Sustainability assessment of products:
A comparison of the methods
Ecological footprint, MIPS (Material Input Per Service Unit) and the Integrated EFORWOOD Sustainability Impact Assessment, by example of two wood products

Master Thesis

by

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Abstract

Environmentally friendly and sustainable production has recently attracted increasing attention. A variety of approaches have been proposed to objectively evaluate and measure how industrial production processes and supply chains may impact sustainability. The European Commission is also taking steps to enhance sustainable production and consumption with an 'action plan on sustainable production and consumption and sustainable industrial policy', released in July 2008. Even though several methods for the life-cycle-wide assessment were developed, no common European standard for the sustainability assessment of products exists, yet. The objective of this study is to compare three contrasting sustainability assessment methods, (i) the ecological footprint (EF), (ii) material input per service unit (MIPS), and (iii) the integrated sustainability impact assessment approach of EFORWOOD (EFORWOOD SIA). The methods are applied to a case study where the manufacturing processes of the two specific wood products solid wood plank and particleboard plank are analyzed. For this case study a generic production chain is assumed, involving an age-class conifer forest, regional transport, sawmilling, and a particleboard mill respectively. The system boundary is defined by the output product in the sawmill and particleboard mill respectively. In a next step the three methods are compared with regard to (1) the relative ranking of the two wood products in terms of their sustainability impacts, and (2) by a set of performance measures such as transparency, comprehensiveness, time, and data requirements. The production of the solid wood plank appeared to be more sustainable regarding the environmental dimension of sustainability except for the MIPS input category 'biotic' (biomass input) under certain assumptions. Concerning the economic and social dimensions of sustainability the result is partially in favor of the particleboard. It could further be concluded that assumptions as well as available and reliable data for the application are just as important as the method itself. Thus, effort has to be put into reliable, updated and freely accessible data as well as transparency in assumptions and system boundaries. The evaluation through a criteria catalogue showed that the three methods have different strengths and weaknesses and cover different aspects of sustainability. Hence no clear preference for one of the methods can be given but a basket of indicators and approaches is recommended.

Keywords: sustainability assessment, sustainability impact assessment, wood products, forestry-wood chain, ecological footprint, MIPS, ToSIA, EFORWOOD, indicators.

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Abbreviations

EF: Ecological Footprint

EFORWOOD SIA: Sustainability impact assessment method developed under the European Commission (FP6) funded project ‘EFORWOOD’

gha: Global hectares

GHG: Greenhouse gas emissions

MI factor: Material intensity value

MIPS: Material Input Per Service unit

PB: Particleboard

PW: Pulpwood

RECW: Recycled wood

RW: Round wood

SERI: Sustainable Europe Research Institute

SIA: Sustainability Impact Assessment

SW: Solid wood

tkm: Ton kilometers

DHB: diameter at breast height

1 Introduction

The concept of sustainability can be understood as a preferable way for a future development. As such, this concept was first mentioned in the Brundtland Report, the final report of the World Commission on Environnment and Development, an expert commission of the United Nations, in 1987. Sustainable development has been defined there as development that *'…meets the needs of the present without compromising the ability of future generations to meet their own needs'* (WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT, 1987, s.p.).

Sustainability is most commonly represented by the three pillars of sustainability expressed by three intersecting circles, representing each one dimension of sustainability: the ecological, also named environmental, economic and social dimension (GIBSON et al., 2005, p. 55f). Representations with more than three interconnected circles exist as well which complement the ecological/environmental[1], economic and social dimensions by a political/institutional and cultural compound (GIBSON et al., 2005, p. 55). Beside these representations which place the human sphere at the same level as the ecosphere, more eco-centric views represent the human sphere embedded in the biosphere.

The vague idea of sustainability has become a key word and, at least on the paper, a leading idea for politics, business and media. The challenge is, however, to transfer the 'golden rule' of sustainability into practical decision-making. Sustainability assessment methods as decision support tools are an option to do so.

The context of this thesis, are initiatives to make production and consumption more sustainable. The overall European framework to make production and consumption in Europe more sustainable is the 'action plan on sustainable production and consumption and sustainable industrial policy', released in July 2008 by the European Commission. This framework has to be seen as a declaration of intent with its core to '…*improve the energy and environmental performance of products and foster their uptake by consumers'* (COMMISSION OF THE EUROPEAN COMMUNITIES, 2008, p. 2). This should be achieved by providing incentives for producers and consumers e.g., through simplified labeling as well as by extending, revising and further developing existing directives and regulations.

An Austrian initiative towards sustainable production and consumption is the project *'Messung und Bewertung der Nachhaltigkeitsqualität von Produkten[2]'* in which the Sustainable Europe Research Institute (SERI), which collaborated in this thesis, was also

[1] The two terms ecological and environmental to indicate the dimension of sustainability are used synonymously.

[2] Translation from German: 'Measurement and Evaluation of the quality of sustainability of products'

involved. In the project, an indicator set consisting of the methods Ecological Footprint and MIPS was tested in order to assess the sustainability of products.

Even though several methods for the life-cycle-wide assessment of the sustainability performance of products were developed, no common European standard for the sustainability assessment of products exists, yet.

2 Objectives

The core objective of this study is to compare three different sustainability assessment methods for products. The differing focus on time and object, a varying integration of nature-society systems (NESS et al., 2007, p. 499) and differing background and methodology of the sustainability assessment methods may lead to different results in evaluating the sustainability of a product. This thesis is thought to be a contribution to the discussion with which method the sustainability of products can be assessed best.

Therefore, the three methods Ecological Footprint, MIPS (Material Input Per Service unit) and the EFORWOOD sustainability impact assessment are applied to the production chains of the two wood products ‘solid wood plank’ and ‘particleboard plank’ and the overall results as well as the results of the different chain stages for the two products are compared. Subsequently the three methods are evaluated by a criteria catalogue.

The specific objectives in this context are:

- **Setting up the example, performing the calculations and comparing the results**
- **Qualitative comparative analysis of the three methods by means of a defined criteria catalogue**

3 Methods

The three sustainability assessment methods EF, MIPS and EFORWOOD SIA have different historical backgrounds, interpretations of the human- nature relationship and the term sustainability and vary in their perception of which indicators should be taken into account to assess sustainability. In this chapter the background and underlying ideas of the three methods and a description of each method is given.

According to NESS et al. (2007, p. 499) the three methods can be positioned among the sustainability assessment tools according to their temporal characteristics, their focus as well as the integration of nature-society systems.

In Fig. 1 a slightly modified graphical presentation of the classification by NESS et al. (2007) is shown.

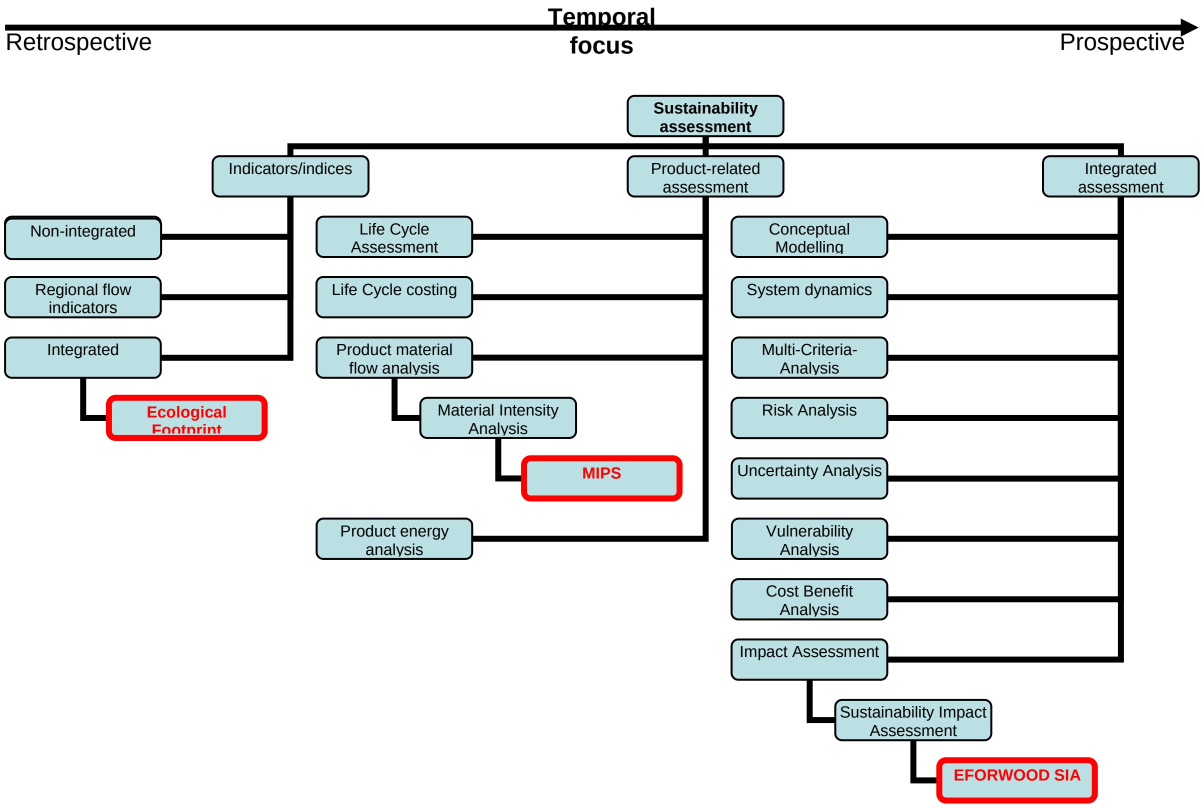

Fig. 1. Ecological Footprint, MIPS and the EFORWOOD SIA in the classification of sustainability assessment methods (NESS et al., 2007, p.500, simplified and complemented by the methods MIPS and EFORWOOD SIA).

According to NESS et al. (2007, p. 500) (Fig.1) the EF as an example of an integrated 'Indicator' approach makes a retrospective on past developments and their results in the present. Its focus is on a change in policy. The method has originally been developed to calculate the use of bioproductive areas by nations. However, it can also be applied to products, as done in this thesis. The EF is a method which is capable to integrate nature-society systems into a single criterion.

MIPS is a material flow based indicator (GILJUM, 2006, p. 15) which considers the material intensity (SCHMIDT-BLEEK et al., 1998). According to the categories of NESS et al. (2007, p. 500) presented in Fig. 1 it can therefore be assigned to the 'Product-related assessment' tools and more precisely to the tools for 'Material Intensity Analysis'. This method is retrospective and prospective at the same time since it regards present products and their services but also how these services can be fulfilled in the future in a less material intensive way.

In contrary to the EF and MIPS which are widely known and applied, the Sustainability Impact Assessment (SIA) of EFORWOOD is an approach developed within the European Commission funded project 'EFORWOOD' of the 'Global change and ecosystems' research activity of the Sixth Framework Programme (FP6). The project aimed to develop a quantitative decision support tool for the Sustainability Assessment of the forestry-wood chains. Regarding the categories of NESS et al. (Fig. 1) it can be assigned to the 'Integrated Assessment' methods which are prospective and can be used as a decision support tool. As an impact assessment tool it looks how different scenarios perform in the three main dimensions of sustainability: ecological/environmental, economic and social.

3.1 Ecological Footprint

Humans are dependent on biologically productive land and sea to fulfill their needs; for the production of the resources they consume and the absorption of waste they generate. However, the available bioproductive area on Earth is limited. The EF is a method to measure humans' demand of biologically productive land or sea and to compare it to the areas available on a global scale.

3.1.1 Background and underlying ideas

The concept of the EF was first published in the book 'Our Ecological Footprint: Reducing Human Impact on the Earth' and presented as an *'…integrated human ecologist approach'* (WACKERNAGEL & REES, 1997). It is an advancement of the model of a regional cupola (p. 16) and builds upon the idea of an ecological carrying capacity and the idea of global dependency on areas around the world. This idea had already predecessors in history.

The basis of the method is the concept of a limited carrying capacity of the Earth. 'Carrying capacity' is a term also used in biology for the maximum animal population that can be sustained by a habitat (TOWNSEND et al., 2003, p. 179f). The carrying capacity of the Earth is limited by the biological capacity of the Earth to provide resources through the process of photosynthesis and its absorbing capacity (GLOBAL FOOTPRINT NETWORK, 2006, p. 1). The biologically productive areas are the provider of this capacity but they are decreasing: The bioproductive land area has diminished in the 20th century from about 6 to 1.5 ha average productive land per person (VAN DEN BERGH & VERBRUGGEN, 1999, p. 63). The productive sea areas (mainly areas near the coast) are stated with 0.55 ha per person by Wackernagel and Rees (1997, p. 28) but may still have decreased since then. According to the founders of the method, the carrying capacity of the Earth is exceeded since the 1980s due to human activities (GLOBAL FOOTPRINT NETWORK, 2006, p. 8): In other words, the ecosystems of the Earth are no longer able to bear the actual growth of economic activities and material consumption, all contributing to the consumption of biologically productive land for the provision of resources and the use as a waste sink. In addition to yearly economic growth, the world population is growing constantly and the per capita use of energy and material is even growing faster than nature can regenerate (WACKERNAGEL & REES 1997, p. 13f). Having noted this, the EF wants to build awareness on this situation and on the limits of the biosphere.

In detail, the EF measures how much bioproductive land or sea area is used up by human activities by taking into account the actual technology (WACKERNAGEL & REES, 1997, p. 76f). The approach expresses the sum of the areas needed for the production of the resources and as waste sinks, not taking into account where they are situated (GLOBAL FOOTPRINT NETWORK, 2006, p. 1). The area consumption can then be compared to the available ecological capacity for a person, a region, nation or worldwide and in this way temporal comparisons of land use can be made. Exceeding the ecological capacity expresses an ecological deficit and is presented as overshoot (GLOBAL FOOTPRINT NETWORK, 2006, p. 2). A global ecological overshoot is possible through the depletion of *'ecological assets'* and/or the *'accumulation of wastes'* (GLOBAL FOOTPRINT NETWORK, 2006, p. 8).

In doing this, the method allows to analyze humans' dependency on the capacity of nature, humans' impacts on ecosystems, the distribution of resource consumption and the consumers around the world. At the same time, the EF gives information about the global productivity to sustain a growing human population in the future (WACKERNAGEL & REES, 1997, p. 23).

Initially, the EF was developed for calculating the bioproductive areas needed by a nation. The method can, however, also be applied for regions, economic sectors, individuals, organizations or products and Wackernagel and Rees (1997, p. 107ff) also proposed to use the EF for environmental education purposes, environmental impact assessments, the comparison of different lifestyles and different technologies, in the domain of traffic, in sustainability reports or to raise the awareness and interest on environmental topics.

The methodological adoption of the EF method for the sustainability assessment of products is a recent development (HUIJBREGTS et al., 2008, p. 799). It was added as a possible application to the Ecological Footprint Standards 2009 (GLOBAL FOOTPRINT NETWORK, 2009, p. 9).

The EF method implies a range of assumptions and inherent concepts. The assumptions are summarized by Ewing et al. (2008, p. 2, cited from Wackernagel et al., 2002) as following:

- Most of the humans' resource use and waste generation flows can be traced back.
- The majority of these flows are measurable in '*biologically productive areas'* which sustain these flows. As some of them cannot be measured and are therefore not considered by the method, the EF is underestimated in a systematic manner.
- Through weighting of the areas according to their bioproductivity, they can be expressed in the common unit *'global hectares'* with *'world average bioproductivity'*.
- As each global hectare expresses one use and every global hectare expresses the same bioproductivity they can be aggregated to the EF or available biocapacity.
- When both, EF and biocapacity are represented in global hectares, they can be compared.
- The ecosystem's regenerative capacity can be exceeded if more biocapacity is demanded than supplied. This situation is called overshoot.

Inherent concepts included in the EF concept are:

- The importance of the second law of thermodynamics for human action, as *'…the area represented by the Ecological Footprint can be conceived as the photosynthetic surface (solar collector) needed to replace the free energy or negentropy dissipated by humans and their industrial metabolisms.'* (REES, 2000, p. 372);
- the relation to the emergy[3] analyses of Howard Odum (REES, 2000, p. 372, cited from Hall, 1995);
- and the *'environmental space'* concept of the Sustainable Europe Campaign (REES, 2000, p. 372, cited from Carley and Spapens, 1998).

The sustainability concept behind the EF originates from a deep ecology perspective (EKINS et al., 2003, p. 168) which heads towards the concept of strong sustainability as the method is based on the critical importance of natural capital (REES, 2000, p. 371, cited from Rees and Wackernagel, 1994). As already mentioned, the planet Earth and the resources are finite and humans as biological beings are dependent on nature. The economy is a growing

[3] embodied energy

subsystem of the ecosphere which does not grow (REES, 2000, p. 371), and the natural resources in the biosphere are the base of this subsystem (WACKERNAGEL & REES, 1997, p. 22).

The concept of the EF claims to be analytical and pedagogical at the same time (WACKERNAGEL & REES, 1997, p. 16). The method aims to raise awareness on the given limits of the Earth's carrying capacity, to develop a common understanding of challenges and threats for living, and to estimate the sequences of possible solutions. In this way, the method may contribute to convert the idea of strong sustainability into concrete actions (WACKERNAGEL & REES, 1997, p. 61) even though the concept is *'…simply one indicator of humanity's engagement'* (REES, 2000, p. 373) and has, according to Wackernagel and Rees (1997, p. 48), to be further developed to reach its full potential.

Main research areas concerning the further development of the method are the improvement of the carbon footprint, the extension of the method to include aspects like biodiversity, unsustainable land use, pollutants, other greenhouse gases than CO_2, multiple land uses etc. (KITZES et al., 2007). Further research has also been proposed on key constants as the CO_2 sequestering potential and equivalence factors. The latter can be either based on estimates of potential crop productivity (EWING et al., 2008, p. 5ff) or on net primary productivity (VENETOULIS & TALBERTH, 2008).

3.1.2 Method

The EF expresses the amount of biologically productive area, which is needed for a specific entity e.g., a product and for the absorption of its waste along its life-cycle, or part of it. This area can be compared to the biocapacity available.

To calculate the EF, the direct area occupation for the product and its material and energy input as well as the indirect area occupation due to the CO_2 emissions, is calculated and expressed in global hectares (gha) (see equation 1). A global hectare expresses a theoretical, average, global productivity (WACKERNAGEL et al., 2005, p. 9).

$$\mathbf{EF\ [gha] = EF_{direct} + EF_{indirect}} \qquad \mathbf{(1)}$$

The area occupation is expressed in the following categories of biologically productive areas (EWING et al., 2008, p. 10ff):

- <u>Cropland</u> is the area for the production of all kind of crops including livestock feeds, oil crops and rubber and is the land use type with the highest bioproductivity.
- <u>Grazing land</u> comprises grassland and *'sparsely wooded land'* (EWING et al., 2008, p. 11) for the production of products from the keeping of animals like dairy products, meat etc.

- Fishing ground is the productive area of freshwater and marine water.
- Forest land is the forested area for the provision of wood and wood based products.
- Built-up land is the area used by humans for settlement, infrastructure, industrial structures and hydroelectric power generation.
- Carbon uptake land also called energy land (VAN DEN BERGH & VERBRUGGEN, 1999, p. 63) is land dedicated to the absorption of anthropogenic emissions (CO_2 or CO_2 equivalents) or the area needed for the substitution of fossil energy.

All categories represent a specific biologically productive area, except for the carbon uptake/energy land. This is the only category which accounts for the waste absorption capacity of the Earth (EWING et al., 2008, p. 14). Whether carbon uptake land comprises only forest areas or also other land use types depends on the calculation method (GLOBAL FOOTPRINT NETWORK, 2006, p. 5) as different approaches are applied to handle the area need due to the use of fossil energy and the resulting CO_2 emissions.

These approaches are summarized by Giljum et al. (2007, p. 12) in the following way:

I. The area requirement is equaled to the area which would be needed to produce the energy through alternative sources, such as biofuels from agriculture or forestry.
II. The area requirement is equaled to the area needed to produce renewable energy especially from timber for future generations in a way that the available energy for humans is not reduced.
III. The area requirement is equaled to the forest area which is necessary for the CO_2 absorption.

The approach of the Global Footprint Network aims to express the carbon uptake land as absorption land for CO_2 and only considers the carbon absorption potential of forests, as it is highest (EWING et al., 2008, p. 13). As for CO_2 emissions, it would also be possible to include the indirect land occupation related to nuclear energy and cement burning in the indirect area (HUIJBREGTS et al., 2008, p. 799).

The different biologically productive areas categorized above as cropland, grazing land etc. have different productivities. As built-up land is estimated to have replaced cropland, the same value of bioproductivity as cropland is given to built-up land (GLOBAL FOOTPRINT NETWORK, 2006, p. 6).

The different productivities have to be converted to their global hectare (gha) equivalents to have a common global measurement unit. The area of global hectares and the actual hectares are normalized to have the same total size. As e.g. cropland has, however, about twice the average productivity on Earth its proportion is about twice if expressed in global hectares (Fig. 2).

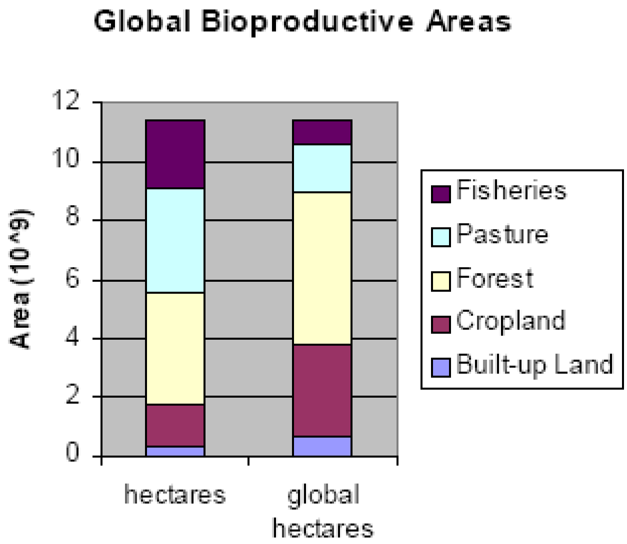

Fig. 2. Global Bioproductive Areas expressed in global hectares and actual hectares by category (WACKERNAGEL et al., 2005, p. 11).

The conversion from hectare (ha) into global hectares (gha) is done by means of yield and equivalence factor (WACKERNAGEL et al., 2005, p. 11).

- Yield factors express the productivities of the land use types (cropland, grazing land etc.) in different countries. The average hectare of cropland in New Zealand for example, produced in 2005 twice as much than the world average hectare of cropland. Yield factors vary from year to year (EWING et al., 2008, p. 4f).

- Equivalence factors convert the area of a specific land use type (e.g. world average cropland) into global hectares. In this way, equivalence factors indicate the relative productivity of the land use types to world average productivity of all land types combined. Equivalence factors are valid for any country in a given year (EWING et al., 2008, p. 5ff).

With the unit ‘global hectare’ it is possible to express the amount of bioproductive hectares which is worldwide used up (WACKERNAGEL et al., 2005, p. 9).

In the standard approach, proposed by the Global Footprint Network, the equivalence factors are calculated from suitability indices taken from the global agro- ecological zones model in combination with data on the actual areas (EWING et al., 2008, p. 5ff).

Tab. 1. Equivalence factors for the year 2005 (EWING et al., 2008, p.6).

Area Type	Equivalence Factor (gha/ha)
Primary Cropland	2.64
Forest	1.33
Grazing Land	0.50
Marine	0.40
Inland Water	0.40
Built-up Land	2.64

In detail, the EF calculation for products, thus, looks the following (HINTERBERGER et al., 2008, p. 14):

The EF of the direct land expressed in global hectares results from the direct area occupation multiplied by the equivalence factor (see equation 2).

$$\mathbf{EF_{direct}\,[gha] = A_{direct} * EqF} \qquad (2)$$

Whereby:
A_{direct}= Area use direct
EqF= Equivalence factor

The EF of the indirect land use also called ‘energy footprint’ is calculated according to the approach applied by the Global Footprint Network as CO_2 uptake land. It results from the multiplication of the production inputs by their CO_2 emissions, divided by the absorption factor and multiplied by the equivalence factor (see equation 3) and is expressed in global hectares.

$$\mathbf{EF_{indirect}\,[gha] = I * E / AF * EqF} \qquad (3)$$

Whereby:
I= Input (Raw material, preliminary material (auxiliary and operating material) and energy input
E= CO_2 emissions
AF= CO_2 absorption factor
EqF= Equivalence factor

3.2 MIPS

MIPS is an acronym and stands for **M**aterial **I**nput **p**er **S**ervice Unit. It was developed at the Wuppertal Institut for Climate, Environment and Energy in Germany. The idea of MIPS is to determine the resources and nature needed to produce a certain product or service with the aim of improving the resource productivity (SCHMIDT-BLEEK, 2000, p. 183).

3.2.1 Background and underlying ideas

The beginnings of the method date back to 1992 when MIPS was proposed by Schmidt-Bleek (HINTERBERGER & SCHMIDT-BLEEK, 1999, p. 53). It is strongly bound to the concept of 'Factor 10'. This concept describes the objective of a dematerialization by a factor of ten: Material flows should be diminished to a tenth in developed countries through the dematerialization of economies (SCHMIDT-BLEEK, 2000, p. 15ff). The dematerialization should be realized with efficient technologies, good ideas and new product design but without renunciation of the quality of life (SCHMIDT-BLEEK, 2000, p. 61). MIPS is seen as a key to realize this objective. To discuss and disseminate this idea, the Factor 10 Club, a group of well-known personalities, was founded by Schmidt-Bleek in 1994 (SCHMIDT-BLEEK, 2000, p. 22ff).

According to MIPS, material consumption, energy consumption and area consumption of a product correlate with its ecological compatibility. The more 'environment' is used for a product, the worse it comes off from an ecological point of view (SCHMIDT-BLEEK, 1994, p. 103). A focus has therefore to be put on the input side of the production, as it is there, where humans first intervene in ecological systems (HINTERBERGER & SCHMIDT-BLEEK, 1999, p. 54, cited from Schmidt-Bleek, 1994). It is hence not enough to look at the output side of production and to recycle as (i) only parts of the material moved by humans is possible to recycle and (ii) because for the recycling once more resources are used up (SCHMIDT-BLEEK, 2000, p. 15).

The quality of mass flows is not differentiated in MIPS. The reasoning behind this is the assumption that the determination of environmental relevancy of material is impossible due to a very complex environment. A life cycle wide MIPS analysis, however, should lead to a system-wide reduction of material inputs and innovations in the development of non-material products and service alternatives (HACKER, 2003, p. 7). It is not only important to look at the end product itself but the whole production or service chain should be traced back. The resource use is analyzed from the 'cradle to the grave' including the production process, the distribution, the use and the disposal or recycling.

Attached to the MIPS method is the perception that economy and ecosphere represent a symbiosis which should be made more sustainable: The economy lives out of the ecosphere and only returns waste and emissions (SCHMIDT-BLEEK, 2000, p. 53). However, the ecosphere can support these impacts only up to a certain threshold which should not be exceeded (SCHMIDT-BLEEK, 2000, p. 14).

This perception of a non-substitutable environment and the idea that for the achievement of ecological sustainability it is necessary to stabilize material flows (HINTERBERGER et al., 1997, p. 12), leads to a strong sustainability concept: The evolution of the ecosphere is, according to Schmidt-Bleek, already disturbed by the extraction of natural resources even if only moved and not even used to increase our wealth (SCHMIDT-BLEEK, 2000, p. 13).

A constitutional part of the method MIPS is the service unit. The most important of a product is the related service that it can fulfill, and not the product itself. Products are most commonly bought not to be possessed but for the service they provide. Designing or consuming products with less resource input while they continue to provide at least the same service (HINTERBERGER & SCHMIDT- BLEEK, 1999, p. 54) can therefore achieve a dematerialization without renunciation of the quality of life. A high material input is only acceptable if the product brings high benefits, as for example public transport which can benefit a lot of people at the same time.

These aspects lead to the following definition of sustainability in MIPS: Sustainability is determined as *'… non-declining number of services per year per person over time*' (HINTERBERGER et al., 1997, p. 11). In a second step, the term sustainability could also be extended and a lifestyle with less need for services envisaged (HINTERBERGER et al., 1997, p. 11). Service units according to the method are meant to express humans 'well being' which should be sustained. On contrary to a materialistic concept of counting the number of products accessible for a person, however, the MIPS concept looks at the utility or services a person needs and desires and how they can be fulfilled with less material input. Less material input can be achieved not only through changes in the production process but also through the use of products which provide a service for a lot of people as public transport or products which supply multiple services. The correlation between service unit, number of people who use the service and number of services provided is further described in chapter 3.2.2 and expressed in equation 6.

In this context Schmidt-Bleek (2000, p. 29) envisions a new orientation of the economy (SCHMIDT-BLEEK, 2000, p. 30) based on a high resource productivity. The concept could give incentives for new or combined product innovations focused on the service unit (SCHMIDT-BLEEK, 2000, p. 186). Thus, MIPS is not only meant to assess the sustainability of existing products; it is also a tool to design new 'ecointelligent' services. Guiding development rules for new products should be longevity, easy repairing, possibility to lease, resource saving production and design as well as multifunctionality (SCHMIDT-BLEEK, 2000, p. 29).

Such a new orientation of the economy would consequently lead to a regionalization. Increased regional employment and positive economic effects could be achieved through the creation of rental companies and immaterial, regional service providers. *'The transition to a sustainable service economy goes along with a regionalization of the economy because services which are person-dependent are not storable in contrast to physical products but have to be provided twenty-four-seven at the location of demand* (SCHMIDT-BLEEK, 2000, p. 75)*.'*[4] This new orientation implies that products should rather be rented than bought and hence could be used more efficiently. This may lead to an increase of longevity of the product as both the service providers and the consumers are interested in long-living and easy-to-repair products (SCHMIDT-BLEEK, 2000, p. 76).
MIPS is a pressure indicator according to OECD and is part of the group of material flow based indicators. Due to consistent accounting, material flow based indicators can be aggregated from the micro level to the macro level (GILJUM, 2006, p. 15). In other words, the concept can be applied to products and services, enterprises, households, regions and economies (RITTHOFF et al., 2002, p. 9). The focus of MIPS is on the micro level of economies: on specific infrastructure, products and services as well as on a combination of those. For the macro level of economies 'material flow accounting and analysis' can be applied (GILJUM, 2006, p. 4).

3.2.2 Method

MIPS measures the input-related environmental impacts by specifying the resources (named 'material') contained in a product or service. As already mentioned, the resource use is analyzed from the 'cradle to the grave'. The resource use is traced back to the point of extraction and broken down into the following material input categories (MI categories) (RITTHOFF et al., 2002, p. 14); the result is expressed separately for each category over the whole process chain:

Abiotic raw material:

- Mineral raw material (used extraction of raw material, such as ores, sand, gravel, slate, granite etc.)
- Fossil energy carriers (e.g. coal, petroleum oil, petroleum gas), unused extraction (overburden, gangue, etc.)

[4] Original German text: *'Der Übergang zu einer zukunftsfähigen Dienstleistungswirtschaft geht einher mit einer Regionalisierung der Wirtschaft, weil personenabhängige Dienstleistungen im Gegensatz zu Sachgütern nicht lagerbar sind, aber rund um die Uhr am Ort der Nachfrage erbracht werden müssen.' (Schmidt-Bleek, 2000, p.75)*

- Soil excavation (e.g. the excavation of earth or sediment)

Biotic raw material[5]:

- Plant biomass from cultivation
- Biomass from uncultivated areas (plants, animals etc.)

Earth movement in agriculture and silviculture:

- Mechanical earth movement or
- Erosion

Water[6]:

- Surface water
- Ground water
- Deep ground water (subterranean)

Air:

- Combustion
- Chemical transformation
- Physical transformation (aggregate state)

Primary material which has no pre-process chain can be immediately assigned to their input category (HINTERBERGER et al., 2008, p. 18). On the other hand, the consideration of indirect material flows or embodied energy due to pre-process chains occurs by means of 'material intensity values' (MI factors), so called '*rucksack* factors' (HINTERBERGER et al., 2008, p. 11). These factors express the embodied material input back to resource extraction (RITTHOFF et al., 2002, p. 28) for the above categories in relation to the weight unit of the used input material, such as kg water/kg preliminary product or kg water/kWh electricity (RITTHOFF et al., 2002, p. 12).

MI factors already exist for some commonly used materials (e.g., steel, aluminum, cement, etc.) and for modules like electricity or transport. On the one hand, MI factors of basic material depend on their natural sources and are therefore determined for example by the geology; on the other hand, MI factors are determined by the mode of transport, the processes and techniques applied to them. MI factors therefore, change over time and hence have continuously to be updated (SCHMIDT-BLEEK, 2004, p. 22). In contrast, if MI factors are not available yet they have to be calculated or estimated with the help of experts.

In detail, for the calculation of MIPS, the MI factor is multiplied by the amount of material used for a product. The sum of all Material Inputs (MI) in relation to the service unit leads to the MIPS value. As opposed to raw material and additives, processed products provide a service and the method can be applied. For raw material and additives the calculation of the material input (MI) is already meaningful without reference to a service (RITTHOFF et al., 2002, p. 12). Equation 4 expresses that the amount of used material multiplied by the MI factor results in the total material input (MI). This MI is equal to MIPS if the service unit is one and multiplied by the number of service units.

[5] Domesticated animals are already part of the technosphere, and are therefore referred back to biomass taken directly from nature e.g., plant or animal fodder.

