the impacts on all three major dimensions of sustainability that consumer electronics have due to their omnipresence in our (daily) lives, definitely warrants a closer look at it.

## 5.2 Making consumer electronics and its supply chain

This very section will at first explain the author's decision to concentrate on one selected consumer electronics device. Then, in general, it will show an exemplary progression of any standard e-product through a simplified, yet holistic supply chain and life cycle. Recourse will be made to the previously established termination of OEMs, ODMs etc. as their place in the supply chain will be illustrated. Not so much attention will be paid just yet to the impacts it exerts on the single dimensions of sustainability. This will be the purpose of the next sections. Last but not least, however, a more thorough in-sight of the selected product's particular supply chain will be given.

For the remainder of this case study – if not indicated otherwise – the consumer electronics device of choice will be a laptop computer, which is also often referred to as notebook or portable computer. This is due to a number of reasons. First, closely examining more than one significant electronics good would go beyond the constraints of this study. Second, laptops are ubiquitous as in that they have become a fundamental and some even argue essential aspect of modern life. (DesAutels & Berthon 2011) This is mirrored by the fact that they are also part of Accenture's 'Big 4' and that their sales have recently even exceeded those of traditional desktop computers (DesAutels & Berthon 2011). Third, out of all products worldwide, the environmental impacts and costs of laptops rank among the very highest. A recent report provided startling news: manufacturing and distributing a portable computer that weighs ten pounds is accompanied by an estimated 40,000 pounds of required materials. (Anderson 1998) With the ever-falling prices for increasingly high performance devices, laptops are a prime example for the in section 2.3 introduced and illustrated so-called externalities. This in turn makes it a prime example for further study. Fourth and last but not least, the e-product industry is very broad and is made up of numerous different appliances. Therefore, a PC system has been selected since it is a highly complex device and its characteristics and results will permit conclusions which are also of value for most other consumer electronics devices. (Duan et al. 2009)

Referring to (Eugster et al. 2008), it is sensible to consider the supply or value chain of consumer electronics in terms of four phases: manufacturing, distribution (trade), consumption (use) and end-of-life (recycling and disposal). This is illustrated in Figure 5-3.

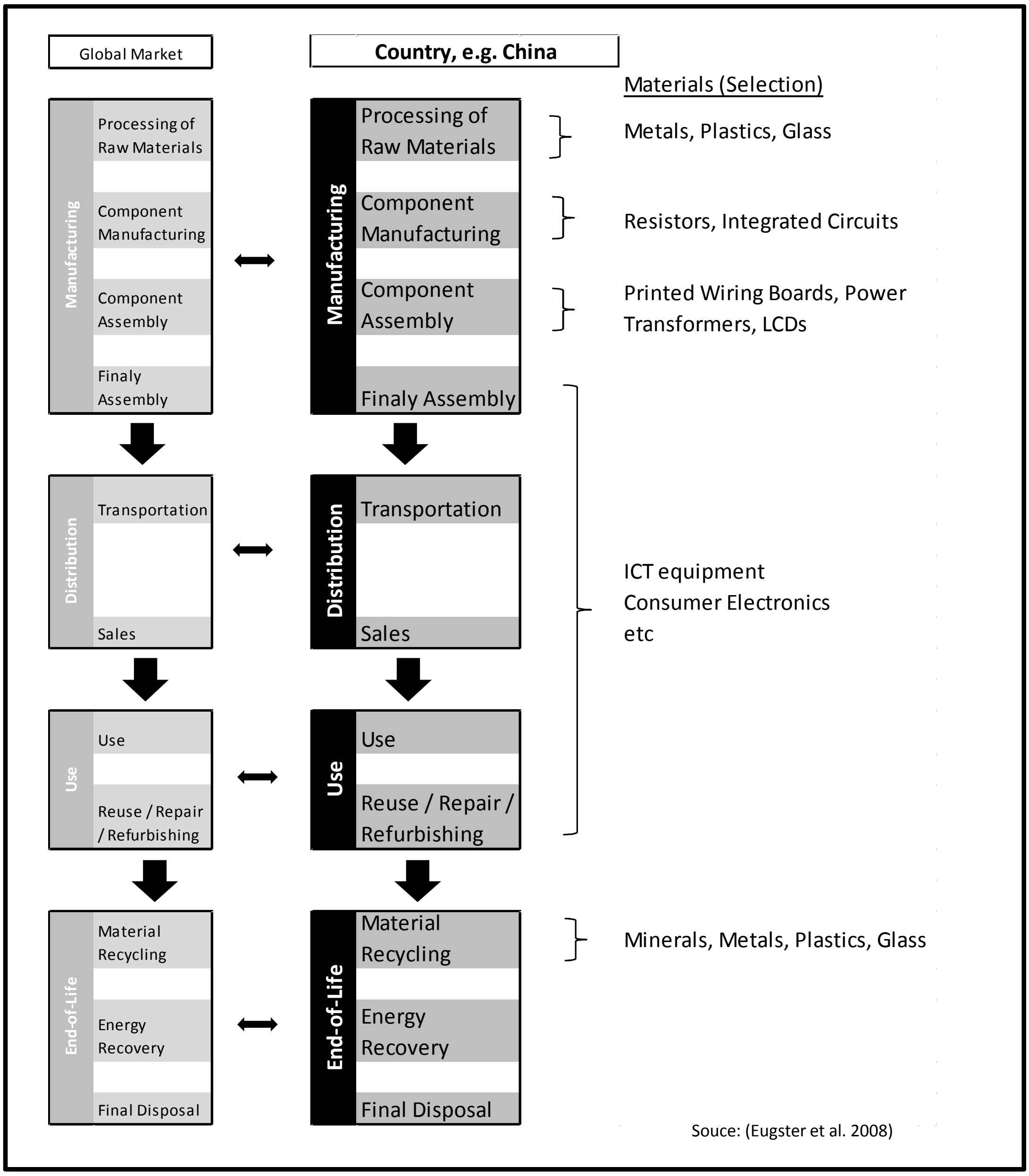



**Figure 5-3: Framework for supply / value chain of consumer electronics sector**

Since value chains for most consumer electronics as well as notebooks in particular are primarily rooted in China, in the following links to China will often be made. (Manhart & Grießhammer 2006) The first out of four phases – the manufacturing phase – is comprised of four processes itself. It is initiated by raw material extraction and its processing. Metals as well as rare earths and plastics belong to the main materials which are dealt with here. The next stages are component manufacturing and assembly and lastly the final assembly. Integrated circuits, printed circuit boards and power transformers are some of the many components manufactured and assembled in (almost) all electronic devices. Manufacturing semiconductors alone requires several of the necessary steps to be performed repeatedly – such as treating semiconductor substances with dopants – so that the production chain may easily consist of more than 100 steps (MIGA 1997), indicating the complexity of production. Notebooks in particular are quite complex as they are generally made up of up to 1,800 to 2,000 parts. (Manhart & Grießhammer 2006) The distribution phase follows manufacturing. It is made up of trade and distribution both domestically and across the globe, i.e. imports and exports. It involves transport to distribution centers, shipping to retail stores etc. The third phase is the use phase and means both the use and reuse of consumer electronics. Here, the closed loop aspect of supply chains of the consumer electronics sector comes into play. Traditionally, supply chains have been understood to be linear, with one stage following the other in a sequential manner. A closed loop supply chain, however, describes the possibility and the actual occurrence of used, repaired or refurbished products reentering the supply chain and thus market. This aspect is of particular relevance for this very sector due to the rapid development and subsequent upgrade and re-design of consumer electronics and the connected obsolescence that many consumers frequently perceive to go along with it. Lastly, the end-of-life phase is divided into a direct waste stream and, analogue to the mentioned closed loop characteristic, a reverse supply chain of e-waste. The latter means the production of secondary raw materials for eventual reintegration in production in the production supply chains. This is reverse flow is illustrated by the red arrow. In general, however, the end-of-life phase is made up of first waste collection, then dismantling, material recycling, energy recovery and finally final disposal. In the United States alone, an approximate 258.2 million units of used electronics (computers, monitors, TVs and mobile phones) were generated in 2010, of which 171.4 million were collected (Toro 2013). These large numbers indicate that not only is there still a lot of unexploited potential, but, even more importantly, that recycling – if performed – can have a major beneficial impact. At each stage, trading, i.e. imports and exports, of raw materials, components, products and services at the respective markets between domestic and global supply chains is illustrated by a double arrow. (Eugster et al. 2008)

Having illustrated the general supply chain, the introduced stakeholders are now placed along it to give the interested reader a better understanding of the consumer electronics sector. As has become customary in the examined industry and has been mentioned, popular OBMs such as Dell or Hewlett-Packard usually do not perform the design and construction of their products themselves anymore, but instead hire contract manufacturers. With notebooks in particular, these are usually Taiwanese companies. The East Asian economic region especially is characterized by a high concentration and density of CMs. The majority of manufacturing is now performed in industrial clusters on China's east coast, where almost all laptop manufacturers maintain huge production facilities. OBMs, on the other hand, focus on the marketing activities. (Manhart & Grießhammer 2006) Further actors of the supply chain which have not yet been introduced in section 5.1 are material suppliers and value-added distributors and retailers (VDR). The task of the first is to source basic raw material which finally go into consumer electronics devices. Oftentimes, a significant share of processing must be done before the raw materials can be moved to the manufacturers of the products. VDRs at last are in charge of product distribution and placement to consumers. Speed to market and timely inventory management are of particular importance in the field of consumer electronics. Retailers are made increasingly responsible for product recycling and take-back schemes. (Eugster et al. 2008) The following Figure 5-4 will now combine previously made remarks and show an e-product supply chain with its actors.

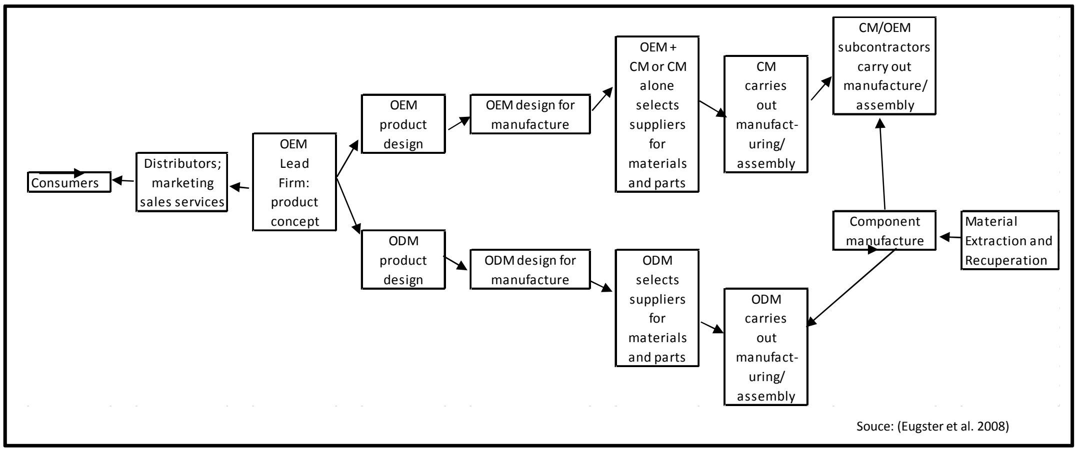



**Figure 5-4: E-product supply chain with an overview of its actors**

Due to external pressure, OBMs have been outsourcing more and more and also increasingly complex activities towards CMs and ODMs, which now offer comprehensives services throughout the entire product life cycle. This has resulted in a fast consolidation process of outsourced activities, which has made many CMs vital global players themselves. (Eugster et al. 2008)

As has been mentioned, a laptop computer consists of up to 1,800 to 2,000 parts, each of which requires several production steps. An in-depth and thorough study of all elements of the value chain would be very time-consuming and not very practical. Therefore as well as for further examinations, the following Figure 5-5 gives a summary of the value chain stages from resource extraction to the marketing of the final device.

| | Production stages | Products and intermediate products | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6. | Marketing | Branded notebook | | | | | | | | | | |
| 5. | Final assembly | Notebook | | | | | | | | | | |
| 4. | Assembly of complex components | Motherboard and network card | LCD display | Optical drive | Hard disk | Keyboard | Touchpad | Battery pack | Power supply | Cooling system | Case | Other |
| 3. | Manufacturing of single components | Microchips | Passive electronic components | Printed circuit boards | Cables | Operator controls | Plug connections | Screw connections | Battery cells | ... | ... | ... |
| 2. | Refining of raw materials | Silicon wafers | Glass products | Raw plastic products | Copper products | Copper-zinc products | ... | ... | Palladium products | Tantalum products | ... | |
| 1. | Resource extraction | Quartz sand | Crude oil | Copper ore | Zinc ore | Bauxite | ... | Palladium ore | Tantalum ore | ... | ... | Scrap metal |

Souce: (Manhart & Grießhammer 2006)

**Figure 5-5: Schematic diagram of the laptop computer value chain**

This is to give an idea of how complex manufacturing of a laptop truly is. And yet, following the global outsourcing process, most OBMs have scaled back or entirely abandoned manufacturing activities, instead concentrating on their core competencies, of which brand management, design and global marketing are a few examples. Regardless of the outsourcing process, OBMs still maintain a firm overview of the value chain as they are highly committed in the costing and quality assertion of the laptop production. (Manhart & Grießhammer 2006) At the same time, they continue to exert a huge influence on the e-waste chain via their post-sale services and decision-making authority in production. (Eugster et al. 2008) Ultimately, profits are still generated where value is added, which is where innovation takes place. This, in turn, is still predominately done and achieved by OEMs.

This is where the developed concept comes into play. While focal companies – OBMs – are increasingly only responsible for marketing and design activities and thus exert sustainability impacts generally limited to mere, oftentimes positive and consequently favorably portrayed social effects, they are essentially the actors that initiated the entire value creation process and "exert great pressure on their suppliers" (Eugster et al. 2008). This what the authors of this study call pseudo sustainability may be significantly reduced through to the assessment proposed in this study's concept.