[6] separated according to processing and cooling water

$$\sum (Mi * MIMi) = MI = MIPS * S$$

$$\begin{aligned} & M1*MIMi && \text{e.g., steel plus rucksack} \\ + & M2*MIMi && \text{...e.g., glass plus rucksack} \\ + & M3*MIMi && \text{...e.g., PVC plus rucksack} \\ + & \ldots && \end{aligned} \quad (4)$$

→ final product (1 unit)…e.g., one car

Whereby:

Mi: Amount of used material (e.g., steel)

MIMi: Material intensity value (*rucksack*) of the input material also expressed as MI factor, MIT, specific material input or ecological *rucksack*

MI: Total material input

MIPS: Material input per service unit, where service unit = 1

S: Service unit

(SCHMIDT-BLEEK, 1994, p. 129, complemented with the terms of RITTHOFF et al., 2002, p. 12 and KROTSCHECK, 1997, p. 664f)

The correlation shown in equation 4 signifies that MIPS can also be expressed as the total material input (MI) divided by the service unit (S) (see equation 5).

$$MIPS= MI/S \quad (5)$$

The resource productivity, expressed by MIPS, can thus be increased (i) by decreasing the material input or (ii) by increasing the benefit/service which a product can provide (HACKER, 2003, p. 7). The service unit is therefore a major idea of MIPS. It is defined as the smallest common service claim that a product can fulfill (SCHMIDT-BLEEK, 2000, p. 169) and can be split up into the number of services multiplied by the number of people who use the product at the same time (see equation 6).

$$S = n * p \quad (6)$$

Whereby:

S= service unit

n= number of services (number of uses, time frame or area)

p= number of people who use the product at the same time

(SCHMIDT-BLEEK, 1994, p. 129)

If this correlation applies depends on the analyzed product or service. Following, some variations for service units are given:

- Glass of orange juice: S = 1
- Bicycle kilometers (S = n)
- Person kilometers in the railway transportation S = n * p
- Number of people living in an apartment for n years S = n * p

The service unit makes different alternatives comparable. The compared alternatives have to fulfill the same service but do not have to be necessarily two products. They can also be *'non-material'* fulfillers of a service (RITTHOFF et al., 2002, p. 12).
The results of a MIPS calculation can also be expressed as the 'ecological *rucksack*' of a product. The 'ecological *rucksack*' is given by the material input minus the weight of the product (SCHMIDT-BLEEK, 2000, p. 82) and is, as well as the MIPS result, given in weight of nature consumed per weight of product (see equation 7).

Ecological rucksack [kg] = MI- weight of product (7)

Beside the 'ecological *rucksack*' the 'water *rucksack*' can be calculated. It is the sum of the water used in the different stages of the production or during the whole life cycle of a product and expresses one part of the 'ecological *rucksack*' (HINTERBERGER et al., 2008, p. 3).

3.3 EFORWOOD SIA

EFORWOOD is a project funded by the European Union under the EU 'Global change and ecosystems' research activity of the 6^{th} framework program. The main product of this project is a Sustainability Impact Assessment tool (SIA) for the forest-based sector taking into account the environmental, economic and social dimension of sustainability. The SIA is realized in form of a software package and allows assessing sustainability impacts due to various internal and external drivers. Drivers can be changes in policies, market conditions, or technology (LINDNER et al., 2009, p. 1)

3.3.1 Background and underlying ideas

The EFORWOOD project started in 2005 and ends in January 2009. The aim of the project EFORWOOD was to create a sustainability impact assessment tool SIA tool for European forestry-wood chains inspired by pre-existing works and methods in the field of Environmental Impact Assessment (RAMETSTEINER et al., 2006, p. 5). Sustainability impact assessment methods are according to Ness et al. (2007) used as a decision support tool for policy-making and project evaluation while attempting to involve stakeholders (NESS et al., 2007, p. 504). This is also an important aspect of the EFORWOOD SIA.

The EFORWOOD SIA is planned to be used as decision support tool for the forest-based industry, policy makers of different levels, consultants and researchers (LINDNER et al., 2009, p. 8). It is aimed to be a tool for providing sound information for all stakeholders when changes concerning the sector arise. The results of the method can be used as transparent base for discussions, negotiations and as a decision-support tool for the different stakeholders with conflicting views regarding the sustainability of a forestry-wood chain (LINDNER et al., 2009, p. 8). Further, the tool could be used for CSR (Corporate Social Responsibility) reports in the future (RAMETSTEINER et al., 2006, p. 5).

EFORWOOD SIA is a process based method. It assesses the impacts of the occurring changes in the forestry-wood chain through indicator values for every process along a defined process chain. Components of the project are a prototype of the ToSIA software, an indicator set consisting of 27 indicators, a database on which the calculations are based and reports of the working groups in different stages of the project.

The EFORWOOD indicators encompass the environmental, economic and social dimension of sustainability. They were chosen in a way that they are valid for the entire forestry-wood chain or parts thereof and to be relevant from local to international level of decision-making (RAMETSTEINER et al., 2006, p. 5).

EFORWOOD SIA can be used as a tool for analyzing and comparing process chains of the forestry-wood sector by indicator values. Optionally, the results can by aggregated by means of Multi-Criteria Analysis or Cost-Benefit Analysis. The method can also be used to analyze material flows along a process chain or to assess indicator values for specific processes defined in the chain. The tool can also be used to make predictions. Therefore, different scenarios to analyze impacts on forestry-wood chains in the future are provided.

To date, three case studies were modeled under EFORWOOD, namely (i) the Scandinavian case study, (ii) the Iberian Peninsula case study and (iii) the Baden-Württemberg case study. They are defined by multiple forestry-wood chains and each of them looks at the forestry-wood sector from a different perspective. The 'Scandinavian case study' is production driven, thus its forestry-wood chains originate in the region. The 'Iberian case study' is consumption driven, hence, the final wood products are consumed within the region. The 'Baden-Württemberg case study' is regionally defined. The wood originates from the region and is also processed and consumed there (LINDNER et al., 2007, p. 11).
Different perspectives as 'forest defined', 'industry defined', 'product defined' or 'regionally defined', allow a broader use of the EFORWOOD tool.

The EFORWOOD SIA wants to present a holistic picture of the sustainability impacts of forestry-wood chains by taking into account in a balanced way the three dimensions of sustainability (environmental, economic and social) (LINDNER et al., 2009, p. 1).
Even though EFORWOOD refers to the general sustainability definition of the 'Brundtland report' (RAMETSTEINER et al., 2006, p. 8f) and puts emphasis on taking into account the three dimensions of sustainability (LINDNER et al., 2009, p. 4) no further definition of sustainability underlies the project. The emphasis given to specific aspects is depending on the user through weighting or balancing the indicators.

3.3.2 Method

EFORWOOD SIA assesses the impacts on changes in the forestry-wood chain through indicator values for every process along the forestry-wood chain (Fig. 3). The indicators encompass the three dimensions of sustainability defined on the Earth summit on Environment and Development in Rio de Janeiro in 1992 (UNEP, 1992).

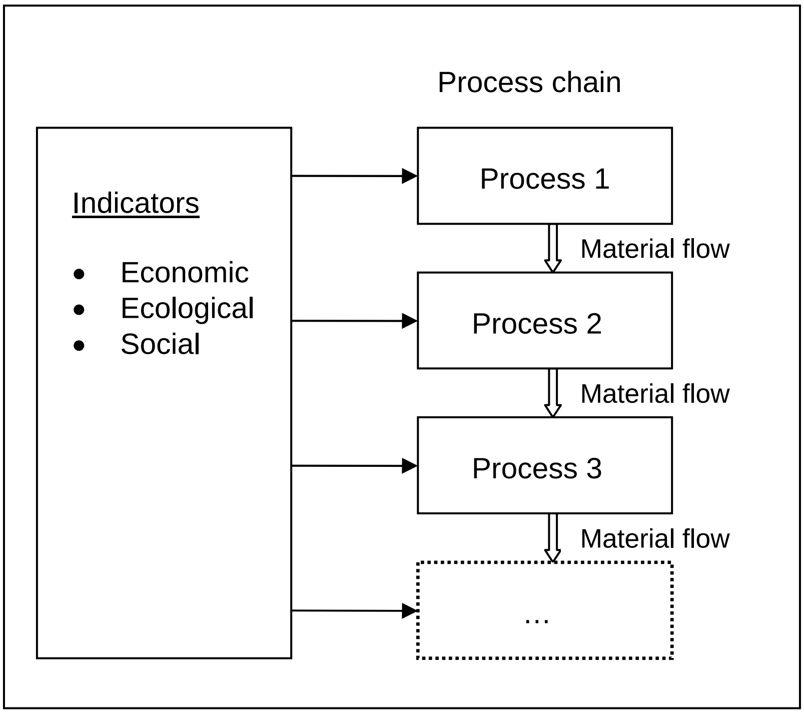

Fig. 3. Calculation of the EFORWOOD SIA: Indicator values are calculated for processes throughout a forestry-wood chain.

In detail, the relative indicator value for each process is multiplied by the material flow to receive an absolute sustainability indicator value for the process (LINDNER et al., 2007, p. 47), in terms of:

Total material flow * (relative indicator value per unit of reference flow) = absolute indicator value **(8)**

The sum of the absolute values of a specific indicator along the entire forestry wood chain is the indicator value for the whole chain. It can then be compared to alternative chains.

As the results of the indicators are expressed in different measurement units, an aggregation of the different indicator results is impossible just like it is also impossible to directly compare the results of different indicators. Thus, for an aggregated result, evaluation methods like Multi-Criteria Analysis or Cost Benefit Analysis are needed and provided also by ToSIA.

The modeling framework of EFORWOOD includes, as already mentioned earlier, the software ToSIA and a database including an indicator set of 27 indicators for all three pillars of sustainability.

- The software tool is a dynamic pathway analysis model (LINDNER et al., 2007, p. 15) and will be available as open source (LINDNER et al., 2007, p. 1).
- With regard to the database, it contains the indicator values for every single process, the definition of processes, information on the reporting units, data sources and

conversion factors. The 27 indicators were chosen according to guidelines by the European Commission (*'Impact Assessment Guidelines of the European Commission'*) and the following reference indicator sets (RAMETSTEINER et al., 2006, p. 13):

- *'Sustainable development indicators for the European Union'* of Eurostat
- *Indicators of Sustainable Development* of the Commission for Sustainable Development of the United Nations
- *Improved Pan-European Indicators for Sustainable Forest Management* of the Ministerial Conference on the Protection of Forests in Europe
- *European Union Rural Indicators* of the PAIS project.

The indicator values for the database were collected by independent experts. The defined processes in EFORWOOD comprise a range of different options as base for simulating different forestry- wood chains, beginning with the plantation of a tree in the forest to the amount of waste generated by the end product. Therefore, it is possible to make calculations from the 'cradle to the grave', even though also chains representing only an excerpt of the life cycle of a product can be analyzed.

3.4 Criteria for the comparison of the methods

The evaluation of the methods is done by means of a criteria catalogue. The list of criteria was composed following impulses from literature (BEST et al. 2008; GILJUM et al., 2006; HUIJBREGTS et al., 2008; HERENDEEN, 2000; KITZES et al., 2007; REES, 2000; SCHMIDT-BLEEK, 1994, 2000; VAN DEN BERGH AND VERBRUGGEN, 1999) and complemented by additional considerations. For this case study it was decided, in consultation with SERI and the Institute for Silviculture/BOKU that the following eight criteria were the most appropriate to evaluate the three methods. To evaluate the extent to which the methods fulfill the criteria, scores from 1 to 5 are assigned, where 1 is low and 5 is high. For more transparency on the evaluation process the scores from 1 to 5 were not defined generally but specific for every criterion.

In the following the eight criteria are defined and the meaning of the scores is described.

Criterion 1: Give directionally robust information

This criterion expresses the need for a sustainability assessment method to be basically right in evaluating if the direction of sustainable development is taken even though it does not have to claim to be precise. According to Giljum et al. (2006, p. 19) it should give *'directionally safe information'.*

Scores:

Score 1: The results of the method cannot give directionally robust information for the objective the method was developed for.

Score 2: There are still discussions among researchers if the results of the method can give directionally robust information for the objective the method was developed for.

Score 3: The results of the method can give directionally robust information for the objective the method was developed for and coincide at least with the overall result of one of the two other methods applied in this study.

Score 4: The results of the method can give directionally robust information for the objective the method was developed for and coincide with the results of the two other methods applied in this study or are described in literature as having strong correlations with other comparable sustainability assessment methods.

Score 5: The results of the method can give directionally robust information for the objective the method was developed for, coincide with the results of the two other methods applied in this study and are described in literature as having strong correlations with other comparable sustainability assessment methods.

Criterion 2: Transparency of the calculation process and the data sources

Transparency is necessary to make it possible to repeat the method and verify the results. Therefore, a written documentation of the calculation process as well as of the data sources is very important.

Scores:

Score 1: Not even the standard procedure or basic concept for the calculation of the method and its data sources are described in a transparent way.

Score 2: The standard procedure or basic concept for the calculation of the method is documented, however, there is a major lack in transparency of assumptions and data sources used.

Score 3: The standard procedure or basic concept for the calculation of the method is well documented but there are still some lacks in transparency of assumptions and data sources used.

Score 4: The standard procedure or basic concept for the calculation of the method is well documented and there is ongoing effort to standardize the procedure, assumptions and data sources to make the calculation more transparent and to produce comparable results.

Score 5: The method is standardized and only standardized assessments are recognized. New assumptions or approaches have to be well documented and indicated as those.

Criterion 3: Based on available and reliable data

The method should be based on data which are collected in most of the countries and which can be evaluated as reliable. By reliability it is meant that the data should have been collected consistently and, concerning generic data, also to be representative.

Scores:

Score 1: The data needed for the application of the method are rare to be collected and are not collected consistently. To assure the data to be representative, too less data are available.

Score 2: The data needed for the application of the method are collected as internal data in enterprises but with lack in consistency for example in time series. The representativity of the data is low.

Score 3: The data needed for the application of the method are collected as internal data in enterprises, in databases or in statistics but there can be lack in consistency of or among the data sources and the representativity varies a lot and is not well documented.

Score 4: The data needed for the application of the method are collected as internal data in enterprises, in databases or by statistics in a consistent way and the representativity even though varying, is well documented.

Score 5: The data needed for the application of the method are public data and collected for standard statistics in every industrialized country or in databases and already since longer time periods. They are collected consistently and the generalized data are representative for a wider geographical entity like a region or country, or a specific industrial sector.

Criterion 4: Feasible within an adequate effort in time and with adequate costs

A sustainability method should be feasible within an adequate time and cost frame otherwise it is unlikely that the method will be widely applied.

Scores:

Score 1: The method is neither feasible within an adequate effort in time nor with adequate costs.

Score 2: The method is either not feasible within an adequate effort in time or with adequate costs.

Score 3: The method would be feasible within an adequate effort and with adequate costs but the method is evaluated as a burden disproportionate to its benefits. The benefits could be increased through various incentives for a more sustainable production.

Score 4: The method is feasible within an adequate effort in time and with adequate costs. The method is evaluated as a burden but proportionate to its benefits.

Score 5: The method is easily feasible within an adequate effort in time and the benefits are evaluated as much higher than the effort and costs.

Criterion 5: Integrated approach

A sustainability assessment method should be based on an integrated sustainability concept. That means that it should consider the three dimensions of sustainability defined on the Earth summit on Environment and Development in Rio de Janeiro in 1992 (UNEP, 1992) which are ecological/environmental, social and economic.

Scores:

Score 1: The method explicitly includes one dimension of sustainability and may have weaknesses in representing this dimension in a comprehensive manner.

Score 2: The method explicitly includes two dimensions of sustainability and may have weaknesses in representing these dimensions in a comprehensive manner.

Score 3: The method explicitly includes one or two dimension/s of sustainability and may have weaknesses in representing this/these dimension/s in a comprehensive manner. In addition, the other dimension/s are implicitly covered by the method.

Score 4: The method explicitly includes all three dimensions of sustainability but may have weaknesses in representing these dimensions in a comprehensive manner. **Score 5:** The method explicitly includes all three dimensions of sustainability and they are all comprehensively represented.

Criterion 6: Communicable

If a sustainability assessment should be heard and considered it has to be understandable also for non scientists and appealing to motivate positive responses. It should *'…capture the public's imagination'* (REES, 2000, p. 374).

Scores:

Score 1: The method is totally unsuitable for communication purposes due to its complexity only understandable by scientists in the field, no vivid representation and no short and clear message which motivates positive responses.

Score 2: The method is difficult to understand for non-scientists but can provide conclusions which can be integrated by experts in their expertise and further into decision making.

Score 3: The method can be understood by non-scientists but no vivid representation as well as no clear and unambiguous message is provided through the result of the method.

Score 4: The method can be understood by non-scientists and a vivid representation of the results is provided but the result does not give a clear and unambiguous message.

Score 5: The method is simple to understand also for non-scientists even though representing complex environmental interactions. With its vivid representation it captures public imagination and its result gives a clear and unambiguous message which motivates positive responses.

Criterion 7: Universal

A sustainability assessment method for products should be applicable to a variety of products and services of different kinds, in different regions of the world and cross-border.

Scores:

Score 1: The method is only applicable to specific products or services and due to various reasons to a limited geographical area and not cross-border.

Score 2: The method is applicable to certain products or service groups or both which have certain common characteristics. The application in different regions or cross-border is not feasible and there is no potential and effort to change this.

Score 3: The method is applicable for certain product or service groups or both which have certain common characteristics. The application in different regions or cross-border is feasible or there is potential to make it feasible.

Score 4: The method is applicable for most products or service groups even though it may be more adequate for some product or service groups. The application in different regions and cross-border is possible. Effort is, however, still necessary to solve remaining methodological difficulties or to adapt the method to a new setting.

Score 5: The method is adequate for most products and services of different kinds and applicable in different regions and cross-border without any additional effort in the application of the method.

Criterion 8: Comprehensive

This criterion means that a sustainability assessment method should include all main environmental input categories: 'abiotic materials', 'biotic materials', 'water' and 'land area'. The focus on 'input' is laid as in the sustainability debate increasingly the opinion prevails that a lot of the major environmental problems (e.g. climate change or loss of biodiversity) are due to excessive use of natural resources for production and consumption. These problems cannot be solved with the output-focused traditional environmental assessments (Hinterberger et al., 2008, p.7).

Scores:

Score 1: The method only considers one environmental category and even this category is not represented in a comprehensive manner.

Score 2: The method considers one or two categories which are comprehensively represented.

Score 3: The method includes one, two or three categories which are comprehensively represented and there is potential to further develop the method to include also the other categories.

Score 4: The method includes all four categories but they are not all comprehensively represented.

Score 5: The method includes all four categories and they are all comprehensively represented.

4 Material

In this chapter, the material which is used for the practical application of the three methods is described. The chapter includes the representation of the defined process chains as well as the definition of the system boundaries applied, the quality and source of the used data and a description of the chosen indicators.

For the comparison of the three methods EF, MIPS and the EFORWOOD SIA, the methods were applied to the production processes of the products solid wood (SW) plank and particleboard (PB) plank, defined in the following:

- The SW plank is a dried spruce plank.
- The PB plank is a raw, grinded, and ready to use flat press standard particleboard for interior use (HASCH, 2002, p. 113), formerly labeled V20 (HASCH, 2002, p. 109), according to the norm DIN EN 312 of 2003 and DIN EN 13968 of 2006 labeled P2 for its use for furniture and interior.

4.1 Process chains

As base for the calculations, two separate process chains shown in Fig. 4 and Fig. 5 were defined, one for each of the two products. Nevertheless, the two products are linked: The wood by-products, which accrue in the sawmill, are the most important raw material input for the particleboard mill. Therefore, a physical mass allocation for joint wood products, as proposed by HASCH (2002, p. 55), was applied. This is also in accordance with EN ISO 14041[7] (HASCH, 2002, p. 55) which recommends, if any, then a physical allocation.

The material flows are assumed the following (Fig. 4 and Fig. 5): When cutting round wood only 62.5% of the mass flow results in sawn timber, 37.5% are wood by-products (HASCH, 2002, p. 106f). The relation between the main product sawn timber to the wood by-products is mainly given through the diameter of the round wood (average annual mean), the cutting program, the quality of the round wood, the size of the flat joints and the cutting technology (HASCH, 2002, p. 105, cited from Fronius, 1992). The allocation takes into account the different moisture of heartwood, sapwood and the bark. The bark, which is seen as waste product, is equally allocated to the products sawn timber and wood by-products. Regarding the material flow between the sawmill and the particleboard mill, it is assumed that in Austria 14% of the wood by-products are used in the particleboard production; the remaining are used for other purposes, such as for the production of heat energy by combusting the by-products for the drying process of the sawn timber (ÖSTERREICHISCHE

[7] Norm on Life Cycle Assessment- Life Cycle Inventory: Goal and scope definition and inventory analysis

ENERGIEAGENTUR, 2008, p. 81). The fraction of pulpwood and recycling wood entering the particleboard mill was assumed according to Hasch (2002, p. 116).

In Fig. 4 and Fig. 5 the process chains for the solid wood (SW) and the particleboard (PB) are presented.

Process chain for the product solid wood plank

Legend:

SW: Solid wood
RW ob: Round wood over bark
WB: Wood by-products

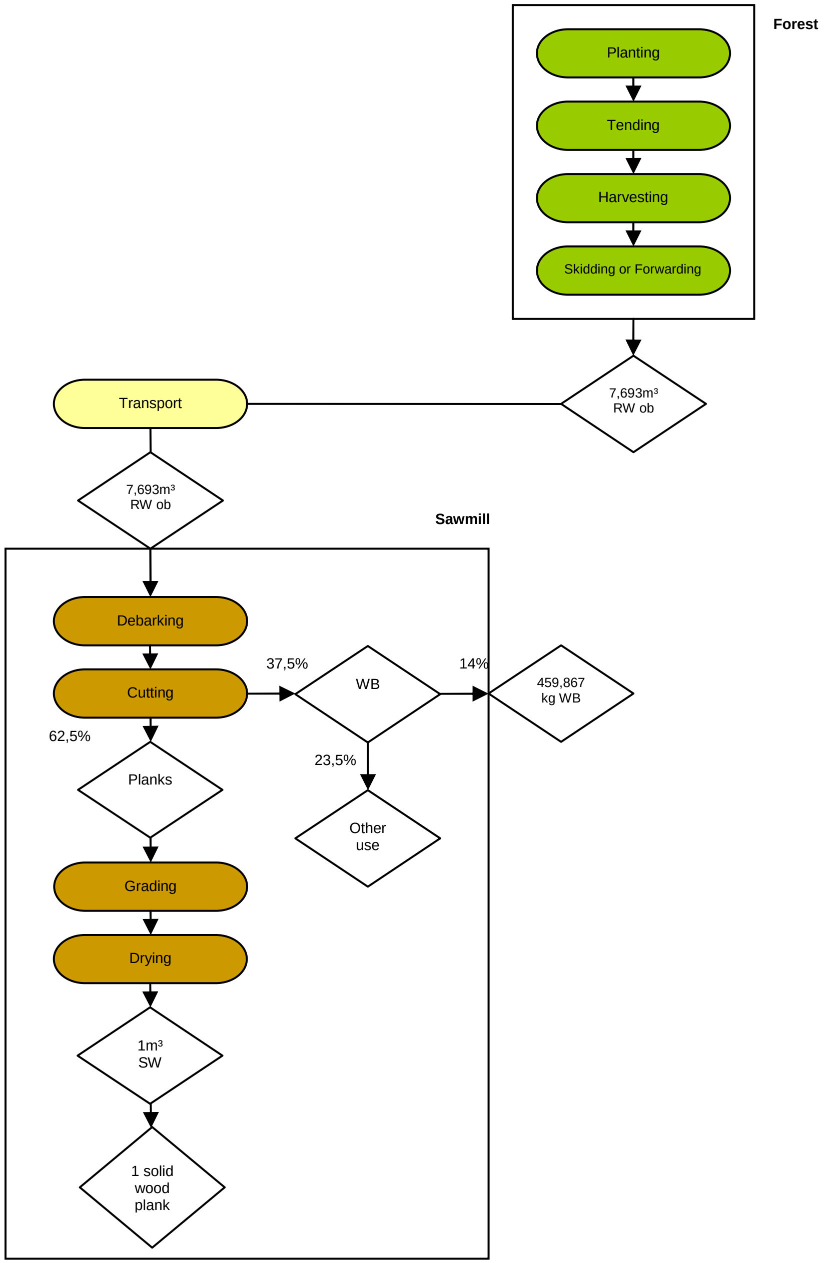

Fig. 4. Process chain for the production of a solid wood plank.

Process chain for the product particleboard plank

Legend:

SW: Solid wood
PB: Particleboard
RW ob: Round wood over bark
PW: Pulpwood
WB: Wood by-products
RECW: Recycled wood

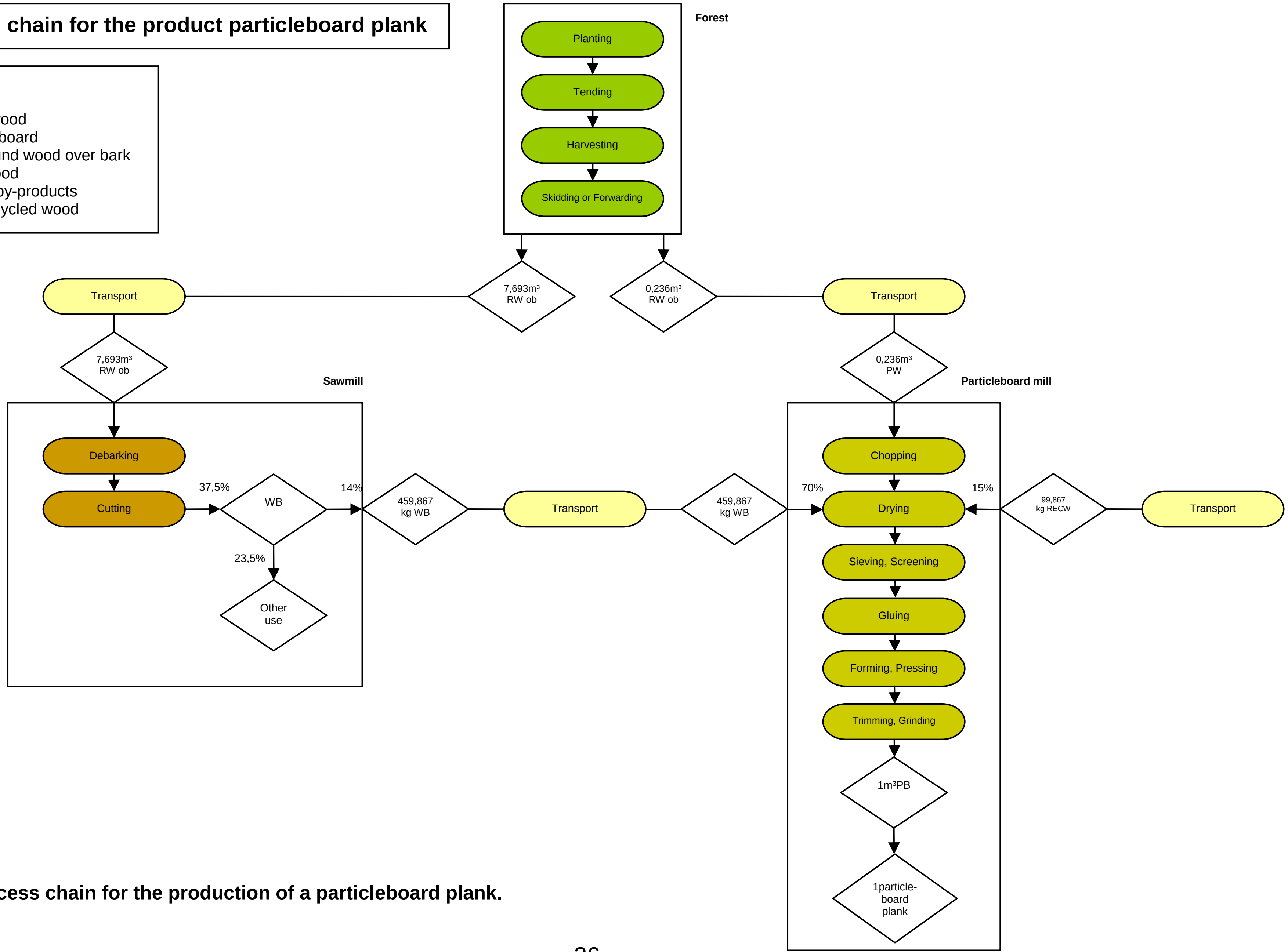

Fig. 5. Process chain for the production of a particleboard plank.

The process chains represent the wood flows, including round wood, wood by-products, pulpwood and recycled wood according to the process step from the forest to the defined end product as well as the processes taking place along the chain.

The end product defined is 1 m^3 SW and 1 m^3 PB respectively. For the production of 1 m^3 spruce SW and also for 1 m^3 PB, more than 1 m^3 of raw material input is needed. This is due to by-products which are generated during the production processes and the splitting of the material flows. With regard to the assumed material flow allocations for the production of 1m^3 SW, 1.6 m^3 round wood ob are needed; for the production of 1m^3 PB 7.693 m^3 of round wood ob are used up. The assumption thereby is that the two products are, as already mentioned, joint and only part of the wood by-products (14%) is available for the particleboard production.

The debranched fresh round wood is transported to the sawmill and is only there, debarked. That is why the material flow to the sawmill and then in the sawmill is expressed as 'over bark' (ob) (see Fig. 4 and Fig. 5) which means with bark . After the sawmilling process, the wood flow is expressed in kilogram (kg) for the wood by-products (459,867 kg) (see Fig. 4 and Fig. 5) and the recycled wood (99,867 kg) which enter the particleboard mill (see Fig. 5). The pulpwood is expressed in cubic meter over bark (m^3 ob). 0,236 m^3 ob of pulpwood enter the particleboard mill (see Fig. 5).

The defined process chains comprise the major processes for the production of SW and PB. For a better comparison of the results, the production steps from the forest to the defined end product are summarized in four modules. This division into modules allows more transparency, flexibility, the possibility of cross-linking and the interchange of these modules (SCHWEINLE, 2000, p. 7).

The four modules are:

- Forest
- Transport
- Sawmill
- Particleboard mill.

The SW production (Fig. 4) includes the modules 'forest', 'transport' and the module 'sawmill'. On the other hand, the particleboard production (Fig. 5) comprises the modules 'forest' (for the production of the round wood entering the sawmill and the pulpwood), 'transport', 'sawmill' and the module 'particleboard mill'. The module 'transport' is divided into four transport ways. In the calculations, the different transport ways are handled separately in a first step and are then in a further step summarized to one module 'transport' for the interpretation of the results. In Tab. 2 the modules included in the process chains of the two products are summarized whereby the transport ways are distinguished.

Tab. 2. Modules along the production chain of the two products solid wood plank and particleboard plank.

Products / Module	Solid wood plank	Particleboard plank
Forest	X	X
Transport 1: Transport of the round wood to the sawmill	X	X
Transport 2: Transport of the wood by-products to the particleboard mill		X
Transport 3: Transport of the pulpwood from the forest to the particleboard mill		X
Transport 4: Transport of the recycled wood to the particleboard mill		X
Sawmill	X	X
Particleboard mill		X

The following processes (see Tab. 3) are assumed for the production of the SW plank and the PB plank and apply as framework to all methods. The transport ways 2, 3 and 4, and the module 'particleboard mill' are only relevant for the particleboard production. The process 'drying' only regards the SW production.

Tab. 3. Processes considered along the production chain of the solid wood plank and the particleboard plank.

<table>
<tr><th>Products / Modules</th><th>Solid wood plank</th><th colspan="2">Particleboard plank</th></tr>
<tr><td><u>Forest</u></td><td>Round wood to enter the sawmill:
• Planting
• Tending
• Harvesting motormanually
• Skidding</td><td>Round wood to enter the sawmill:
• Planting
• Tending
• Harvesting motormanually
• Skidding</td><td>Pulpwood:
• Planting
• Tending
• Harvesting fully mechanized
• Forwarding with forwarder</td></tr>
<tr><td><u>Transport</u></td><td>• Transport 1: Transport of the round wood from the forest to the sawmill</td><td colspan="2">• Transport 1: Transport of the round wood from the forest to the sawmill
• Transport 2: Transport of the pulpwood from the forest to the particleboard mill
• Transport 3: Transport of the wood by-products from the sawmill to the particleboard mill
• Transport 4: Transport of the recycled wood to the particleboard mill</td></tr>
<tr><td><u>Sawmill</u></td><td>• Debarking
• Cutting
• Drying</td><td colspan="2">• Debarking
• Cutting</td></tr>
<tr><td><u>Particleboard mill</u></td><td></td><td colspan="2">• Chopping
• Chipping
• Drying
• Sieving and Screening
• Gluing
• Forming and Pressing
• Trimming and Grinding</td></tr>
</table>

For the EFORWOOD SIA, the specific corresponding processes, chosen from the EFORWOOD database (case study Baden-Württemberg) are the following:

<u>Module 'forest':</u>

For the round wood entering the sawmill:

- Spruce regeneration
- Development of young spruce
- Development of spruce in medium phase
- Adult spruce development
- Harvesting motormanual (DBH[8] > 35 cm, slope ≤ 30 %)
- Skidding (DBH > 35 cm, slope ≤ 30%)

For the pulpwood:

- Spruce regeneration
- Development of young spruce
- Development of spruce in medium phase

[8] diameter at breast height

- Harvesting fully mechanized (Spruce, DBH ≤ 35 cm; slope ≤ 30 %)
- Forwarding with forwarder (Spruce, DBH ≤ 35 cm; slope ≤ 30 %)

Module 'transport':

- Transport 1: 'Transport of spruce long logs'
- Transport 2: 'Transport of spruce pulpwood'
- Transport 3: 'Transport of chips'

As the transport way of the recycled wood to the particleboard mill is not covered in the EFORWOOD case study Baden-Württemberg, this transport process was added to the EFORWOOD dataset by adopting the distance value from HASCH (2002, p. 124) for the calculation of the EFORWOOD indicator 'transport'; the other EFORWOOD indicator values for this process were assumed to be the same as for the transport way 'transport of spruce pulpwood'.