## 5.3 Application of the developed concept on the ECG sector

Now that an overview of the consumer electronics industry, its supply chain and its actors as well its characteristics has been given, an exemplary application of the developed concept is attempted. Fundamental in it being used is the availability of reliable and transparent data. Hence, several data sources such as manifold papers, homepages of initiatives and organizations as well as sustainability databases (GaBi among others) have been identified and examined.

After examining a wealth of sources it has to be concluded that the availability of both general and specific data is exactly as has been suggested in chapter 2.2.3. There is no dearth of data in the field of environmental impact assessment of both processes and products in the consumer electronics supply chain and sector. The real issues lie elsewhere. As for the social dimension of sustainability there has recently been a spike of publications dealing with this aspect as well and yet there still is a huge data gap that needs to be addressed. The discovered situation for Life Cycle Costing approaches is even more restricted for this specific sector. In general, however, many pitfalls regarding the acquisition of reliable and accurate data could be identified, an overview of which the following enumerated list will give:

1) Missing data for the social – including handling of e-waste – and economic dimension.
2) Focal or lead companies exert great pressure over their suppliers and other supply chain actors.

3) And yet oftentimes, those focal companies do not have sufficient control over their suppliers, let alone the value chain in general.
4) There is no data available, often connected to there being no access.
5) Difficulty of conducting a classic Life Cycle Assessment.

Though all points will lead to the conclusion that an application of the developed concept would be much more sensible than current approaches, point five in particular poses great potential to convince practitioners and scholars alike. Additionally, it must be stated, however, that the developed concept stands and falls with the particular kind of data that it needs. The following paragraphs will thus explain in more detail the problems the consumer electronics companies and industry at large are confronted with at present and why this makes an application of the concept still impossible today.

**Missing data for the social dimension.** As a still valid rule as of today, for any industry made up of heavy industrial and more complex products, the social aspects have generally not been studied adequately. This is largely due to the huge number of different materials and components electronic devices are generally made up of. Consequently, documenting and evaluating social impacts even for production alone is very difficult. As a consequence, many studies do not even consider nor care about social aspects (Prakash et al. 2010), thus failing to advance science. Even though corporate social responsibility (CSR) measures are gradually being implemented, it is believed that a fairly produced computer appears to be far in the future. (Manhart & Grießhammer 2006) This often inadequately addressed social dimension of sustainability is of particularly significance especially in this very industry as electronic products, with computers leading the way, are related to an abundance of social aspects in the progress of their production, use and end-of-life. Hence, it is commonly agreed that only an entire life cycle analysis allows a clear synopsis of the various issue areas. (Manhart & Grießhammer 2006) Furthermore, incorporating extreme scenarios such as recycling and disposal of notebooks in developing countries with stunted recycling infrastructure and facilities would clearly have to be part in an integral part of any reasonable sustainability assessment as it has enormous potential effects. However, there simply appears to be no data available in any of the data bases. (Prakash et al. 2012)

**Focal or lead companies exert great pressure over their suppliers and other supply chain actors.** As Sturgeon (2007) pointed out in his study and has been tried to convey in this thesis as well, OEMs, ODMs and CMs all have huge authority and potential to apply pronounced leadership on manufacturers and subcontractors alike. In fact, "it is not unusual for lead firms, CM and ODMs to exert great pressure on their suppliers to adopt the newest technology to streamline quality control and facilitate tracking." (Eugster et al. 2008) A newspaper article gives a nice account of the ordinary business routine and practice in the electronics industry: When Apple is in the process of selecting new suppliers for their products, suppliers attempt to do their utmost to become part of the supply chain, which – as they are permitted only a tiny fraction of the profit – they can only achieve by cutting costs, for instance through replacing expensive chemicals with cheaper alternatives or pushing their employees to the limits. (Duhigg & Barboza 2012) “You can set all the rules you want, but they’re meaningless if you don’t give suppliers enough profit to treat workers well,” (Duhigg & Barboza 2012) one former Apple execute was quoted as saying by the newspaper. He concluded that if margins were reduced to a minimum, cutbacks in safety is the logical consequence on the part of the suppliers. In such an environment, it comes as no surprise that assessing sustainability is of no pressuring concern for most suppliers as they engage in a fight for survival on a daily basis.

**And yet oftentimes, those focal companies do not have sufficient control over their suppliers, let alone the value chain in general.** As has previously been addressed elsewhere, a consolidation process among OEMs has been the consequence of the large investments necessary to lead research and development as their core competencies. Similarly, there has also been consolidation within CMs and ODMs. As a result, those entities have increased their significance in the consumer electronics supply chains so that decision-making authority has now shifted and spread across the entire supply chain. A prime example for this trend is the increased participation of CMs as well as ODMs in the early stages of product design. One result of this development that has taken place is that unlike in the past when OEMs determined all suppliers, CMs and ODMs now contract and manage their own suppliers independently of the lead firm. (Eugster et al. 2008) The consumer electronics and particularly laptop industry are a perfect example of the swift reduction in production depth. The actual manufacturers of the notebooks are very specialized entities and most often outsource themselves all of their production steps other than the mounting of components and final assembly of the end product, which they retain in their competency. This development can be observed in an increasing amount of parts of the supply chain, “resulting in an almost indeterminable proliferation of actors and subsidiary industries.” (Manhart & Grießhammer 2006) Another rather unique element of the consumer electronics industry is the required swiftness to market caused by the high innovation rate. Therefore, it is very common for standardized products (e.g. plug connections) to be provided on-time, which requires a certain infrastructure and organizational structures as well. It is because of this that “at no single point in the value chain is there a complete overview of all the actors and locations involved.” (Manhart & Grießhammer 2006) This makes the application of the developed concept currently impossible.

**There is no data available, often connected to there being no access.** One examined study concludes that at present only those parts of the supply chain that are directly linked to the specific product can be assessed for social impacts. Oftentimes, however, this is not enough, as the inaccessibility of certain relevant pieces of information renders calculations for the entire supply chain very hard indeed. (Manhart & Grießhammer 2006) The authors of the same study do not expect this problem to change considerably soon, which is why it is to be assumed that analyses will further rely on various and unstructured information obtained from different data sources. Corresponding databases do not seem to be in development. (Manhart & Grießhammer 2006) The above mentioned newspaper article also applies in and for this category. It is currently oftentimes not possible to obtain data from various actors along the supply chain, especially those at the lower end of it. The top-down approach turns out to be questionable as lead firms with all their might can exert enormous pressure on their suppliers which essentially and eventually have to pay deference. As a consequence, standards will be lowered, sustainability measures not be heeded anymore. Tracking of sustainability impacts is abandoned as it is not regarded to help the company be profitable, to help the suppliers in their quest to please the lead companies. Though most OEMs and increasingly CMs as well have social and environmental codes of conduct they claim to abide by, CSR programs have largely failed to bring substantial change and improvements. (Brown 2010) Besides, there is no equivalent system for the lower stages of the supply chain. Another study with a more global scope recognized there was a lack of data regarding the manufacture of electronic products and its global supply chain. It is partially because of this, they argue, that it was not yet possible to account for geographic variations in, for instance, energy use throughout the supply chain. Furthermore, the study concluded that the temporal uncertainty was likely to be considerable following the swift changes in the products and consumer electronics sector in general. (Deng et al. 2011) It has also been found that there still was no Chinese national life cycle inventory database available and that there is generally only very little public data concerning PC systems. (Duan et al. 2009) Feng and Ma [2008] determined that certain data, such as data connected to the aluminum and copper production, were impossible to be obtained immaculately in and for China, which is why inferences and assumptions based on advanced countries have to made. (Feng & Ma 2009) This may lead to very different results, however. What is true of the previous category also applies here: the nearly impenetrable mixture of actors in the supply chain. (Manhart & Grießhammer 2006) Though (focal) companies are largely aware of the issues, the complexity of both the products they produce and the supply and value chain – containing very difficult supplier and subcontractor relationships – they are embedded in, pose great challenges in terms of obtaining adequate and sensible data. The predominant secrecy due to competitive reasons is not of assistance in this regard. (Manhart & Grießhammer 2006) It is stated that not even the suppliers themselves are aware neither of the stages which are not directly linked to a certain product nor of the conditions that surround production. (Manhart & Grießhammer 2006)

**Difficulty of conducting a classic Life Cycle Assessment and hence even heightened validity of the developed concept.** One essential pitfall in conducting a comprehensive product life cycle assessment is the fact that a fields research in the life cycle data of consumer electronics, in particular of laptop computers, is connected to enormous expenditures both in terms of times and financial resources. (Prakash et al. 2012) This is why a full study including all sections of the value chain is considered to be “almost impracticable.” (Manhart & Grießhammer 2006) And yet, the obtained data uncertainties are considered to be huge (Prakash et al. 2011) For instance, for emissions of GHG alone – which is only a little part of a thorough assessment of all three dimensions of sustainability – there are disparate findings. The total emissions of a laptop computer over its entire life cycle which are caused by the manufacturing phase alone, for instance, range from 57 % to 93 % according to several studies.

(Prakash et al. 2010; Andrae & Andersen 2010) Prakash et al. (2012) admit, however, that such variable numbers are always connected to uncertainty due to the fact that there is only little data available if at all regarding the use of resources in the early stages of a supply chain. (Prakash et al. 2012) Perception of reliability is generally weakened by LCA studies of an identical product producing entirely different, sometimes even contradictory results (Lenzen & Munksgaard 2006; Farrell et al. 2006). An often quoted example in literature is the life cycle energy that is required to manufacture a particular desktop computer, with the results ranging from 1,000-8,300 MJ per computer. (Deng et al. 2011) In spite of numerous attempts to deal with this uncertainty, the problem could not yet been resolved, neither from a methodological nor practice perspective. (Deng et al. 2011; Williams et al. 2009) This most likely has to do with the sheer complexity of consumer electronics. Furthermore, a limitation of classical assessment methodologies come into play when social impacts need to be examined. Eugster et al. (2008) argue that social impacts and problems simply cannot be associated directly to particular products (Eugster et al. 2008), which is further indication of the validity of the factory floor and black box measurement of the developed concept and its subsequent allocation and accumulation. This shortcoming of traditional life cycle assessment methods comes as no surprise given that in praxis they are primarily used by producers to assess and evaluate the efficiency and impact of products within the rather limited boundaries of the production process. For external data, various sources are used, which furthers adds to the inaccuracy and randomness observed. (DesAutels & Berthon 2011) Another main weakness of existing life cycle studies found in literature is that they are usually and based on proprietary or confidential data, which makes it virtually impossible, to decompose and analyze the various findings. (Williams 2004) In addition, the same study points out that for most LCAs in the field of electronic products, many important steps both regarding the supply chain as a whole and the manufacturing process in particular have been left out. (Williams 2004) Adding to the inadequacy of current and available studies, most do not sufficiently consider how data may be different from facility to facility, country to country. This is of particular significance in the consumer electronics industry as a highly globalized industry, where almost all products pass through a number of nations. (Williams 2004) In combination with the other inadequacies of LCA, the type of sustainability measurement proposed in this study's concept appears even more beneficial as it provides more transparency, less arbitrariness and fewer demands on the actors in terms of data collection.

**Concluding remarks.** One last shortcoming of current measurement methodologies this study feels the need to address is the fact that although most social and environmental impacts are incurred in and attributed to China, the international community at large is predominately responsible for it. OEMs are the companies which are occupied with design and marketing activities and are thus the initiators of the supply chain, causing all the later impacts and having a direct influence on the magnitude of them. Therefore, the proposed measurement along with the subsequent first allocation, accumulation and lastly second allocation of sustainability impacts poses huge potential. On the whole, however, it must be concluded that the availability, reliability and transparency of data is still very limited. On a positive note, however, an increased willingness among some companies could be observed to permit access to internal documents to foster a picture. (Manhart & Grießhammer 2006)

To put it all in a nutshell, there is no generally accessible data available for public and free use, which could be used as a data basis for the practical application and capability analysis of the developed concept. Huge pitfalls have been identified to be present in two areas in particular:

- On site data considering sustainability impacts on all three dimensions, which is required for impact assessment.
- Data that is accessible to the public on the product portfolio, volume of turnover and sales, which is required for impact allocation. This is particularly true for SMEs.

This, however, was to be expected, because as of yet, there are no legally binding regulations let alone oftentimes there is no perceived need to assess sustainability impacts on a factory level. Especially at the lower end of the value chains but not only there, companies do generally not collect data yet that is related to sustainability. Quite a number of reasons have been identified. In addition to the presented ones above in this section, the previously illustrated reasons of insufficient resources both in terms of time and finances as well as missing skills must not be forgotten and also play a role.

Summing up, additional research is required to evaluate the concept. Though this may come as disappointment in the course of this study, it is exactly the presented current situation that proves the inevitability of there being a change in assessing (global) product sustainability toward an approach as has been proposed in chapter 4.

For the sake of holism, the next section will therefore give an overview on several studies' results regarding life cycle assessment of laptop computers as well as incurred sustainability impacts that go along with it.

## 5.4 Presentation of selected case studies

Following the disillusioning data availability illustrated in the previous section and the realization that, consequently, the developed tool cannot yet be applied, this very section attempts to make amends by giving an overview of selected case studies in the field of sustainability assessment dealing with the previously chosen consumer electronics device of choice, the laptop computer. After presenting some of the results of these studies, this section will give a general outline of the most prominent and striking sustainability impacts on both the environmental and social dimensions and in which life cycle stages they occur.

It is not this study's aim to conduct a life cycle assessment of consumer electronics. Not only would this be beyond the scope of this thesis, it would also not be expedient due to two reasons. One, many studies have been done on that very matter already and second, the results are very inaccurate due to the explained reasons. This section will therefore only give a brief overview of some common findings in literature. As was to be expected following the statements made in section 5.3, LCAs for, in particular, consumer electronics often make benchmarking a very tough task due to the huge amount of required data and their inherent opaqueness nature. (Andrae & Andersen 2010) In their study, Andrae and Anderson (2010) reached the conclusion that while LCAs for phones and TVs are generally consistent, LCAs for laptop computers frequently provide conflicting results. (Andrae & Andersen 2010) And this is in spite of the fact that there exists no research providing a full cradle to grave LCA assessment of laptops with a broad and thorough assessment of the sustainability impacts on all dimensions. (DesAutels & Berthon 2011) Thereby, most studies focus on the results for $CO_2$ equivalents ($CO_2$e), which is often expressed as the global warming potential during the next 100 years (GWP100). (Andrae & Andersen 2010) This simplification has its merit as the already stated report from Anderson (1998) recently showed that a substantial 40,000 pounds of materials needs to be processed and distilled for the manufacture and distribution of a single laptop, once more showing the complexity and difficulty of the production and hence assessment of a laptop computer. This is consistent with section 4.3.4, where an alternative approach to assess sustainability was introduced, which could function as a catalyst and temporary substitute till time is ripe for the actual application of a kind of concept as has been introduced here. The huge appeal of this is the easy communication and comparison it provides.

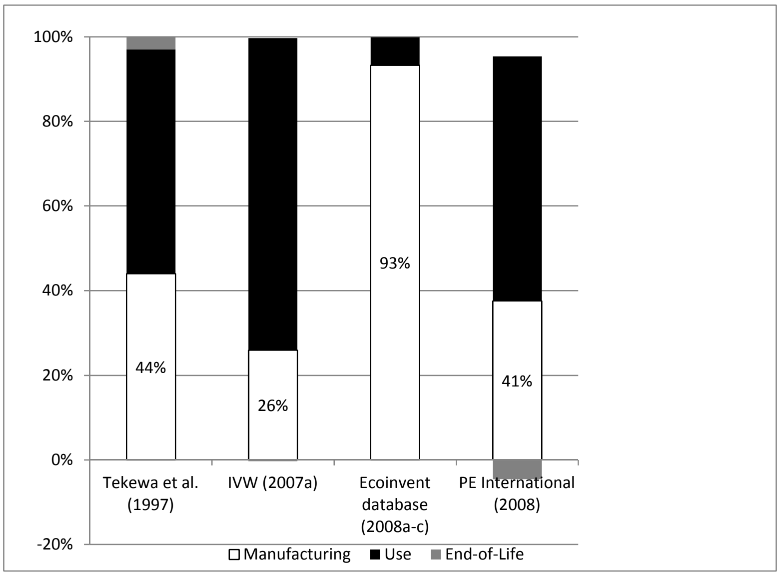
Andrae and Andersen (2010) conducted an extensive literature review and extracted four different studies for a comparative study of their findings regarding the global warming potential of notebooks. (Andrae & Andersen 2010) They are illustrated in the following Table 3.

| Description of device | Weight (kg)/piece | Kg CO2e/piece | Kg CO2e/Kg | % Production and transports | % Use | % End-of-life |
|---|---|---|---|---|---|---|
| Laptop, Europe, IVF (2007a), cradle-to-grave | 2.5 | 360 | 140 | 26 | 74 | -0.3 |
| Laptop PC, Switzerland, Ecoinvent database (2008a, b, c), cradle-to-grave | 3.2 | 660 | 210 | 93 | 6.6 | 0.1 |
| Laptop, global, PE International (2008), cradle-to-grave | 1.5 | 410 | 270 | 41 | 63 | -5 |
| Laptop PC, Japan, Tekewa et al. (1997), cradle-to-grave | n. a. | 260 | | 44 | 53 | 3 |
| Laptop PC, China, Lu et al. (2006), cradle-to-grave | 2.3 | 54 | 23 | n.a. | n.a. | n.a |

Souce: (Andrae & Anderson 2010)

**Table 3: Summary of life cycle $CO_2$e emissions of laptfops**

As can be seen, there are huge differences depending on the data basis and study. The outcomes vary between 54 Kg $CO_2$e and 660 Kg $CO_2$e. These findings are more clearly and more graphically edited and illustrated in the following Figure 5-6:




Souce: (Andrae & Anderson 2010)

**Figure 5-6: $CO_2$e shares of life cycle phases for laptop computers**

Conspicuously, the share the manufacturing stage exerts ranges from 26 % to 93 % across the examined studies. The authors reached the conclusion and inferred that the ecoinvent study exaggerates the influence and impact manufacturing has on the emissions of GHG seeing that that result is very inconsistent with the others. (Andrae & Andersen 2010) What can definitely be concluded, however, is the fact that the manufacturing and use phase contribute the most overall impact and that obviously manufacturing has a much larger sustainability impact as had previously been assumed. (Prakash et al. 2010) It is because of this finding that another study done by O'Connell and Stutz (2010) set out to analyze the manufacturing process more thoroughly in order to find out the impact certain individual components have. The results can be seen in Figure 5-7. (O'Connell & Stutz 2011)

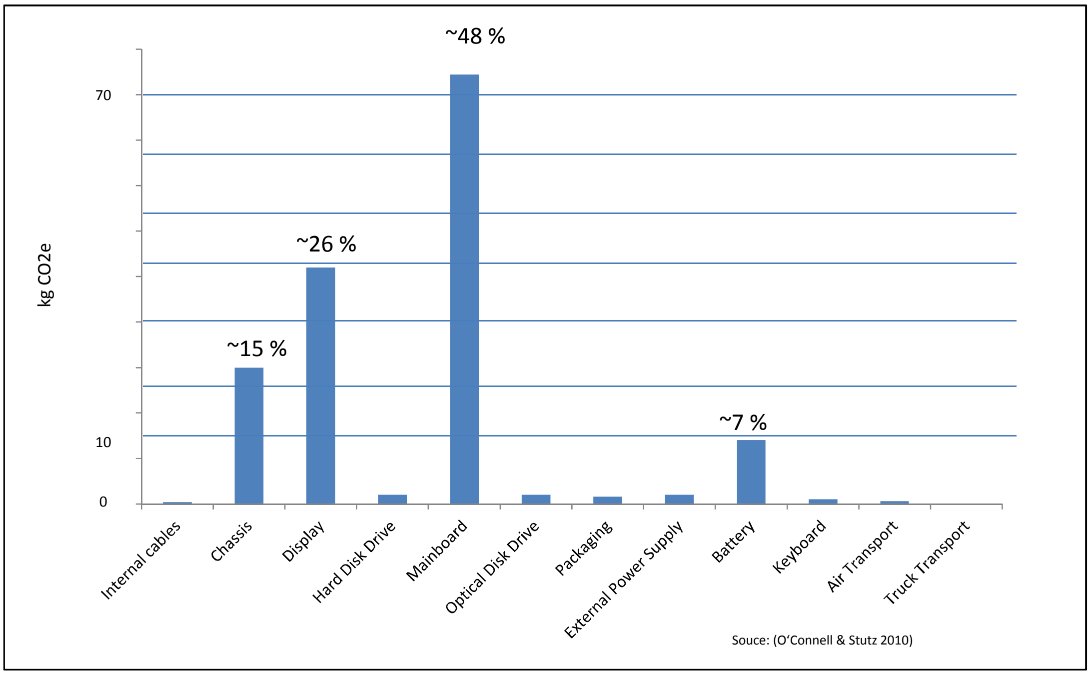



**Figure 5-7: Impact on total $CO_2$e emission of main components of a laptop computer**

The mother- or mainboard is with 48 % of the share of emissions by far the source with the most potent environmental impact in the production of laptops, which is largely due to the substantial use of integrated circuits. This solution is consistent with the study of Eugster et al. (2008).

A more in-depth life cycle assessment was provided by Prakash et al. (2012) which analyzed the impacts for additional life cycle stages. There findings are summarized in Table 4 and Figure 5-8. (Prakash et al. 2012)

| | EuP Lot3 | EcoInvent2.2 | UBA-FuE intention + EcoInvent 2.2 (End-Of-Life Business-As-Usual) |
|---|---|---|---|
| **End of life** | -1 | -1.05 | -1.17 |
| **Use** | 138.5 | 138.5 | 138.5 |
| **Purchase trip** | 1.4 | 1.4 | 1.4 |
| **Distribution** | 10 | 27.4 | 29 |
| **Manufacturing** | 81 | 195.8 | 214.2 |
| **Sum** | 230 | 362 | 362 |

Souce: (Prakash et al. 2012)

**Table 4: Absolute values (in kg) of $CO_2$e emissions in the life cycle stages in which they occur**

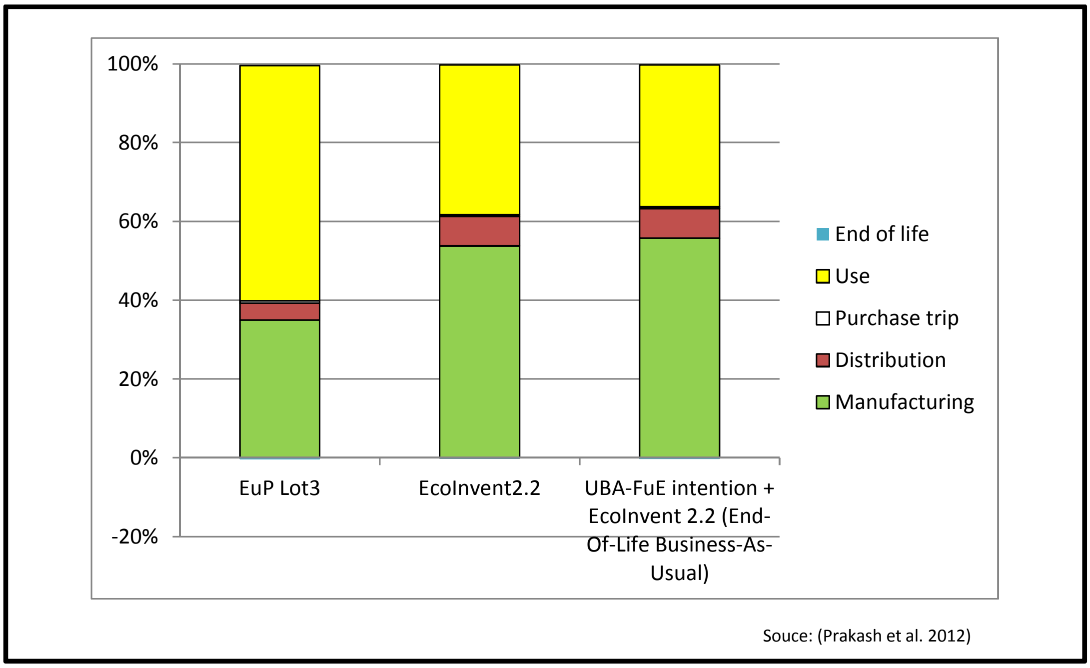



**Figure 5-8: $CO_2$e shares of life cycle phases for the assessed scenarios**

As can be seen, the environmental impacts of the end-of-life phase as well as the ones connected to the trip to purchase the item can almost be neglected. For more information, the interested reader may be referred to the study of Prakash et al. (2012). Their findings are somewhat consistent with the previously illustrated results of the literature review provided by Andrae and Anderson (2010). However, the use phase is in both cases relatively highly overdrawn as a lifespan of five or four years respectively is assumed. The actual lifespan today has, however, as mentioned decreased to a mere two to three years, which is why the emissions of GHG of the use phase of a notebook has shrunk to only about 25 % of the total emissions. (Prakash et al. 2011)

After a brief overview of current (e-)LCAs dealing with laptops has been given, the next paragraphs will now try to create a more holistic picture regarding their sustainability by addressing other environmental impacts as well as social impacts along the supply chain.

The major social and environmental challenges of the consumer electronics industry and in particular manufacturing countries which are primarily based in Asia deal with the production itself, the use phase and last but not least the disposal and recycling of products. In a global context, the use and end-of-life stages of the supply chain enter the lime light and must be given special emphasis to. Eugster et al (2008) summarize the key environmental impacts, organized according to their occurrence, in the following way: (Eugster et al. 2008) For a more lucid overview, their findings are presented in Figure 5-9.