Module 'sawmill':

- Softwood sawmill gate
- Softwood sawmill

Module 'particleboard mill':

- Particleboard mill gate
- Particleboard mill

For the calculation along the process chain the measuring unit cubic meter (m^3) was used. However, as the unit 'm^3' does not take into account the different properties and characteristics, which are relevant for the application possibilities of the two materials; a service unit was defined to present the results. The concept of a 'service unit' is adopted from the method MIPS.

The service unit defined is a plank of solid wood (SW) and particleboard (PB) respectively of a dimension of 100 x 20 cm and a bearing capacity of 25 kg. The representation of the results per defined plank of a certain bearing capacity has higher informative value than the unit 'm^3' as the bearing capacity is an important property (among other factors like price or weight) in the selection of one of the products.

A bearing capacity of 25 kg results in different thicknesses of the two planks and therefore in a different amount of planks received from 1 m^3. 1 m^3 SW is equal to 952.4 SW planks and 1m^3 of PB equals 416.7 PB planks. The amount of planks was calculated by a simple momentum equation. The result per m^3 is divided by the amount of planks to receive the result expressed in the service unit 'plank of a dimension of 100 x 20 cm and a bearing capacity of 25 kg'. For a reasonable comparison with other studies, however, the results are given additionally per m^3 in Annex 4.

4.2 System boundaries

A clear definition of the system boundaries is of major importance for the comparison of different products as the extent of the system may significantly influence the outcome of the results (HASCH, 2002, p. 102). Further, a clear definition of the system boundaries is necessary:

- To quickly recognize asymmetries in the system boundaries when comparing two products with each other;
- To identify significant differences in the analyzed systems even if the system boundaries seem the same at first sight (SCHWEINLE, 2000, p. 6).

With regard to the comparison of the three methods to assess sustainability, the analysis is limited to the production processes of a SW plank and a PB plank illustrated in the two process chains (see Fig.4 and Fig. 5). The analysis starts in the forest and ends at the defined finished product in the sawmill and in the particleboard mill respectively. This system boundary had to be set due to time constraints and enabled to keep the focus of the thesis on the comparison of the three methods. However, the original MIPS would clearly recommend an assessment *'from cradle to grave'* (RITTHOFF et al., 2002, p. 11). For the EF and the EFORWOOD SIA, also intermediate products can be calculated when a clear description of the system boundaries on the products' life cycle is given (GLOBAL FOOTPRINT NETWORK, 2009, p. 9, LINDNER et al., 2007, p. 10).

The work refers to conditions in Germany and Austria. Concerning the time frame, the analysis is based on data extracted between 1995 and 2005, with the earliest data included in the life cycle inventory of Hasch (2002, p. 101). Due to the plausibility check with the Austrian wood industry, however, the data could be validated as being still up-to-date.

With regard to the frame, of which material inputs enabling the processes are considered along the chain (Tab. 3), system boundaries had to be set as well. The system boundaries are set to consider:

- Raw material,
- preliminary products,
- auxiliary and
- operating material.

On the other hand, the following pre-process chains, infrastructure and inputs were not considered:

- Production of machines, vehicles and facilities,
- exceptional inputs such as accidents or repairs,
- road construction and,

- the inputs for administration.

This setting of the system boundaries is in line with the method MIPS (SCHMIDT-BLEEK et al., 1998, p. 74ff; RITTHOFF et al., 2002, p. 12f). According to MIPS, generally *'All materials are counted, which are removed by human beings from their natural deposits'* (RITTHOFF et al., 2002, p. 13). In this way, a system boundary between the ecosphere and the technosphere is drawn. However, as this system boundary would be too extensive, a specific process chain is analyzed and cut-off criteria are defined, which determine the pre-process chains that do not have to be considered. Cut-off criteria are set *'…under practical and methodological viewpoints'* (RITTHOFF et al., 2002, p. 13), as it can be e.g., *'…the production technologies, the production buildings or even the production of auxiliary and operating materials'* (RITTHOFF et al., 2002, p. 13). The disregarded chains should *'…have negligible influence on the final result'* (RITTHOFF et al., 2002, p. 13).

In this study, the set cut-off criteria do not include the production technologies and production buildings but include auxiliary and operating materials. These cut-off criteria correspond to the example of a MIPS calculation, given in Schmidt-Bleek et al. (1998, p. 79).

For the EF, the methodological rules for the determination of the system boundaries are still not specifically determined (HINTERBERGER et al., 2008, p. 17); this is due to the relatively new application of the EF to products. In the EF Standards 2009 (GLOBAL FOOTPRINT NETWORK, 2009, p. 9) it is referred to the standards of Life Cycle Assessments (EN ISO 14040 and 14044), which is relevant in the context because data from Life Cycle Assessments are adopted in this study. The used data sources of Schweinle (2000) and Hasch (2002) comply with this standard. Further system boundaries in the application of the EF were aligned to the methodical rules of MIPS with the scope of having consistent system boundaries among the compared methods. On the contrary to MIPS and EFOROOD SIA, the production buildings are considered in the EF calculation through the direct area use, which is an intrinsic aspect of the method.

In comparison to the EF and MIPS, EFORWOOD is an approach, which is not focused on material inputs and outputs but its focus is on processes which are evaluated through indicators. Overlappings with the EF and MIPS concern the inputs 'energy' and 'water' which are expressed in EFORWOOD by the indicators 'energy use' and 'water use' as well as the module 'transport' expressed in ton kilometers (tkm) in all three methods.

Put into practice the defined system boundaries meant the following for the different modules:

- For the module 'forest', for which a basic variant of forest management is assumed, the fuel and oil input used for the harvesting machines accounts as the environmental impact. The preliminary product 'tree seedling material' could not be considered due to lack of information.

- For the module 'transport' the distance and freight of the transported good is considered and expressed in tkm. In the methods EF and MIPS, the upstream production of the fuel per tkm is included in the CO_2 value regarding the EF and the MI factor concerning MIPS. The EFORWOOD SIA only considers the amount of tkm.
- For the modules 'sawmill' and 'particleboard mill', the material and energy flow inputs given in Hasch (2002) were taken as data base. As the data for the PB production showed greater detail, these data were aligned with the data for the sawmill to reach consistency among the modules. Moreover, the inputs according to Hasch (2002, p. 116ff) named 'other' could not be considered, even though they make up more than 1% of the operating supplies' mass in the particleboard production. The boundary was set because no further specification of 'other' is made and the author could not be contacted for further information. The recycled wood is considered without its preliminary chain. This was defined according to the concept of MIPS. Recycled products are assumed to have an ecological *rucksack* of 0 because they are already taken into account in their first life cycle (SCHMIDT-BLEEK et al., 1998, p. 37).The transport of the recycled wood to the particleboard mill, however, is considered.

The list of the input data considered in the different modules for the EF and MIPS is given in Annex 2. Thereby, the raw material produced in the forest (round wood for the sawmill and pulpwood) is allocated to the module 'forest'. For the EFORWOOD SIA the raw data for the calculation are shown in Annex 3. It was decided to show the raw data and not the input data for the EFORWOOD SIA to allow a better traceability regarding the data of the EFORWOOD database, which may be updated since the values were adopted in May 2009. The conversion factors used to transform the raw data into input data for the calculation are shown in Annex 1.

On the contrary to the cut- off criteria regarding the frame of consideration of inputs, which is defined consistently for all three methods, the depth of analysis is immanent to the methods: For the EF and MIPS the upstream production processes of the inputs to a module, the 'ecological *rucksack*', is considered through the MI factors and the CO_2 values. In comparison, the indicator values in the EFORWOOD SIA in general[9] only consider the specific process and no embodied material use.

[9] Some exceptions e.g. for the indicator 'energy generation and use' exist (see system boundary description of the indicator in chapter 4.4).

4.3 Data

The input data are beside the method itself the major factor, which influences the result of a sustainability assessment. In the application of the three sustainability assessment methods on the production chains of a SW plank and a PB plank in this thesis, different data sources had to be used. Different data sources imply variations concerning the type of the data (aggregated or specific), the transferability to another context (e.g., to Austria), the consistency among the data (e.g., concerning system boundaries and different underlying assumptions) and the uncertainty range of the data.

4.3.1 Type and source of data

In Tab. 4 and Tab. 5 the type of data and the different data sources used for the application of the three methods are shown. A differentiation was made between ‘generic and derived data’, ‘specific and empirical data’, and ‘model-based and estimated data’. This differentiation was adopted from the EFORWOOD data collection protocol (BERG, 2008, p. 5). ‘Specific and empirical data’ include follow-up routines from enterprises, data from experiments or scientific measurements and branch statistics. ‘Generic and derived data’ are collected by official statistics. ‘Model-based and estimated data’ include data generated through models and expert judgment (BERG, 2008, p. 5).

EF and MIPS: For the methods EF and MIPS the main data sources were the EFORWOOD database (EFORWOOD, 2009) regarding inputs which overlap with the EFORWOOD SIA, and the data sources Hasch (2002) and Schweinle (2000). EFORWOOD values were taken for the transport distances (except for the transport of the recycled wood) as base for calculating the ton kilometers (tkm) of the module ‘transport’ and the fuel input for the harvesting and skidding/forwarding processes of the round wood and the pulpwood. The energy input for the modules ‘sawmill’ and ‘particleboard mill’ was complemented with data from the EFORWOOD database as well and energy scenarios were determined (see chapter 5.5). The further resource inputs for the modules ‘forest’, ‘sawmill’ and ‘particleboard mill’ are based on the data sources of Hasch (2002) and Schweinle (2000).

The CO_2 values and MI factors are taken from the sources that are specified in Tab. 4; the information to calculate the direct area use for the module ‘forest’, ‘sawmill’ and ‘particleboard mill’ was derived from the forest definition of the EFORWOOD SIA and personal communications by an Austrian sawmill and an Austrian particleboard mill regarding the built areas of the premises[10]. In Tab. 4 the data type and data source for the EF and MIPS calculation are summarized.

Tab. 4. Type and source of the data used in the calculations of the EF and MIPS.

Data for the application of the EF and MIPS	Type of data	Data source
Forest input data		
• Fuel input for the processes plantation and tending	- Generic and derived data	Schweinle (2000)
• Fuel input for the processes harvesting and skidding/forwarding	- Specific and empirical data or - Generic and derived data	EFORWOOD database (EFORWOOD, 2009)
• Machine oil input for chain saw	- Generic and derived data	Riezinger (2008) and Westermayer (2006)
• Machine oil input for harvester	- Generic and derived data	Schweinle & Thoroe, (2001)
Transport km		
• Transport 1: Transport of the round wood from the forest to the sawmill • Transport 2: Transport of the pulpwood from the forest to the particleboard mill • Transport 3: Transport of the wood by-products from the sawmill to the particleboard mill	- Generic and derived data or - Model-based and estimated	EFORWOOD database (EFORWOOD, 2009)
• Transport 4: Transport of the recycled wood to the particleboard mill	- Specific and empirical data	Hasch (2002)
Sawmill input data		
• Round wood • Colors • Saw blades, stellites, steel strips • Sum oil (transmission fluid, hydraulic oil, motor oil, lubricating oil) • Sum fats	- Generic and derived data or - Specific and empirical data	Hasch (2002)
Particleboard mill input data		
• Pulpwood • Wood by- products	- Specific and empirical data	Hasch (2002)

[10] Due to data privacy, company information are made anonymous.

Data for the application of the EF and MIPS	Type of data	Data source
• Recycled wood • Lamination agent • Formaldehyde- catcher substances (technical urea) • Hardener (ammonium nitrate) • Hydrophobizing substances (paraffin) • Sum marker color • Sum oils (thermo / heat transfer oil, hydraulic oil, motor oil, transmission oil, anti-corrosion oil) • Sum fats • Sum lubricants • Tools for wood cutter • Steel strips • Compression mats		
Energy input for the modules 'sawmill' and 'particleboard mill':		
• Electricity use • Direct fuel use • Heat from renewable sources • Heat from fossil sources	- Specific and empirical data or - Generic and derived data	Energy scenarios with data from: Hasch (2002) and EFORWOOD database (EFORWOOD, 2009) complemented by own calculation of the energy use for wood drying with the help of personal communication from Buksnowitz (2009)
EF direct area calculations		
• Forest area	- Generic and derived data	Derived from the forest definition of the EFORWOOD SIA calculation
• Built area of sawmill • Built area of particleboard mill	- Specific and empirical data	Personal communication by an Austrian sawmill and Austrian particle-board mill
CO_2 values for the EF calculation of the inputs for 'forest', 'sawmill' and 'particleboard mill' listed above	- Generic and derived data	Umweltbundesamt (2007)
	- Generic and derived data or - Specific and empirical data	Umweltbundesamt (2008)

Data for the application of the EF and MIPS	Type of data	Data source
	- Generic and derived data	RETEC group (2003)
	- Generic and derived data	Bußwald et al. (2006)
MI factors for the MIPS calculation of the inputs for 'forest', 'sawmill' and 'particleboard mill' listed above	- Calculated from specific or empirical data	Wuppertal Institute for Climate, Environment and Energy (2003 and s.a.)
	- Calculated from specific or empirical data	Schmidt-Bleek (2000)
	- Generic and derived data	own calculation with information by Recknagel et al., 2009 and Neubarth & Kaltschmitt (2000)
	- Calculated from specific or empirical data	Hacker (2003)

EFORWOOD SIA: The EFORWOOD SIA is based on data from the EFORWOOD database (EFORWOOD, 2009) with the following exceptions:

- Data for the transport distance of the recycling wood are taken from Hasch (2002) as this process is not included in the database.
- For the first four EFORWOOD processes of the module 'forest' (see chapter 4.1) no values for the indicator 'energy use' were given. Therefore, the dataset was complemented with data from Schweinle (2000). The fossil energy input for 'plantation' by Schweinle (2000, p. 98) was assigned to the EFORWOOD process 'spruce regeneration'; the fossil energy input for the process 'tending' (SCHWEINLE, 2000, p. 100) was assigned to the EFORWOOD process 'development of young spruce'.
- The scenario calculations of the indicator 'energy use' are based on data from different sources (see chapter 5.5), namely the EFORWOOD database (EFORWOOD database, 2009) and Hasch (2002). These were complemented with an own calculation of the energy use for the drying of the sawn wood as this process is not included in the value of Hasch (2002).
- Data for the indicator 'water use' for the processes 'softwood sawmill' and 'particleboard mill' are adopted from Hasch (2002). The EFORWOOD data were evaluated as implausibly high compared to the empirical sources, such as the value given by the company Stora Enso in the environmental statement for one of their sawmills (STORA ENSO TIMBER BRAND, 2005, p. 12).

- Data values for the indicator ‘production cost’ and ‘gross value added (at factor cost)’ concerning the processes ‘harvesting motormanual’, ‘skidding’, ‘harvesting fully mechanized’, ‘forwarding with forwarder’ are adapted to Austrian prices and costs with information of ÖSTAT (ÖSTAT, 2009a; ÖSTAT 2009b) and BMLFUW (2008).

In Tab. 5 a summary of the data sources and type of data for the EFORWOOD SIA indicator values is given. A description of the indicators is given in chapter 4.4.

Tab. 5. Data sources and type of data for the EFORWOOD SIA.

Indicator values for the applicaton of the EFORWOOD SIA		**Type of data**	**Data source**
• Gross value added (at factor cost) • Production cost • Energy use • Water use • Employment • Occupational accidents • Wages and salaries • Greenhouse gas emissions		- Specific and empirical data, - Generic and derived data or - Model-based and estimated	EFORWOOD database (EFORWOOD, 2009)
• Transport distances and freight	Transport way o 1: Transport of the round wood from the forest to the sawmill o 2: Transport of the pulpwood from the forest to the particleboard mill o 3: Transport of the wood by-products from the sawmill to the particleboard mill	- Generic and derived data or - Model-based and estimated	EFORWOOD database (EFORWOOD, 2009)
	o 4: Transport of the recycled wood to the particleboard mill	- Specific and empirical data	Hasch (2002)
• Water use for the processes ‘softwood sawmill’ and ‘particleboard mill’		- Specific and empirical data	Hasch (2002)
• Energy use for the processes spruce		- Generic and	Schweinle (2000)

Indicator values for the applicaton of the EFORWOOD SIA		**Type of data**	**Data source**
regeneration and 'development of young spruce'		derived data	
• Energy use for the processes 'softwood sawmill' and 'particleboard mill'		- Specific and empirical data or - Generic and derived data	Energy scenarios with data from: Hasch (2002) and EFORWOOD database (EFORWOOD, 2009) complemented by own calculation of the energy use for wood drying with the help of personal communication from Buksnowitz (2009)
Prices for round wood and pulpwood at the forest road for derivation of indicator value for • Gross value added (at factor cost) for the processes 'harvesting motormanual', 'harvesting fully mechanized', 'skidding' and 'forwarding' • Production cost for the processes 'harvesting motormanual', 'harvesting fully mechanized', 'skidding' and 'forwarding'		- Generic and derived data	ÖSTAT (2009a and 2009b)
		- Generic and derived data	BMLFUW (2008)

4.3.2 Transferability of data

The main data sources were from Germany (SCHWEINLE, 2000; HASCH, 2002; UMWELTBUNDESAMT, 2008; WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, 2003) and the EFORWOOD database with data from the Baden-Württemberg case study. If available, the data were complemented with data from Austria, e.g., for the MIPS method the MI value for electricity is based on the Austrian mix of sources for electricity; and the CO_2 value for 'heating oil heavy' to generate the energy input 'heat from fossil sources' is specified for Austria. If no CO_2 values were found for Austria or Germany in the database ProBas (UMWELTBUNDESAMT, 2008), the value for Europe or Switzerland was chosen instead. To validate the German data of Hasch (2002) for Austria, an Austrian sawmill operator and three Austrian particleboard producers were asked to evaluate the plausibility of the data.

4.3.3 Consistency among data sources

To conduct a consistency check among the different data sources is much more difficult than to consider the aspects described above. For example, the relevant processes in the sawmill and particleboard mill, are not further described, neither in the EFORWOOD database (EFORWOOD, 2009) nor in the work done by Hasch (2002). Therefore, only main processes are considered in the two sources and then shown in the process chains.
To avoid inconsistencies among different data sources it was attempted to rely on the same data sources for all inputs, e.g., regarding the CO_2 values or MI factors as far as possible. Regarding the modules 'sawmill' and 'particleboard mill' inconsistency in the data were avoided by adapting the inventory that was given for the particleboard mill to the data availability for the sawmill and by applying the defined system boundaries and cut-off criteria (see chapter 4.2).

4.3.4 Uncertainty range

The different data sources encompass different degrees of representativity and plausibility. The main data sources can be characterized as following:

- The data used by Schweinle (2000) are generic data from Germany and were reviewed for plausibility as stated by Schweinle (2000, p. 30). However, there is no information on how representative the data are.
- The data taken from Hasch (2002) comprise data on material flows for the sawmill and the particleboard mill. The generic sawmill data were reviewed for plausibility with

interviews (p. 111). The data on the particleboard mill were collected from seven particleboard mills in Germany with a production capacity of 1.762 Mio m^3 particleboards that represent 20% of the German PB production. Plausibility checks by experts of the Austrian sawmill and particleboard industry could show that the data are transferable to Austria.

- Regarding the data of the EFORWOOD database (EFORWOOD, 2009), completeness of the data and individual values are checked (LINDNER et al., 2007, p. 40). For indicator values for which the plausibility seemed to be uncertain, different scenarios were calculated as for the indicator 'energy use' or the data were taken from a different source (see chapter 4.3.1). For the indicator 'water use' the data from Hasch (2002) were taken because the EFORWOOD data did not seem to be plausible compared to other empirical data (STORA ENSO TIMBER BRAND, 2005, p. 12). The indicator was kept, however, for the analysis of the overlapping indicators in the frame of the comparison of the three methods. The representativity of the values in the EFORWOOD database varies from 'low' to 'high'.

4.4 Indicators

According to LINSTER (2003, p. 5) an indicator is *'…a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value'.* Indicators for a sustainability assessment therefore give a summary on conditions, preferably concerning the different dimensions of sustainability. Used over longer time periods indicators are able to show trends.

EF and MIPS: The results of the two methods EF and MIPS represent aggregated indicators (GILJUM et al., 2007, p. 44; SMEETS & WETERINGS, 1999, p. 13). The EF expresses the 'area use' of an entity as an indicator for the 'area demand', which then can be compared to the available land based on the carrying capacity of the Earth. It also comprehends the indicator CO_2 footprint.

MIPS is an aggregated efficiency indicator (SMEETS & WETERINGS, 1999, p. 13). It assesses the amount of resource input needed for a product and is categorized in the categories 'abiotic', 'biotic', 'water', 'air' and 'earth moved'. The five resource input categories represent the indicators aggregated on a service unit level. However, they cannot further be aggregated to one indicator value. From the input category water also the indicator 'water *rucksack*' of a product can be calculated.

EFORWOOD SIA: In contrast to the two prior methods, the EFORWOOD SIA is based on an indicator set which comprises the three dimensions of sustainability (ecological/environmental, economic and social) that are relevant for the forestry-wood chain.

This indicator set can then be applied to different chains. For this thesis, a selection of nine indicators was made. This selection was made due to incompleteness of the Baden-Württemberg case study dataset in the EFORWOO database at the moment of starting the calculations. The nine chosen indicators are following described: Their definition and system boundaries are described in the EFORWOOD 'Manual for data collection for Regional and European cases' (BERG, 2008).

(1) **Gross value added (GVA) (at factor cost) [€]:** This indicator is defined in the following way:

GVA at factor cost = GVA at basic prices - taxes on production + subsidies on production.

The GVA at basic prices is calculatet by substracting the intermediate consumption at purchaser's prices from the basic price of the output.

Whereby:

Intermediate consumption: e.g., tree seedling material, energy, maintenance of buildings etc.

Purchaser's price: price actually paid by the purchaser of the intermediate consumption

Output: e.g., timber and firewood

Basic price: price receivable by the producers from the purchaser for a unit of a good or service produced as output minus any tax payable on that unit as a consequence of its production or sale (i.e. taxes on products) plus any subsidy receivable on that unit as a consequence of its production or sale (i.e. subsidies on products). Transport charges invoiced separately by the producer are excluded.

System boundaries: Only those prices of inputs and outputs which are used to produce the specified outputs of a given process are included.

In Fig. 6 the general procedure for the calculation of the GVA is summarized.

Output at basic prices	(1)
- Intermediate consumption at purchasers' prices	(2)
= GVA at basic prices	(3) = (1) – (2)
- Other taxes on production	(4)
+ Other subsidies on production	(5)
= GVA at factor cost	(6) = (3) – (4) + (5)

Fig. 6. General procedure for the calculation of the indicator 'gross value added (at factor cost)' (BERG, 2008, p. 13).

(2) **Production cost [€]:** This indicator expresses the average production cost per process. It should be expressed without value added tax (VAT) and other indirect taxes, and all the costs should be reported in nominal values. The transport cost is allocated among different cost categories.

System boundaries:

- Only the most important non-timber food products and marketed services (e.g. recreation) should be included.
- Insurance costs should be included.
- Non-operating costs, such as administration costs, leasing rental fees, land rent, etc. are included.
- The costs associated with the services and processes which are indirectly related to a product, e.g., administration of companies, should also be included.

(3) **Energy use total [kWh]:** This indicator includes the subcategories 'heat from renewable and fossil sources', 'direct fuel use' (renewable and fossil fuel) and 'electricity use' (from renewable sources, fossil sources and the grid).

System boundaries: All the energy which is used in the processes is included; also the supply chains of the energy to the forestry wood chain are included. The latter was, however, not yet included in the EFORWOOD data values used in this application.

'Energy use' also enters the calculations of the EF and MIPS. In the methods EF and MIPS the supply chains of the energy to the forestry wood chains are considered by means of the indirect area use due to CO_2 emissions (‘energy footprint’) regarding the EF and by means of the MI factors regarding MIPS.

(4) **Water use [m^3]:** This indicator expresses the freshwater intake by the industry.
System boundaries: Data on the water use that are related to energy generation in the industry are included, whereas the water use related to the energy supply chains, the water use for the production of machinery and the auxiliary material is not. However, the data given in the EFORWOOD database for this indicator seemed implausibly high and were hence substituted by referring to the data from Hasch (2002). This concerns the modules ‘sawmill’ and ‘particleboard mill’.

‘Water use’ is also considered in the calculation of MIPS.

(5) **Distance by mode - road transport - loaded [km]:** This indicator expresses the transport distances covered during the processes. With this information and the defined material flows in the process chains, the intensity of the transportation in terms of ton kilometers (tkm) can be expressed.
System boundaries:

- Only the transport of the freight is included in this indicator.
- The transport of workers to and from the respective working places is excluded.
- In the dataset of Baden-Württemberg, a regional defined case study, the political border of the region is also seen as the border for the consideration of the distance kilometers.

The intensity of transportation in terms of ton kilometers (tkm) is also needed for the calculation of the EF and MIPS.

(6) **Employment [absolute numbers]:** This indicator is defined as the total number of employed persons, expressed in person years (py). In these calculations, the values were converted to h/m^3.

(7) **Occupational accidents [absolute numbers]:** This indicator gives the absolute number of accidents per 1000 employees per reporting unit.
System boundaries: The administrative work and management staff work are allocated to the processes.

(8) **Wages and salaries [€]:** This indicator expresses the wages and salaries as gross earnings before any tax or contributions to social security by the worker and the employer are subtracted. The intention is to collect the data on the total amount of money that is spent on salaries and wages. As a social indicator, it is better the higher its value is. However, it does not necessary be equal to the labor costs.

(9) **<u>Greenhouse gas emissions [kg CO_2 equivalents]:</u>** This indicator aggregates the greenhouse gas emissions like CO_2, methane and nitrous oxide from the machinery during the production process as well as the greenhouse gas emissions from the wood combustion along the chains. It covers both biotic and fossil CO_2. The internally sequestered carbon in the chain is subtracted. The account for biotic CO_2 is balanced at the end of the life of a wood product.
System boundaries: The indicator does not consider the transport of workers or the machinery to the production process.

One greenhouse gas (CO_2) enters the calculation of the EF. By means of CO_2 emissions and a CO_2 absorption factor the 'energy footprint' is calculated.

Two of the indicators (1 and 2) represent the economic dimension, four (indicators 3, 4, 5 and 9) are indicators for the environmental dimension and three indicators (6, 7, 8) represent the social dimension. The aim was to apply as many indicators of the EFORWOOD indicators as possible with the available data.

The unbalanced in the representation of the three dimensions (economic, environmental, social) with the choice of these indicators is not intended but can be considered in a Cost Benefit or Multi-Criteria Analysis by only admitting trade-offs between the indicators but not within the three overall dimensions of sustainability.

5 Case study

In this chapter, assumptions behind the calculations and specific aspects in the application of the three methods, presented in chapter 3, are described. This enables a better traceability and understanding of the application procedures in this specific case study.

5.1 General assumptions

The calculations of the methods comprise common assumptions for all three methods, method specific assumptions and specific aspects concerning the application of the methods on the case study.

In this context, all three methods have in common that they are based on the two process chains and system boundaries (see chapter 4.2), which define the frame of considered input elements and processes. Further common assumptions are:

- The two wood products are joint.
- The analysis is product-based and hence, the result is calculated for 1 m^3 SW and 1 m^3 PB; in a further step the results are expressed for a SW plank and a PB plank (see chapter 4.1). This output-based view implicates that the initial round wood input differs for the two products.
- The ecological *rucksack* for the wood by-products was allocated according to the wood mass flow percentage which is used for their production. This means that the wood by-products entering the sawmill carry their *rucksack* from the forest and the sawmill. This decision was made as wood-by products are a precious resource, demanded by the particleboard industry, the paper industry and for the energy generation from woody biomass. On the other hand, wood by-products could also be considered as a waste product of the sawn timber production. To find out if this change in assumption on wood by-products has an impact on the results, a scenario was calculated for all three methods based on the definition of wood by-products as waste (see chapter 5.5).

In addition to these general assumptions, valid for all three methods, specific aspects for the application of each of the methods apply.

5.2 Ecological Footprint

The specific aspects in the application of the method EF are the following:

- As expressed in equation 1 (chapter 3.1.2) the EF is composed of the direct and indirect area use of a product. The direct area considered in this case study is the area needed to produce the output product e.g. forest area and built-up area of the sawmill for the production of $1m^3$ solid wood. The direct area use of the product inputs (preliminary products, auxiliary and operating materials) could not yet be considered in this case study due to lack of data.
- The indirect area use is expressed in forest area which is necessary to absorb the CO_2 emissions arising from the use of fossil energy in the direct production process or the production of the preliminary products, auxiliary and operating materials. This is one of the options described in chapter 3.1.2 used also by the Global Footprint Network (EWING et al., 2008, p. 13) to calculate the energy land or 'energy footprint'. The amount of CO_2 release in tons of either the energy input or the preliminary product, auxiliary or operating material, is divided by a CO_2 absorption factor and multiplied by the equivalence factor of the area type 'forest', which is assumed to be 1.35 as in the application described by SERI (HINTERBERGER et al., 2008, p. 18). The absorption factor assumed is 4.983 t/ha/yr (UMWELTBUNDESAMT, 2007).
- The EF expressed in global hectares is thus the sum of the direct area use of the output product in the different modules plus the potential area needed for the CO_2 uptake.

Hence, the calculation of the EF looks the following (Tab. 6).

Tab. 6. Calculation procedure of the EF.

Inputs module sawmill		Direct area use [ha/m³ SW]	Input amount	Unit [/m³ SW]	t CO_2 [/m³ SW]	CO_2 absorption factor	Equivalence factor	Result area use [gha/m³ SW]
Direct area use	Built area	0,00003	/	/	/	/	2,2	0,00007
Absorption area energy input	Fuels	/	73,5	kWh	0,02	4,98324	1,35	0,005
	…							
Absorption area preliminary, auxiliary and operating materials	Sum oils	/	0,09	kg	0,00001	4,98324	1,35	0,000003
	…							
Sum								0,005

The assumptions and calculation procedure corresponds to the application of the method by SERI[11].

5.3 MIPS

The specific aspects in the application of the method MIPS are the following:

- The service unit which has been chosen in this application of MIPS and which is applied also for the two other methods is a ‘plank of a dimension of 100 x 20 cm and a bearing capacity of 25 kg’. This service can be provided by a SW plank as well as by a PB of a certain thickness (see chapter 4.1).
- Due to the fact that in this application only the production process is analyzed, the number of usages and the number of consumers of the plank (see equation 6) is not relevant.
- MIPS is calculated in accordance with the general description of the method in chapter 3 by multiplying the amount of input (kg, kWh or tkm) by the MI factor for the categories ‘abiotic’, ‘biotic’, ‘water’ and ‘air’. As the category ‘earth moved’ is not relevant for the analyzed inputs, this category is not presented in the results.

As example, the calculation for the material input category ‘abiotic’ is shown (Tab. 7). The results express the abiotic material input of fuels and oil in the sawmill. The same procedure is applied for the other input categories (‘biotic’, ‘water’ and ‘air’) and the results of each category along the chain are summed up.

Tab. 7. Calculation procedure of MIPS for the input category ‘abiotic’.

Inputs module sawmill	Input amount	Unit	MI factor abiotic	Unit	Results	Unit
Fuels	73,5	kWh	1,36	kg/kWh	99,96	kg
Sum oil	0,09	kg	1,22	kg/kg	0,11	kg
Sum					100,07	kg

The assumptions and calculation procedure corresponds to the application of the method by SERI.

5.4 EFORWOOD SIA

The specific aspects in the application of the EFORWOOD SIA are the following:

[11] Sustainable Europe Research Institute, Vienna; webpage: www.seri.at

- Only the concept, method and the database of the EFORWOOD project were applied in this thesis but not the software ToSIA.
- If available and plausible, the indicator values are taken from the case study Baden-Württemberg in the EFORWOOD database (EFORWOOD, 2009). Exceptions are listed in chapter 4.3.1 and are summarized in Tab. 5.
- In the current example a material flow of 1000 m^3 of round wood under bark (ub) is defined to enter each of the two defined process chains. It is broken down to 1 m^3 of each product and plank respectively at the end of the process chain.

  The assumption behind this system definition is that the PB production is heavily bound to the sawmill industry. For a better comparability of the two chains the same material flow entering the chain has to be assumed. The 1000 m^3 fresh round wood for both of the chains are assumed to be from the same forest, which is an age-class Norway spruce (Picea abies) forest with a rotation period of 100 years and a mean annual increment of 10 m^3 /ha/year.

- For the SW, the 1000 m^3 round wood ub entirely enter the sawmill. The flows are then split according to the physical mass flows defined in the process chain (see chapter 4.1). 62.5% of the 1000 m^3 become sawn timber.