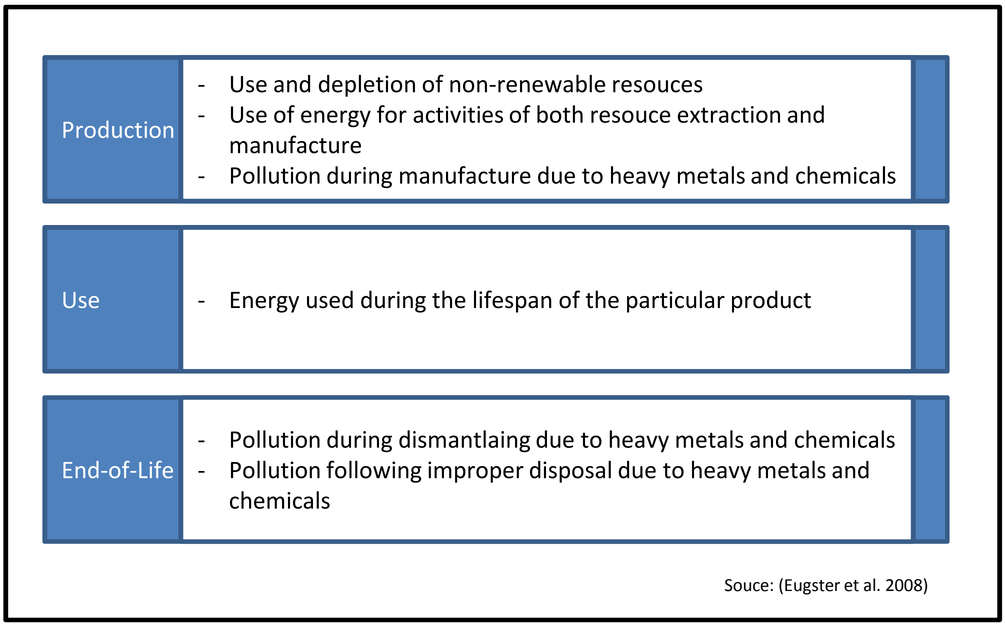



**Figure 5-9: Major environmental impacts during main life cycle stages**

At the same time, the most significant negative social impacts often are tightly connected to the environmental impacts. Therefore and following statements made throughout the entire study, it comes as no surprise that social impacts most frequently and apparently occur at the production and end-of-life stages of the value chain. Figure 5-10 presents the summary of Eugster et al. in this regard. (Eugster et al. 2008)

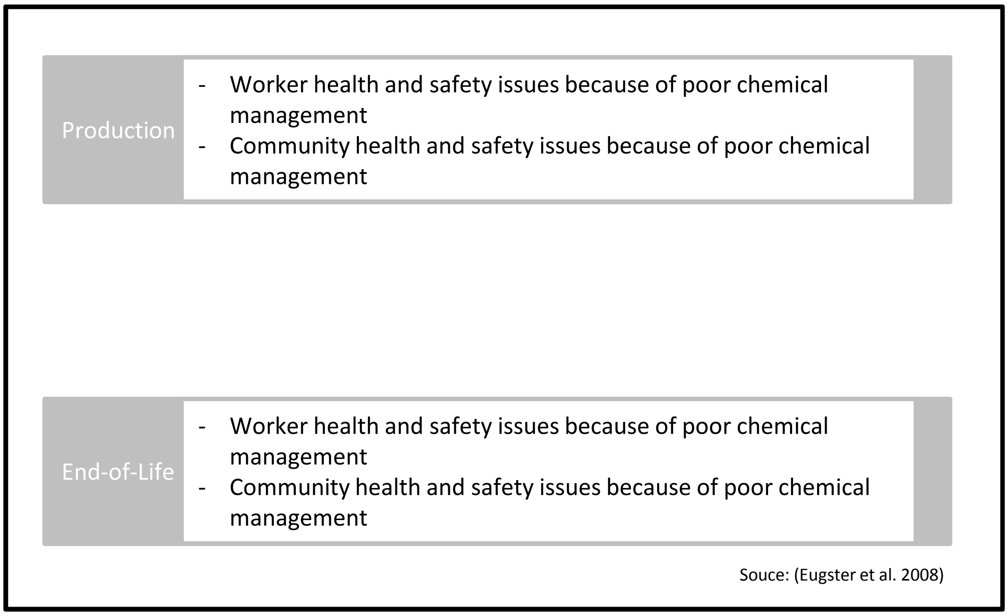



**Figure 5-10: Major social impacts during main life cycle stages**

With China being the country with the biggest actual impact on sustainability, it must be stated that despite all negative effects the production and dealings with consumer electronics have on both the environment and society, the single most positive contribution the sector has is to both national and local economies within China. It is one of the key drivers of the economy, creating jobs, increasing wealth, helping China make the transition to a first world country. (Eugster et al. 2008)

Since this thesis is also meant to serve as a guide for better access to the entire topic of sustainability and especially its assessment in the sector of consumer electronics, the following tables gives a clear overview of literature having dealt with it. A selection of papers assessing different consumer electronics – ranging from monitors, to laptops and personal desktop computers till mobile phones – has been provided.

| No. | Source | Year | Topic | Results |
|---|---|---|---|---|
| 1 | Socolof, M. L. et al.: Environmental life-cycle impacts of CRT and LCD desktop computer displays | 2005 | Environmental impacts of CRT and LCD computer monitors incurred over their entire life cycle are presented for 20 impact categories and compared to one another. | Detailed figures of processes included in analysis as well as impact results are given. Results of primary and secondary data collection are presented. Both types of monitors have categories in which they dominate the other type. |
| 2 | Andrae, A.; Andersen, O.: Life cycle assessments of consumer electronics - are they consistent? | 2010 | Collecting and comparing LCA studies of consumer electronic products to determine if there is consistency between the many studies | Focus is on GWP and CO2 equivalents in general. Most studies are found to be of comparable quality, yet especially for computers studies occasionally are contradictory. Results of different studies are presented. |
| 3 | Williams, E.: Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input-Output Methods | 2004 | A calculation of estimating nature is performed in order to determine the total amount of energy and fossil fuels that are required for computer manufacturing. | The high energy intensity of manufacturing could be shown. The life cycle energy use of a computer is presented to be dominated by production, which leads to the conclusion that extending the usable lifespan is benefical when trying to mitigate the energy impacts. |
| 4 | Choi, B. et al: Life Cycle Assessment of a Personal Comptuer and its Effective Recycling Rate | 2006 | Following encouragement by the Korean government, this study investigates the life cycle environmental impacts of PCs and determines a desirable recycling rate of the end-of-life stage. | The study once more shows that design for environment, if implemented n the product design stage, improves the environmental performance. It could also be shown that current recycling methods are not yet effective in terms of reducing the environmental burden. |
| 5 | Deng, L. et al.: Economic-balance hybrid LCA extended with uncertainty analysis: case study of a laptop computer | 2011 | A laptop computer is examined - especially regarding its energy use - by means of employing a hybrid LCA. | Results show that the manufacturing phase is the most energy consuming phase with 62-70% of the total energy of a laptop in its lifespan. The authors thus propose to extend the lifespan as an important strategy to manage life cycle energy of laptop computers. |

**Table 5: Selected literature on assessing sustainability in the CE sector (Part 1)**

| No. | Source | Year | Topic | Results |
|---|---|---|---|---|
| 6 | Duan, H. et al.: Life cycle assessment study of a Chinese desktop personal computer | 2008 | Due to the enormous and growing influence and significance of China in the consumer electronics market, a detailed and modular LCA is performed to investigate the environmental performance of Chinese PCs. | The LCA study shows that the manufacturing and use phase of desktop computers are of highest environmental performance. Especially the integrated circuits and LCD screens are the parts contributing most to the impact. It is shown that the end-of-life phase, if done sensibly, can lead to significant environmental benefits. |
| 7 | Kim, S. et al.: Life Cycle Assessment Study of Color Computer Monitor | 2001 | LCA is performed to investigate environmental performance of a computer monitor in order to be able to identify hot spots and to introduce life cycle thinking at the product design phase already. | It is shown that the use phase is the phase that contributes the most by giving an account of the environmental performance of all production steps and life cycle stages. The authors recommend that LCA should be carried out in parallel with product design. |
| 8 | Krishnan, N. et al.: A Hybrid Life Cycle Inventory of Nano-Scale Semiconductor Manufacturing | 2008 | An extensive library is developed containing plentiful useful information, such as typical materials, energy requirements and emissions in the field of manufacturing modern microprocessors. | The result of this work is a comprehensive data set and methodology that can be used to estimate and improve the environmental performance of many electronics. |
| 9 | Frey, S. et al.: Ecological Footprint Analysis Applied to Mobile Phones | 2006 | Ecological footprints are used as an aggregate measure of sustainability to extend LCA studies done on mobile phones which mainly focus on toxicity, end of life management and energy use, thus ignording wider sustainability implactions. | Results of three footprint mobile phone case studies are presented. A database was developed to establish the land areas consumed by the impacts mobile phones have. Environmental burdens of mobile phones and their life cycle stages are calculated and operated with.. |
| 10 | DesAutels, P.; Berthon, P.: The PC (polluting computer): Forever a tragedy of the commons? | 2010 | It is investigated whether computers that are claimed to have been manufactured sustainably are more expensive for the consumer. | The study gives a good account of external costs, of how costs are shifted. Findings indicate that the hypothesis that manufacturers raise the cost to the consumer following the introduction of sustainability stanards could not be accepted. |

**Table 6: Selected literature on assessing sustainability in the CE sector (Part 2)**

**Critical appraisal.** Summing up, the goal pursued in this very chapter of proving the practical suitability of the developed and proposed concept by means of a case study in the consumer electronics sector could not be achieved. Nevertheless, in combination with the previous chapter, the analysis of existing studies on sustainability of e-products, laptop computers in particular, provided interesting insights in the industry and as to why an application of the approach drafted in this study is currently not within reach. Firstly, a lack of capacity of the authors to conduct deeper investigations (e.g. expert interviews) thwarts data collection. Secondly and even more importantly, the structure of the supply chain in the sector that is encountered today make it very difficult to gather site-specific data. If data gaps can be closed in the future – for instance via collaborative initiatives and projects – the developed concept can offer a powerful tool to increase the overall sustainability of products across the entire life cycle.

## 5.5 More detailed life cycle assessment of laptop computers

After a broad overview of some LCAs regarding laptop computers has been given and a number of general key environmental and social impacts in the CE sector provided in the previous section, this study will now present a more in-depth analysis and assessment of the consumer electronics product of choice, a laptop computer. One of the most comprehensive existing study of a notebook computer spanning slightly more than 400 pages done by Ciroth and Franze (2011b) will be shed light on in the course of this very section. (Ciroth & Franze 2011b) The goal and scope, the system boundaries and many other useful pieces of information of the study as well as an extract and summary of the life cycle impact assessments will now be displayed in the following paragraphs. It is not this thesis' aim to recite every single result that was obtained, but instead concentrate on major results to create and illustrate a better picture of the product system of a laptop computer and its influences, impacts and effects. Additionally, a focus – corresponding to the topic and set of objectives of this study – will be on the global aspect and scale of this industry and the applied life cycle thinking in the CE sector.

Ciroth and Franze applied the UNEP/SETAC guidelines as have been introduced in section 2.2 and its subsections in and for their S-LCA. Hence, this very study has been purposely selected in order to give a an example of a realistic and real case of an application, which rounds out this study nicely. Presenting Ciroth and Franze's study has also been selected for its merit in conducting both an S-LCA and E-LCA in a parallel fashion on this very complex product. It is one of the very first studies to have ever done that, which is why their social life cycle impact assessment methodology will have to be briefly presented as there is no internationally accepted one just yet. The study was conducted by Ciroth and his company GreenDeltaTC in the name of the government of Belgium which wants to promote sustainable development. If the interested reader feels a desire for more and more thorough information than will already be given, taking a closer look at the actual study by Ciroth and Franze 'LCA of an Ecolabeled Notebook: Consideration of Social and Environmental Impacts Along the Entire Life Cycle' (2011b) is recommended.

**Goal, scope and system boundaries of the study.** As has been pointed out already, the investigated and presented study is one of the very first to apply the UNEP/SETAC guidelines for S-LCA of products in a complex context and product system which reflects a value chain with significant sustainability impacts. A laptop computer, more than most other devices, is an appropriate example case study to use as this electronic product is embedded in a global supply chain and, due to it containing many different metals, plastics, chemicals and numerous electronic parts and components, causes huge social and environmental impacts. A more specific goal of the study was to identify social and environmental hotspots over the entire life cycle of a recent notebook for office use which is available in Europe, Belgium in particular, so that the sustainability performance could be better understood and consequently be improved. Following some remarks made earlier, the examined notebook is produced in China. It is ordered over the internet from and delivered to Brussels, Belgium. Although this particular setting may not be too representative as the US and China – to only name two global players – are much bigger consumer markets than Belgium, this very extensive case study's focus was on Belgium and most if not all their findings are still applicable even when ordered from and shipped to some other place since other life cycle phases – as is about to be shown – contribute much more to the environmental and social burdens. The end-of-life scenario examined assumes that 20% of the collected laptops are reused, i.e. recycled, and thus sent back to China after the end of the European lifespan and the other 80% are recycled in Belgium. Due to data gaps, the large and hazardous share of informal recycling in China, which is cause for significant social and environmental issues, was not part of the E-LCA. The specific and precise example of the manufacturing of the particular laptop computer ASUS UL50Ag is given in the study. The components and the respective companies' locations considered will be clearly shown once more in Figure 5-12 when presenting the results of the S-LCA. The following shortened table is to give a brief overview of the components examined in the study and where they were fabricated. A clear dominance of China can be observed.

| Component | | Site |
|---|---|---|
| Mainboard | | China |
| Hard Drive Disk (HDD) | | China |
| Processor | | - |
| Memory (RAM) | | South Korea |
| Display | | |
| | LCD panel | produced in Taiwan, assembled in China |
| | Bezel | China |
| Case | | - |
| Keyboard | | China |
| Touchpad | | China |
| Battery Pack | | |
| | Assembly | China |
| | Plastics | - |
| | Circuit board | - |
| | Cells | Korea |
| Drive | | Philippines |
| Fan | | China |
| Speakers | | - |
| Camera | | - |
| Graphic card | | - |
| W-Lan card | | China |
| Power supply | | China |

**Table 7: Components and the sites of their fabrication considered in (Ciroth and Franze 2011b)**

The following processes are also considered: extraction of copper, extraction of cobalt under co-production of nickel, extraction of gold, extraction of tin, mining of bauxite, production of plastics, production of non-ferrous metals and production of glass. The following Figure 5-11 gives an overview of the investigated product system both from the social and environmental perspective.

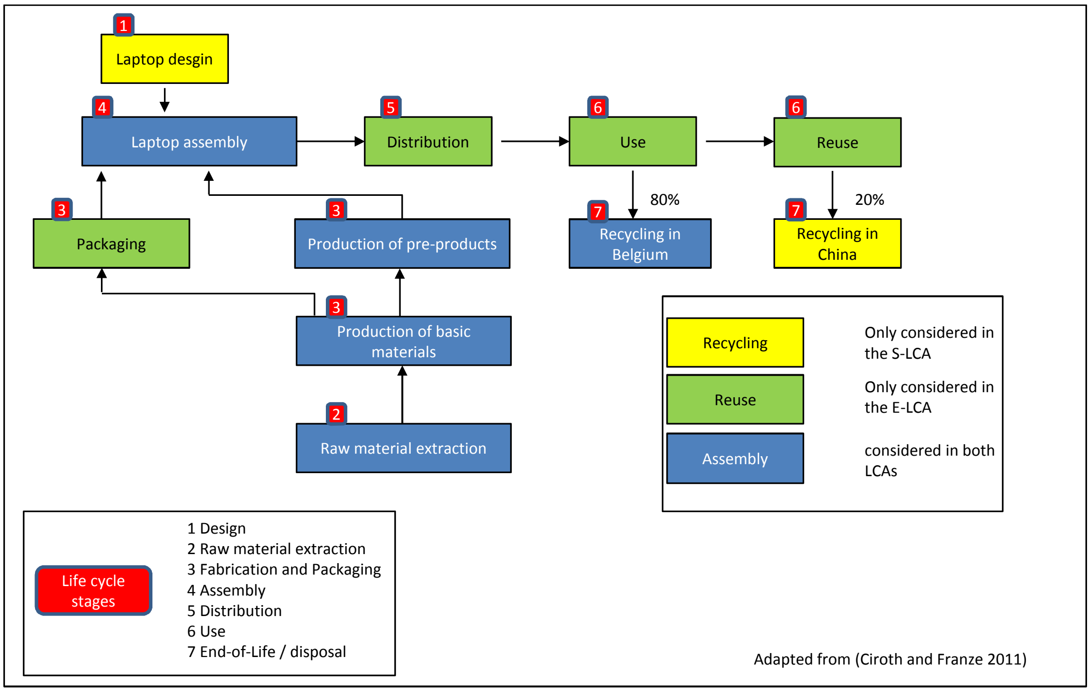



**Figure 5-11: Flow chart of the presented product system of a laptop computer**

Assumptions made, data types and sources used etc. in this very comprehensive study can all be looked up in the study itself and will not be presented in detail here.

**Social Life Cycle Assessment.** As has been presented in section 2.2.3.3 and illustrated in Figure 2-10, Ciroth and Franze also first had to identify all relevant stakeholder categories and determine the so-called subcategories, which in turn refer to the impact categories. The respective indicators then had to be filled with data. The analyzed impact categories which are based on the UNEP/SETAC guidelines are as follows:

- Working conditions
- Health and safety
- Human rights
- Socio-economic repercussions

- Indigenous rights including cultural heritage
- Governance

GreenDeltaTC developed an impact assessment methodology – which is already a huge achievement in itself as there is no internationally accepted impact assessment methodology available just yet – which allows both quantitative and qualitative data to be considered. For the sake of transparency, solely midpoints are considered.

Their invented rating scale also takes into account the performance of the examined sectors and companies in relation to the situation in the country/region and does not merely assess impacts as an E-LCA study does. The impacts of the company/sector are assessed with regard to the selected impact categories. A color system using European school grades (which range from grade 1, i.e. very good performance or positive impacts, to grade 6, i.e. very poor performance and very negative impacts) is employed to assess each subcategory twice. Although a schematic example of such a table would be helpful in understanding their methodology, this is not in the scope of this thesis, which will only present their extensive and complex results in an edited fashion. For further information, the reader may please be referred to the examined study itself.

**Environmental Life Cycle Assessment.** The ecoinvent database was used as a basis and the method "ReCIPe" was chosen for calculating and determining the environmental impacts, which is a very recent life cycle impact assessment method and recommended by LCA experts. It combines the midpoint and endpoint approach. The following 17 midpoint impact categories were addressed: climate change human health, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, fresh water ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, metal depletion, fossil depletion and terrestrial ecotoxicity. The three endpoint categories damage to human health, damage to the ecosystem and damage to resource availability were also addressed. While a midpoint-based assessment has the advantage of giving a transparent analysis due to the very many impact categories, some of them are so specific that they are quite difficult to interpret. This is why midpoints are transformed into endpoints by means of normalization, thus obtaining easier to understand, yet less detailed and less certain data. The weights attributed to the three endpoint categories are 40%, 40% and 20% for human health, ecosystem quality, and depletion of resources respectively.

**Major results.** The extensive and very complex study of Ciroth and Franze warrants a much more thorough and closer study as has been done. As has previously been stated, however, this section's goal is to show and trace some of the environmental and social aspects on a global scale, attempting to determine where the most significant impacts and thus hotspots for improvement are. This objective is pursued by displaying a number of world maps, in which Ciroth and Franze's findings are incorporated. First of all, however, the result of their Social-Life Cycle Impact Assessment summarized for all stakeholder groups (i.e. workers, local communities, society, value chain actors) is illustrated as a whole at large in Figure 5-12

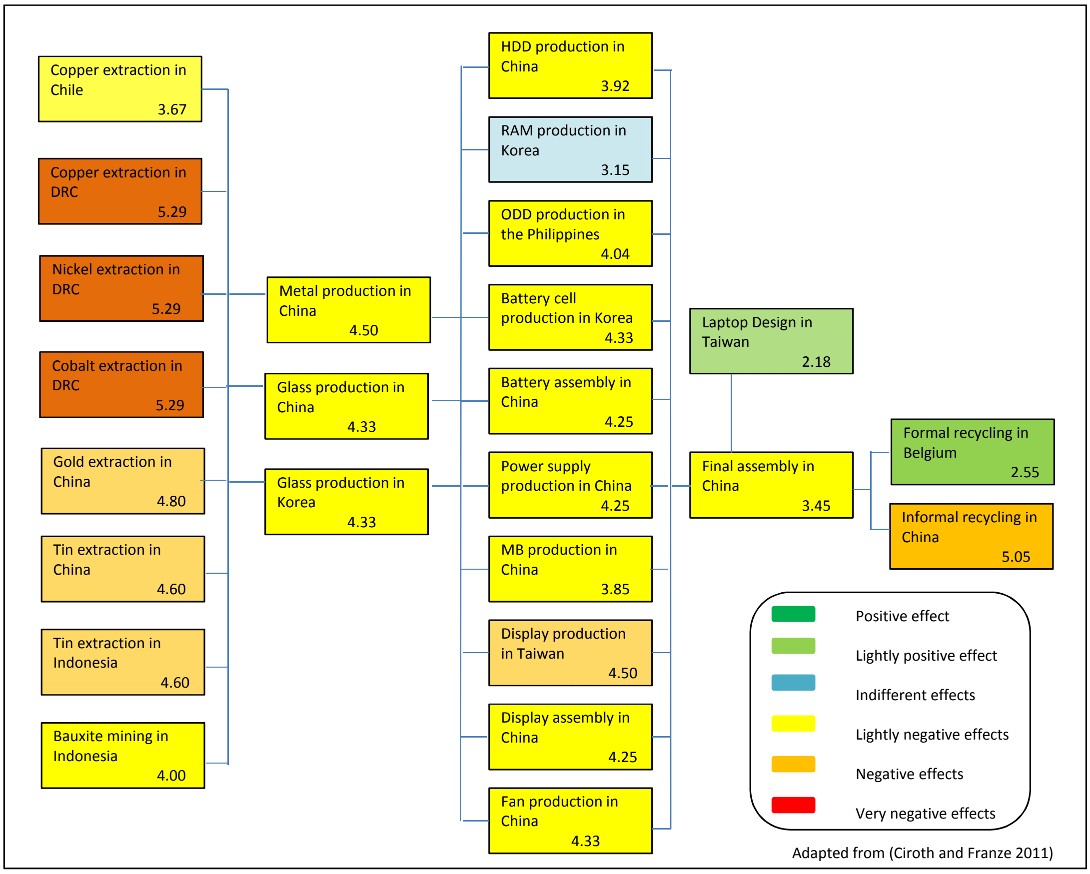



**Figure 5-12: Summary of the S-LCIA for all stakeholder groups combined**

As can be seen, only very few supply chain activities have an effect that could be considered somewhat positive in terms of the social impacts and burden they exert over the stakeholders. In the following, these results are inserted in several world maps according to their life cycle stage and occurrence.

Figure 5-13 illustrates the results of the social life cycle impact assessment for the first two life cycle stages of design and raw material extraction.

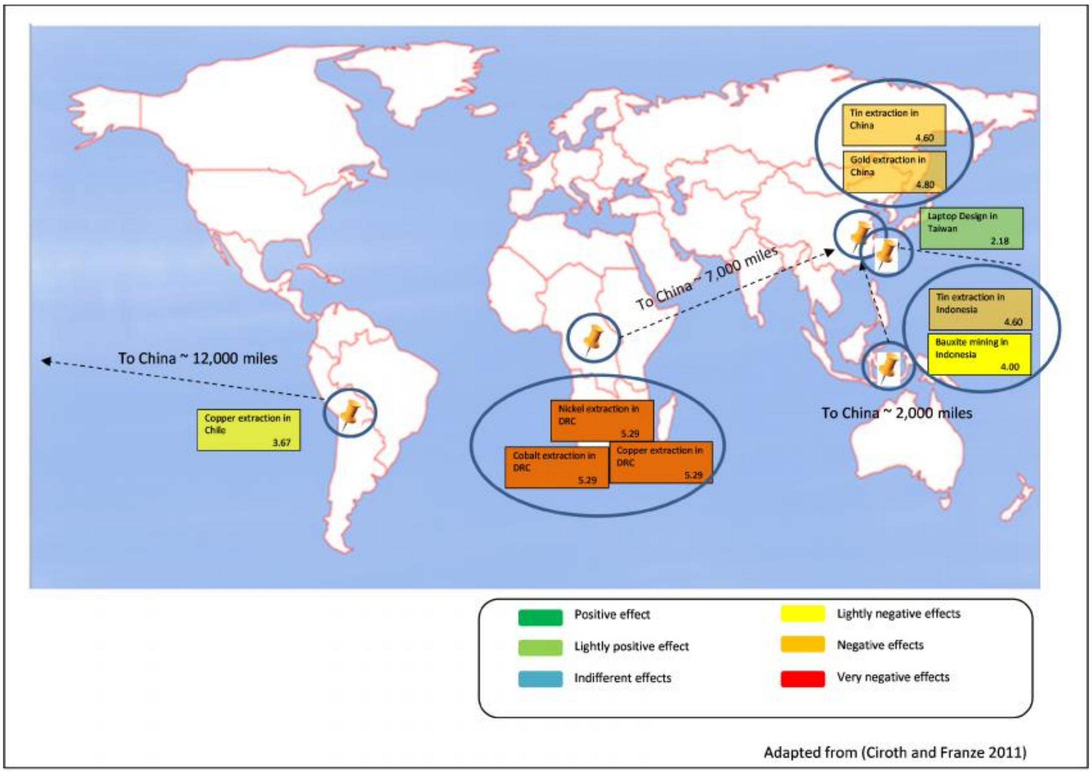



**Figure 5-13: Social impact assessment results of raw material extraction and design for laptop**

As becomes apparent, mining activities do have significant societal issues connected to them. Material extraction in the Democratic Republic of the Congo shows particularly negative effects, with corruption, child and forced labor work and very restricted freedom of association only part of the issues. The design done in Taiwan, on the other hand, has – especially in comparison to the other displayed activities – rather positive effects.

Figure 5-14 now shows the social impact assessment results of the production of basic materials required by laptop computers. This entails the production of non-ferrous metals such as aluminum, copper and tin among many others.

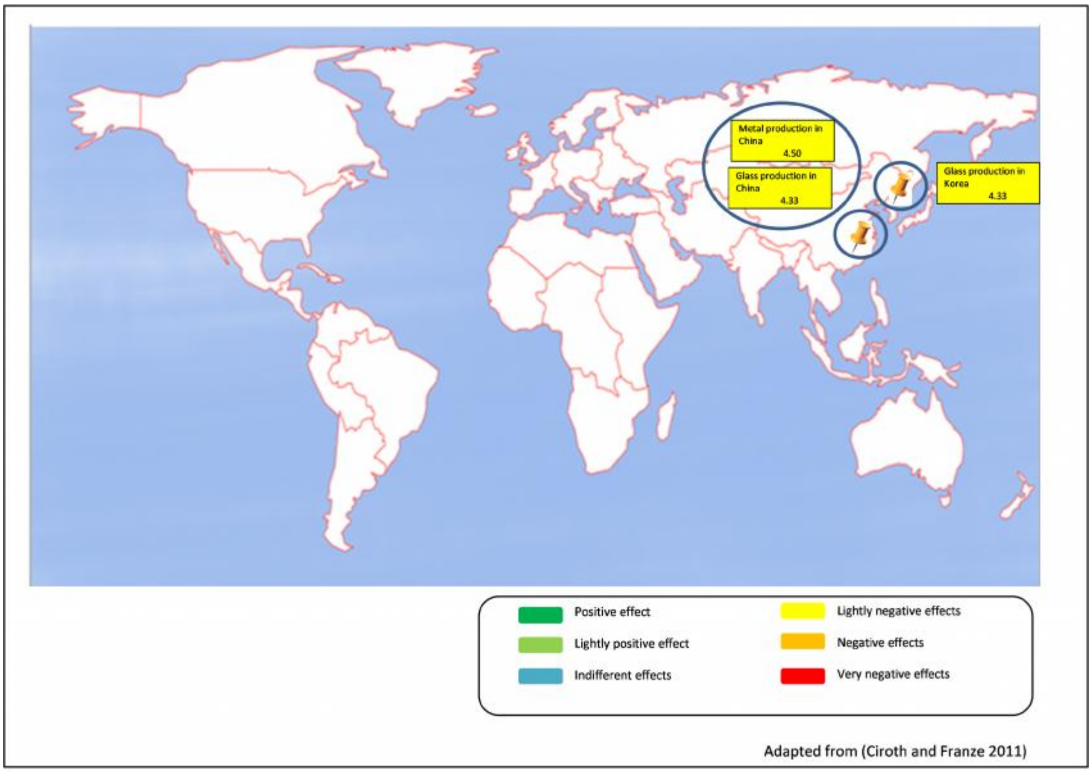



**Figure 5-14: Social impact assessment results of production of basic materials (e.g. plastics)**

The obtained results are rather poor with all three displayed activities only scoring between lightly negative and negative effects. Part of the reason for this poor performance is the huge energy and water use connected to the production of non-ferrous metals, which has negative effects particularly on local communities. Other issues are among many more resource consumption, hazardous emissions, corruption and forced labor, exercised in several labor camps.