- For the PB production the 1000 m^3 input to the chain are split among round wood input and pulpwood input according to the mass flows defined in the process chain to get 1 m^3 PB at the end of the chain (see chapter 4.1). The defined mass flows corresopond to 970 m^3 round wood and 30 m^3 pulpwood. 14% of the 970 m^3 entering the sawmill continue into the particleboard mill as wood by-products. In addition, 30 m^3 of recycled wood enter the PB chain at the particleboard mill.

- The material flow along the process chain is expressed in round wood or fractions of it. For the multiplication of the indicator values with the material flow, conversion factors are necessary: The indicator values per process have to be converted and expressed per m^3 of round wood ub as the material flow is expressed. The assumptions on raw densities and conversion factors are listed in Annex 1.

- As described in the method description (3.3.2) the relative indicator value is multiplied by the material flow to receive an absolute sustainability indicator value for a process. The results per process are then aggregated to an indicator result over the whole chain and broken down to 1 m^3 by dividing them by the amount of m^3 which can be made out of the material flow amount of 1000 m^3 round wood ub entering the process chain.

The calculation thus, looks the following. It is shown for the indicators ‘production cost’ and ‘energy use’ regarding the process ‘softwood sawmill’ (Tab.8):

Tab. 8. Calculation procedure of the EFORWOOD SIA.

Indica-tors	Process softwood sawmill				Aggregated indicator result [/material flow]	Aggregated indicator result [/m³ SW]
	Indicator value [/m³ RW ub]	Material flow [m³ RW ub]	Fraction of end-product	Result		
Produc-tion cost	81[€]	1000 [m³ RW ub]	0,625	50625 [€]	∑process results [€]	∑process results/ 625 [€]
Energy use	1080 [kWh]	1000 [m³ RW ub]	0,625	675000 [kWh]	∑process results [kWh]	∑process results/ 625 [kWh]
…						

5.5 Scenario definitions

Scenario calculations complement the calculations and concern all three methods. The following scenarios were calculated:

I. **Energy scenarios:** The data variability among the data sources concerning the energy input for the modules ‘sawmill’ and ‘particleboard mill’ is very high. It ranges within a factor of 8 in the sawmill (653 kWh/m³ SW - 5456 kWh/m³ SW) and a factor of 6 in the particleboard mill (1049 kWh/m³ PB - 6306 kWh/m³ PB). Additionally, the energy use was identified as the most decisive factor for all three results. Therefore, three energy scenarios were calculated and applied to each of the three methods. The data source with the lowest energy input values for the sawmill and particleboard mill is from Hasch (2002); the highest values for the energy inputs are found in the EFORWOOD database. These two sources were taken as data base for the three energy scenarios.

   - Energy scenario 1 was calculated with the ‘total energy input’ value of Hasch (2002, p. 112 and p. 118).
   - Energy scenario 3 was calculated with the ‘total energy input’ value taken from the EFORWOOD database.
   - Energy scenario 2 finally, was calculated with the average value between the two values of energy scenario 1 and 3.

   ‘Energy scenario 1’ therefore, describes a very energy efficient sawmill or particleboard mill. On the other hand ‘energy scenario 3’ stands for a very energy inefficient one. In the PB production where both the modules ‘sawmill’ and ‘particleboard mill’ are included, an overall result for ‘energy scenario 1’ means that ‘energy scenario 1’ is assumed for both of the modules ‘sawmill’ and ‘particleboard mill’.

For the methods EF and MIPS the different energy inputs have to be differentiated due to different CO_2 values and MI factors with regard to the specific energy inputs, such as 'heat from renewable sources' and 'heat from fossil sources'. Therefore, the fractions of the different energy inputs of the total energy input had to be defined. Since the EFORWOOD database was intended to be the main data base if values are available and plausible, the fractions of the different energy uses on the total energy input are based on the fractions according to EFORWOOD.

Since only the EFORWOOD database made a distinction between 'direct fuel use from fossil sources' and 'direct fuel use from renewable sources' as well as a distinction of the electricity sources, this distinction could not be considered. The fuel use in the energy scenarios was considered as ‚fossil fuel' as only 0.02% of the direct fuel use of the EFORWOOD data came from renewable fuels and only regarding the process 'particleboard mill'. Regarding the use of electricity, the total sum of used electricity of the EFORWOOD database was taken for the calculation and no distinction made between the sources of electricity. For the calculations of EF and MIPS, Austrian values for the CO_2 and MI factors were applied which represent the Austrian electricity mix.

II. **Scenario 'Wood by-products as waste (WB = 0)':** As mentioned above, the wood by-products, which are generated as the round wood is cut to sawn timber, are defined as valuable resources and not as waste. This is the assumption underlying the basic calculations. To analyze the difference of considering these wood by-products as waste products of the sawmill industry, a scenario was calculated for all three methods: In the scenario, the resource inputs for producing the wood by-products are fully allocated to the main product SW; in MIPS' words no ecological *rucksack* was assumed for the wood by-products in the modules 'forest', 'sawmill' and for the transport way 'transport of the round wood to the sawmill'. The transport of the wood by-products to the particleboard mill and the processes in the particleboard mill, however, are assigned to the wood by-products. Tab. 9 summarizes the two scenarios.

Tab. 9. Summary of the scenarios 'energy' and 'wood by-products as waste': reason for its calculation and description.

Scenarios		Reason	Description
Energy scenarios (for the modules 'sawmill' and 'particleboard mill')	Energy scenario 1	High level of data variations of available data sources	Calculation with different energy input values (see scenario description in 5.5)
	Energy scenario 2		
	Energy scenario 3		
Scenario 'Wood by-products as waste (scenario WB = 0)'		Testing of the assumption: Wood by-products are considered as waste and not as valuable products in comparison to the sawn timber	Resource inputs are fully allocated to the main product.

6 Results

In this chapter the results of the case study for all three methods and the results of the evaluation of the methods by means of the criteria catalogue are presented.

6.1 Case study

The application of the three assessment methods was accomplished on the defined case study based on the process chains and system boundaries described in chapter 4 and the assumptions given in chabpter 5.

Firstly, the results of every method under the basic assumptions including the different energy scenarios are described and shown. In a next step the results are shown assuming the wood by-products as waste, which is expressed in ‘scenario WB = 0’ (see chapter 5.5). In this scenario the resource inputs to produce the wood by-products and the processes regarding the module ‘forest’, ‘sawmill’ and for the transport way ‘transport of the round wood to the sawmill’ are fully allocated to the SW. Under the ‘scenario WB = 0’, in MIPS’ words no ecological *rucksack* is assumed for the wood by-products. The calculations of the ‘scenario WB = 0’ include as well the three energy scenarios.

Regarding the representation of the results the following should be noticed:

- The results are expressed per service unit ‘plank’ as defined in chapter 4.1.
- The outmatching values in the comparison of the two products are highlighted. A highlighted result signifies that the product outperforms in the specific module or input category in comparison to the other product. Regarding the methods EF and MIPS lower values outreach higher values. Regarding the EFORWOOD SIA, however, for some indicators (gross value added (at factor cost), employment, wages and salaries) higher values outperform lower values. Concerning the EFORWOOD indicators ‘production cost’, ‘energy use’, ‘water use’, ‘greenhouse gas emissions’, ‘transport’ and ‘occupational accidents’, low values outperform high values.
- For a comparison of the results among the MIPS input categories, among the modules and among the overall results of the methods the ratios between the results of the two products are shown. ‘Ratio’ is defined as the ratio between the higher and the lower result when comparing the two products. In the case of the EFORWOOD indicator ‘gross value added (at factor cost)’ it can be negative. As the ratio value was calculated with the original values containing more decimal places as the ones shown, it may slightly deviate if calculating it from the shown values.

- The overall results expressed per m^3 (/m^3) which sometimes may vary in comparison to the results expressed per plank (/plank), are given in Annex 4 to make the comparison of the results to other studies easier possible. Their table number labeled with 'A' corresponds to the equivalent table number expressed per plank in this chapter.

In chapter 6.1.4 the results of the different methods regarding the basic assumption as well as for 'scenario WB = 0' are compared.

6.1.1 Ecological Footprint

The results of the assessment method EF show the following (Tab. 10 and Fig. 7): In total, over the whole chain, the SW plank receives a better result than the PB plank if the 'energy scenario 1' for the SW plank is compared to the 'energy scenario 1' for the PB plank. The same result is valid for the comparison of the 'energy scenario 2' and 'energy scenario 3' of the SW plank to the 'energy scenario 2 and 3' for the PB plank respectively. However, this result is not valid if the different energy scenarios are combined. In detail, the better overall result for the SW plank is due to better results for the SW in the modules 'forest' and 'transport'. The PB plank, on the other hand outperforms the SW in the module 'sawmill'.

The highest difference between the results of the two products emerges with regard to the module 'transport', in which the ratio is 18.3 (Tab.10). The higher value for the product PB plank compared to the result of the SW plank is due to a higher amount of transport kilometers and thus CO_2 emissions. For the module 'sawmill' the ratios are 2.3. The ratio concerning the module 'forest' is 3.1. Overall, the ratios of the two product chains as a whole are between 4.6 and 7.2 depending on the specific energy scenario.

The overall result as well as the result of the module 'sawmill' change if the energy efficiencies (see description of the energy scenarios in 5.5) are changed: If the 'energy scenario 1' is assumed in the overall result to stand for the PB plank in comparison to the 'energy scenario 3' for the SW plank, the PB plank outperforms the SW plank.

For the overall result this signifies that if a bad performance ('energy scenario 3') concerning energy efficiency is assumed for the production of the SW plank in the module 'sawmill' compared to the production of a PB plank produced very energy efficiently ('energy scenario 1') in the modules 'sawmill' and 'particleboard mill', the PB plank would be evaluated as being more sustainable. Regarding the module 'sawmill' as well the result changes if the different energy scenarios are combined: If a medium ('energy scenario 2') or bad performance ('energy scenario 3') is assumed for the PB plank compared to a SW plank produced very energy effiiciently ('energy scenario 1') in the module 'sawmill' the SW outperforms the PB in that module.

In Tab. 10 the numerical results expressed in global hectares (gha) for the SW plank and for the PB plank subdivided into the four modules 'forest', 'transport', 'sawmill' and 'particleboard mill' are presented including the ratios between the results of the two products.

Tab. 10. The Ecological Footprint (EF) results for the products solid wood (SW) and particleboard (PB) whereby the results higlighted represent the outperforming results.

Modules \ Products	EF SW [gha/plank]	EF PB [gha/plank]	Ratio between the higher and the lower result
Forest	0,000004	0,000011	**3,1**
Transport	0,000001	0,000021	**18,3**
Sawmill			
Energy scenario 1	0,000040	0,000018	**2,3**
Energy scenario 2	0,000184	0,000080	**2,3**
Energy scenario 3	0,000329	0,000142	**2,3**
Particleboard mill			
Energy scenario 1	/	0,000269	**/**
Energy scenario 2	/	0,000823	**/**
Energy scenario 3	/	0,001376	**/**
Overall result			
Energy scenario 1	0,000044	0,000319	**7,2**
Energy scenario 2	0,000189	0,000934	**4,9**
Energy scenario 3	0,000333	0,001550	**4,6**

In Fig. 7, the overall results of the method EF are presented graphically. The results depend on the energy scenarios 1, 2 and 3 for the modules 'sawmill' and 'particleboard mill'.

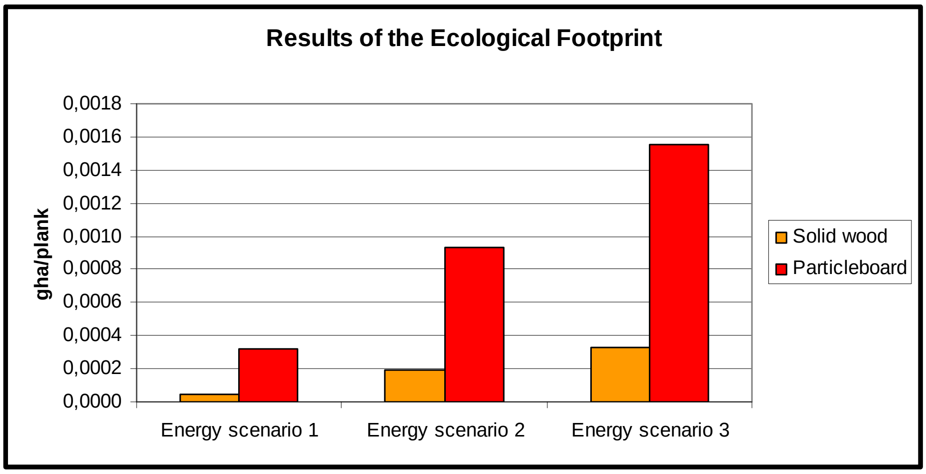

Fig. 7. Results gained by applying the method EF.

<u>Results of the 'scenario WB = 0':</u>

The resource inputs to produce the wood by-products and the processes regarding the module 'forest', 'sawmill' and for the transport way 'transport of the round wood to the sawmill' are in this scenario fully allocated to the SW. Assuming a same energy efficiency for the production of the two products in the modules 'sawmill' and 'particleboard mill', the overall results do not change in comparison to the results under the basic assumptions (Tab. 11). This is also valid for the module 'transport'. Regarding the module 'forest', however, the PB plank achieves a better result than the SW plank. The module 'sawmill' is not considered for the PB production under this scenario, thus, all values are 0 and the PB plank outperforms the SW plank in this module.

Hence, for the EF the 'scenario WB = 0' does not have any impacts on the overall result assuming the same level of energy efficiency but it does have an impact on the result for the module 'forest'. The ratios under this scenario vary between 2.5 regarding the module 'forest' and 7.3 regarding the module 'transport'.

The comparison of the results for the SW plank and PB plank under the 'scenario WB = 0' is given in Tab.11.

Tab. 11. The Ecological Footprint (EF) results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0' whereby the results higlighted represent the outperforming results.

Products / Modules	EF SW scenario WB = 0 [gha/plank]	EF PB scenario WB = 0 [gha/plank]	Ratio between the higher and the lower result
Forest	0,000006	0,000002	**2,5**
Transport	0,000001	0,000008	**7,3**
Sawmill			
Energy scenario 1	0,000063	0,000000	**/**
Energy scenario 2	0,000295	0,000000	**/**
Energy scenario 3	0,000526	0,000000	**/**
Particleboard mill			
Energy scenario 1	/	0,000269	**/**
Energy scenario 2	/	0,000823	**/**
Energy scenario 3	/	0,001376	**/**
Overall result			
Energy scenario 1	0,000070	0,000280	**4,0**
Energy scenario 2	0,000301	0,000833	**2,8**
Energy scenario 3	0,000533	0,001387	**2,6**

6.1.2 MIPS

The overall result of the sustainability assessment method MIPS shows, like the EF, that the production of the SW plank is more sustainable than the one of the PB plank if comparing the results at the same level of energy efficiency. As for the EF, combinations concerning the energy scenarios can, however, change the result (Tab. 12). The overall result of MIPS can change for the input category ‘air’ if a good performance (‘energy scenario 1’) is assumed for the modules ‘sawmill’ and ‘particleboard mill’ in the process chain of the PB plank and a bad performance (‘energy scenario 3’) is assumed for the production of the SW plank in the module ‘sawmill’ (Tab. 12). The ratios of the process chain as a whole considering the three energy scenarios vary between 2.7 and 36.7 (Tab. 12): The highest ratio concerns the input category ‘water’.

Tab. 12. The overall MIPS results for the products solid wood (SW) and particleboard (PB) whereby the results higlighted represent the outperforming results.

Products / Overall results	MIPS SW [kg/plank]	MIPS PB [kg/plank]	Ratio between the higher and the lower result
Energy scenario 1			
abiotic	0,191	2,266	**11,9**
biotic	0,883	2,415	**2,7**
water	1,678	23,075	**13,8**
air	0,360	2,059	**5,7**
Energy scenario 2			
abiotic	0,718	6,400	**8,9**
biotic	0,883	2,415	**2,7**
water	1,678	61,554	**36,7**
air	1,659	6,592	**4,0**
Energy scenario 3			
abiotic	1,246	10,533	**8,5**
biotic	0,883	2,415	**2,7**
water	7,951	100,032	**12,6**
air	2,957	11,125	**3,8**

In Fig. 8 the overall results of the method MIPS as described above, are presented graphically and for each input category and energy scenario.

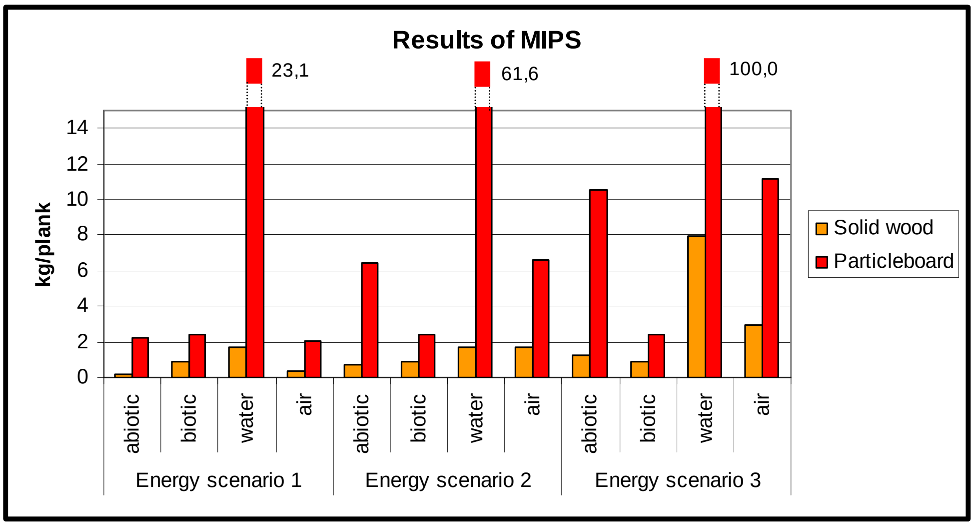

Fig. 8. Results gained by applying the method MIPS.

With regard to the results per module it can be stated following: The SW plank outperforms the PB plank with ratios between 2.7 and 18.3 in both the modules ‘forest’ and ‘transport’ (Tab. 13 and Tab. 14) concerning all input categories, except for the input category ‘biotic’ in the module ‘transport’. For the input category ‘biotic’ in the module ‘transport’ the value is 0 for both products. In the module ‘sawmill’ (Tab. 15) the PB plank outreaches the SW plank regarding the input category ‘air’ for all three energy scenarios (1,2,3). The ratios lie between 24.3 and 25 (Tab.15). This means that the input of air is much lower for the production of the PB plank than for the SW plank. On the other hand, the SW plank outperforms the PB plank in the module ‘sawmill’ regarding the categories ‘abiotic’, and ’water’. The value of the category ‘biotic’ is 0 for the two products as the wood input is already accounted for in the module ‘forest’ where it is produced.

If the ‘energy scenario 1’ or ‘energy scenario 2’ for the PB process chain is compared to ‘energy scenario 2’ or ‘energy scenario 3’ of the SW process chain (Tab.15) the result of the module ‘sawmill’ can switch to a better performance for the PB plank regarding the input categories ‘abiotic’ and ‘water’. In Tab. 13 to Tab. 16 the results per module and the ratios between the results of the SW plank and the PB plank are represented. Tab. 16 shows the results for the module ‘particleboard mill’ which is only relevant for the product PB plank. Therefore, no comparison and determination of ratios is possible.

Tab. 13. The MIPS results for the products solid wood (SW) and particleboard (PB) regarding the module ‘forest’ whereby the results higlighted represent the outperforming results.

Products / Module forest	MIPS SW [kg/plank]	MIPS PB [kg/plank]	Ratio between the higher and the lower result
abiotic	0,016	0,056	**3,5**
biotic	0,883	2,415	**2,7**
water	0,116	0,401	**3,5**
air	0,000	0,001	**3,5**

Tab. 14. The MIPS results for the products solid wood (SW) and particleboard (PB) regarding the module ‘transport’ whereby the results higlighted represent the outperforming results.

Products / Module transport	MIPS SW [kg/plank]	MIPS PB [kg/plank]	Ratio between the higher and the lower result
abiotic	0,028	0,516	**18,3**
biotic	0,000	0,000	**0,0**
water	0,203	3,719	**18,3**
air	0,007	0,121	**18,3**

Tab. 15. The MIPS results for the products solid wood (SW) and particleboard (PB) regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill	MIPS SW [kg/plank]	MIPS PB [kg/plank]	Ratio between the higher and the lower result
Energy scenario 1			
abiotic	0,146	0,302	**2,1**
biotic	0,000	0,000	**0,0**
water	1,360	2,950	**2,2**
air	0,353	0,015	**24,3**
Energy scenario 2			
abiotic	0,674	1,390	**2,1**
biotic	0,000	0,000	**0,0**
water	6,273	13,586	**2,2**
air	1,652	0,066	**24,9**
Energy scenario 3			
abiotic	1,202	2,479	**2,1**
biotic	0,000	0,000	**0,0**
water	11,186	24,222	**2,2**
air	2,951	0,118	**25,0**

Tab. 16. The MIPS results for the product particleboard (PB) regarding the module 'particleboard mill' whereby the results higlighted represent the outperforming results.

Products / Module particleboard mill	MIPS SW [kg/plank]	MIPS PB [kg/plank]	Ratio between the higher and the lower result
Energy scenario 1			
abiotic	/	1,392	**/**
biotic	/	0,000	**/**
water	/	16,005	**/**
air	/	1,922	**/**
Energy scenario 2			
abiotic	/	4,437	**/**
biotic	/	0,000	**/**
water	/	43,847	**/**
air	/	6,404	**/**
Energy scenario 3			
abiotic	/	7,483	**/**
biotic	/	0,000	**/**
water	/	71,690	**/**
air	/	10,886	**/**

Results of the 'scenario WB = 0':

By comparing the results under the 'scenario WB = 0' (Tab. 17,18,19 and 20) the following can be shown: Regarding the overall result and the result of the module 'forest' (Tab. 18) the result changes compared to the case in which no scenario is assumed. The PB plank achieves a better result for all input categories in the module 'forest' (Tab. 18) and in the overall result for the input category 'biotic' (Tab.17). The ratios of the overall results vary between 1.1 for the input category 'biotic' and 6.9 for the input category 'water' regarding the 'energy scenario 1'; the ratios for the module 'forest' vary between 1.6 and 5.8. Concerning the results of the module 'transport' (Tab. 19) no difference emerges in the result compared to the basic scenario (Tab.14). The SW plank outperforms the PB plank in the module 'transport' with a ratio of 7.3. The module 'sawmill' (Tab. 20) is not relevant for the product PB plank under the 'scenario WB = 0', therefore all its values are 0 and thus, outperform the SW plank.

Hence, the 'scenario WB = 0' has impacts on the final result of the method MIPS regarding the input category 'biotic' and regarding the module 'forest' for all input categories.

In Tab. 17 to Tab. 20 the comparison of the results for the SW plank and the PB plank under the 'scenario WB = 0' are given.

Tab. 17. The overall MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0' whereby the results higlighted represent the outperforming results.

Products / Overall results	MIPS SW scenario WB = 0 [kg/plank]	MIPS PB scenario WB = 0 [kg/plank]	Ratio between the higher and the lower result
Energy scenario 1			
abiotic	0,288	1,615	**5,6**
biotic	1,412	1,345	**1,1**
water	2,563	17,611	**6,9**
air	0,572	1,971	**3,4**
Energy scenario 2			
abiotic	1,132	4,660	**4,1**
biotic	1,412	1,345	**1,1**
water	10,424	45,453	**4,4**
air	2,650	6,453	**2,4**
Energy scenario 3			
abiotic	1,977	7,705	**3,9**
biotic	1,412	1,345	**1,1**
water	18,286	73,296	**4,0**
air	4,728	10,934	**2,3**

Tab. 18. The MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Products / Module forest	MIPS SW scenario WB = 0 [kg/plank]	MIPS PB scenario WB = 0 [kg/plank]	Ratio between the higher and the lower result
abiotic	0,026073	0,016352	**1,6**
biotic	1,412454	0,241581	**5,8**
water	0,184963	0,116472	**1,6**
air	0,000362	0,000228	**1,6**

Tab. 19. The MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Products / Module transport	MIPS SW scenario WB = 0 [kg/plank]	MIPS PB scenario WB = 0 [kg/plank]	Ratio between the higher and the lower result
abiotic	0,028	0,206	**7,3**
biotic	0,000	0,000	**0,0**
water	0,203	1,490	**7,3**
air	0,007	0,048	**7,3**

Tab. 20. The MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill	MIPS SW scenario WB = 0 [kg/plank]	MIPS PB scenario WB = 0 [kg/plank]	Ratio between the higher and the lower result
Energy scenario 1			
abiotic	0,234	0,000	**/**
biotic	0,000	0,000	**/**
water	2,175	0,000	**/**
air	0,565	0,000	**/**
Energy scenario 2			**/**
abiotic	1,078	0,000	**/**
biotic	0,000	0,000	**/**
water	10,037	0,000	**/**
air	2,643	0,000	**/**
Energy scenario 3			**/**
abiotic	1,923	0,000	**/**
biotic	0,000	0,000	**/**
water	17,898	0,000	**/**
air	4,721	0,000	**/**

6.1.3 EFORWOOD SIA

Concerning the majority of the indicators, EFORWOOD SIA concludes, likewise the other two assessment methods, that the SW plank is more sustainable than the PB plank. Nevertheless, an aggregation procedure, which is not part of this thesis, would be necessary to make a valid statement on the overall result of the indicator set. Regarding the overall result (Tab. 21) only three indicators evaluate the PB plank as being more sustainable. They are the indicators 'gross value added (at factor cost)' with a ratio of 2 'employment' with a ratio of 3.6 and 'wages and salaries' with a ratio of 5.4. The latter are social indicators and can be seen in the context of job provision through the particleboard mill and the upstream transport. The ratios concerning the result for the whole process chain vary between the values 2 and 2292.4 for the indicator 'water use'. Moreover, high differences occur also for the following indicators linked to transport:

- The indicator 'transport' shows a ratio of 18.3.
- The indicator 'greenhouse gas emissions' shows a ratio of 25.8.
- The ratios of the indicator 'energy use' vary between 9.6 ('energy scenario 3') and 12.1 ('energy scenario 1'). For the EFORWOOD SIA the energy scenarios only affect the indicator 'energy use'. In comparison to the two other methods, a combination of different energy scenarios does, however, not change the result.

Regarding the indicator 'occupational accidents', 4.7 times less accidents happen in the PB plank production compared to the SW plank production.

Tab.21 represents the overall results and their ratios for the indicators of the EFORWOOD SIA.

Tab. 21. The overall EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) whereby the results higlighted represent the outperforming results.

Products / Overall results Indicators		Indicator result SW	Unit [/plank SW]	Indicator result PB	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,094	€	0,185	€	2,0
Production cost		0,175	€	0,935	€	5,3
Energy use	Energy scenario 1	0,411	kWh	4,988	kWh	12,1
	Energy scenario 2	1,844	kWh	18,260	kWh	9,9
	Energy scenario 3	3,276	kWh	31,532	kWh	9,6
Water use		3,70E-07	m³	8,49E-04	m³	2292,4
Greenhouse gas emissions		0,095	kg CO_2 equiva-lents	2,456	kg CO_2 equiva-lents	25,8
Transport		0,029	tkm	0,525	tkm	18,3
Employment		0,003	h	0,012	h	3,6
Occupational accidents		1,40E-07	absolute number/ 1000 employ-ees	6,58E-07	absolute number/ 1000 employ-ees	4,7
Wages and salaries		0,019	€	0,101	€	5,4

In Fig. 9 and Fig. 10, the results of the SW plank and the PB plank are expressed for each indicator. The higher indicator value among the two product results is set to 1. Fig. 9 shows the results for those indicators for which higher values signify a better result. This applies for the indicators ‘gross value added (at factor cost)’, ‘employment’ and ‘wages and salaries’.

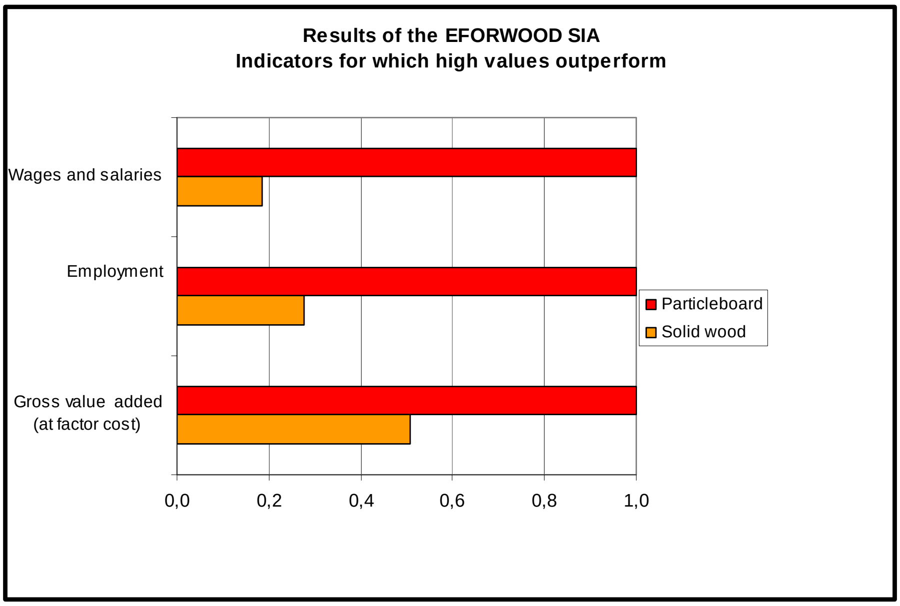

Fig. 9. Results gained by applying EFORWOOD SIA: Indicators for which high values outperform.

Fig. 10 shows the relation of the results for the SW plank to the PB plank on a scale from 0 to 1. In this figure, those indicators are shown, for which lower values compared to the second product signify a better result.

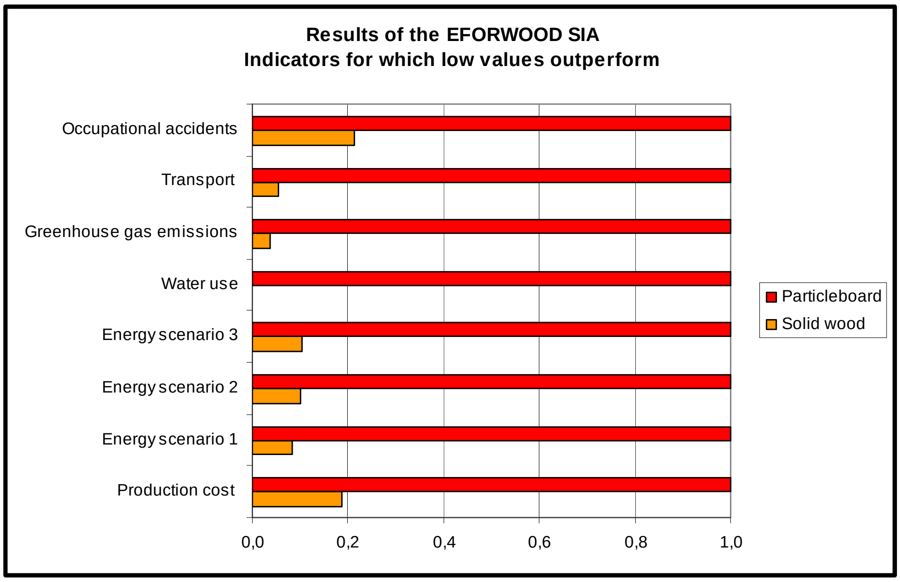

Fig. 10. Results gained by applying the EFORWOOD SIA: Indicators for which low values outperform.

Concerning the results per module, it can be stated that, except for the indicators ‘gross value added (at factor cost)’, ‘employment’ and ‘wages and salaries’, the SW plank outperforms the PB plank in any module: Tab. 22 shows the results for the module ‘forest’, Tab. 23 for the module ‘transport’, Tab. 24 for the module ‘sawmill’ and Tab. 25 for the module ‘particleboard mill'. The results for the module ‘particleboard mill’ only concern the product PB.

The highest ratios in the results occur for the module ‘transport’ (Tab. 23) with ratios between 3 for the indicator ‘gross value added (at factor cost)’ and 18.3 for the indicator ‘transport’. The ratios for the module ‘forest’ (Tab. 22) vary between 2.6 and 3.5 with the highest values for the indicator ‘energy use’, and as such are valid for all three energy scenarios. In the module ‘sawmill’ (Tab. 24) the ratios for all indicators are 2.5 except for the indicator ‘transport’ which has a value of 0 as no transport takes place.

Since only the direct industrial water input is accounted for, the values are 0 for both products in the modules ‘forest’ (Tab. 22) and ‘transport’ (Tab. 23) regarding the EFORWOOD indicator ‘water use’. For the indicator ‘transport’, only the module ‘transport’ is relevant. In the modules ‘forest’ and ‘sawmill’, the values are therefore 0 (Tab. 22 and Tab. 24). The different transport ways covered along the process chain are summarized in the indicator value ‘transport’ (Tab. 23).

In Tab. 22-25 the results per module for the EFORWOOD SIA are shown.