The next Figure 5-15 illustrates the last activities of the fabrication or manufacturing phase before final assembly. Although the majority of these activities has rather negative effects again with most of them scoring worse than grade 4, it must be acknowledged that some values are even in the high 3-point range, the RAM production Korea even in the low 3-point range with all others closer to 4 than 5. So even though the social impacts are still rather negative – changes must clearly be done – they are not as bad as in other parts of the supply chain, which may be due to them being closer to the focal company and endproduct. Most of these products a selection of which is presented is tangible and somewhat easier to trace, thus there may be more incentive to do well.

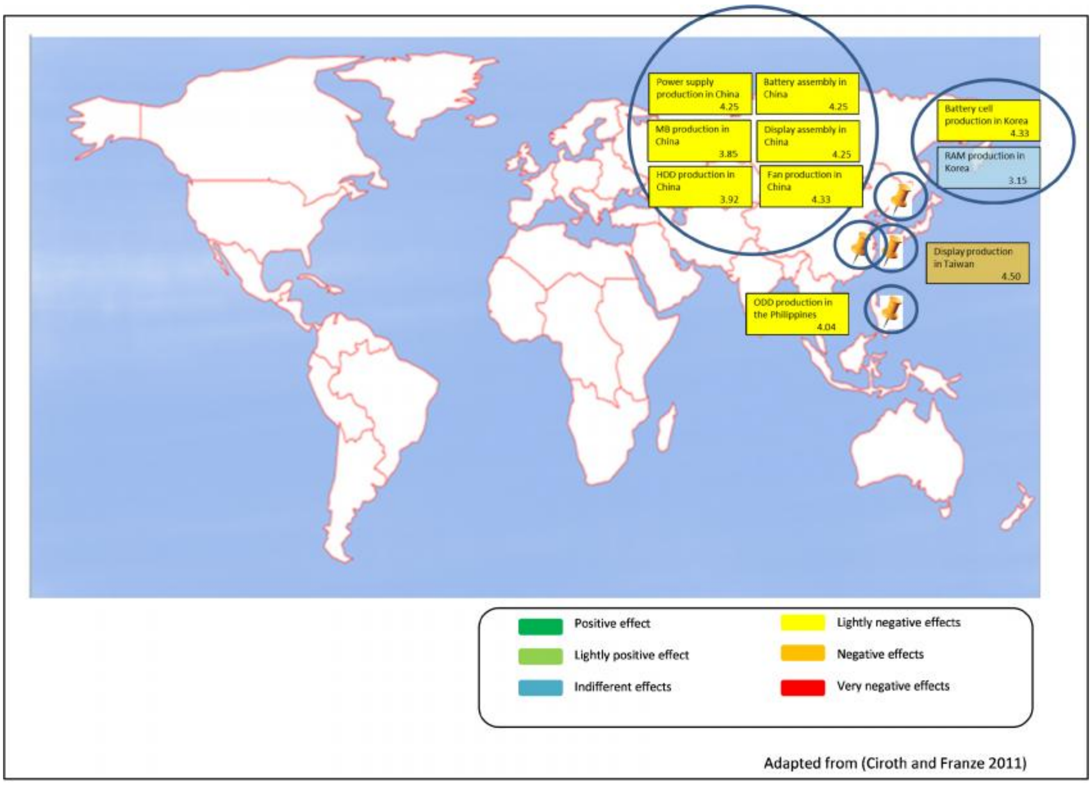



**Figure 5-15: Social impact assessment results of production / fabrication of pre products**

Once more and especially in above Figure 5-15 it becomes apparent that Asian countries dominate the CE sector with most of the value added activities based in China and some of its surrounding countries.

Figure 5-16 is the last figure showing the results of the conducted social impact assessment by Ciroth and Franze (2011b).

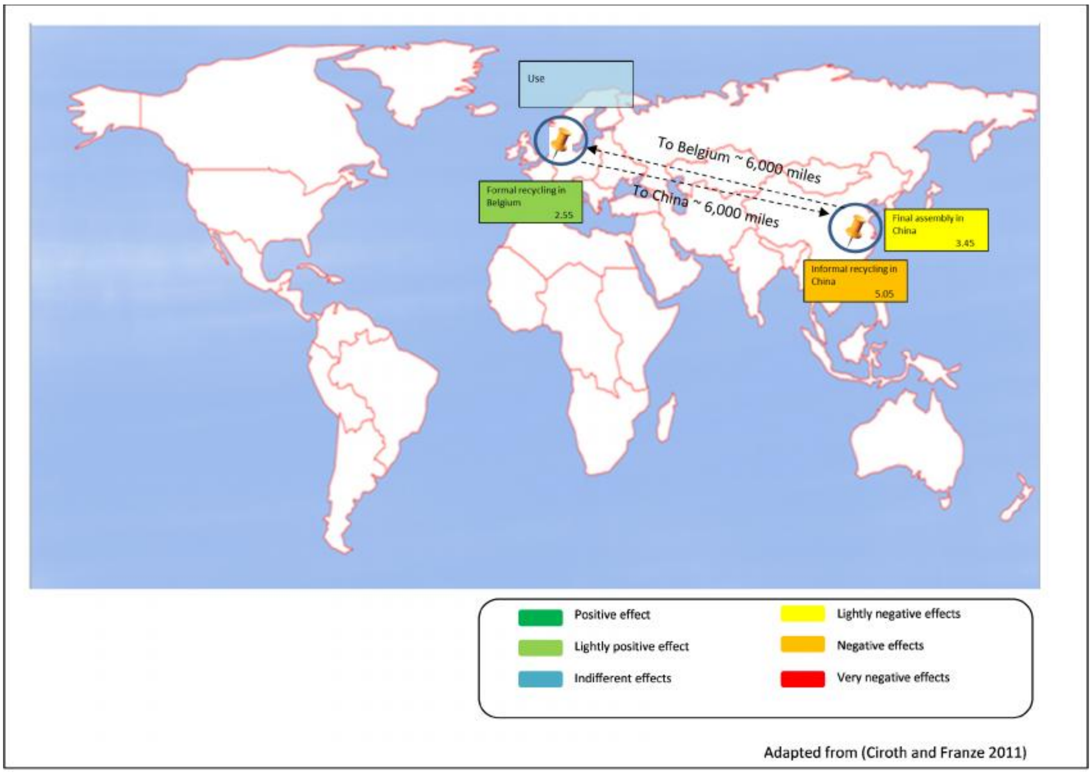



**Figure 5-16: Social impact assessment results of final assembly, use and recycling of laptop**

Quite a number of issues were connected with the investigated assembly company and yet, with it scoring a 3.45 out of 6, it is – sadly – among the relatively better activities in the supply chain. The scientists performed their study on behalf of the Belgian government, which is why the use phase and transportation is displayed with regard to Belgian, which is due to its small population no significant consumer market. Those are mainly in the United States and ever-growing China itself. The recycling performed in Europe, Belgium, is largely free of negative social issues with a score of 2.55. An entirely different picture is presented by the informal recycling process in

China. Although the import of e-waste is illegal since 2000, the amount of it has gradually been increasing, making it the most significant waste flow of the planet. A large portion is shipped back to Asia where the products are frequently dismantled and taken apart to extract the valuable materials and shipped to African countries, where they are mostly continued to be used, as more often than not, laptop computers as well as other CE devices are still functioning, but are just outdated.

After giving a comprehensive account of the results obtained in the social life cycle assessment, this study will now present the major results of the environmental life cycle impact assessment since Ciroth and Franze (2011b) again went in meticulous detail. First, the results of the midpoint assessment are illustrated in Figure 5-17. For the analysis of the characterization, Ciroth and Franze (2011b) divided the life cycle into five groups: transport, production, packaging, use and disposal. Transport merely includes the transport from Shanghai to Taipei and from there to Brussels. The impact of the transport stage is therefore in reality likely to be much higher since the raw materials obtained in Africa and South Asia as well as all other intermediates of the supply chain need to be transported to the corresponding facilities in Asia which has so far not been accounted for. Additionally, the US as a major consumer market is even further away from China as is Belgium.

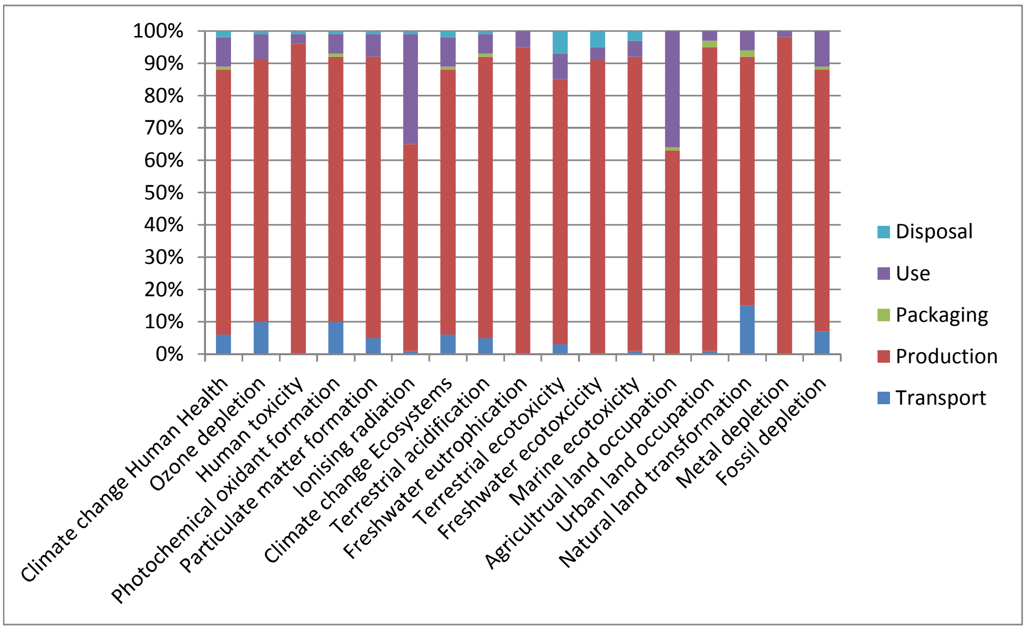
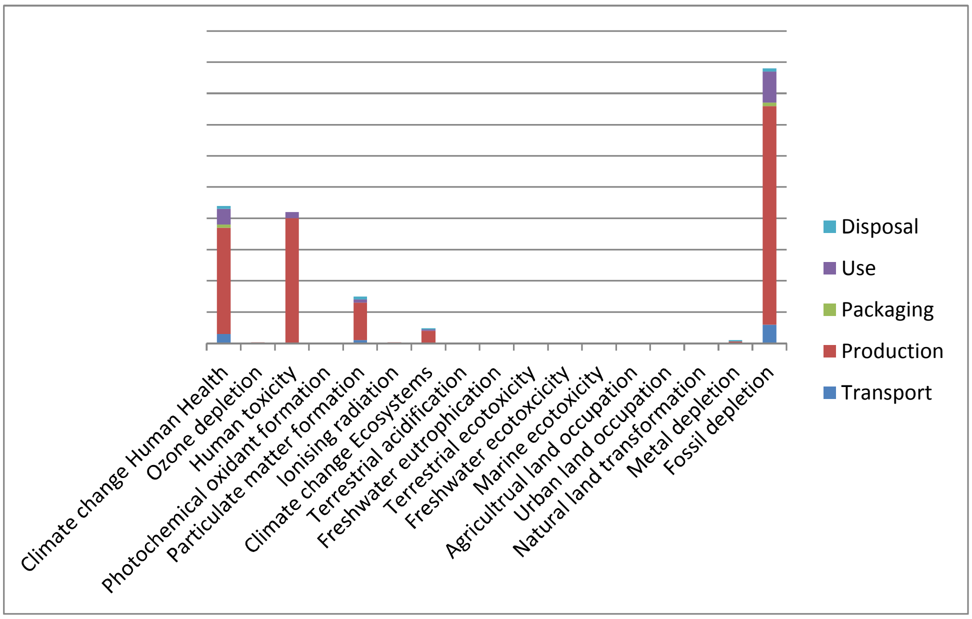



**Figure 5-17: Environmental results of the characterization**

The characterization displays that production is by far the dominant contributor to the environmental burden out of all life cycle stages. The use phase which includes the reuse phase is second when it comes to contributing to the environmental impacts. Packaging, transport and disposal all have quite low impacts, especially in comparison to the other life cycle stages. These results somewhat support the findings of previously in section 5.4 illustrated studies and their assessment of majorly carbon dioxide equivalents.

In order to find out the environmental hot spots across the entire life cycle, normalization was applied. The investigated study provides details regarding the normalization set and procedure. This thesis only presents the results of which in Figure 5-18.




Adapted from (Ciroth and Franze 2011)

**Figure 5-18: Results of the normalized midpoint assessment.**

Impact categories that are of relevance for the considered product system were found out to be climate change (human health and ecosystems), human toxicity, particulate matter formation and above all fossil depletion. Furthermore, it can be concluded that the production of a notebook really does cause the majority of the environmental effects, which is consistent to studies introduced earlier. Use phase and transport also have quite a noticeable effect, which is likely to be even higher due to the selected system boundaries.