Tab. 22. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Products / Module forest Indicators		Indicator result SW	Unit [/plank SW]	Indicator result PB	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,051	€	0,131	€	2,6
Production cost		0,032	€	0,089	€	2,8
Energy use	Energy scenario 1	0,011	kWh	0,037	kWh	3,5
	Energy scenario 2	0,011	kWh	0,037	kWh	3,5
	Energy scenario 3	0,011	kWh	0,037	kWh	3,5
Water use		0,000	m³	0,000	m³	0,0
Greenhouse gas emissions		0,003	kg CO_2 equiva-lents	0,011	kg CO_2 equiva-lents	3,5
Transport		0,000	tkm	0,000	tkm	0,0
Employment		0,002	h	0,006	h	2,6
Occupational accidents		8,16E-08	absolute number/ 1000 employ-ees	2,15E-07	absolute number/ 1000 employ-ees	2,6
Wages and salaries		0,007	€	0,018	€	2,7

Tab. 23. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Module transport Indicators / Products		Indicator result SW	Unit [/plank SW]	Indicator result PB	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,042	€	0,128	€	**3,0**
Production cost		0,056	€	0,221	€	**3,9**
Energy use	Energy scenario 1	0,011	kWh	0,100	kWh	**9,2**
	Energy scenario 2	0,011	kWh	0,100	kWh	**9,2**
	Energy scenario 3	0,011	kWh	0,100	kWh	**9,2**
Water use		0,000	m³	0,000	m³	**0,0**
Greenhouse gas emissions		0,003	kg CO_2 equiva-lents	0,028	kg CO_2 equiva-lents	**9,5**
Transport		0,029	tkm	0,525	tkm	**18,3**
Employment		2,08E-04	h	0,002	h	**9,7**
Occupational accidents		3,52E-08	absolute number/ 1000 employ-ees	3,01E-07	absolute number/ 1000 employ-ees	**8,5**
Wages and salaries		0,002	€	0,013	€	**5,7**

Tab. 24. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill Indicators		Indicator result SW	Unit [/plank SW]	Indicator result PB	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,001	€	0,002	€	**2,5**
Production cost		0,087	€	0,214	€	**2,5**
Energy use	**Energy scenario 1**	0,390	kWh	0,956	kWh	**2,5**
	Energy scenario 2	1,822	kWh	4,469	kWh	**2,5**
	Energy scenario 3	3,255	kWh	7,982	kWh	**2,5**
Water use		3,70E-07	m³	9,09E-07	m³	**2,5**
Greenhouse gas emissions		0,089	kg CO_2 equiva-lents	0,219	kg CO_2 equiva-lents	**2,5**
Transport		0,000	tkm	0,000	tkm	**0,0**
Employment		5,06E-04	h	1,24E-03	h	**2,5**
Occupational accidents		2,28E-08	absolute number/ 1000 employ-ees	5,59E-08	absolute number/ 1000 employ-ees	**2,5**
Wages and salaries		0,010	€	0,024	€	**2,5**

Tab. 25. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'particleboard mill' whereby the results higlighted represent the outperforming results.

Products / Module particleboard mill Indicators		Indicator result SW	Unit [/plank SW]	Indicator result PB	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		/	/	-0,075	€	/
Production cost		/	/	0,411	€	/
Energy use	Energy scenario 1	/	/	3,895	kWh	/
	Energy scenario 2	/	/	13,654	kWh	/
	Energy scenario 3	/	/	23,413	kWh	/
Water use		/	/	0,001	m³	/
Greenhouse gas emissions		/	/	2,198	kg CO_2 equivalents	/
Transport		/	/	0,000	tkm	/
Employment		/	/	0,002	h	/
Occupational accidents		/	/	8,64E-08	absolute number/1000 employees	/
Wages and salaries		/	/	0,047	€	/

Results of the 'scenario WB = 0':

For the EFORWOOD SIA the results under the 'scenario WB = 0' (Tab. 26) compared to the case in which no scenario is assumed (Tab. 21) change for the indicator 'gross value added (at factor cost)' and 'employment'. Regarding the indicator 'gross value added (at factor cost)' the outreaching result switches from the PB plank to the SW plank, the same is valid for the result of the indicator 'employment'.

Under the 'scenario WB = 0' the value for the PB plank of the indicator 'gross value added (at factor cost)' becomes negative. This is due to a negative value in the data source for the module 'particleboard mill'. This negative value has a major weight under this scenario due to the assumption that the module ‘forest’ and ‘sawmill’ are not relevant for the product PB plank (see chapter 5.5). The ratios under this scenario vary between -3.3 for the indicator ‘gross value added (at factor cost) and 1431.2 for the indicator ‘water use’.

In Tab. 26 the comparison of the results for the products SW plank and PB plank under the ‘scenario WB = 0’ is given.

Tab. 26. The overall EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the ‘scenario WB = 0’ whereby the results higlighted represent the outperforming results.

Products / Overall results Indicators		Indicator result SW Scenario WB=0	Unit [/plank SW]	Indicator result PB Scenario WB=0	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,150	€	-0,046	€	**-3,3**
Production cost		0,281	€	0,505	€	**1,8**
Energy use	Energy scenario 1	0,664	kWh	3,980	kWh	**6,0**
	Energy scenario 2	2,956	kWh	13,738	kWh	**4,6**
	Energy scenario 3	5,248	kWh	23,497	kWh	**4,5**
Water use		5,93E-07	m³	8,48E-04	m³	**1431,2**
Greenhouse gas emissions		0,152	kg CO_2 equiva-lents	2,222	kg CO_2 equiva-lents	**14,6**
Transport		0,029	tkm	0,211	tkm	**7,3**
Employment		5,11E-03	h	3,71E-03	h	**1,4**
Occupational accidents		2,23E-07	absolute number/ 1000 employ-ees	3,16E-07	absolute number/ 1000 employ-ees	**1,4**
Wages and salaries		0,030	€	0,056	€	**1,9**

Compared per module, the results change as following if the ‘scenario WB = 0’ is applied. The results for the module ‘forest’ change for all indicators into the opposite (Tab. 22 compared to Tab. 27). The ratios for the ‘scenario WB = 0’ are between 1.5 and 14.3 (Tab. 27). For the module ‘transport’ changes occur for the indicators ‘gross value added (at factor cost)' and 'production cost' (Tab. 23 compared to Tab. 28). The ratios are between 1.1 and 7.3. The highest ratio regards the indicator 'transport' (Tab. 28).

As in the 'scenario WB = 0' the module 'sawmill' (Tab. 29) is not considered (see scenario description in chapter 5.5) all values for the PB plank are 0. Thus, for those indicators for which high values are evaluated as more sustainable ('gross value added (at factor cost))', 'employment' and 'wages and salaries') the SW plank outperforms the PB plank in this module. On the other hand, for those indicators for which low values signify a better result, the PB plank, with values of 0, outperforms the SW plank.

In Tab. 27- 29 the results per module are shown.

Tab. 27. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Products / Module forest Indicators		Indicator result SW Scenario WB=0	Unit [/plank SW]	Indicator result PB Scenario WB=0	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,081	€	0,006	€	14,3
Production cost		0,051	€	0,011	€	4,5
Energy use	Energy scenario 1	2,30E-02	kWh	1,09E-02	kWh	2,1
	Energy scenario 2	2,30E-02	kWh	1,09E-02	kWh	2,1
	Energy scenario 3	2,30E-02	kWh	1,09E-02	kWh	2,1
Water use		0,000	m³	0,000	m³	0,0
Greenhouse gas emissions		4,96E-03	kg CO_2 equivalents	3,36E-03	kg CO_2 equivalents	1,5
Transport		0,000	tkm	0,000	tkm	0,0
Employment		0,004	h	3,08E-04	h	12,8
Occupational accidents		1,31E-07	absolute number/1000 employees	1,53E-08	absolute number/1000 employees	8,6
Wages and salaries		0,011	€	0,001	€	8,1

Tab. 28. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Products / Module transport Indicators		Indicator result SW Scenario WB=0	Unit [/plank SW]	Indicator result PB Scenario WB=0	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,067	€	0,024	€	**2,8**
Production cost		0,090	€	0,083	€	**1,1**
Energy use	Energy scenario 1	0,017	kWh	0,073	kWh	**4,2**
	Energy scenario 2	0,017	kWh	0,073	kWh	**4,2**
	Energy scenario 3	0,017	kWh	0,073	kWh	**4,2**
Water use		0,000	m^3	0,000	m^3	**0,0**
Greenhouse gas emissions		0,005	kg CO_2 equiva-lents	0,021	kg CO_2 equiva-lents	**4,4**
Transport		0,029	tkm	0,211	tkm	**7,3**
Employment		3,33E-04	h	1,50E-03	h	**4,5**
Occupational accidents		5,63E-08	absolute number/ 1000 employ-ees	2,14E-07	absolute number/ 1000 employ-ees	**3,8**
Wages and salaries		0,004	€	0,007	€	**2,0**

Tab. 29. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill Indicators		Indicator result SW Scenario WB=0	Unit [/plank SW]	Indicator result PB Scenario WB=0	Unit [/plank PB]	Ratio between the higher and the lower result
Gross value added (at factor cost)		0,002	€	0,000	€	/
Production cost		0,140	€	0,000	€	/
Energy use	Energy scenario 1	0,623	kWh	0,000	kWh	/
	Energy scenario 2	2,915	kWh	0,000	kWh	/
	Energy scenario 3	5,208	kWh	0,000	kWh	/
Water use		5,93E-07	m³	0,000	m³	/
Greenhouse gas emissions		0,143	kg CO_2 equivalents	0,000	kg CO_2 equivalents	/
Transport		0,000	tkm	0,000	tkm	/
Employment		0,001	h	0,000	h	/
Occupational accidents		3,65E-08	absolute number/1000 employees	0,000	absolute number/1000 employees	/
Wages and salaries		0,015	€	0,000	€	/

6.1.4 Comparison of the results

In this chapter the results described in the section above are summarized and compared. Regarding the overall result (Tab. 30), the methods EF and MIPS assess the production of a SW plank as being more sustainable than the production of a PB plank. For the assessment through the EFORWOOD SIA, no overall result of the indicators can be expressed because an aggregation procedure is necessary to compare the two products by one value. However, it can be stated that the majority of indicators identifies the SW plank as more sustainable compared to the PB plank. These results are shown in Tab. 30.

Thereby the following has to be noticed:

'X' expresses that the product outperforms the other product in the specified module and for the specified method. 'Outperform' for the EF means to have a smaller ecological footprint, for MIPS it means less material input and for the EFORWOOD SIA it means less environmental impact.

'/' expresses that the value of the result is 0.

Tab. 30. Comparison of the overall results of the three methods whereby 'X' represents the outperforming results.

OVERALL RESULTS			
Methods / **Products**		**Solid wood**	**Particleboard**
EF		X	
MIPS	Abiotic	X	
	Biotic	X	
	Water	X	
	Air	X	
EFORWOOD SIA	Gross value added (at factor cost)		X
	Production cost	X	
	Energy use	X	
	Water use	X	
	Greenhouse gas emissions	X	
	Transport	X	
	Employment		X
	Occupational accidents	X	
	Wages and salaries		X

The results per module for the three methods are summarized in Tab. 31, Tab, 32 and Tab. 33. Tab. 31 shows the results of the module 'forest'. In this module, the SW plank clearly outperforms the PB plank, except for the EFORWOOD economic indicator 'gross value added (at factor cost)' and the social indicators 'employment' and 'wages and salaries'.

Tab. 31. Comparison of the results of the three methods for the module 'forest' whereby 'X' represents the outperforming results.

MODULE FOREST			
Methods \ **Products**		**Solid wood**	**Particleboard**
EF		X	
MIPS	Abiotic	X	
	Biotic	X	
	Water	X	
	Air	X	
EFORWOOD SIA	Gross value added (at factor cost)		X
	Production cost	X	
	Energy use	X	
	Water use	/	/
	Greenhouse gas emissions	X	
	Transport	/	/
	Employment		X
	Occupational accidents	X	
	Wages and salaries		X

In the module 'transport' (Tab. 32) the same is valid as for the module 'forest' (Tab. 31): The SW plank outperforms the PB plank except for the EFORWOOD economic indicator 'gross value added (at factor cost)' and the social indicators 'employment' and 'wages and salaries'.

Tab. 32. Comparison of the results of the three methods for the module 'transport' whereby 'X' represents the outperforming results.

MODULE TRANSPORT			
Methods \ Products		**Solid wood**	**Particleboard**
EF		X	
MIPS	Abiotic	X	
	Biotic	/	/
	Water	X	
	Air	X	
EFORWOOD SIA	Gross value added (at factor cost)		X
	Production cost	X	
	Energy use	X	
	Water use	/	/
	Greenhouse gas emissions	X	
	Transport	X	
	Employment		X
	Occupational accidents	X	
	Wages and salaries		X

Regarding the module 'sawmill' (Tab. 33), the PB plank outperforms the SW plank for the method EF and the MIPS input category 'air', and thus, corresponds to the indicator results of 'gross value added (at factor cost)', 'employment' and 'wages and salaries'.

Tab. 33. Comparison of the results of the three methods for the module 'sawmill' whereby 'X' represents the outperforming results.

MODULE SAWMILL			
Methods / **Products**		**Solid wood**	**Particleboard**
EF			X
MIPS	Abiotic	X	
	Biotic	/	/
	Water	X	
	Air		X
EFORWOOD SIA	Gross value added (at factor cost)		X
	Production cost	X	
	Energy use	X	
	Water use	X	
	Greenhouse gas emissions	X	
	Transport	/	/
	Employment		X
	Occupational accidents	X	
	Wages and salaries		X

<u>Results of the 'scenario WB = 0'</u>

If comparing the overall results gained from the application of the three methods assuming 'scenario WB = 0' (Tab. 34), the result remains the same for the method EF as if the 'scenario WB = 0' was not applied (Tab. 30): The SW is evaluated as more sustainable. Regarding MIPS, the input category 'biotic' switches in favor of the PB plank compared to the basic results in which all four input categories assess the SW as more sustainable. For the majority of the EFORWOOD SIA indicators the SW plank outperforms the PB plank as well, however, the indicators for which the PB plank outperforms the SW plank, change under the 'scenario WB = 0'. Under the 'scenario WB = 0' the PB plank outperforms the SW plank only regarding the indicator 'wages and salaries'.

Tab. 34. Comparison of the overall results of the three methods under the 'scenario WB = 0'; 'X' represents the outperforming results.

OVERALL RESULTS			
Methods	**Products**	**Solid wood scenario WB = 0**	**Particleboard scenario WB = 0**
EF		X	
MIPS	Abiotic	X	
	Biotic		X
	Water	X	
	Air	X	
EFORWOOD SIA	Gross value added (at factor cost)	X	
	Production cost	X	
	Energy use	X	
	Water use	X	
	Greenhouse gas emissions	X	
	Transport	X	
	Employment	X	
	Occupational accidents	X	
	Wages and salaries		X

In the module ‘forest’ (Tab. 35) the PB plank outperforms the SW plank for the method EF, all MIPS input categories and for the EFORWOOD SIA indicators ‘production cost’, ‘energy use’, ‘greenhouse gas emissions’ and ‘occupational accidents’. The indicators ‘gross value added (at factor cost)’, ‘employment’ and ‘wages and salaries’ assess the SW plank as more sustainable. This is the exact opposite result in comparison to the case where no scenario is assumed for the module ‘forest’ (Tab. 31).

Tab. 35. Comparison of the results of the three methods for the module ‘forest’ whereby ‘scenario WB = 0’ is assumed; ‘X’ represents the outperforming results.

MODULE FOREST			
Methods \ **Products**		**Solid wood scenario WB = 0**	**Particleboard scenario WB = 0**
EF			X
MIPS	Abiotic		X
	Biotic		X
	Water		X
	Air		X
EFORWOOD SIA	Gross value added (at factor cost)	X	
	Production cost		X
	Energy use		X
	Water use	/	/
	Greenhouse gas emissions		X
	Transport	/	/
	Employment	X	
	Occupational accidents		X
	Wages and salaries	X	

For the module ‘transport’ (Tab. 36) only the EFORWOOD SIA indicators ‘production cost’, ‘employment’ and ‘wages and salaries’ evaluate the PB plank as more sustainable.

Tab. 36. Comparison of the results of the three methods for the module ‘transport’ whereby ‘scenario WB = 0’ is assumed; ‘X’ represents the outperforming results.

MODULE TRANSPORT			
Methods / **Products**		**Solid wood scenario WB = 0**	**Particleboard scenario WB = 0**
EF		X	
MIPS	Abiotic	X	
	Biotic	/	/
	Water	X	
	Air	X	
EFORWOOD SIA	Gross value added (at factor cost)	X	
	Production cost		X
	Energy use	X	
	Water use	/	/
	Greenhouse gas emissions	X	
	Transport	X	
	Employment		X
	Occupational accidents	X	
	Wages and salaries		X

Regarding the module 'sawmill' (Tab. 37) for all indicators for which high values outperform ('gross value added (at factor cost)', 'employment', 'wages and salaries') the SW plank outperforms the PB plank. On the contrary, for the indicators for which low values are evaluated as more sustainable than higher values, the PB plank outperforms the SW plank.

Tab. 37. Comparison of the results of the three methods for the module 'sawmill' whereby 'scenario WB = 0' is assumed; 'X' represents the outperforming results.

MODULE SAWMILL			
Methods	**Products**	**Solid wood scenario WB = 0**	**Particleboard scenario WB = 0**
EF			X
MIPS	Abiotic		X
	Biotic	/	/
	Water		X
	Air		X
EFORWOOD SIA	Gross value added (at factor cost)	X	
	Production cost		X
	Energy use		X
	Water use		X
	Greenhouse gas emissions		X
	Transport	/	/
	Employment	X	
	Occupational accidents		X
	Wages and salaries	X	

6.2 Evaluation of the methods

In this chapter the methods are evaluated by means of the criteria catalogue and the scores defined in chapter 3.4. The criteria are:

1. Give directionally robust information
2. Transparency of the calculation process and the data sources
3. Based on available and reliable data
4. Feasible within an adequate effort in time and with adequate costs
5. Integrated approach
6. Communicable
7. Universal
8. Comprehensive

For every criterion and method in a first step observations and arguments are listed for the evaluation of the criterion, in a second step the method is given a numerical score from 1 to 5 where 1 is low and 5 is high. Even though the scores were not defined generally but specific for every criterion (see chapter 3.4) the assignment of the scores can only be indicative.

6.2.1 Criterion 1: Give directionally robust information

Ecological Footprint:

The EF is not meant to be an overarching indicator for sustainability but has to be seen as a key indicator for environmental sustainability which focuses on the research question of how much biocapacity is used up by humans and their activities (WACKERNAGEL & SILVERSTEIN, 2000, p. 394; GILJUM et al., 2007, p. 67).

In the calculation of this thesis, assuming the basic assumptions, the EF method showed the same overall results (concerning the whole process chain) as MIPS and the majority of the EFORWOOD indicators. In the module ‘sawmill’, however, the EF clearly prefers the PB plank whereas this is not so evident for the methods MIPS and the EFORWOOD SIA.

Huijbregts et al. (2008, p. 805) could also show that the EF has similar gross ranking results. In their study, the EF was compared to the life cycle impact assessment method Ecoindicator 99[12]. They could demonstrate that in a comparison between Ecoindicator 99 and EF (2630 products and services analyzed), except for products in which the mineral consumption as well as process-specific metal and dust emissions were high, the two methods showed results with only small variations. This shows the weakness of the EF as stand-alone

[12] Damage oriented impact assessment

indicator concerning non-renewable sources (see also criterion 8). Other aspects of sustainability which are not represented by the EF are the biodiversity and the conservation of ecosystems, the quality of land use, the human impacts on the decrease of biocapacity e.g., through degradation of soil, acidification, pollutants, water or climate change (KITZES et al., 2007; VAN DEN BERGH AND VERBRUGGEN, 1999), and economic and social aspects as well.

Unsolved questions, which according to Best et al. (2008, p. 55) influence the result of the method, are the calculation of the ‘energy footprint’ and the consideration of multiple land use as well as the question if land area dedicated to the absorption of CO_2 relates to real or theoretical land area. Others argue that the EF area is in any case underestimated in the method (WACKERNAGEL & SILVERSTEIN, 2000, p. 394) as many ecological impacts are not accounted for in the EF.

It can therefore be concluded that there are still discussions among researchers if the results of the method can give directionally robust information for the objective the method was developed for, even though the results correspond to other comparable sustainability assessment methods.

Score: 2

There are still discussions among researchers if the results of the method can give directionally robust information for the objective the method was developed for.

MIPS:

MIPS is a material flow based sustainability indicator. Its basic assumption is that the less resource extraction is needed for the production of a product, and more specific for the production of a service unit, the more sustainable is the product.

In this case study the overall results (under the basic assumptions) of the MIPS calculation correlated with the results of the method EF and the majority of the EFORWOOD indicators. Differences in the results occurred in the module ‘sawmill’. In comparison to the EF, MIPS evaluates the PB plank only better for the input category ’air’.

The developer of MIPS states that with the method at least trend-setting decisions (SCHMIDT-BLEEK, 2000, p. 19) can be made. However, as the method can only give save information on what it is measuring, its results only show the quantity of material flows of a product. The quality of material flows is not considered. This may lead to differing results compared to other sustainability assessment methods and unpopular conclusions. According to Hertwich et al. (1997, p. 16) this leads to the conclusion that the potential of the method for an undesirable outcome is high. MIPS would for example evaluate it as positive if a smaller amount of a toxic substance substitutes a high amount of a harmless substance with less environmental impact. Another example for an unpopular outcome could be shown by

(KROTSCHECK, 1997, p. 675). In his calculation of MIPS, fossil energy is preferred over the use of energy from biomass due to a higer material input for the latter.

There is still effort needed to consider the quality of material flows. An idea of how to do this is TOPS - Ecotoxicity per Service Unit - which takes into account the impacts of specific substances and is proposed to be combined with MIPS (SCHMIDT-BLEEK, 2000, p. 176f).

Apart from the data of the resource input necessary for a process, the result of MIPS is also strongly dependent on the MI factors. They have to represent reality for a directionally robust result. To take new technologies and efficiency gains in the production processes into consideration and also to assess sustainability over time, it is important that the MI factors are updated regularly. Up to now a general list of MI factors for material, fuels and transport services mostly for Germany or Europe is provided by the Wuppertal Institute (WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, 2003; WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, s.a.). The up-to-datedness has to be evaluated through the user of the data (WUPPERTAL INSTITUTE FOR CLIMATE, ENVIRONMENT AND ENERGY, 2003, p. 1).

It can therefore be concluded that MIPS is able to give directionally robust information regarding quantitative material flows, for what it was developed. Other aspects cannot (yet) be evaluated by the method.

Score: 3

The results of the method can give directionally robust information for the objective the method was developed for and coincide at least with the overall result of one of the two other methods applied in this study.

EFORWOOD SIA:

Under the basic assumptions the majority of the EFORWOOD indicators (6 of 9) coincide with the overall result of the two other methods. Compared per module, differences can be identified in the module ‘sawmill’ compared to the EF method and the input MIPS input category ‘air’. Only three indicators of the EFORWOOD SIA (‘gross value added (at factor cost)’, ‘employment’ and ‘wages and salaries’) evaluate the PB plank as more sustainable in that module.

The two components that contribute most to give directionally robust information for the EFORWOOD SIA are the selection of the indicators and the database.

The EFORWOOD database offers a list of 27 indicators covering the environmental, economic and social dimension of sustainability. For a specific application, the relevant indicators have to be chosen. A balanced ratio between the three dimensions of sustainability is envisioned (LINDNER et al., 2009, p. 4). To gain for an overall assessment result, two methods for valuation and aggregation of indicators are implemented (Cost-Benefit Analysis and Multi-Criteria Analysis).

The second important point to consider for a directionally robust result is the reliability of the data and the question if the data on which the assessment is based are representative (see also criterion 3). Due to the fact that the EFORWOOD SIA has only recently been developed during the EU project EFORWOOD it has not been commented, evaluated or analyzed in literature yet. However, as the indicator set was selected for the topics of the forestry-wood sector taking into account already existing, comprehensive and acknowledged datasets (RAMETSTEINER et al., 2006, p. 13ff) it can be assumed that the indicator set well represents the sector and can therefore give directionally robust results if the data in the database are reliable (see criterion 3).

Score: 3

The results of the method can give directionally robust information for the objective the method was developed for and coincide at least with the overall result of one of the two other methods applied in this study.

6.2.2 Criterion 2: Transparency of the calculation process and its data sources

Ecological Footprint:

The concept of the standard calculation process of the EF is transparent and has been frequently described (WACKERNAGEL & REES, 1997; WACKERNAGEL et al., 2005; EWING et al., 2008). Especially the Global Footprint Network, a network comprising leading Footprint practitioners, cities, nations, businesses, scientists, NGOs and academics is active in promoting the EF methodology. It publishes a detailed written documentation of the calculation methodology and works on the standardization of the method among all users. The first standard was published in 2006 and was revised in 2009. It contains both compulsory standards which have to be fulfilled for a study certification by the Global Footprint Network and recommended guidelines (GLOBAL FOOTPRINT NETWORK, 2009, p. 1).

Nevertheless, critical voices appear as well. For methodological variations a detailed documentation is often missing on the selection of constants, assumptions, system boundaries or the techniques applied in order to solve data gaps. This is especially relevant as the EF method is a highly aggregated indicator which includes several selection steps. The missing transparency of the calculation process and its data sources is criticized by KITZES et al. (2007, p. 5) as well as by SCHAEFER et al. (2006, p. 9) and described as a weakness of the method by BEST et al. (2008, p. 62). They especially denounce the common missing transparency in the derivation of constants and functions as the equivalence factors.

Thus, still intransparencies can be found but there is a lot of effort to standardize the method.
Score: 4
The standard procedure or basic concept for the calculation of the method is well documented and there is ongoing effort to standardize the procedure, assumptions and data sources to make the calculation more transparent and to produce comparable results.

MIPS:

The standard concept of MIPS is presented and explained in a variety of sources (SCHMIDT-BLEEK, 1994; SCHMIDT-BLEEK, 2000; SCHMIDT-BLEEK, 2004) but an internationally standardized procedure for qualitative differences in the calculation of Material Flow Analysis of which the method MIPS is part, does not exist yet (GILJUM, 2006, p. 17[13]).

A transparent description of the calculation procedure including a calculation sheet and calculation examples was published by the Wuppertal Institute in 2002 (RITTHOFF et al., 2002). The Wuppertal Institute also provides a list of MI factors for different materials, fuels and transport services (WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, 2003) including information on the referred region. Their calculation is based on information from third parties or literature and is documented in the 'Wuppertal Papers' which can be found on the website of the institute[14]. However, MI factors calculated by other practitioners for their studies are not systematically collected and provided for general use.

Thus, the standard procedure or basic concept for the calculation of the method is well documented. However, the MI factors can still be a source of missing transparency. This is especially valid for those materials for which no validated values exist yet but which have to be calculated by the different practitioners themselves.
Score: 3
The standard procedure or basic concept for the calculation of the method is well documented but there are still some lacks in transparency of assumptions and data sources used.

EFORWOOD SIA:

The calculation process of EFORWOOD is transparent and is accomplished by the software ToSIA, the predominant outcome of the EFORWOOD project. It is well described in the deliverables (Deliverable 1.4.3 and 1.4.5) (LINDNER et al., 2007) of the project. Due to the

[13] This page number refers to the pdf version of the source.
[14] http://www.wupperinst.org/

fact that the calculation is planned to be done by the software, no standardization of the calculation process itself is necessary.

For the data collection as input for the database, however, standardization is needed. The database is evaluated under this criterion because it is a constitutional part of the method. A data collection protocol (BERG, 2008) describing the measurement units, system boundaries, possible data sources, the calculation mode including the conversion factors, module specifications and recommendations was elaborated and should provide the basis for a consistent dataset. However, this is still not yet fully achieved (see also criterion 3). Especially, assumptions on processes for which the values are provided in the database lack in detail and therefore in transparency. A better description of the processes would help to make it easier to trace back the data and to avoid data inconsistencies.

It can therefore be concluded that the method itself is well documented but that there are still lacks in the application of the data collection guidelines and therefore in transparency. These problems can, however, be solved through the validation of the values in the database and the provision of additional metadata.

Score: 3

The standard procedure or basic concept for the calculation of the method is well documented but there are still some lacks in transparency of assumptions and data sources used.

6.2.3 Criterion 3: Based on available and reliable data

Ecological Footprint:

Data necessary for the calculation of the EF are the following:

- Direct area use of the product by process step (e.g., forest area) and the direct area use of the preliminary materials (auxiliary and operating material[15])[16],
- energy input and input of raw material, preliminary products (auxiliary and operating material) for every production step,
- the transport kilometers and the weight of freight
- and the embodied energy expressed in CO_2 emissions for each material and energy input.

Data on the inputs for the different production processes as well as the information on transport are documented on enterprise level but can also be found in literature or in databases. Therefore, they can be evaluated as available data. Specific data from

[15] It depends on the system boundaries defined whether they are included or not.
[16] Only the direct area use of the output product of the specific module was considered in this application of the method.

enterprises can be assumed to be accurate in reflecting reality as enterprises usually keep exact account on their input material. However, they are not representative. The reliability of generic data may vary. Less available are the area occupation of preliminary products. If no direct collaboration with an enterprise is intended or the goal is to assess an average product as in this study, large and consistent databases are necessary or extensive and time-consuming research in literature has to be accomplished.

In these calculations the CO_2 values are taken from the environmental database 'ProBas' (UMWELTBUNDESAMT, 2008). Other specific data sources used are the following: Hasch (2002), Umweltbundesamt (2007), RETEC group (2003), Bußwald et al. (2006) as well as own calculations based on the forest defined for the forest area and information of an Austrian sawmill and an Austrian particleboard mill for the built-up areas. The use of different data sources goes along with difficulties in consistency and variations on how representative the data are.

Score: 3

The data needed for the application of the method are collected as internal data in enterprises, in databases or in statistics but there can be lack in consistency of or among the data sources and the representativity varies a lot and is not well documented.

MIPS:

For the calculation of MIPS, the amount of resource inputs as raw material, preliminary products (auxiliary and operating material) water and information on transport (transport kilometers and freight) are necessary. In addition MI factors for all input products representing the material intensity of the inputs are necessary.

Data on resource input of a production process are available at enterprise level but can often be found also in literature or in databases and can therefore be evaluated as available data. As for the EF its reliability relies on the data source.

The second kind of information needed for the calculation of the method MIPS are the material intensity values (MI factors) of the input resources, divided into the categories 'abiotic', 'biotic', 'water', 'air' and 'earth moved'. If MI factors are not already available, the collection of these data is time consuming and difficult as the necessary information is seldom surveyed, difficult to trace back and the access to enterprise data often denied due to data privacy. A variety of MI factors were, however, already calculated in a systematic manner by the Wuppertal Institute for Climate, Environment and Energy. They are provided at the website of the institute (WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, 2003) and the Austrian Factor 10 institute website (WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, s.a.). The values are mainly available for generalized European or German conditions. Concerning accuracy of the data which are mainly taken from third parties or literature (see also criterion 2) the Wuppertal Institute does not take any liability (WUPPERTAL INSTITUTE FOR CLIMATE, ENVIRONMENT AND ENERGY, 2003, p. 1). MI factors calculated by other practitioners for their studies are not systematically collected and provided for general use.

Although Schmidt-Bleek (2000, p. 155f) argues that the provided MI factors should be satisfactory as a guidance value, a danger in simplified, averaged and not updated MI factors may exist. Especially the up-to-datedness of MI factors is important as a variety of factors like technology or production processes influence the result and may lead to wrong conclusions.

<u>Score: 3</u>

The data needed for the application of the method are collected as internal data in enterprises, in databases or in statistics but there can be lack in consistency of or among the data sources and the representativity varies a lot and is not well documented.

<u>EFORWOOD SIA:</u>

The EFORWOOD SIA receives data from the database but data can also be provided by the user through the revision of the database data or the entry of new data (LINDNER et al., 2007, p. 43). The aim for the database is to provide data on European wide material flows. In this study the data are taken from the EFORWOOD regional case study of Baden-Württemberg and were complemented by data from Schweinle (2000) and Hasch (2002) (see chapter 4.3.1).

The data in the database consist on the one hand of static data, which were used for this analysis, on the other hand on dynamic data, which define the chain structure and the definition of which products flow in each linkage. The dynamic data can be edited by the user to suit the user's particular needs and to define a process chain (LINDNER et al., 2007, p. 43). The data for the database were provided by researchers in the project and are still not completed. That is why a selection of indicators has been taken for this comparative analysis. The data are gathered from different statistics, research data and modeling outputs (LINDNER et al., 2007, p. 40). Expert judgments are used, particularly with qualitative indicators as well (LINDNER et al., 2007, p. 29).

For the consistency of the data, a data collection protocol that defines measurement units, system boundaries, possible data sources, the calculation mode including the conversion factors, module specifications and recommendations (see also criterion 2) is used by the data collectors. In addition, data quality controls and validation are part of the concept. *'…data quality control represents an important part of the data gathering task in EFORWOOD'* (LINDNER et al., 2007, p. 40). The concept on how the validation of the data should be secured is well described on the same page and Lindner points out: *'Both* *completeness of the data and individual values are checked'.* Metadata describe the content and quality of indicator values (LINDNER et al., 2007, p. 41).

However, in practice the availability and reliability of the data is the main weakness of the EFORWOOD SIA. Inconsistencies concerning the database indicator values still exist and some values are not representative. Metadata which should describe the content and the quality of the data (LINDNER et al., 2007, p. 41) are often not given or given insufficiently to be traced back. Thus, the compliance with the data collection protocol where the indicators as well as reference units are described and possible sources on where to find the data are given, is to the experience of the author, still deficient.

Score: 3

The data needed for the application of the method are collected as internal data in enterprises, in databases or in statistics but there can be lack in consistency of or among the data sources and the representativity varies a lot and is not well documented.