These very results can be illustrated in a different and what some may consider to be a more obvious and clear way via the following Figure 5-19

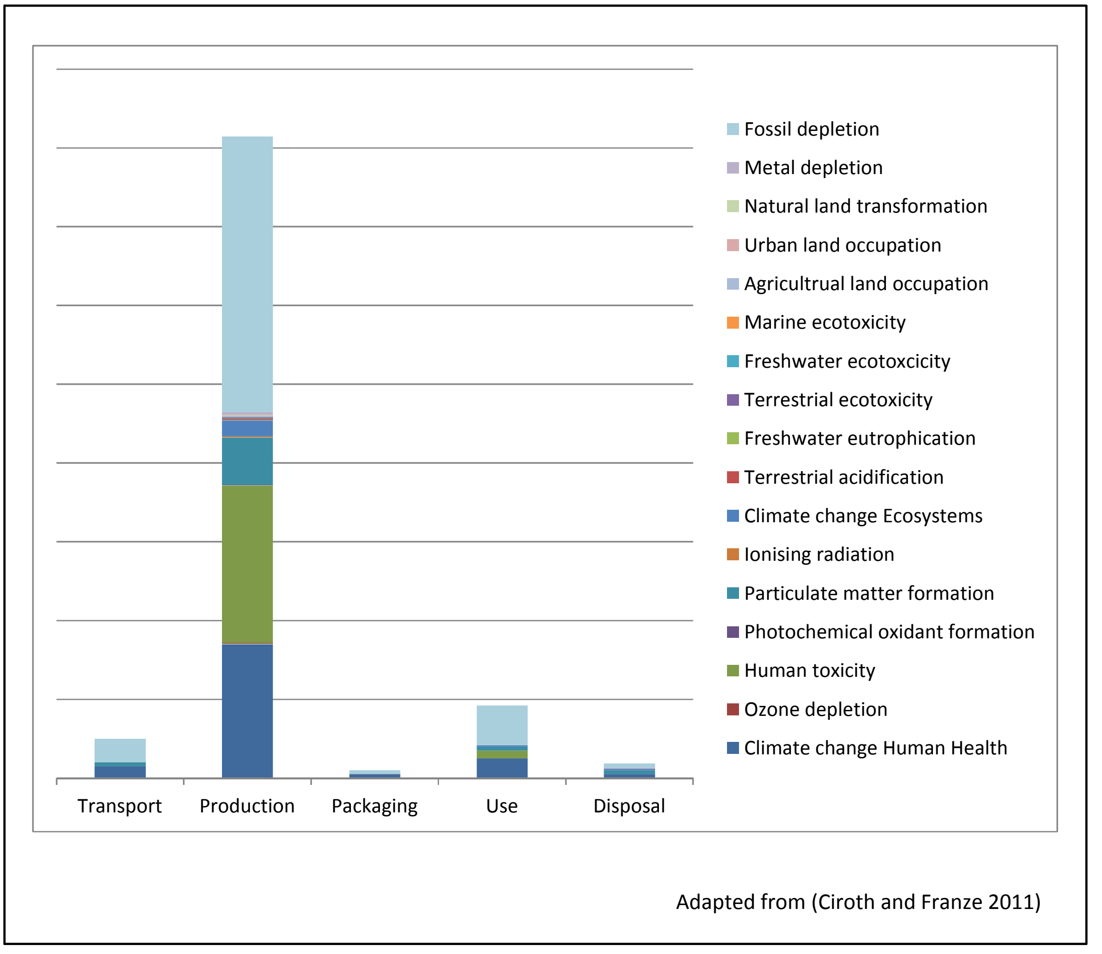



**Figure 5-19: Environmental impacts of all life cycle stages**

Depicted in the global world map that has been used throughout this section, the following picture is obtained for the given study which can be seen in Figure 5-20. The environmental impacts that are incurred in the various life cycle stages are depicted at the site of their occurrence. As can be seen, the Asian continent with China in the lead are at a major risk. More attention needs to be focused on this part of the world.

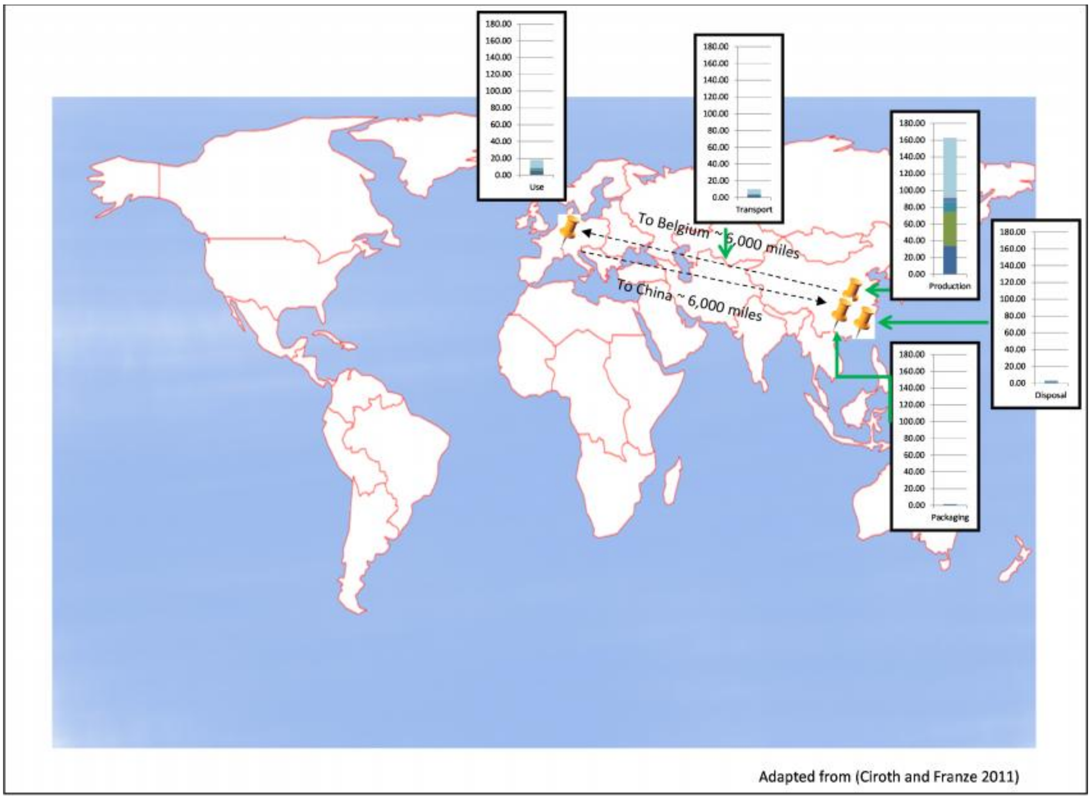



**Figure 5-20: Environmental impacts of the various life cycle stages according to where they are incurred**

Last but not least, the obtained results from the endpoint assessment are presented in the following two Figures.

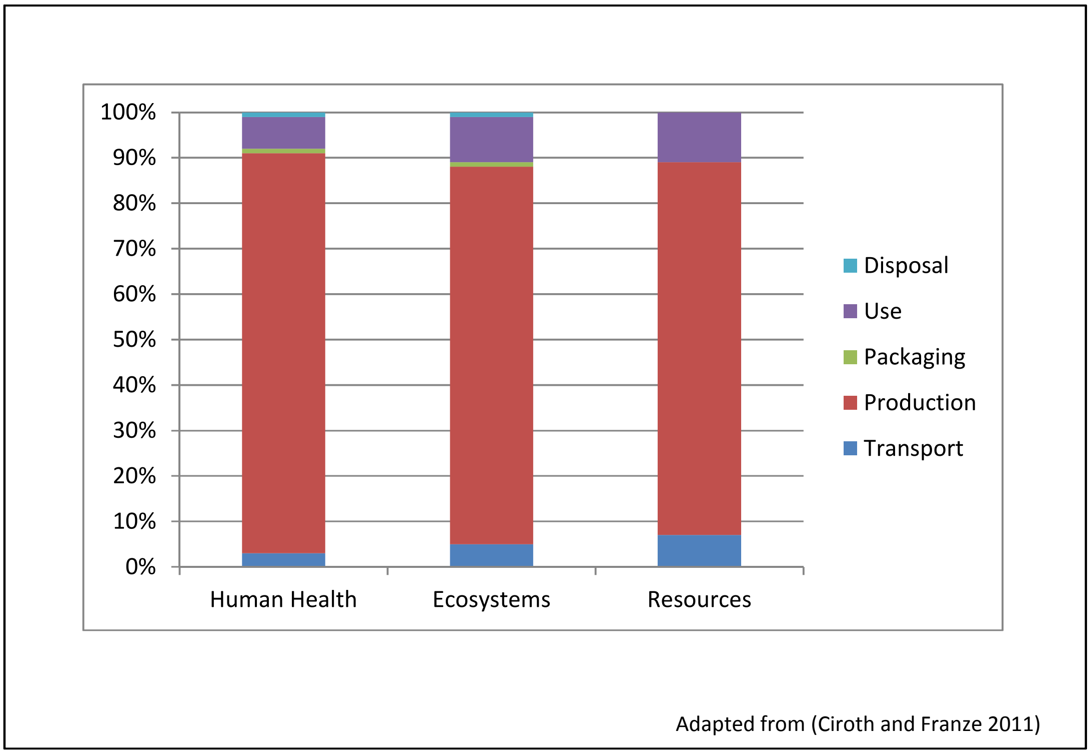
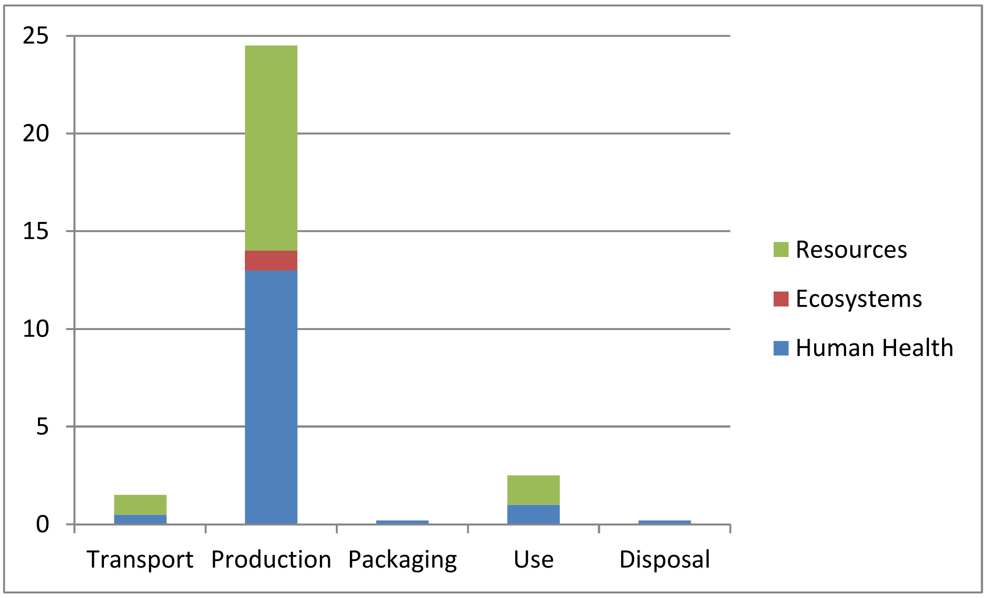



**Figure 5-21: Results of the endpoint assessment**

Figure 5-21 shows that disposal and packaging life cycle stages hardly have any effect on the three examined endpoints human health, ecosystems and resources. Once more, however, the production of the notebook is the major cause of the environmental impacts, followed by the use phase and transportation phase.

If these results are normalized as was done earlier already and is again shown in Figure 5-22, the picture gets even clearer. Since the majority of production steps and resources are done and extracted in Asia and in particular China, the population there is put at most harm and the resources are depleted in the most significant fashion as can be seen in Figure 5-22.




Adapted from (Ciroth and Franze 2011)

**Figure 5-22: Results of the endpoint assessment single score (in pt)**

Figure 5-23 shows the normalized endpoint assessment results. As can be seen, the categories human health and resources are the only two categories that are of concern. The damage to the ecosystem quality is almost negligible according to their findings.

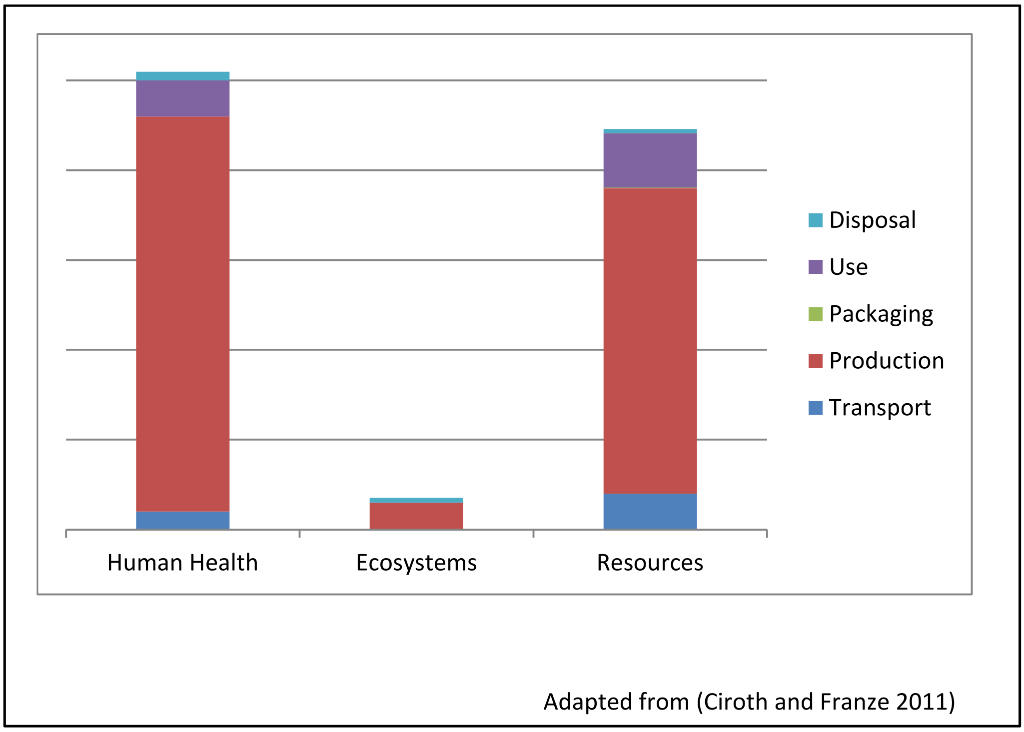



**Figure 5-23: Results of the normalized endpoint assessment**

## 5.6 Excursus into development of CE industry and overview of location decisions

With the undeniable omnipresence of Asian countries and yet dominant US global players in the consumer electronics market, it is only justified and logically expedient to take a closer look at history and at what factors have driven this development in order to create a more holistic picture in this study. The subsequent paragraphs will therefore provide a brief excurses into the past and the reasons for why the majority of the supply chain actors have settled in countries like, in particular, China. This will ultimately lead to shedding some light on some location decisions that have played and continue to play a major role in this specific industry.