6.2.4 Criterion 4: Feasible within an adequate effort in time and with adequate costs

Ecological Footprint:

The most time consuming aspect of the sustainability assessment calculation with the EF is the data collection, preparation and conversion into the right units. Thus, the key are once more available and reliable data.

For the calculations in this thesis, data collection and preparation took most of the time. It was time consuming to find the appropriate data, to compare the consistency among the data sources, to check the plausibility and to convert data into the right units to undertake the calculations. Due to the fact that except for the CO_2 values the necessary data are information known by enterprises (see also criterion 3) a strong collaboration with industry is an advantage and the use of databases, if available, is recommended to save time.

The calculation itself is a routine if the chain which should be analyzed is defined and the assumptions and system boundaries are set. If data are available, the method is therefore definitely feasible within an adequate effort in time. Best et al. (2008, p. 48) judge the calculation of the EF as a method which does not impose a burden disproportionate to its benefits. Regarding costs, the same possible costs due to access fees for databases may accrue as for other sustainability assessment methods or Life Cycle Assessments.

Score: 4

The method is feasible within an adequate effort in time and with adequate costs. The method is evaluated as a burden but proportionate to its benefits.

MIPS:

Likewise the EF, data collection and preparation as well as conversion of the data into the necessary units is time consuming, especially if the data have to be empirically collected or adopted from different data sources in literature or from databases. It took most of the time in this thesis and is also confirmed by Schmidt-Bleek et al. (1998, p. 21f) to be the most time consuming part in the application of the method.

The calculation itself is a multiplication which can be automated. In addition to the data on the material inputs for the different processes, MI factors are needed. For a variety of materials MI factors are already available (see also criterion 2, 3 and 4). If they are not available or existing values shall be deeper investigated or updated, MI factors need to be calculated or estimated. In that case additional time effort is necessary. Concerning costs, the same possible costs due to access fees for databases may accrue as for other sustainability assessment methods or Life Cycle Assessments.

Due to the easy calculation method and a comparable time effort for data collection and preparation to the EF it can be concluded that the method is proportionate to its benefits. Ritthoff et al. (2002, p. 9f) state as well that the effort is reasonable. For enterprises, the application of the MIPS concept can even bring an additional benefit as the approach can contribute to detect potentials for the reduction of resource inputs and hence save costs (RITTHOFF et al., 2002, p. 9).

Score: 4

The method is feasible within an adequate effort in time and with adequate costs. The method is evaluated as a burden but proportionate to its benefits.

EFORWOOD SIA:

It is intended that the calculation is automated in the software ToSIA. This is also necessary if more complex process chains than the one defined in this study should be calculated. The process chain can be defined in ToSIA and is calculated with the data from the database which can be complemented by the user (LINDNER et al., 2007, p. 43) (see also criterion 3). If the necessary data are available in the database and if they are reliable and collected according to the data collection protocol, the method is applicable within an adequate effort in time. However, experience showed that not all data were in the reference units they should be and the representativity of some of the data was low. One reason therefore is that the data validation is still in progress at the point in time this thesis is accomplished. In this study, the preparation of the data and the development of scenarios if data seemed implausible, thus, took additional time. Most of ToSIA is open source and is therefore available for free to any user. Expert help will, however, still be needed when applying the tool.

The experience of this study showed that the EFORWOOD SIA method is more time-consuming in comparison to the EF and MIPS. This is, however, mainly due to the fact that the software ToSIA was not used in this application and because the database was not fully validated at the time of starting the calculations. Thus, likewise to the other methods, the data preparation took a lot of time; in addition the setting of the calculation was time-consuming. If the database is fully validated and data collection made more transparent, the burden of the method will be in any case proportionate to the benefits of the method.

Score: 4

The method is feasible within an adequate effort in time and with adequate costs. The method is evaluated as a burden but proportionate to its benefits.

6.2.5 Criterion 5: Integrated approach

Ecological Footprint:

The EF method does not consider the social or economic dimensions of sustainability and *'…does not produce a complete picture of ecological sustainability' (*REES, 2000, p. 372) although there is potential for development. The Global Footprint Network as well as Rees acknowledge that the method EF should be used together with other indicators for a more complete assessment of complex systems (GLOBAL FOOTPRINT NETWORK, 2009, p. 11f; REES, 2000, p. 373). Issues as depletion of non-renewable resources, toxic material, greenhouse gases other than CO_2, impacts on human health, as well as social, economic and cultural aspects of sustainability are not covered in the EF (GLOBAL FOOTPRINT NETWORK, 2009, p. 11f). Furthermore, basic economic rationalities as marginal cost thinking are missing in the EF concept (VAN DEN BERGH & VERBRUGGEN, 1999, p. 65f).

This incompleteness regarding the three dimensions of sustainability is strongly bound to the definition of sustainability behind the method. The perception is that the technosphere and within the social and economic dimensions of sustainability, are embedded in the biosphere and are dependent on it for the provision of resources and the discharge of waste. This idea leads to the conclusion that staying within the limits of biocapacity is the minimum ecological requirement for sustainability (WACKERNAGEL & SILVERSTEIN, 2000, p. 394). According to Best et al. (2008, p. 49) thus, the EF represents a *'warning light'* for the degradation of the natural resources in a long-term view.

Concerning the environmental aspect of sustainability the EF is not a comprehensive method either as its only focus is the land use. The following important aspects of environmental sustainability are missing:

- Consideration of sustainable and unsustainable land use:

The originally proposed concept of EF does not envisage a distinction between sustainable and unsustainable land use which is subject of critique (BICKNELL et al., 1998, p. 158, VAN DEN BERGH AND VERBRUGGEN, 1999, p. 65). Intensive agriculture with high pesticide use, possible groundwater pollution and soil depletion thus may lead to a smaller EF than e.g., extensive areas of land use cultivated according to organic farming with less or no negative effects on the environment. However, this point of critique may be solved with adjusted yield factors. Ferguson (2001, p. 2) has applied this solution for the EF calculation of Australia and the USA but states that there is a big difficulty in determining and quantifying unsustainable land use.

- Biodiversity and allocation of space for other species: Even though attempts exist to reserve a certain percentage of land for the conservation of biodiversity or for other species (CHAMBERS, 2001, p. 34) these aspects are not considered in the EF method yet.
- Consideration of emissions other than CO_2 and persistent pollutants: The method does not consider other emissions than CO_2 or the quality of resource inputs as e.g., persistent substances, harmful for humans and animals through the pollution of water, soil or air. The only way those substances influence the result of the EF is by decreasing the overall biocapacity which can be detected through longer time series. There are, however, attempts to incorporate other greenhouse gases than CO_2 into the calculation and express them in CO_2 equivalents (LENZEN & MURRAY, 2001, p. 229). Synthetic gases are not integrated at all in the calculations as for them no biological absorption capacity can be defined (BEST et al., 2008, p. 58).
- Moreover, the EF does not take the scarcity of non-renewable resources into account: Non-renewable resource use is only considered through the areas needed to absorb CO_2 (see also criterion 8).

Score: 1

The method explicitly includes one dimension of sustainability and may have weaknesses in representing this dimension in a comprehensive manner.

MIPS:

Explicitly the method only focuses on the environmental dimension of sustainability by measuring the material flows from the ecosphere to the economy for human use. The concept of MIPS is based on the perception of a symbiosis between humans/economy and ecosphere. It is assumed that every extraction or movement of material has impacts on the stability of the ecosphere (SCHMIDT-BLEEK, 2000, p. 38). Like the EF, also MIPS is based on a concept of sustainability where the human sphere - called technosphere by Schmidt-Bleek - is embedded in the ecosphere and is connected with it through material flows. All materials extracted will once be returned to nature (SCHMIDT-BLEEK et al., 1998, p. 36). In this approach only the main system boundary between ecosphere and technosphere is of relevance.

However, the MIPS approach implicitly also covers economic and social aspects of sustainability. MIPS is an eco-efficiency criterion and can directly be used in the realm of economics as a management tool which fosters innovations and on the same time can guide the economic development into a more environmental friendly direction. The method can also be used as a leading idea for an *'…ecological economic policy'* (HINTERBERGER & SCHMIDT-BLEEK, 1999, p. 54).

The social dimension of the MIPS concept can be found in the anthropocentric focus on the service of products and the quality of life. The key focus for newly designed products and services is not the product itself but the fulfillment of human needs for a good quality of life. MIPS does not demand renunciation but a new dematerialized quality of life (SCHMIDT-BLEEK, 2000, p. 61).

The approach of combating environmental problems is changed by MIPS. Individual measures and end of pipe solutions should be substituted by a more global and fundamental change in tackling human impacts on the environment (SCHMIDT-BLEEK, 2000, p.61). Nevertheless, MIPS cannot comprehensively cover the ecological/environmental dimension of sustainability. Giljum et al. (2006, p. 17) express it the following. '*The sole focus on the reduction of aggregated resource use is a necessary, but not sufficient, precondition for achieving environmental sustainability'.*

A weakness in representing the environmental dimension of sustainability is that the method does not distinguish between the use of renewable and non- renewable resources and the quality of material flows. Nevertheless, the use of renewable sources may have less environmental impacts and be more sustainable. It may often also be of higher relevance to the ecosphere to release a small amount of a toxic substance in comparison to a high amount of inert material.

Score: 3

The method explicitly includes one or two dimension/s of sustainability and may have weaknesses in representing this/these dimension/s in a comprehensive manner. In addition, the other dimension/s are implicitly covered by the method.

EFORWOOD SIA:

The method considers all three dimensions of sustainability (ecological/environmental, economic, social) by means of indicators for every aspect. Out of 27 indicators the method consists of, 10 cover the environmental, 9 the economic and 8 the social dimension. There is no inherent valuation of the importance of the different dimensions among each other. In this study 9 indicators were extracted of the indicator set comprising 4 environmental indicators, 3 social indicators and 2 economic indicators. The selection was made according to data availability and overlaps to the other analyzed methods for a better comparison.

The EFORWOOD indicator set was developed to cover the forestry-wood sector in Europe and its chains. It was developed within the project by a working group, which took the sustainability indicator development and guidelines of the EU into consideration. Especially the *'Sustainable Development Indicators of the European Union'* and the *'Impact Assessment Guidelines'* of the European Commission were taken into account (RAMETSTEINER et al., 2006, p. 13) which makes the indicator set comprehensive for the adressed sector. A detailed description of the indicator set development is given in EFORWOOD Deliverable 1.1.1 (RAMETSTEINER et al., 2006).

Even though EFORWOOD takes the three dimensions of sustainability defined in Rio as frame, the tool is not based on a specific definition of sustainability on the contrary to the other two analyzed methods. The approach wants to cover in a comprehensive way the different dimensions leading to sustainability; the focus on specific aspects of sustainability is the subjective decision of the user or user group through weighting/ balancing of the indicators. This can be done during an aggregation procedure e.g., Multi-Criteria Analysis.

Score: 5

The method explicitly includes all three dimensions of sustainability and they are all comprehensively represented.

6.2.6 Criterion 6: Communicable

Ecological Footprint:

The communicability of a complex matter is the main strength of the method and contributes to the suitability of the method to address a broad public (BEST et al., 2008, p. 51). *'It … provides a conceptually simply, intuitively appealing way to incorporate sustainability goals into the planning process'* (BICKNELL et al., 1998, p. 160). This strength is due to its vividness as an image, the simplicity to understand for everyone, the aggregation to a single dimension and a clear threshold. To date, the method is mostly known to calculate the footprint of nations and footprints for individuals but as the footprint calculation for products relies on the same concept, the communicability is also valid for the sustainability assessment of products.

The commonly known image of a huge foot or footprint on our small globe captures public imagination and is quickly memorized also in childrens' minds. It can be understood by everyone that humans cannot use more land or biocapacity than available. This simple statement can lead to positive responses if solutions are given in addition on how everyone can reduce his/her footprint. The summary of the complex interactions between consumption, production and resource use into one indicator gives an easy and clear message and can be taken as '*warning light'* (BEST et al., 2008, p. 59). On the other hand, the simplicity of the EF method is also criticized. Van den Bergh and Verbruggen (1999, p. 63) for example, claim that the reduction of the EF to a single dimension (gha) is a too simplistic way of dealing with the complex system interactions between humans and the biosphere. In their opinion the method should be extended and complemented by scenarios and economic models to be more realistic.

Another aspect contributing to the communicability of the method is its credible and concrete upper bound constraint - the limits of biocapacity - which makes it a tangible target to reach. This strength is also pointed out by Chambers (2001, p. 30).

The strength in communicability makes the EF a perfect educational and awareness rising tool, which is already widely acknowledged and used. A lot of institutions around the globe, especially municipal and local administrations, educational institutions, companies and NGOs apply it for this purpose. According to a study by Barrett (GILJUM et al., 2007, p. 21 cited from Barrett et al., 2004) 100% of the local administrations in Great Britain who use the EF state that the main goal of its use is public awareness rising on sustainable consumption. The method is also used in Austria for this purpose: 'Forum Umweltbildung' for example, has prepared information and a didactical booklet on how the EF can be tackled in class (FORUM UMWELTBILDUNG, 2009, s.p.).

Score: 5

The method is simple to understand also for non-scientists even though representing complex environmental interactions. With its vivid representation it captures public imagination and its result gives a clear and unambiguous message which captures public imagination and motivates positive responses.

MIPS:

The calculation of MIPS with its low methodological complexity is an easy to understand and to calculate procedure also for non-scientists if the necessary data are available. Hertwich et al. (1997, p. 14) call it *'…the simplest material-balance based approach imaginable'*. Due to its simplicity of converting an inventory into an aggregated result it can be used as an educational tool in a variety of forms and is also applied for that purpose (HERTWICH et al., 1997, p. 19). The Wuppertal Institute has elaborated the project 'MIPS für Kids' as a pedagogical tool for environmental education and the Factor 10 institute offers the internet platform 'MIPS academy' where the concept of MIPS and a new, less material intensive product design, can be explored. The 'ecological *rucksack*' concept which is based on the concept of MIPS is also widely used as educational tool. The image of an 'ecological *rucksack*' of a product or 'water *rucksack*' if considering only the resource input category 'water' is very imaginative and vivid.

Contrary to the EF, the result of the MIPS method is disaggregated into 5 resource input categories. This may affect the communicability of the results in a negative way. According to Krotscheck (1997, p. 665), the disaggregating makes the result less meaningful for decision-making. On other hand, however, the result becomes more transparent and retraceable.

Regarding an upper border up to which resource inputs shall be reduced, the message in MIPS is: The less resource input per service unit - the more resource efficient - the better. A clear threshold however, which answers the question of '*how efficient for ecosustainability*', is unanswered (KROTSCHECK, 1997, p. 669).

A negative aspect for a good communicability of the method can also be its high potential for undesirable outcomes (HERTWICH et al., 1997, p. 16); an undesirable outcome means that the results of MIPS can be against common sense. Examples are a preference for fossil fuels over biomass (KROTSCHECK, 1997, p. 675) or less recycling if the resource input for the recycling process is disproportionally high. Examples like these can decrease the credibility of the method as they contradict what people have learnt before. The acceptance of the method may therefore be hindered (KROTSCHECK, 1997, p. 679) and a lot of effort would be needed for a change in awareness.
Score: 4
The method can be understood by non-scientists and a vivid representation of the results is provided but the result does not give a clear and unambiguous message.

EFORWOOD SIA:

The EFORWOOD SIA was developed for the forestry-wood sector. The target group for its application is the forest-based industry, policy makers, consultants and researchers (LINDNER et al., 2009, p. 8). A more general use of the method beyond the forestry-wood sector is not envisioned within the project. This has to be kept in mind when discussing the aspect of communicability.

The concept of the method is very simple and understandable also for non-scientists and due to the fact that the calculation itself is intended to be calculated by the software ToSIA also the application will be simple. Emphasis has therefore to be put on the user interface which is the most important aspect for an appealing and simple use of the method (LINDNER et al., 2007, p. 48). For fast learning and the application of the tool, a graphical user interface and context- help is envisioned (LINDNER et al., 2007, p. 48). However, the use of the tool is intended to be accompanied by an expert.

In comparison to the EF and MIPS, however, the EFORWOOD SIA is not appealing and does not capture user's imagination. It is simply a calculation method without vivid image associated. Nevertheless, the method can motivate positive responses for the target user group: The environmental, economic and social dimensions of different forestry-wood chains can be analyzed, which contributes to awareness rising on trade-offs between the three dimensions of sustainability and can support decision-making.

A further aspect which contributes to communicability is a clear objective and message: The EFORWOOD SIA does not aim at a specific threshold to reach sustainable development and does not communicate a clear message. The method provides a framework - the indicators- to describe the three dimensions of sustainability; the emphasis within the three dimensions is then defined by the user's preferences.

Score: 2

The method is difficult to understand for non-scientists but can provide conclusions which can be integrated by experts in their expertise and further into decision making.

6.2.7 Criterion 7: Universal

Ecological Footprint:

Initially developed for the national level, the method can also be applied for other geographical entities, enterprises and products. There is no conceptual constraint on which products it cannot be applied. Due to its weakness, however, in representing mineral consumption as well as process-specific metal and dust emissions (HUIJBREGTS et al., 2008, p. 805) the use on products for which these components play a major role, is not recommended.

Moreover, the representation of non-renewable resources, emissions and pollutions other than CO_2 is weak (see also criterion 8 and criterion 1). The application of the EF to assess services could not be found in literature but is imaginable.

Concerning the application in different geographical regions no limits other than data availability exist. There is a global upper border, the global biocapacity, to which the results of different calculation levels are compared. The calculation for nations is already applied in many countries of the world and useful for international comparisons.

A weakness of the existing footprint method is the consideration of cross-border trade flows. The EF cannot express where on Earth the negative environmental impacts take place as the origin of imports is not considered (GILJUM et al., 2007, p. 64).

Score: 4

The method is applicable for most products or service groups even though it may be more adequate for some product or service groups. The application in different regions and cross-border is possible. Effort is, however, still necessary to solve remaining methodological difficulties or to adapt the method to a new setting.

MIPS:

The method can be applied to all products and services (SCHMIDT-BLEEK, 2004, p. 24). For products which do not provide a service themselves as e.g., raw material, only the material input is calculated which in relation to a weight unit expresses the material intensity (MIT) of a product (RITTHOFF et al., 2002, p. 13). Hertwich et al. (1997, p. 14) express this universalism by saying that the method has already been applied for products like catalytic converters as well as for yogurt. MIPS could also be applied for the granting of licenses and certificates, for the determination of insurance rates, for taxes and tariffs, for the assignment of credits, the determination of prices, standards, norms, scale of charges, fees and subsidies as well as for the selection of (scientific) projects and other (political) decisions (SCHMIDT-BLEEK, 2004, p. 24). However, it has to be borne in mind that MIPS does not reflect the quality of material flows and is therefore unsuitable to take this aspect into account.

Given that the material flows can be traced back, the method can be applied in every country and cross-border. An adaptation of the MI factors to regional conditions, however, is necessary (WUPPERTAL INSTITUTE FOR CLIMATE ENVIRONMENT AND ENERGY, 2003, p. 1).

Score: 5

The method is adequate for most products and services of different kinds and applicable in different regions and cross-border without any additional effort in the application of the method.

EFORWOOD SIA:

The method was developed for forestry-wood chains which can be analyzed from a forest defined, industry-defined, consumption-defined or regionally-defined perspective (LINDNER et al., 2007, p. 14). Products and services can be the endpoint of the chain (LINDNER et al., 2007, p. 12). At the moment, the method is not envisioned for products other than wood products. A broader use of the concept and the indicators could, however, be possible as most of the indicators are not sector-specific but could be applied also for other industries.

The EFORWOOD SIA defines Europe as its system boundary and the chain structure and database are set up for this area. Due to the fact that the method is general and scalable, it would also be possible to apply the method everywhere in the world within defined system boundaries by defining forestry-wood chains and creating databases. Within the European borders also cross-border calculations are possible with the EFORWOOD SIA. Impacts beyond the European borders, however, would not be considered in the European forestry-wood chain under the defined setting (LINDNER et al., 2009, p.8).

Score: 4

The method is applicable for most products or service groups even though it may be more adequate for some product or service groups. The application in different regions and cross-border is possible. Effort is, however, still necessary to solve remaining methodological difficulties or to adapt the method to a new setting.

6.2.8 Criterion 8: Comprehensive

Ecological Footprint:

The method focuses on the consumption of renewable resources, energy and land as well as CO_2 emissions. It therefore covers the environmental input categories 'abiotic', 'biotic' and 'land'. As it focuses on those resources which can be supplied by bioproductive areas it is an appropriate tool to represent renewable resources (GILJUM et al., 2007, p. 66). Non-renewable resources, however, which can be part of abiotic (e.g. ores) or biotic (e.g. fossil fuel) resources are not well represented by the method (see also criterion 1 and 7).

Concerning the category 'land', the EF method combines two dimensions of land use: Firstly it expresses the direct land use which is the actual land occupied for the supply of products or for infrastructure. Secondly, the indirect land use as the hypothetical land use for the absorption of CO_2 emissions or to provide alternative energy sources is calculated. This aggregation of real and hypothetical land use is a point for critique (GILJUM et al., 2007, p. 47). On the other hand, one of the developers of the method - Wackernagel - argues that only in this way the real overshoot of the Earth's biocapacity can be expressed (GILJUM et al., 2007, p. 47).

The category 'water' is not tackled in the original footprint. The integration of 'water use' is, however, on the research agenda for the further development of the method (KITZES et al., 2007, p. 18).

Score: 3

The method includes one, two or three categories which are comprehensively represented and there is potential to further develop the method to include also the other categories.

MIPS:

Except for the category 'land', all environmental input categories are included in the MIPS concept. In addition, the category 'earth moved' is considered by the method. The MIPS result is expressed in disaggregated form for each category. A comparison of two products in which the different categories show varying values as well as an aggregated result is not possible. In practice, however, the categories ‘abiotic’ and ‘biotic’ are seen as equivalent and addable when trying to reach a dematerialization (SCHMIDT-BLEEK, 2004, p. 23). The disaggregation of the categories is criticized by some (KROTSCHECK, 1997, p. 665) because it may lead to a loss in decision capacity. On the other hand, it makes the result more transparent and allows more accurate information on where a reduction of resource input is reasonable.

The parameter ‘land’ is not included in the MIPS concept. For a high number of industrial products and dependent services the contribution of this category would also not be significant due to the fact that the specific area requirement is low. However, for agricultural and forestry products as well as for buildings and infrastructure, this is not the case. The inclusion of the area would be meaningful for their impact. There is an idea to include this parameter in a further developed concept based on MIPS and to express it in ‘area intensity per service unit[17]’. To also take into account the impacts of specific substances, a combination of the MIPS concept with an interpretation of eco-toxicology is considered, expressed in ‘ecotoxicity per service unit[18]’ (SCHMIDT-BLEEK, 2000, p. 176f). The MIPS concept has thus the potential to be enlarged and to consist of the following three components for a broader calculation of the pressure on environment (SCHMIDT-BLEEK, 2000, p. 177):

- Material Intensity per Service Unit (MIPS),
- Ecotoxicity per Service Unit
- Area Intensity per Service Unit.

Score: 3

The method includes one, two or three categories which are comprehensively represented and there is potential to further develop the method to include also the other categories.

EFORWOOD SIA:

The indicator set of the method contains indicators covering all main input categories. In addition, the indicator set contains output related indicators. The input related indicators are the following:

- ‘Resource use inclusive recycled material’: This indicator includes the volume of renewable material in total (wood and other renewable material) and the volume of non renewable material, both subdivided according to their origin (virgin or recycled). The indicator thus takes implicitly into account abiotic as well as biotic resources.

[17] abbreviated in German as ‘FIPS’
[18] abbreviated in German as ‘TOPS’

- ‘Energy generation and use’: This indicator includes heat and direct fuel use as well as the electricity use, classified each by its origin from renewable or fossil sources. It therefore considers abiotic as well as biotic resources.
- ‘Water use’: This indicator is subdivided into ‘freshwater intake by industry’ and ‘water use of the forest ecosystem’
- ‘Forest resources’: This indicator comprises sub-indicators covering ‘forest and other wooded land area’ and the ‘balance of afforestation and deforestation’. It therefore covers the input category ‘land’.

Indicators describing output categories are the indicators ‘greenhouse gas emissions’, ‘water and air pollution’ and ‘generation of waste’.

The indicator set was developed in reference to already existing comprehensive indicator sets and guidelines such as the *‘Sustainable Development Indicators for the European Union’* (SDI-Eurostat) and the *‘Improved Pan-European Indicators for Sustainable Forest Management’* of the Ministerial Conference on the Protection of Forests in Europe (MCPFE) and the *‘Impact Assessment Guidelines’* of the European Commission (RAMETSTEINER et al., 2006, p. 13). Therefore, the set can be evaluated as a comprehensive set of all input categories relevant for the sector.

In the selected indicator set for the case study in this study the categories ‘water’, ‘biotic’ and ‘abiotic’ contained in the indicator ‘energy generation and use’ are covered. In addition, the output is covered by the indicator ‘greenhouse gas emissions’. For the assignment of the score, however, the full list of indicators is evaluated.

<u>Score: 5</u>

The method includes all four categories and they are all comprehensively represented.

6.2.9 Summary

In Tab. 38 the results of the evaluation through the criteria catalogue for the three methods are summarized.

Tab. 38. Results of the evaluation through the criteria catalogue for each method.

	Ecological Footprint	MIPS	EFORWOOD SIA
Criterion 1: Give directionally robust information	2	3	3
Criterion 2: Transparency of the calculation process and the data sources	4	3	3
Criterion 3: Based on available and reliable data	3	3	3
Criterion 4: Feasible within an adequate effort in time and with adequate costs	4	4	4
Criterion 5: Integrated approach	1	3	5
Criterion 6: Communicable	5	4	2
Criterion 7: Universal	4	5	4
Criterion 8: Comprehensive	3	3	5

The evaluation showed that the three methods differ in their strengths and weaknesses especially concerning the criteria ‘integrated approach’ (criterion 5) and ‘communicability’ (criterion 6).

- The driver for the EFORWOOD SIA to receive a higher score for the criterion ‘integrated approach’ is that its indicators consider all three dimensions of sustainability whereas the EF only focuses on environmental sustainability and thereby only on land use. As the EF, MIPS is a method to evaluate the environmental sustainability. However, implicitly the method also touches the economic and social dimension of sustainability.
- Regarding the criterion ‘communicability’ on the contrary, high scores are assigned to the EF and MIPS due to the simplicity of the concepts to understand also for non-scientists, their vivid representation (illustration of a big footprint on a small Earth and the image of a *rucksack* for MIPS). However, the disaggregation of the result and a missing quantified upper boundary as objective to reach for ecoefficiency can lead to an unclear and ambigous message by the MIPS result which may hinder positive responses. Therefore, the method MIPS is assigned a lower score than the EF. As the EFORWOOD SIA needs expert help to be applied and does not provide a vivid representation, a low score is assigned regarding this criterion.

For other criteria, however, no differences between the methods exist or the differences were evaluated as small. Indifference was rated for the criteria ‘based on available and reliable data' (criterion 3) and 'feasible within an adequate effort in time and with adequate costs' (criterion 4).

The following points can be drawn:

- Data availability and reliability is a major issue for all three methods and is related to difficulties. Data gathering and preparation is also the most time-consuming part for all three methods and it dependens on the specific application if data (including MI factors and CO_2 values) are readily available. Costs concern the data acquisition and the working hours. All in all, the application of all three methods was, however, evaluated as a burden proportionate to its benefit.
- Concerning the criterion 'transparency of the calculation process and the data sources' (criterion 2) none of the methods could clearly outreach the others; in all three methods elements are contained which are not fully transparent. The EF got a higher score as there already exists an official standard published by the Global Footprint Network.
- Regarding the criterion 'comprehensive' the EFORWOOD SIA outperforms the two other methods as the set of 27 indicators covers all main input categories which are set to be 'abiotic material', 'biotic material', 'water' and 'land area'. Regarding the other two methods (EF and MIPS) only three input categories are included, however, there is potential to further develop the methods to include the fourth input category.
- Concerning the criterion 'universal', MIPS was assigned the highest score as it is applied for most products and services of different kind and cross-border. The EF on the other hand, is weak in representing non renewable sources and is not recommended to be used for products in which mineral consumption as well as process-specific metal and dust emissions (HUIJBREGTS et al., 2008, p. 805) play a major role. There also exist difficulties in considering cross-border trade flows. The EFORWOOD SIA and its indicator set is especially designed for the forestry-wood sector in Europe. However, as the indicators are general and the method is scalable there is potential to adopt the method for other regions in the world and other sectors.
- For the criterion 'give directionally robust information' (criterion 1) MIPS and the EFORWOOD SIA are assigned the same score. Both methods are evaluated to give directionally robust information for what they were developed; a comprehensive indicator set for the EFORWOOD SIA, and the potential of MIPS to measure the quantity of material flows of a product. In addition, the majority (except for the indicators 'gross value added (at factor cost)' 'employment' and 'wages and salaries') of the EFORWOOD indicators and all input categories of MIPS coincide with the overall results of the two other methods applied in this study. The EF receives a score

of 2 as there are still discussions among researchers whether the method can assess what it was developed for.

Fig. 11 points out the differences in the scores of the three methods, regarding the different criteria.

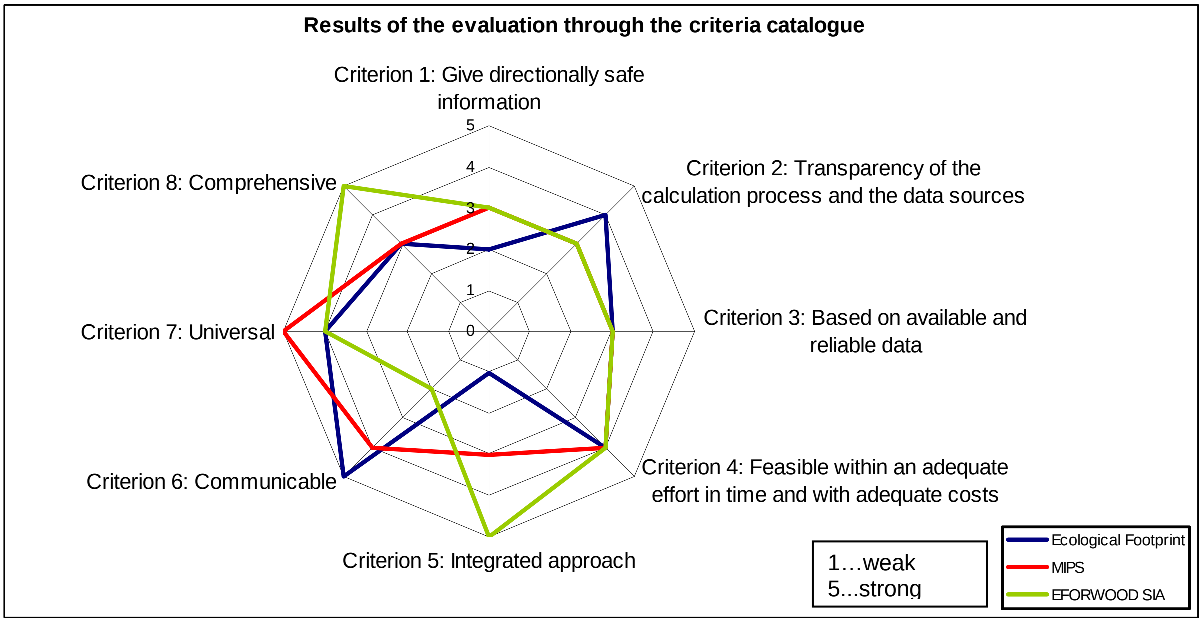

Fig. 11. Results of the evaluation through the criteria catalogue.

7 Discussion

In this chapter the calculations and the analysis are discussed. Chapter 7.1 is dedicated to assumptions in the calculations, the results, the scenarios calculated and problems arising during the calculation procedure. In chapter 7.2 the results of the analysis by means of the criteria catalogue are discussed.

7.1 Case study

To express the results, the concept of a ‘service unit’ was adopted from MIPS. The results of the calculations are expressed in the service unit ‘plank of a dimension of 100 x 20 cm and a bearing capacity of 25 kg’. The particular service unit was chosen for expressing the results as the measuring unit ‘m^3’ disregards that the two tested materials have different characteristics. The chosen service unit on the contrary does consider one important property difference of the two wood based materials: the bearing capacity. This criterion is relevant for the application possibilities of the two materials.

The results expressed in m^3 are divided by the amount of planks with this property, which can be cut out from 1 m^3 SW and 1 m^3 PB. As more planks can be produced from 1 m^3 SW (952.4 for the SW versus 416.7 for the PB), the SW expressed in plank slightly benefits of this unit regarding the indicators for which low values signify a higher performance. This applies to the methods EF, MIPS and the EFORWOOD SIA, except for the indicators ‘gross value added (at factor cost)’, ‘employment’ and ‘wages and salaries’. Concerning the indicators for which high values signify a higher performance the measuring unit ‘plank of a dimension of 100 x 20 cm and a bearing capacity of 25 kg’ benefits the PB.
As the defined service unit is not a measurement unit which is generally used, in Annex 4 the results are also given per m^3 to enable the comparability with other studies.

The result shows that over the whole defined process chain, the SW performs better than the SW according to the methods EF and MIPS. This result applies for the majority of the EFORWOOD indicators as well. The economic indicator ‘gross value added (at factor cost)’ and the two social indicators ‘employment’ and ‘wages and salaries’, however, assessed the PB plank better in comparison to the SW. The two latter indicators can be associated with the provision of jobs in the particleboard mill and by the upstream transport. Hence, the result shows that social and economic sustainability may stand in opposition to the environmental dimension of sustainability. Contrary to EFORWOOD SIA, MIPS and EF do not consider the social and economic dimension of sustainability. They are assessment methods for only the environmental dimension of sustainability. By assessing the resource productivity, MIPS implicitly assesses, however, where resource input, and therefore costs could be reduced which contributes to economic sustainability.

The results per chain stages, expressed in this study by the modules ‘forest’, ‘transport’, ‘sawmill’ and ‘ particleboard mill’, show that the most differences among the compared methods occur in the module ‘sawmill’. In the module ‘forest’ and ‘transport’, the results reflect the overall results which were described above. Regarding the module ‘sawmill’, also for the input category ‘air’ of the method MIPS and the method EF the PB plank performs better. That complies with the EFORWOOD indicators ‘gross value added (at factor cost)’, ‘employment’ and ‘wages and salaries’.

The MIPS input category ‘air’ shows a better result for the PB plank in the module ‘sawmill’ which is due to the fact that a lot of air is used in the drying process of the SW planks. The drying process is expressed by the input ‘heat from fossil sources’ and ‘heat from renewable sources’. For the MIPS input categories ‘abiotic’ and ‘water’, the drying process of the SW has a lower impact so that the PB outperforms the SW only if the result is expressed per m^3. By breaking down the result to the measuring unit ‘plank’, the result switches in favor of the SW. The better result for the PB plank in the module ‘sawmill’ of the method EF can also be attributed to the the drying process of the SW planks. For this method it is, however, especially driven by the CO_2 emissions of the input ‘heat from renewable sources’.

Energy has the most important impact on the results of the two methods EF and MIPS. Regarding the EFORWOOD SIA energy only affects the indicator ‘energy use’, thus, this statement is only valid for this particular indicator. The assessment of energy consumption is handled differently by every method. The EF calculates the area which is needed to absorb the CO_2 emissions generated by the use of energy, such as fuel, electricity, heat from fossil sources and renewable sources. MIPS, on the other hand, looks at the resource input which is needed for the generation of the energy source in the categories ‘abiotic’, ‘biotic’, ‘water’, ‘air’ and ‘earth moved’. This value is then multiplied with the amount of energy used. For the EFORWOOD SIA, the indicator ‘energy use’ should, according to the data collection protocol (BERG, 2008), consider the amount of energy which enters the different processes along the process chain and the embodied energy to produce this energy. In the values taken from the EFORWOOD database, however, pre-process chains were not considered according to the data collector.

Data variability among the different data sources regarding energy was high for the modules ‘sawmill’ and ‘particleboard mill’. A high variation regarding energy use in the PB production industry was also confirmed by experts of the particleboard industry to reflect reality (personal communication, Austrian particleboard industry). Therefore, three different energy scenarios were calculated for those modules. The scenarios show that with differing energy scenario combinations the results for the methods EF and MIPS can change compared to the case when a same level of energy efficiency is assumed for the sawmill and the particleboard mill. For the EF method and the MIPS input category 'air', the overall result changes if in the process chain of the PB plank a good performance ('energy scenario 1') is assumed for the modules 'sawmill' and 'particleboard mill' and for the production of the SW plank a bad performance ('energy scenario 3') is assumed in the module sawmill. This signifies that the PB plank is assessed as better in comparison to the SW plank if a bad performance regarding energy efficiency is assumed for the SW plank in the module 'sawmill' compared to a PB plank which is produced very energy efficiently in the chain stages 'sawmill' and 'particleboard mill'. These observations show the importance of having reliable data, the necessity to base the calculations on the same data source for different products and to set the same system boundaries. This is especially relevant when products are compared that are calculated by different practitioners or institutions. If a high data variability reflects reality scenarios should be calculated. Only then, a clear statement can be made if one product performs better than the other.

Beside the energy scenarios, the 'scenario WB = 0' was calculated. This scenario tests the impact on the following change in assumption: in the basic assumption of this thesis the *rucksack* (resource input and processes for its production) of the wood by-products regarding the module 'forest', the transport way 1 and the module 'sawmill' is considered and assigned to the product PB. The wood by-products are thus seen as valuable resource with a range of uses and not as waste. In the 'scenario WB = 0', however, the wood by-products are assumed as waste. Their *rucksack* of the module 'forest', transport way 1 and the module 'sawmill' is fully assigned to the main output product of the sawmill, the SW. The transport of the wood by-products to the particleboard mill and the processes in the particleboard mill remain fully assigned to the PB.

The results gathered by calculating this scenario show that the result changes for the MIPS input category 'biotic' as well as for the EFORWOOD indicators 'gross value added (at factor cost)' and 'employment'. The MIPS input category 'biotic' favors the PB plank under this scenario; contrarily the indicators 'gross value added' and 'employment' favor the SW plank. Regarding the different process chain stages, the result switches compared to the basic assumption and favors the PB plank for the EF method and all MIPS input categories regarding the modules 'forest' and 'sawmill'. The EFORWOOD indicators switch to the opposite. For the module ''transport', the result changes for the indicators 'gross value added (at factor cost)' and 'production cost' compared to the case in which no scenario is assumed. The results for the EF method and MIPS stay the same in the module transport. Overall, the result from this particular scenario means that the assumption can change the overall result of the MIPS method and the EFORWOOD SIA method. Regarding the modules 'forest' and 'sawmill' the 'scenario WB = 0' can change the results of all three methods.

Problems arising within the calculation process concerned especially the data issue. As the EFORWOOD database does not provide all necessary data for the application of the other two methods, EFORWOOD data had to be complemented. Where the EFORWOOD data seemed implausible, e.g., for the indicator 'water use' or no EFORWOOD data were available as for e.g. for the fuel input regarding the tending process, completion was necessary. These conditions led to difficulties in the consistency concerning the processes and the system boundaries. Moreover, metadata were sometimes missing to specify certain processes. The latter problem applied equally to the data of the EFORWOOD database and of Hasch (2002); for example, neither data source gives an exact description of the considered processes in the sawmill. This brought along certain difficulties in terms of deciding which depth of analysis is possible with the available data so that the result of all three methods can be compared. Therefore, only the basic processes which take place in the forest, the sawmill and the particleboard mill were assumed. For a better consistency, EFORWOOD data were taken for all three methods and throughout the defined process chains if available and plausible. The missing transparency concerning the available data and their data sources had to be solved by means of expert estimations. This was applied to the data for the drying process of the sawmill. Moreover, the data of Hasch (2002) concerning the particleboard mill were tested by involving anonymously the Austrian particleboard industry.

Concerning energy use, differences in the two main data sources and other compared sources were overcome by calculating different energy scenarios. This decision was considered necessary because energy was identified as a major influence on the result. Furthermore, data variability of total energy use ranged for the sawmill within a factor of 8 (653 kWh/m^3 SW - 5456 kWh/m^3 SW) and for the particleboard mill within a factor of 6 (1049 kWh/m^3 PB - 6306 kWh/m^3 PB).

High differences in input data between the sawmill and the particleboard mill occurred also for the water use. The values in the data of Hasch (2002) which were taken for the calculation are 0.621kg/m^3 SW for the sawmill and 228.5 kg/m^3 PB for the particleboard mill. This big difference could be empirically evaluated for the sawmill with Stora Enso Timber Brand (2005), and for the particleboard mill through personal communication from the Austrian particleboard mill industry as being in the right magnitude. The data of EFORWOOD with 8105 kg/m^3 SW and 5625 kg/m^3 PB seemed to be implausibly high. Further investigations would have to be made on this input factor and different water scenarios could be calculated.

The described difficulties made it necessary to make assumptions which are described in detail in chapter 4 and 5. Within this research and the calculation processes, emphasis was specifically put on an uniform use of data for all three methods, uniform system boundaries and transparency of data sources and assumptions. However, as the EFORWOOD data were not fully validated at the time of accomplishing this thesis, the results have to be accepted with reservation and generalization is difficult to make due to the specific case study.

7.2 Comparison of the methods

The importance of available and reliable data, which appeared to be challenging as described above, is evaluated by one of the evaluation criteria.The analysis showed that the three methods can be equally estimated regarding this aspect. Hence, a score of 3 can be given for the criterion ‘based on available and reliable data’ as all three methods are affected by the same difficulties concerning the data. Regarding available data, EFORWOOD SIA has a slight advantage when it comes to the data requirements for the three methods. This advantage results from its general concept which does not consider pre-process chains but only expresses indicator values for the processes in the defined chain. As the data are the core of a credible result, a lot of emphasis should be put on this aspect. On the one hand, the choice of data sources and their reliability is up to the user of the method; on the other hand, the user relies in any case on the available data. Generally, databases are a possible source of data. However, there is still potential to make them more comprehensive. In addition, not all of them are freely accessible (e.g., Ecoinvent).

For the criterion ‘feasible within an adequate effort in time and with adequate costs’, the same score was assigned to the three methods as well. All three methods were evaluated as being feasible within an adequate effort in time, and as a burden but proportionate to its benefits. If the EFORWOOD database is fully validated and the ToSIA software is used, an advantage in this criterion for the EFORWOOD SIA is probable, compared to the two other methods.

With regard to all other criteria, each method has its strengths and weaknesses which imply recommendations towards the use of the method for specific applications:

The EF received once in the evaluation the highest score for one criterion. Two times the method was assigned the highest score compared to the other two methods. Its major strength turned out to be the communicability. The EF is a perfect tool to make people aware that our living space is limited and that each of our action has implications on approaching or exceeding this limit. The tool is already widely used for educational and awareness rising purposes and has still more potential to further do so.

As Huijbregts et al. (2008) could show, the EF is also a suitable tool for assessing the sustainability of products bearing in mind the weaknesses of the tool when representing some components such as mineral consumption or non-renewable resources. Therefore, the common criticism on the EF which is, that it is useful as a describing tool but not as an analytical tool (FERGUSON, 2002, p. 304), is not fully tenable. However, still unsolved questions exist in the scientific community, e.g., regarding the 'energy footprint' which is significant for the result. The scientific discussion is hence challenged by whether the EF can give answers to what it was developed for. This aspect brought a low score for the criterion 'give directionally robust information'. On the other hand, the EF was evaluated to be strong regarding the aspects 'universal' because it has a global target and can be applied not only to products but also to individuals and geographical entities. For the latter uses, the method is already applied globally.

For the criterion 'transparency of the calculation process and the data sources', the EF leads the way in comparison to the other two methods as official standards were elaborated by the Global Footprint Network. These standards contain both compulsory standards for a study certification by the Global Footprint Network and recommended guidelines (GLOBAL FOOTPRINT NETWORK, 2009, p. 1). Even though there is potential to integrate other aspects, the EF assesses only the environmental dimension of sustainability with the focus on land use. The economic and social dimensions are neglected in the method. For a more comprehensive conclusion on the sustainability of products other methods should hence complement the EF method. Moreover, attempts should be made to further develop the method in order to include aspects which have not been considered yet and to encourage the improvement of the key constants (KITZES et al., 2007, p. 4f).

MIPS is once assigned the highest possible score in the evaluation. The main strengths of the method turned out to be the potential to be used for the whole range of products which provide a service, for services themselves and also a variety of other applications, such as for licenses to evaluate resource use. A cross-border application is possible if data are available. In addition the method MIPS is strong regarding communicability.

The method successfully expresses the quantity of material flows. This is evaluated by the criterion 'give directionally robust information'. The transparency of the calculation process and the data sources are also given satisfactory as the method is well documented; even though some aspects as system boundaries could be further standardized.

Contrarily to the other two methods, the MIPS method provides a totally new approach to achieve environmental sustainability and hence countervails the common perception that environmental sustainability goes along with renouncement of the quality of life and economic losses. As it demands dematerialization in all areas of life, the three dimensions of sustainability are touched implicitly. The approach, however, would have to be complemented with other assessing methods to better indicate the impacts of dematerialization for the social and economic dimensions of sustainability. Still, the method is not an integrated approach as e.g. the EFORWOOD SIA.

A weakness of the method is that MIPS only looks at the quantity of material flows, the quality of material flows is not considered at all. This can have a significant impact on the environmental sustainability. Overall, efforts are made to make the MIPS concept more comprehensive by additionally integrating the 'ecotoxicity per service unit' and the 'area intensity per service unit'. The focus on input materials, which increasingly prevails the recent sustainability debate, is already well realized by the developers and makes the method hence a promising approach for the future.

The EFORWOOD SIA was twice assigned the highest score possible and twice it was the method with the highest score per criterion. The main strength of the EFORWOOD SIA is considering the three dimensions of sustainability and thus to be an integrated approach. It is the only indicator which explicitly considers social and economic aspects as well. This aspect makes it a sustainability assessment method, which concerning the coverage of different aspects does not have to be complemented by other methods for the purpose it was developed for. The method is also the most comprehensive in considering the main environmental input categories in its indicator set. Regarding the depth of analysis, however, the two other methods are more global than the EFORWOOD SIA as they consider pre-process chains, embodied in the production of a product, which the EFORWOOD SIA only does for some indicators.

A weakness of the method concerns the communicability. EFORWOOD SIA was not intended to reach the broader public, and cannot fulfill this task. In addition, expert knowledge is needed for the application of this method. As the method is scalable and the majority of the indicators are general, the method would also be applicable to other sectors and regions of the world, given that the database is adapted.

To get an aggregated result of the different indicators, measured in different units, they have to be brought to a common scale of dimensionless preference values (WOLFSLEHNER et al., 2006, p. 6). This can be done by an aggregation procedure e.g. a Cost Benefit Analysis or a Multi-Criteria Analysis, two tools which are provided by the EFORWOOD software. This step, however, was not part of this study.

In the Multi-Criteria Analysis, a weighting on the indicator importance and indicator values by the stakeholder or stakeholder group is done (WOLFSLEHNER et al., 2006, p. 8). The EFORWOOD SIA has thus the potential to become a suitable tool for sustainability impact assessments especially when the involvement of stakeholders is important. Overall, further refinement and an extension and validation of the database are, however, needed as the EFORWOOD SIA is not yet fully mature.

Regarding the three methods, a clear preference for one of the three methods is not possible to give. The EF and MIPS only consider the environmental dimension or, as for MIPS, touch the other two dimensions only implicitly. Therefore, they have to be complemented by other assessment methods to fulfill the sustainability demand as defined on the Earth summit on Environment and Development in Rio de Janeiro in 1992 (UNEP, 1992). EFORWOOD SIA on the other hand, is still in development and to date focused only on a specific sector.

8 Conclusion

In this thesis three sustainability assessment methods (Ecological Footprint, MIPS (Material Input Per Service Unit) and EFORWOOD Sustainability Impact Assessment) were compared and analyzed. The broader context therefore, are initiatives for sustainable production and consumption in Europe and particularly in Austria. This study should serve as a methodological background paper showing a case study on which the three methods were applied and the strengths and weaknesses of the methods are summarized.

The result from the application of the methods suggests that the overall result does not differ among the three methods regarding the environmental sustainability, which was assessed by the method Ecological Footprint, MIPS and the EFORWOOD indicators 'energy use, 'water use', 'transport' and 'greenhouse gas emissions': The SW plank is assessed as performing better than the PB plank except for the input category 'biotic' under the 'scenario WB = 0'.

It can be further concluded that for the economic and social dimensions of sustainability which was measured only by the EFORWOOD SIA on the contrary, the result is not as clear. The PB plank is evaluated as performing better for the indicator 'wages and salaries' and in the basic assumption also for the indicators 'gross value added' and 'employment'.

This demonstrates very well the often prevailing discrepancies between the economic/social and environmental dimension of sustainability. As the methods EF and MIPS only look at the environmental aspect of sustainability, they have to be complemented with other assessment tools to also take the other two dimensions into account. The results from the evaluation by means of the criteria catalogue showed further that the EFORWOOD SIA cannot significantly outscore the other methods regarding the other criteria even if it is the only integrated approach taking all three dimensions into account.

Concluding, all three methods have strengths and weaknesses, which make them more or less suitable for applying them on certain products and under certain conditions. The EF is a very good awareness rising tool that with some reservation may also be a good tool to analyze the sustainability of products. MIPS is a fundamentally different approach: It focuses on the material input and aims to reduce the resource use in all areas of life. It is thus a very suitable method to assess the human interference in the ecosphere by excessive resource use for production and consumption. The EFORWOOD SIA, on the other hand, is a new approach applied to assess the sustainability impacts of the forestry-wood sector. It is a good tool to assist policy and decision making by providing a profound collection of information and faciliating different weighting and aggregation procedures for a holistic assessment. Even though still in its early stage, this method has the potential to be extended to other sectors and to other regions of the world.

Summarized it can be said that the three analyzed sustainability assessment methods assess sustainability from different but complementary perspectives and none of the methods is able to capture the whole picture. It can therefore be concluded that a combination of different approaches would be best to comprehensively assess the sustainability of a product. Best et al. (2008) also point out that a basket of indicators can better cover the width of sustainability than a stand-alone indicator. For this reason it could also be imaginable to integrate the MIPS concept one day into the EFORWOOD SIA by extending the indicator ‘resource use’.

From the experience in this thesis it can further be concluded that assumptions as well as available and reliable data for the application are just as important as the method itself: Available and reliable data are crucial for any sustainability assessment of products if the goal is to create a credible result.

Thus, a vision would be to have a European-wide, reliable, updated and freely accessible database which contains data from European enterprises and statistics and can be used as base for European-wide sustainability assessments for products.

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Annex 1: Assumption of raw densities and conversion factors

Assumptions of raw densities:

Raw density of spruce round wood ub: 427kg/ m^3 (KOOPERATIONSPLATTFORM FORST HOLZ PAPIER, 2006, p.109)

Conversion factors needed from raw data to needed data for all three methods:

1 m^3 ub = 1,1 m^3ob
1 t atro[19] ob = 2,33 solid cubic meter spruce wood
1MJ= 0,278 kWh

Conversion factors for the calculation of the methods Ecological Footprint and MIPS:

Solid wood:

<u>Input data energy:</u>

MJ/t atro round wood ob to kWh/m^3 sawn timber = *1,6[20]*0,427*0,278
MJ/m^3 round wood ub to kWh/m^3 sawn timber =*1,6*1,1*0,278

<u>Input data other materials:</u>

kg/ t atro ob to kg/ m^3 sawn timber= * 1,6 * 0,427

Conversion factors for the calculation of the EFORWOOD SIA:

x/ha/year to x/m^3 RW ub: /654[21]*0,8
x[22]/tons to x/m^3 RW ub: *0,427
x/m^3 SW to x/m^3 RW ub: /1,6 /1,1
x/m^3 RW ob to x/m^3 RW ub: /1,1

Employment:
absolute number of persons in full-time equivalents which equals person years (py) in reference year per reporting unit

py/ ha to h/m^3 ub: /1000 * 1600
py/ m^3 ub to h/m^3 ub: *1600
py/t to h/ m^3 ub: * 0,427 * 1600

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[19] absolute dry
[20] To produce 1m^3 of sawn timber 1.6 m^3 round wood are necessary (see also process chain of the solid wood)
[21] From yield table: Bavarian spruce quality 10
[22] ‘X’ stands for the unit in which any indicator value is expressed as kg, Euros etc.

Annex 2: Input data for the methods EF and MIPS

Input data for the application of the method EF on the products solid wood and particleboard regarding the module 'forest'

Inputs module forest		**ha/m³ RW ob**	**kWh/m³ RW ob**	**kg/m³ RW ob**	**kg/m³ PB**	**CO_2 rucksack [t O_2/kWh]**	**CO_2 rucksack [t O_2/kg]**	**Data source amount of input**	**Data source CO_2 values**
Direct area use: forest		1,90E-03						area calculation: forest assumptions EFORWOOD	
Raw material produced	**wood logs including moisture**			840,763			0,00E+00	input amount: Hasch, 2002	CO_2 emissions from biogenic carbon sources are not considered as defined in PAS 2050; BSI 2008
	pulpwood				100,667		0,00E+00		
Operating/ auxiliary materials	chain oil			0,135			8,85E-05	input amount: Riezinger, 2008 and Westermayer, 2006	CO_2:Fette und Öle (fats and oils); Hasch, 2002
	sum oil motor saw			0,135			8,85E-05		CO_2:Fette und Öle (fats and oils); Hasch, 2002
	motor oil			0,009			8,85E-05	input amount: Schweinle and Thoroe, 2001	CO_2:Fette und Öle (fats and oils); Hasch, 2002
	hydraulic oil			0,009			8,85E-05		CO_2:Fette und Öle (fats and oils); Hasch, 2002
	chain lubricating oil			0,045			8,85E-05		CO_2:Fette und Öle (fats and oils); Hasch, 2002
	sum oil harvester			0,063			8,85E-05		CO_2:Fette und Öle (fats and oils); Hasch, 2002
	fuel input plantation		0,382			2,66E-04		input amount: Schweinle, 2000	
	fuel input fostering		0,300			2,66E-04			
	fuel input harvesting motormanual round wood for sawmill (RW)		4,129			2,66E-04			
	fuel input skidding round wood for sawmill (RW)		6,479			2,66E-04			

Inputs module forest		ha/m³ RW ob	kWh/m³ RW ob	kg/m³ RW ob	kg/m³ PB	CO_2 rucksack [t O_2/kWh]	CO_2 rucksack [t O_2/kg]	Data source amount of input	Data source CO_2 values
Energy input	fuel input harvesting fully mechanized pulpwood (PW)		11,000			2,66E-04		input amount: EFORWOOD database, 2009	CO_2: Diesel; RETEC group, 2003
	fuel input forwarding with forwarder pulpwood (PW)		9,491			2,66E-04			
	sum fuel (plantation, fostering, harvest, skidding) round wood for sawmill (RW)		11,291			2,66E-04		input amount: Schweinle, 2000 and EFORWOOD database, 2009	
	sum fuel (plantation, fostering, harvest, forwarding) pulpwood (PW)		21,173			2,66E-04			

Legend:
RW: round wood
ob: over bark
PB: particleboard

Input data for the application of the method EF on the products solid wood and particleboard regarding the module 'transport'

Inputs module transport		**km**	**CO_2 rucksack [t CO_2/tkm]**	**Data source amount of input**	**Data source CO_2 values**
Transport 1	**distance**	40		input amount: EFORWOOD database, 2009	
	ton kilometers		1,45E-04		CO_2: LKW 2005 (truck transport); Umweltbundesamt, 2007
Transport 2	**distance**	100		input amount:EFORWOOD database, 2009	
	ton kilometers		1,45E-04		CO_2: LKW 2005 (truck transport); Umweltbundesamt, 2007
Transport 3	**distance**	146		input amount: EFORWOOD database, 2009	
	ton kilometers		1,45E-04		CO_2: LKW 2005 (truck transport); Umweltbundesamt, 2007
Transport 4	**distance**	106		input amount: Hasch, 2002	
	ton kilometers		1,45E-04		CO_2: LKW 2005 (truck transport); Umweltbundesamt, 2007

Input data for the application of the method EF on the products solid wood and particleboard regarding the module 'sawmill'

Inputs module sawmill		**ha/m³ ST**	**kWh/m³ RW ob**	**kg/m³ RW ob**	**CO_2 rucksack [t O_2/kWh]**	**CO_2 rucksack [t O_2/kg]**	**Data source amount of input**	**Data source CO_2 values**
Direct area use: sawmill		3,00E-05					area use: personal communication Austrian sawmill	
Auxiliary and operating materials	**colours**			0,001		1,64E-03	input amount: Hasch, 2002	CO_2: Deckfarbe (color);Umweltbundesamt, 2008
	saw blades, stellites, steel strips			0,255		2,57E-03		CO_2: Blasstahl (steel); Hasch, 2002
	transmisssion fluid			0,015		8,85E-05		CO_2: Fette und Öle (fats and oils); Hasch, 2002
	hydraulic oil			0,016		8,85E-05		CO_2: Fette und Öle (fats and oils); Hasch, 2002
	motor oil			0,005		8,85E-05		CO_2: Fette und Öle (fats and oils); Hasch, 2002
	lubricating oil			0,054		8,85E-05		CO_2: Fette und Öle (fats and oils); Hasch, 2002
	sum oils			0,090		8,85E-05		CO_2: Fette und Öle (fats and oils); Hasch, 2002
	sum fats			0,003		8,85E-05		CO_2: Fette und Öle (fats and oils); Hasch, 2002
	heat from renewable sources Energy scenario 1		306,137		3,71E-04			CO_2: Feuerung Holzschnitzel (combustion of chips); Hasch, 2002
	heat from renewable sources Energy scenario 2		1431,723		3,71E-04			
	heat from renewable sources Energy scenario 3		2557,309		3,71E-04			
	heat from fossil sources Energy scenario 1		16,327		4,24E-05			CO_2: Öl leicht EU (oil light European Union); Umweltbundesamt, 2008
	heat from fossil sources Energy scenario 2		76,359		4,24E-05			

Inputs module sawmill		ha/m³ ST	kWh/m³ RW ob	kg/m³ RW ob	CO_2 rucksack [t O_2/kWh]	CO_2 rucksack [t O_2/kg]	Data source amount of input	Data source CO_2 values
Energy input	**heat from fossil sources** Energy scenario 3		136,390		4,24E-05		input amount: Hasch, 2002 complemented with own calculation of drying process and EFORWOOD database, 2009; see energy scenario descriptions chapter 5.5	
	direct fuel use Energy scenario 1		73,473		2,66E-04			CO_2: Diesel; RETEC group, 2003
	direct fuel use Energy scenario 2		343,613		2,66E-04			
	direct fuel use Energy scenario 3		613,754		2,66E-04			
	electricity use Energy scenario 1		12,245		3,75E-04			CO_2: average electricity mix Austria; Bußwald et al., 2006
	electricity use Energy scenario 2		57,269		3,75E-04			
	electricity use Energy scenario 3		102,292		3,75E-04			

Legend:
RW: round wood
ob: over bark
ST: sawn timber

Input data for the application of the method EF on the products solid wood and particleboard regarding the module ‘particleboard mill’

Inputs module particleboard mill		**ha/m³ PB**	**kWh/m³ PB**	**kg/m³ PB**	**CO_2 rucksack [t O_2/kWh]**	**CO_2 rucksack [t O_2/kg]**	**Data source amount of input**	**Data source CO_2 values**
Direct area use: particleboard mill		3,00E-05					area use: personal communication Austrian particleboard mill	
Preliminary products	sum wood by-products			459,867		0,00E+00	input amount: Hasch, 2002	CO_2 emissions from biogenic carbon sources are not considered as defined in PAS 2050; BSI 2008
	sum recycled wood			99,867		0,00E+00		
Auxiliary and operating materials	**lamination agent**			54,600		1,32E-03		CO_2: Formaldehyd (formaldehyde); Hasch, 2002
	formaldehyde- catcher substances (techn.urea)			0,620		8,16E-04		CO_2: Harnstoff (urea); Umweltbundesamt, 2008
	hardener (ammoniumnitrate)			0,420		6,23E-04		CO_2: Ammoniumnitrat (ammoniumnitrate); Umweltbundesamt, 2008
	hydrophobizing substances (paraffin)			2,500		4,87E-05		CO_2: Hydrophobierungsmittel (hydrophobizing substances); Hasch, 2002
	marker color for organic solvents			0,002		1,64E-03		CO_2: Deckfarbe (colour); Umweltbundesamt, 2008
	other marker colour			0,011		1,64E-03		
	sum marker color			0,013		1,64E-03		
	thermo/heat transfer oil			0,015		8,85E-05		CO_2:Fette und Öle (fats and oils); Hasch, 2002
	hydraulic oil (chipping machine)			0,028		8,85E-05		
	other hydraulic oil			0,016		8,85E-05		
	motor oil and transmission oil			0,012		8,85E-05		
	anti-corrosion oil			0,005		8,85E-05		

Inputs module particleboard mill		**ha/m³ PB**	**kWh/m³ PB**	**kg/m³ PB**	**CO_2 rucksack [t O_2/kWh]**	**CO_2 rucksack [t O_2/kg]**	**Data source amount of input**	**Data source CO_2 values**
	other oil			0,003		8,85E-05		
	sum oils			0,079		8,85E-05		
	sum fats			0,009		8,85E-05		
	sum lubricants			0,088		8,85E-05		
	tools for chipping machine			0,041		2,57E-03		CO_2:Blasstahl (steel); Hasch, 2002
	steel strips			0,440		2,57E-03		
	compression mats			0,002		2,57E-03		
Energy input	**heat from renewable sources** Energy scenario 1		671,470		3,71E-04		input amount: Hasch, 2002 and EFORWOOD database, 2009; see energy scenario descriptions chapter 5.5	CO_2: Feuerung Holzschnitzel (combustion of chips); Hasch, 2002
	heat from renewable sources Energy scenario 2		2353,675		3,71E-04			
	heat from renewable sources Energy scenario 3		4035,880		3,71E-04			
	heat from fossil sources Energy scenario 1		62,950		4,24E-05			CO_2: Öl leicht EU; Umweltbundesamt, 2008
	heat from fossil sources Energy scenario 2		220,657		4,24E-05			
	heat from fossil sources Energy scenario 3		378,364		4,24E-05			
	direct fuel use Energy scenario 1		272,785		2,66E-04			CO_2: Diesel; RETEC group, 2003
	direct fuel use Energy scenario 2		956,180		2,66E-04			
	direct fuel use Energy scenario 3		1639,576		2,66E-04			

Inputs module particleboard mill		ha/m³ PB	kWh/m³ PB	kg/m³ PB	CO_2 rucksack [t O_2/kWh]	CO_2 rucksack [t O_2/kg]	Data source amount of input	Data source CO_2 values
	electricity use Energy scenario 1		41,967		3,75E-04			CO_2: average electricity mix Austria; Bußwald et al., 2006
	electricity use Energy scenario 2		147,105		3,75E-04			
	electricity use Energy scenario 3		252,242		3,75E-04			
Legend: PB: particleboard								

Input data for the application of the method MIPS for the products solid wood and particleboard regarding the module ‘forest’

Inputs module forest		**kWh/m³ RW ob**	**kg/m³ RW ob**	**kg/m³ PB**	**MI factor abiotic (t/t)**	**MI factor biotic (t/t)**	**MI factor water (t/t)**	**MI factor air (t/t)**	**Data source amount of input**	**Data source MI factor**
Raw material produced	**wood logs including moisture**		840,763		0,000	1,000	0,000	0,000	input amount: Hasch, 2002	MI: direct wood input
	pulpwood			100,667	0,000	1,000	0,000	0,000		
Auxiliary and operating materials	chain oil		0,135		1,220	0,000	4,300	0,008	input amount: Riezinger, 2008 and Westermayer, 2006	MI: crude oil; Wuppertal Institute for Climate, Environment and Energy, 2003
	sum oil motor saw		0,135		1,220	0,000	4,300	0,008		
	motor oil		0,009		1,220	0,000	4,300	0,008	input amount: Schweinle and Thoroe, 2001	
	hydraulic oil		0,009		1,220	0,000	4,300	0,008		
	chain lubricating oil		0,045		1,220	0,000	4,300	0,008		
	sum oil harvester		0,063		1,220	0,000	4,300	0,008		
Energy input	fuel input plantation	0,382			1,360	0,000	9,700	0,019	input amount: Schweinle, 2000	
	fuel input fostering	0,300			1,360	0,000	9,700	0,019		
	fuel input harvesting motormanual round wood for sawmill (RW)	4,129			1,360	0,000	9,700	0,019		
	fuel input skidding round wood for sawmill (RW)	6,479			1,360	0,000	9,700	0,019		

Inputs module forest		kWh/m³ RW ob	kg/m³ RW ob	kg/m³ PB	MI factor abiotic (t/t)	MI factor biotic (t/t)	MI factor water (t/t)	MI factor air (t/t)	Data source amount of input	Data source MI factor
	fuel input harvesting fully mechanized pulpwood (PW)	11,000			1,360	0,000	9,700	0,019	input amount: EFORWOOD database, 2009	MI: Diesel; Wuppertal Institute for Climate, Environment and Energy, 2003
	fuel input forwarding with forwarder pulpwood (PW)	9,491			1,360	0,000	9,700	0,019		
	sum fuel (plantation, fostering, harvest, skidding) round wood for sawmill (RW)	11,291			1,360	0,000	9,700	0,019	input amount Schweinle, 2000 and EFORWOOD database, 2009	
	sum fuel (plantation, fostering, harvest, skidding) pulpwood (PW)	21,173			1,360	0,000	9,700	0,019		

Legend:
RW: round wood
ob: over bark
PB: particleboard
MI: material intensity value

Input data for the application of the method MIPS for the products solid wood and particleboard regarding the module ‘transport’

Inputs module transport		**km**	**MI factor abiotic (t/t)**	**MI factor biotic (t/t)**	**MI factor water (t/t)**	**MI factor air (t/t)**	**Data source amount of input**	**Data source MI factor**
Transport 1	distance	40					input amount: EFORWOOD database, 2009	
	ton kilometers		0,980	0,000	7,070	0,230		MI:Transport/tkm; Schmidt-Bleek, 2000
Transport 2	distance	100					input amount: EFORWOOD database, 2009	
	ton kilometers		0,980	0,000	7,070	0,230		MI:Transport/tkm; Schmidt-Bleek, 2000
Transport 3	distance	146					input amount: EFORWOOD database, 2009	
	ton kilometers		0,980	0,000	7,070	0,230		MI:Transport/tkm; Schmidt-Bleek, 2000
Transport 4	distance	106					input amount: Hasch, 2002	
	ton kilometers		0,980	0,000	7,070	0,230		MI:Transport/tkm; Schmidt-Bleek, 2000