The consumer electronics industry has experienced a lot of international competition since the half of the last century. Until around the 1950s, the Western world and above all the United States had dominated the sector of CE. (Kotabe et al. 2008) Shortly after the end of the Second World War, however, the advent of Japanese competition occurred and more and more firms started entering the market. They quickly became a significant force to be reckoned with. (Kotabe et al. 2008; Borrus 1997) As consumer electronics swiftly established themselves in Japanese society, their companies – spurred by the rapid and considerable growth of the market – developed competitive advantages through fast learning processes and low labor costs. (Kotabe et al. 2008) US-American companies subsequently also started to understand that they could lower their costs and thus be more competitive if they subcontracted less expensive assembly and, at a later stage, manufacturing operations to Asia. As a consequence, outsourcing became widely popular with many US companies in the 1960s and 1970s. This led to many Japanese companies acquiring Western technology, enabling to beat their competition with both advanced and inexpensive products. (Kotabe et al. 2008) Outclassed by their Eastern competitors, the Western World became so worried by Japanese firms entering their domestic market that the US-Americans even used interventionist policies in order to bolster the domestic industry. (Borrus 1988; Kotabe et al. 2008) This in turn resulted in even further outsourcing so that, for instance, by the late 1960s, there was not a single US-American manufacturer of radios left in the United States. (Partner 1999)

This was meant to serve as an example of the huge turnarounds this industry has experienced throughout its existence. Through problems of their own which this study will not elaborate on, Japanese consumer electronics companies – though still very strongly represented through large powerhouses such as Sony or Toshiba among others – have largely had to concede market shares back to their US-American competitors. Their rise back to prominence and US technical leadership will now briefly be illustrated. The consumer electronics market is considered to be a 'new product market' which is characterized by a competition to set defacto market standards. (Borrus 1997) US companies such as Apple, Microsoft or Intel among many others have been hugely successful in defining products, setting and controlling the standards, which is why – through the US choices becoming global standards again – they have again assumed dominant positions on global markets. (Borrus 1997) For this to be possible, however, organizational shifts and a general development were required. Key for Western and as such particularly US-American firms was their move away from traditional integration in production organization towards Asia-based production networks centered in the China Circle – i.e. China, Hong Kong and Taiwan – and Singapore. (Borrus 1997) Asian affiliates of mainly US electronic companies were set up as part of production networks spanning many countries. What at first only started out as local assembly affiliates, they soon grew in competency. Not only did this step relieve US companies of the state of being dependent on their Japanese counterparts, it also allowed them to significantly decrease production costs and turnaround times. They were able to do that and still keep up with the fast technological progress. This in turn enabled the American companies to pioneer strategies of continuous and lasting innovation. (Borrus 1997) The cheap and yet industrious Asian labor lastly made it possible for US-American companies to be competitive again. Gradually, US affiliates were increasingly upgraded and were allowed to perform more and more value-added, sophisticated tasks and activities. With them getting more autonomous, the affiliates' sourcing process included a growing number of local parts and components, which ultimately helped the Asian markets to prosper. For instance, many local electronics manufacturers from countries such as Taiwan as well as their respective governments concentrated an increasing share of their investments on electronics. (Borrus 1997; Callon 1995; Kraemer & Dedrick 1996) Since these developments had been largely successful, the division of labor between US-American and Asian-based operations – connected through the goal of their production networks serving the US firms' advanced markets – became progressively more elaborate and deeper. This allowed American companies to focus more of their resources on core competencies such as new product definitions and the necessary sills to create, maintain and evolve the so-called de-facto market standards. (Borrus 1997)

Consequently, the Asian affiliates of US firms further evolved over time into what they have become now, namely “capable local Asian producers [... that are …] increasingly skilled suppliers of components, subassemblies and, in some cases, entire systems.” (Borrus 1997) Therefore and as has been stated, almost no global OEM player in the sector of consumer electronics performs manufacturing on their own anymore, with Asian ODMs and CMs gaining more and more responsibility. With there now being a fierce predatory competition especially regarding the price of products and profit margins having dropped to an average of 3 % only (Taylor 2014), the mentioned substantial consolidation process has now found its way into the CE sector. As a consequence, big businesses have been created as they are at an advantage due to economies of scale, which enables them – among many others – to produce at lower costs due to higher unit shipments and very rationalized processes. (Manhart & Grießhammer 2006)

Last but not least, some of the underlying location decisions, motives and reasons which have contributed to the above sketched development and hence structure of the CE industry will now be extracted and summed up. Since all of these processes have been and still are working in favor of Asia and in particular China – which possess a “growing global dominance as the principal source of e-products” (Eugster et al. 2008)

–  and with the situation expected to not alter considerably, the following remarks will thus concentrate on Asia and China.  A summary of the most fundamental reasons of why the consumer electronics market is now predominately based in China and Asia will now be given. (Wong & El-abd 2003)

With particularly India and China the world's two most highly populated countries, it is expected that even more companies of industrial machinery, i.e. CE companies and their suppliers as well, will set up shop in Asia. In light of the huge and still largely untapped and unsaturated market and the enormous quantity of customers, which is only increasing as a result of those countries' ascend from emerging to developed status, these markets are highly attractive. Therefore, a race has begun to decrease the distance to their customers as swiftly as possible to saturate the market.  Being located in the Asian region is also very advantageous for another reason. Since consumer electronics generally require manifold components – laptop computers, as has been mentioned, even up to 2,000 – the entire production process comes to a stop, if there are issues connected to availability or quality with even only of the individual parts. This is why it is understood to be beneficial and pivotal to be situated close to large customers geographically seen. (Manhart & Grießhammer 2006) Especially the Chinese government has very successfully fostered and bolstered foreign investments in high technology through a range of measures and incentives. The electronics industry is heavily subsidized. To attract investments, companies are lured with a combination of preferential tax treatments, discounts on utilities and logistical support and loan subsides and many more. (PwC 2004; AA 2005) Another incentive that is nowadays somewhat involuntarily supplied is the lacking, but mainly not enforced environmental and social regulations, which is an attractive reason for many companies to offshore their activities. (Jahns et al. 2006) Furthermore, the world-class infrastructure the Chinese government has invested extensive resources in establishing provides an excellent foundation for doing business, with a modern and efficient highway system, airports and cargo harbors. (Wong & El-abd 2003)Another reason that must not be missing is the initial reason many companies started to look towards Asia in the past, the low labor cost. (Kinkel & Maloca 2009) Although minimum wages have increased by 100 to 150 % over a course of ten years, China still remains among those countries offering the lowest cost of work. (Wong & El-abd 2003)If this was not attractive enough as it is, particularly the Chinese are renowned for their discipline and hard work ethic. Their labor force will thus more than likely continue to be exceptional. (Wong & El-abd 2003)This is mirrored in the continued relocation of R&D- and marketing centers to China. To keep pace with and learn from the rest of the world, many Chinese universities have been operating successful partnerships with well-known overseas universities and each year, a large number of well-educated, young graduates enter the job market, providing work at a salary level that is highly attractive for Western companies. China today thus offers a complete supply chain service to the consumer electronics industry, which makes it one of the, if not the most quickly growing country in the sector. (Wong & El-abd 2003)The following Figure 5-11 sums up some of these most influential aspects.

1. Complete supply chain and ample availability of local source components.
2. World-class infrastructure.
3. Large market.
4. Low labor cost.
5. High-quality R&D from foreign investment.
6. Culture with a strong work ethic.
7. Governmental incentives (e.g. subsidies, support)

**Figure 5-24: Summary of most influential aspects having contributed to the Asian and Chinese advent in the CE sector**

# 6 SUMMARY AND CONCLUSIONS

Now that the main body of this study has been completed, this very last chapter will give both a summary of this thesis as well as concluding remarks. Where it appears adequate, some hints and ideas regarding future research will be provided.

In the beginning of the study, the background and basic concept of sustainability was provided. Due to the huge dynamism, prevalence and relevance of this particular field of study, the evolutionary development of its coming to existence and understanding have been explained in order to provide a holistic and more thorough picture. The extraction of relevant and significant data out of the huge pool of literature led the authors lastly define the novel and not yet (deeply) researched term 'Global Product Sustainability'. As part of the thorough literature review this thesis set out to conduct and provide, an in-depth analysis was done of the underlying principles and methodologies most currently available measurement and assessment approaches of sustainability (performance) fall back on and use. This proofed to be rather difficult because of the enormous wealth of literature that exists on the matter, with a continuous flow of more and more indicators being proposed by different studies. Consequently, confusion among scholars, practitioners and people who are generally interested in the topic has steadily increased over the past few decades. One of this literature review's and thesis's main contribution was therefore to provide some much needed clarity and structure and to sensibly condense the countless pieces of information that have accumulated in the process of this ever-increasingly important matter. An existing set of a limited amount of indicators (the framework provided by NIST, see chapter 2) was deemed to be useful for an integrated, holistic assessment of sustainability. At the end of the second chapter, frequently used and popular methods currently used in industry to assess products were introduced with the aim to be inspired by those methodologies and to extract helpful aspect for the development of the own concept in chapter 4. It had to be concluded, however, that they all are still very difficult and time-consuming in their appliance on top of them being quite imprecise. This theoretical chapter finished by giving an explanation of portentous externalities, which are costs that need to be factored in for a holistic assessment, but which currently are not. Oftentimes, this leads to wrong decisions, which is why the awareness of their existence was attempted to be bolstered.

Based upon the literature review of existing and used tools and the elements that could be extracted from them in the previous chapter, in chapter 3 it was possible to issue and define a number of requirements that the developed concept ought to fulfill for it to pose any significant chance of ever making a contribution. Especially the characteristics of transparency, credibility, country- and site-specific as well as source-based were considered to be of particular importance regarding requirements that might potentially be deemed "newer" in comparison to traditional ones such as holistic, easy and fast. Contemplating the enormous wealth of requirements – which, oftentimes, cancel out or at least contradict each other – posed by a sensible assessment tool, it comes as no surprise that the world is still in need of such a much desired tool.

In chapter 4, the main chapter of this study, the concept was finally developed factoring in all previous findings and research and illustrated with an example taken from the consumer electronics sector. At first, a so-called problem solving cycle was applied through which the authors came to several insights. Consequently, the synectics approach was applied for the development of the concept. It is a methodology which is based upon alienation through which the authors were able to conceive new ideas. Hence, new areas of research were discovered and exploited. A fundamental discovery proved to be the possibility to apply the principles of allocation, more precisely those of economic allocation. With the help of this newly acquired knowledge, the authors were thus able to develop and illustrate the concept. Rather than strenuously measuring the impacts of specific products and the specific processes they require, the developed concept proposes to measure all sustainability impacts at a meta level as it is more often than not to contribute certain health issues of workers to particular products. It was realized that linking impacts to products is generally very delicate and frequently lavish. When a company, however, is viewed as a black box, all of its impacts through its inputs and outputs (e.g. emissions) can be measured and assessed rather easily. The concept thus proposes that these global measurements of each company in a supply chain are then broken down to the specific products with which they contribute in that particular supply chain in question via economic allocation. This allocation is based on a partitioning factor, which essentially is the share of the total profit of a company that is generated by the particular product, which is the multiplication of its sold amount and its current market price. These sustainability impacts are then forwarded to the next actor in the value chain. This way, the impacts are accumulated until the focal company, possessing the entirety of all the impacts in its data, gets to fairly and transparently attribute the impacts over the entire supply chain in a recursive matter. Madanchi's (2013) sustainability factory assessment tool proved to be a valuable auxiliary for this kind of concept. An alternative was additionally provided and introduced in form of the Product Carbon Footprint (PCF) methodology, which has the potential to be a catalyst for assessment of sustainability impacts at large.

Last but not least, the authors hoped to be able to apply their newly developed concept in a case study. The industry of choice was the consumer electronics sector, which was subsequently introduced. It could be found that its largely situated and dominated by countries in Asia. It was exemplary shown how a laptop computer – which was decided to be the most significant consumer electronics item – is manufactured and how it finds its way to the end user through all of the single life cycle stages. After such a thorough introduction to the examined country was made, it had to be concluded due to all of the findings made throughout the process that as of today, the developed concept cannot yet be applied. Various reasons could be identified and were addressed. One of the key issues is the lack of data that is available and that could be used. This in turn has manifold roots as well. Another major problem that was encountered is the sheer complexity of the global value chain that is characteristic of the consumer electronics market, a consequence of which is that oftentimes big focal companies themselves do not have an overview of their suppliers. To live up to its promise and original intent, the study nevertheless provided some results of sustainability assessment studies in the field of consumer electronics, particularly laptop computers. Several studies were analyzed to show what life cycle stages incur the most significant sustainability impacts and what parts of the devices cause the largest share of which. The analysis was only conducted regarding social and environmental impacts. The economic dimension was deliberately not included as it is suggested in literature that it is on a different level, being simultaneously an enabler and a final goal. (Golini et al. 2014)

All in all the majority of the goals this study set out to achieve could be achieved. However, the one key goal of assessing GPS in the field of CE with the help of the developed tool could not be fulfilled. Analyzing the consumer electronics industry especially, however, warranted the validity of proposed tool. So far it could not be applied for the lack of data that was encountered. There is, however, still potential for future research on this topic, especially when it comes to gathering the right kind of data, which should essentially be much easier to acquire. A new paradigm is needed, which will take time to spread.

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