Input data for the application of the method MIPS for the products solid wood and particleboard regarding the module 'sawmill'

Inputs module sawmill			**kWh/m³ RW ob**	**kg/m³ RW ob**	**MI factor abiotic (t/t)**	**MI factor biotic (t/t)**	**MI factor water (t/t)**	**MI factor air (t/t)**	**Data source amount of input**	**Data source MI factor**
Auxiliary and operating materials	**water**			0,683	0,010	0,000	1,300	0,001	input amount: Hasch, 2002	MI: water; Wuppertal Institute for Climate, Environment and Energy, 2003
	colours			0,001	2,200	0,000	0,000	0,000		MI: Wuppertal Institute for Climate, Environment and Energy, s.a., Richtwert Farbe Wand
	saw blades, stellites, steel strips			0,255	9,320	0,000	81,900	0,772		MI: plate, hot dipped, galvanised, basic oxygen steel; Wuppertal Institute for Climate, Environment and Energy, 2003
	transmisssion fluid			0,015	1,220	0,000	4,300	0,008		MI: crude oil; Wuppertal Institute for Climate, Environment and Energy, 2003
	hydraulic oil			0,016	1,220	0,000	4,300	0,008		
	motor oil			0,005	1,220	0,000	4,300	0,008		
	lubricating oil			0,054	1,220	0,000	4,300	0,008		
	sum oils			0,090	1,220	0,000	4,300	0,008		
	sum fats			0,003	1,220	0,000	4,300	0,008		
Energy input	**heat from renewable sources**	Energy scenario 1	306,137		0,000	0,000	0,000	1,080		MI: air needed by combustion own calculation with information by Recknagel et al., 2009 and Neubarth & Kaltschmitt, 2000
		Energy scenario 2	1431,723		0,000	0,000	0,000	1,080		
		Energy scenario 3	2557,309		0,000	0,000	0,000	1,080		
	heat from fossil sources	Energy scenario 1	16,327		1,360	0,000	9,400	0,019		MI: heating oil light; Wuppertal Institute for
		Energy scenario 2	76,359		1,360	0,000	9,400	0,019		

Inputs module sawmill			**kWh/m³ RW ob**	**kg/m³ RW ob**	**MI factor abiotic (t/t)**	**MI factor biotic (t/t)**	**MI factor water (t/t)**	**MI factor air (t/t)**	**Data source amount of input**	**Data source MI factor**
		Energy scenario 3	136,390		1,360	0,000	9,400	0,019	input amount: Hasch, 2002 complemented with own calculation of drying process and EFORWOOD database, 2009; see energy scenario descriptions chapter 5.5	Climate, Environment and Energy, 2003
	direct fuel use	Energy scenario 1	73,473		1,360	0,000	9,700	0,019		MI: Diesel oil; Wuppertal Institute for Climate, Environment and Energy, 2003
		Energy scenario 2	343,613		1,360	0,000	9,700	0,019		
		Energy scenario 3	613,754		1,360	0,000	9,700	0,019		
	electricity use	Energy scenario 1	12,245		1,190	0,000	33,200	0,330		MI: electricity; Hacker, 2003
		Energy scenario 2	57,269		1,190	0,000	33,200	0,330		
		Energy scenario 3	102,292		1,190	0,000	33,200	0,330		

Legend:
RW: round wood
ob: over bark
MI: material intensity value

Input data for the application of the method MIPS for the products solid wood and particleboard regarding the module 'particleboard mill'

Inputs module particleboard mill		kWh/m³ PB	kg/m³ PB	MI factor abiotic (t/t)	MI factor biotic (t/t)	MI factor water (t/t)	MI factor air (t/t)	Data source amount of input	Data source MI factor
Preliminary products	sum wood by-products		459,867	0,000	1,000	0,000	0,000	input amount: Hasch, 2002	MI: direct wood input
	sum recycled wood		99,867	0,000	0,000	0,000	0,000		MI: Recycled wood= defined as 0
Auxiliary and operating materials	**lamination agent**		54,600	1,110	0,000	30,000	0,980		MI: formaldehyde; Wuppertal Institute for Climate, Environment and Energy, 2003
	formaldehyde- catcher substances (techn.urea)		0,620	3,450	0,000	44,600	1,820		MI: urea; Wuppertal Institute for Climate, Environment and Energy, 2003
	hardener (ammoniumnitrate)		0,420	1,430	0,000	58,000	0,990		MI: liquid ammonium nitrate; Wuppertal Institute for Climate, Environment and Energy, 2003
	hydrophobizing substances (paraffin)		2,500	1,220	0,000	4,300	0,008		MI: crude oil; Wuppertal Institute for Climate, Environment and Energy, 2003
	process water (public grid)		96,200	0,010	0,000	1,300	0,001		MI: water; Wuppertal Institute for Climate, Environment and Energy, 2003
	process water (pond)		78,900	0,010	0,000	1,300	0,001		
	other process water		53,400	0,010	0,000	1,300	0,001		
	sum process water		228,500	0,010	0,000	1,300	0,001		
	marker colour for organic solvents		0,002	2,200	0,000	0,000	0,000		MI: Wuppertal Institute for Climate, Environment and Energy, s.a., Richtwert Farbe Wand
	other marker colour		0,011	2,200	0,000	0,000	0,000		
	sum marker colour		0,013	2,200	0,000	0,000	0,000		
	tools for chipping machine		0,041	9,320	0,000	81,900	0,772		MI: plate, hot dipped, galvanised, basic oxygen steel; Wuppertal Institute for Climate, Environment and Energy, 2003
	steel strips		0,440	9,320	0,000	81,900	0,772		
	compression mats		0,002	9,320	0,000	81,900	0,772		

Inputs module particleboard mill			kWh/m³ PB	kg/m³ PB	MI factor abiotic (t/t)	MI factor biotic (t/t)	MI factor water (t/t)	MI factor air (t/t)	Data source amount of input	Data source MI factor
	thermo/heat transfer oil			0,015	1,220	0,000	4,300	0,008		MI: crude oil; Wuppertal Institute for Climate, Environment and Energy, 2003
	hydraulic oil (chipping machine)			0,028	1,220	0,000	4,300	0,008		
	other hydraulic oil			0,016	1,220	0,000	4,300	0,008		
	motor oil and transmission oil			0,012	1,220	0,000	4,300	0,008		
	anti-corrosion oil			0,005	1,220	0,000	4,300	0,008		
	other oil			0,003	1,220	0,000	4,300	0,008		
	sum oils			0,079	1,220	0,000	4,300	0,008		
	sum fats			0,009	1,220	0,000	4,300	0,008		
	sum lubricants			0,088	1,220	0,000	4,300	0,008		
Energy input	**heat from renewable sources**	Energy scenario 1	671,470		0,000	0,000	0,000	1,080	input amount: Hasch, 2002 and EFORWOOD database, 2009; see energy scenario descriptions chapter 5.5	MI: air needed by combustion own calculation with information by Recknagel et al., 2009 and Neubarth & Kaltschmitt, 2000
		Energy scenario 2	2353,675		0,000	0,000	0,000	1,080		
		Energy scenario 3	4035,880		0,000	0,000	0,000	1,080		
	heat from fossil sources	Energy scenario 1	62,950		1,360	0,000	9,400	0,019		MI: heating oil light; Wuppertal Institute for Climate, Environment and Energy, 2003
		Energy scenario 2	220,657		1,360	0,000	9,400	0,019		
		Energy scenario 3	378,364		1,360	0,000	9,400	0,019		

Inputs module particleboard mill			kWh/m³ PB	kg/m³ PB	MI factor abiotic (t/t)	MI factor biotic (t/t)	MI factor water (t/t)	MI factor air (t/t)	Data source amount of input	Data source MI factor
	direct fuel use	Energy scenario 1	272,785		1,360	0,000	9,700	0,019		MI: Diesel oil; Wuppertal Institute for Climate, Environment and Energy, 2003
		Energy scenario 2	956,180		1,360	0,000	9,700	0,019		
		Energy scenario 3	1639,576		1,360	0,000	9,700	0,019		
	electricity use	Energy scenario 1	41,967		1,190	0,000	33,200	0,330		MI: electricity; Hacker, 2003
		Energy scenario 2	147,105		1,190	0,000	33,200	0,330		
		Energy scenario 3	252,242		1,190	0,000	33,200	0,330		

Legend:
PB: particleboard
MI: material intensity value

Annex 3: Raw data for the EFORWOOD SIA

Raw data for the application of the EFORWOOD SIA for the product solid wood regarding the module 'forest'

Processes / Indicators			1000144 Spruce regeneration		1000145 Development of Young spruce		1000146 Dev. Spruce in medium phase		1000147 Adult spruce development		1000148 Harvesting motormanual, DBH >35 cm slope <= 30		1000533 Skidding, DBH >35 cm slope <= 30		Data source
Indicator name		**Unit**	**Indica-tor value**	**Repor-ting unit**	**Indica-tor value**	**Repor-ting unit**	**Indica-tor value**	**Repor-ting unit**	**Indica-tor value**	**Repor-ting unit**	**Indicator value**	**Reporting unit**	**Indica-tor value**	**Repor-ting unit**	
Gross value added (at factor cost)		€	-14,192	/ha and year	0,000	/ha and year	562,511	/ha and year	1480,485	/ha and year	22,000	/m³ RW ub	22,000	/m³ RW ub	EFORWOOD database, 2009, data modified for processes: 'Harvesting motormanual', 'Skidding', 'Harvesting fully mechanised', 'Forwarding with forwarder'
Production cost		€	21,673	/ha and year	0,775	/ha and year	25,850	/ha and year	25,850	/ha and year	15,000	/m³ RW ub	15,000	/m³ RW ub	
Energy use	Energy scenario 1	kWh	0,382	/m³ RW ob	0,300	/m³ RW ob	0,000	/ha and year	0,000	/ha and year	3,754	/m³ RW ub	5,890	/m³ RW ub	EFORWOOD database, 2009 and Schweinle, 2000 for processes 'Spruce regeneration' and 'Development of young spruce'
	Energy scenario 2	kWh	0,382	/m³ RW ob	0,300	/m³ RW ob	0,000	/ha and year	0,000	/ha and year	3,754	/m³ RW ub	5,890	/m³ RW ub	
	Energy scenario 3	kWh	0,382	/m³ RW ob	0,300	/m³ RW ob	0,000	/ha and year	0,000	/ha and year	3,754	/m³ RW ub	5,890	/m³ RW ub	
Water use		m³	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/m³ RW ub	0,000	/m³ RW ub	EFORWOOD database, 2009
Employment		absolute number of persons in full-time equivalents in reference year per reporting unit	1,77E-04	/ha and year	8,59E-06	/ha and year	2,86E-04	/ha and year	2,86E-04	/ha and year	1,27E-03	/m³ RW ub	1,99E-04	/m³ RW ub	
Occupational accidents		absolute number per 1000 employees per reporting unit	1,98E-05	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	6,96E-05	/m³ RW ub	8,03E-06	/m³ RW ub	
Wages and salaries total		€	5,139	/ha and year	0,388	/ha and year	12,925	/ha and year	12,925	/ha and year	5,368	/m³ RW ub	0,985	/m³ RW ub	
Greenhouse gas emissions		kg CO_2 equivalents	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	1,085	/m³ RW ub	1,869	/m³ RW ub	

Raw data for the application of the EFORWOOD SIA for the product particleboard regarding the module ‘forest’

Indicators \ Processes			1000144 Spruce regeneration		1000145 Development of Young spruce		1000146 Dev. Spruce in medium phase		1000147 Adult spruce development		1000143 Harvesting fully mechanised (Spruce, DBH <= 35 cm; Slope <= 30 %)		1000531 Forwarding with forwarder (Spruce, DBH <= 35 cm; Slope <= 30 %)		Data source
Indicator name		Unit	Indica-tor value	Repor-ting unit	Indica-tor value	Repor-ting unit	Indica-tor value	Repor-ting unit	Indica-tor value	Repor-ting unit	Indicator value	Reporting unit	Indicator value	Reporting unit	
Gross value added (at factor cost)		€	-14,192	/ha and year	0,000	/ha and year	562,511	/ha and year	1480,485	/ha and year	5,000	/m³ RW ub	5,000	/m³ RW ub	EFORWOOD database, 2009, data modified for pro-cesses: 'Harvesting motormanual', 'Skid-ding', 'Harvesting fully mechanised', 'Forwar-ding with forwarder'
Production cost		€	21,673	/ha and year	0,775	/ha and year	25,850	/ha and year	25,850	/ha and year	10,000	/m³ RW ub	10,000	/m³ RW ub	
Energy use	Energy scenario 1	kWh	0,382	/m³ RW ob	0,300	/m³ RW ob	0,000	/ha and year	0,000	/ha and year	10,000	8,628	5,890	/m³ RW ub	EFORWOOD database, 2009 and Schweinle, 2000 for processes 'Spruce regeneration' and 'Development of young spruce'
	Energy scenario 2	kWh	0,382	/m³ RW ob	0,300	/m³ RW ob	0,000	/ha and year	0,000	/ha and year	10,000	8,628	5,890	/m³ RW ub	
	Energy scenario 3	kWh	0,382	/m³ RW ob	0,300	/m³ RW ob	0,000	/ha and year	0,000	/ha and year	10,000	8,628	5,890	/m³ RW ub	
Water use		m³	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/m³ RW ub	0,000	/m³ RW ub	EFORWOOD database, 2009
Employment		absolute number of persons in full-time equivalents in reference year per reporting unit	1,77E-04	/ha and year	8,59E-06	/ha and year	2,86E-04	/ha and year	2,86E-04	/ha and year	1,54E-04	/m³ RW ub	1,85E-04	/m³ RW ub	
Occupational accidents		absolute number per 1000 employees per reporting unit	1,98E-05	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	6,75E-06	/m³ RW ub	2,01E-05	/m³ RW ub	
Wages and salaries total		€	5,139	/ha and year	0,388	/ha and year	12,925	/ha and year	12,925	/ha and year	1,142	/m³ RW ub	1,190	/m³ RW ub	
Greenhouse gas emissions		kg CO_2 equivalents	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	0,000	/ha and year	3,174	/m³ RW ub	2,739	/m³ RW ub	

Raw data for the application of the EFORWOOD SIA for the products solid wood and particleboard regarding the module 'transport'

Processes / Indicators			1000152 Transport of spruce long logs		1000575 Transport of spruce pulpwood		1000168 Transport of chips		Transport of recycled wood		Data source
Indicator name		**Unit**	**Indicator value**	**Reporting unit**	**Indicator value**	**Reporting unit**	**Indicator value**	**Reporting unit**	**Indicator value**	**Reporting unit**	
Gross value added (at factor cost)		€	40,152	/m³ RW ub	13,899	/m³ RW ub	7,663	/ton	13,899	/m³ RECW	EFORWOOD database, 2009, process 'Transport of recycled wood' added and indicator values assumed to be the same as for 'Transport of spruce pulpwood'
Production cost		€	53,710	/m³ RW ub	57,525	/m³ RW ub	15,557	/ton	57,525	/m³ RECW	
Energy use	Energy scenario 1	kWh	10,278	/m³ RW ub	22,402	/m³ RW ub	43,480	/ton	22,402	/m³ RECW	
	Energy scenario 2	kWh	10,278	/m³ RW ub	22,402	/m³ RW ub	43,480	/ton	22,402	/m³ RECW	
	Energy scenario 3	kWh	10,278	/m³ RW ub	22,402	/m³ RW ub	43,480	/ton	22,402	/m³ RECW	
Water use		m³	0,000	/m³ RW ub	0,000	/m³ RW ub	0,000	/ton	0,000	/m³ RECW	
Transport distance		km	40,000	/m³ RW ub	100,000	/m³ RW ub	146,000	/ton	106,000	/m³ RECW	EFORWOOD database, 2009 and Hasch, 2002 for process 'Transport of recyled wood'
Employment		absolute number of persons in full-time equivalents in reference year per reporting unit	1,24E-04	/m³ RW ub	6,94E-04	/m³ RW ub	1,37E-04	/ton	6,94E-04	/m³ RECW	EFORWOOD database, 2009
Occupational accidents		absolute number per 1000 employees per reporting unit	3,35E-05	/m³ RW ub	1,88E-04	/m³ RW ub	2,55E-09	/ton	1,88E-04	/m³ RECW	
Wages and salaries total		€	2,170	/m³ RW ub	2,029	/m³ RW ub	4,530	/ton	2,029	/m³ RECW	
Greenhouse gas emissions		kg CO_2 equivalents	2,781	/m³ RW ub	6,061	/m³ RW ub	12,380	/ton	6,061	/m³ RECW	

Raw data for the application of the EFORWOOD SIA for the products solid wood and particleboard regarding the module ‘sawmill’

Processes / **Indicators**			**1000157 mill gate: Rundwood sorting and transporting car**		**1000161 Softwood sawmill medium 50000-150000 m³ band saw**		**Data source**
Indicator name		**Unit**	**Indicator value**	**Reporting unit**	**Indicator value**	**Reporting unit**	
Gross value added (at factor cost)		€	0,000	/m³ RW ub	0,946	/m³ RW ub	EFORWOOD database, 2009
Production cost		€	2,250	/m³ RW ub	80,883	/m³ RW ub	
Energy use	Energy scenario 1	kWh	6,450	/m³ RW ub	401,732	/m³ RW ob	Hasch, 2002 complemented with own calculation of drying process and EFORWOOD database, 2009; see energy scenario descriptions chapter 5.5
	Energy scenario 2	kWh	6,450	/m³ RW ub	1902,514	/m³ RW ob	
	Energy scenario 3	kWh	6,450	/m³ RW ub	3403,295	/m³ RW ob	
Water use		m³	0,000	/m³ RW ub	0,621	/m³ RW ob	Hasch, 2002
Employment		absolute number of persons in full-time equivalents in reference year per reporting unit	1,67E-05	/m³ RW ub	6,67E-04	/ton	EFORWOOD database, 2009
Occupational accidents		absolute number per 1000 employees per reporting unit	0,000	/m³ RW ub	5,08E-05	/ton	
Wages and salaries total		€	0,578	/m³ RW ub	20,064	/ton	
Greenhouse gas emissions		kg CO_2 equivalents	3,783	/m³ RW ub	142,901	/m³ST	

Raw data for the application of the EFORWOOD SIA for the product particleboard regarding the module ‘particleboard mill’

Indicators / Processes			1000158 Particleboard mill gate (from pulpwood to short logs sorted)		1000165 Particleboard mill		Data source
		Unit	**Indicator value**	**Unit**	**Indicator value**	**Unit**	
Gross value added (at factor cost)		€	0,000	/m³ input	-20,328	/m³ input	EFORWOOD database, 2009
Production cost		€	3,900	/m³ input	106,700	/m³ input	
Energy use	Energy scenario 1	kWh	8,881	/m³ input	1040,291	/m³ PB	Hasch, 2002 complemented with own calculation of drying process and EFORWOOD database, 2009; see energy scenario descriptions chapter 5.5
	Energy scenario 2	kWh	8,881	/m³ input	3668,736	/m³ PB	
	Energy scenario 3	kWh	8,881	/m³ input	6297,181	/m³ PB	
Water use		m³	0,000	/m³ input	228,500	/m³ PB	Hasch, 2002
Employment		absolute number of persons in full-time equivalents in reference year per reporting unit	1,40E-05	/m³ input	7,14E-04	/ton	EFORWOOD database, 2009
Occupational accidents		absolute number per 1000 employees per reporting unit	0,000	/m³ input	5,45E-05	/ton	
Wages and salaries total		€	0,486	/m³ input	28,481	/ton	
Greenhouse gas emissions		kg CO_2 equivalents	2,385	/m³ input	589,723	/m³ PB	

Annex 4: Results expressed per m³

Ecological Footprint:

Tab. A 10. The Ecological Footprint (EF) results for the products solid wood (SW) and particleboard (PB) whereby the results higlighted represent the outperforming results.

Modules \ Products	EF SW [gha/m³]	EF PB [gha/m³]
Forest	0,003	0,005
Transport	0,001	0,009
Sawmill		
Energy scenario 1	0,038	0,007
Energy scenario 2	0,175	0,033
Energy scenario 3	0,313	0,059
Particleboard mill		
Energy scenario 1	/	0,112
Energy scenario 2	/	0,343
Energy scenario 3	/	0,573
Overall result		
Energy scenario 1	0,042	0,133
Energy scenario 2	0,180	0,389
Energy scenario 3	0,318	0,646

Tab. A 11. The Ecological Footprint (EF) results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0' whereby the results higlighted represent the outperforming results.

Modules \ Products	EF SW scenario WB = 0 [gha/m³]	EF PB scenario WB = 0 [gha/m³]
Forest	0,005	0,001
Transport	0,001	0,003
Sawmill		
Energy scenario 1	0,060	0,000
Energy scenario 2	0,281	0,000
Energy scenario 3	0,501	0,000
Particleboard mill		
Energy scenario 1	/	0,112
Energy scenario 2	/	0,343
Energy scenario 3	/	0,573
Overall result		
Energy scenario 1	0,067	0,117
Energy scenario 2	0,287	0,347
Energy scenario 3	0,507	0,578

MIPS:

Tab. A 12. The overall MIPS results of the products solid wood (SW) and particleboard (PB) whereby the results higlighted represent the outperforming results.

Products / Overall results	MIPS SW [kg/m³]	MIPS PB [kg/m³]
Energy scenario 1		
abiotic	181,502	944,318
biotic	840,763	1006,186
water	1598,197	9615,353
air	343,074	857,903
Energy scenario 2		
abiotic	684,114	2666,723
biotic	840,763	1006,186
water	1598,197	25649,401
air	1579,838	2746,891
Energy scenario 3		
abiotic	1186,726	4389,129
biotic	840,763	1006,186
water	7572,522	41683,450
air	2816,602	4635,879

Tab. A 13. The MIPS results of the products solid wood (SW) and particleboard (PB) regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Products / Module forest	MIPS SW [kg/m³]	MIPS PB [kg/m³]
abiotic	15,520	23,529
biotic	840,763	1006,186
water	110,099	167,113
air	0,216	0,327

Tab. A 14. The MIPS results for the products solid wood (SW) and particleboard (PB) regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Products / Module transport	MIPS SW [kg/m³]	MIPS PB [kg/m³]
abiotic	26,781	214,816
biotic	0,000	0,000
water	193,209	1549,745
air	6,285	50,416

Tab. A 15. The MIPS results for the products solid wood (SW) and particleboard (PB) regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill	MIPS SW [kg/m³]	MIPS PB [kg/m³]
Energy scenario 1		
abiotic	139,201	126,007
biotic	0,000	0,000
water	1294,888	1229,323
air	336,573	6,069
Energy scenario 2		
abiotic	641,812	579,399
biotic	0,000	0,000
water	5974,325	5661,415
air	1573,337	27,599
Energy scenario 3		
abiotic	1144,424	1032,791
biotic	0,000	0,000
water	10653,762	10093,506
air	2810,101	49,129

Tab. A 16. The MIPS results for the product particleboard (PB) regarding the module 'particleboard mill' whereby the results higlighted represent the outperforming results.

Products / Module particleboard mill	MIPS SW [kg/m³]	MIPS PB [kg/m³]
Energy scenario 1		
abiotic	/	579,966
biotic	/	0,000
water	/	6669,172
air		801,091
Energy scenario 2		
abiotic	/	1848,979
biotic	/	0,000
water	/	18271,128
air	/	2668,548
Energy scenario 3		
abiotic	/	3117,992
biotic	/	0,000
water	/	29873,085
air	/	4536,006

Tab. A 17. The overall MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0' whereby the results higlighted represent the outperforming results.

Overall results \ Products	MIPS SW scenario WB = 0 [kg/m³]	MIPS PB scenario WB = 0 [kg/m³]
Energy scenario 1		
abiotic	274,334	672,827
biotic	1345,221	560,534
water	2441,189	7338,478
air	545,147	821,381
Energy scenario 2		
abiotic	1078,513	1941,841
biotic	1345,221	560,534
water	9928,289	18940,435
air	2523,970	2688,838
Energy scenario 3		
abiotic	1882,692	3210,854
biotic	1345,221	560,534
water	17415,388	30542,391
air	4502,792	4556,296

Tab. A 18. The MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Module forest \ Products	MIPS SW scenario WB = 0 [kg/m³]	MIPS PB scenario WB = 0 [kg/m³]
abiotic	24,832	6,814
biotic	1345,221	100,667
water	176,159	48,534
air	0,345	0,095

Tab. A 19. The MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Module transport \ Products	MIPS SW scenario WB = 0 [kg/m³]	MIPS PB scenario WB = 0 [kg/m³]
abiotic	26,781	86,048
biotic	0,000	0,000
water	193,209	620,772
air	6,285	20,195

Tab. A 20. The MIPS results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill	MIPS SW scenario WB = 0 [kg/m³]	MIPS PB scenario WB = 0 [kg/m³]
Energy scenario 1		
abiotic	222,721	0,000
biotic	0,000	0,000
water	2071,821	0,000
air	538,517	0,000
Energy scenario 2		
abiotic	1026,900	0,000
biotic	0,000	0,000
water	9558,920	0,000
air	2517,340	0,000
Energy scenario 3		
abiotic	1831,079	0,000
biotic	0,000	0,000
water	17046,019	0,000
air	4496,162	0,000

EFORWOOD SIA:

Tab. A 21. The overall EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) whereby the results higlighted represent the outperforming results.

Overall results Indicators \ Products		Indicator result SW	Unit [/m³ SW]	Indicator result PB	Unit [/m³ PB]
Gross value added (at factor cost)		89,364	€	77,183	€
Production cost		166,999	€	389,463	€
Energy use	Energy scenario 1	391,617	kWh	2078,478	kWh
	Energy scenario 2	1755,964	kWh	7608,882	kWh
	Energy scenario 3	3120,310	kWh	13139,285	kWh
Water use		3,53E-04	m³	0,354	m³
Greenhouse gas emissions		90,712	kg CO_2 equivalents	1023,329	kg CO_2 equivalents
Transport		27,328	tkm	218,650	tkm
Employment		3,039	h	4,806	h
Occupational accidents		1,33E-04	absolute number/1000 employees	2,74E-04	absolute number/1000 employees
Wages and salaries		17,735	€	42,195	€

Tab. A 22. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Module forest Indicators \ Products		Indicator result SW	Unit [/m³ SW]	Indicator result PB	Unit [/m³ PB]
Gross value added (at factor cost)		48,265	€	54,433	€
Production cost		30,156	€	37,122	€
Energy use	**Energy scenario 1**	10,264	kWh	15,576	kWh
	Energy scenario 2	10,264	kWh	15,576	kWh
	Energy scenario 3	10,264	kWh	15,576	kWh
Water use		0,000	m³	0,000	m³
Greenhouse gas emissions		2,954	kg CO_2 equivalents	4,572	kg CO_2 equivalents
Transport		0,000	tkm	0,000	tkm
Employment		2,359	h	2,660	h
Occupational accidents		7,77E-05	absolute number/1000 employees	8,97E-05	absolute number/1000 employees
Wages and salaries		6,419	€	7,450	€

Tab. A 23. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Module transport Indicators \ Products		Indicator result SW	Unit [/m³ SW]	Indicator result PB	Unit [/m³ PB]
Gross value added (at factor cost)		40,152	€	53,184	€
Production cost		53,710	€	92,030	€
Energy use	Energy scenario 1	10,278	kWh	41,570	kWh
	Energy scenario 2	10,278	kWh	41,570	kWh
	Energy scenario 3	10,278	kWh	41,570	kWh
Water use		0,000	m³	0,000	m³
Greenhouse gas emissions		2,781	kg CO_2 equivalents	11,530	kg CO_2 equivalents
Transport		27,328	tkm	218,650	tkm
Employment		0,198	h	0,839	h
Occupational accidents		3,35E-05	absolute number/1000 employees	1,25E-04	absolute number/1000 employees
Wages and salaries		2,170	€	5,366	€

Tab. A 24. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Module sawmill Indicators / Products		Indicator result SW	Unit [/m³ SW]	Indicator result PB	Unit [/m³ PB]
Gross value added (at factor cost)		0,946	€	1,015	€
Production cost		83,133	€	89,202	€
Energy use	Energy scenario 1	371,075	kWh	398,165	kWh
	Energy scenario 2	1735,422	kWh	1862,114	kWh
	Energy scenario 3	3099,769	kWh	3326,063	kWh
Water use		3,53E-04	m³	3,79E-04	m³
Greenhouse gas emissions		84,977	kg CO_2 equivalents	91,181	kg CO_2 equivalents
Transport		0,000	tkm	0,000	tkm
Employment		0,482	h	0,517	h
Occupational accidents		2,17E-05	absolute number/1000 employees	2,33E-05	absolute number/1000 employees
Wages and salaries		9,146	€	9,813	€

Tab. A 25. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) regarding the module 'particleboard mill' whereby the results higlighted represent the outperforming results.

Module particleboard mill Indicators / Products		Indicator result SW	Unit [/m³ SW]	Indicator result PB	Unit [/m³ PB]
Gross value added (at factor cost)		/	/	-31,449	€
Production cost		/	/	171,108	€
Energy use	Energy scenario 1	/	/	1623,158	kWh
	Energy scenario 2	/	/	5689,585	kWh
	Energy scenario 3	/	/	9756,012	kWh
Water use		/	/	0,354	m³
Greenhouse gas emissions		/	/	916,042	kg CO_2 equivalents
Transport		/	/	0,000	tkm
Employment		/	/	0,790	h
Occupational accidents		/	/	3,60E-05	absolute number/1000 employees
Wages and salaries		/	/	19,566	€

Tab. A 26. The overall EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0' whereby the results higlighted represent the outperforming results.

Overall results Indicators \ Products		Indicator result SW scenario WB = 0	Unit [/m³ SW]	Indicator result PB scenario WB = 0	Unit [/m³ PB]
Gross value added (at factor cost)		142,982	€	-18,978	€
Production cost		267,198	€	210,248	€
Energy use	Energy scenario 1	632,037	kWh	1658,270	kWh
	Energy scenario 2	2814,992	kWh	5724,718	kWh
	Energy scenario 3	4997,947	kWh	9791,165	kWh
Water use		5,65E-04	m³	0,354	m³
Greenhouse gas emissions		145,140	kg CO_2 equivalents	925,994	kg CO_2 equivalents
Transport		27,328	tkm	87,744	tkm
Employment		4,863	h	1,545	h
Occupational accidents		2,13E-04	absolute number/1000 employees	1,32E-04	absolute number/1000 employees
Wages and salaries		28,375	€	23,157	€

Tab. A 27. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'forest' whereby the results higlighted represent the outperforming results.

Module forest Indicators \ Products		Indicator result SW scenario WB = 0	Unit [/m³ SW]	Indicator result PB scenario WB = 0	Unit [/m³ PB]
Gross value added (at factor cost)		77,225	€	2,370	€
Production cost		48,249	€	4,741	€
Energy use	Energy scenario 1	21,873	kWh	4,563	kWh
	Energy scenario 2	21,873	kWh	4,563	kWh
	Energy scenario 3	21,873	kWh	4,563	kWh
Water use		0,000	m³	0,000	m³
Greenhouse gas emissions		4,727	kg CO_2 equivalents	1,402	kg CO_2 equivalents
Transport		0,000	tkm	0,000	tkm
Employment		3,775	h	0,129	h
Occupational accidents		1,24E-04	absolute number/1000 employees	6,36E-06	absolute number/1000 employees
Wages and salaries		10,270	€	0,553	€

Tab. A 28. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'transport' whereby the results higlighted represent the outperforming results.

Module transport Indicators \ Products		Indicator result SW scenario WB = 0	Unit [/m³ SW]	Indicator result PB scenario WB = 0	Unit [/m³ PB]
Gross value added (at factor cost)		64,243	€	10,101	€
Production cost		85,936	€	34,399	€
Energy use	**Energy scenario 1**	16,444	kWh	30,542	kWh
	Energy scenario 2	16,444	kWh	30,542	kWh
	Energy scenario 3	16,444	kWh	30,542	kWh
Water use		0,000	m³	0,000	m³
Greenhouse gas emissions		4,449	kg CO_2 equivalents	8,546	kg CO_2 equivalents
Transport		27,328	tkm	87,744	tkm
Employment		0,317	h	0,626	h
Occupational accidents		5,37E-05	absolute number/1000 employees	8,92E-05	absolute number/1000 employees
Wages and salaries		3,472	€	3,037	€

Tab. A 29. The EFORWOOD SIA indicator results for the products solid wood (SW) and particleboard (PB) under the 'scenario WB = 0', regarding the module 'sawmill' whereby the results higlighted represent the outperforming results.

Products / Module sawmill Indicators		Indicator result SW scenario WB = 0	Unit [/m³ SW]	Indicator result PB scenario WB = 0	Unit [/m³ PB]
Gross value added (at factor cost)		1,514	€	0,000	€
Production cost		133,013	€	0,000	€
Energy use	Energy scenario 1	593,720	kWh	0,000	kWh
	Energy scenario 2	2776,675	kWh	0,000	kWh
	Energy scenario 3	4959,630	kWh	0,000	kWh
Water use		0,001	m³	0,000	m³
Greenhouse gas emissions		135,964	kg CO_2 equivalents	0,000	kg CO_2 equivalents
Transport		0,000	tkm	0,000	tkm
Employment		0,771	h	0,000	h
Occupational accidents		3,47E-05	absolute number/1000 employees	0,000	absolute number/1000 employees
Wages and salaries		14,633	€	0,000	€