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PROCEEDINGS

Life Cycle Management for WPC producers and manufacturers

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Keywords: Life Cycle Assessment, Life Cycle Management, Terrace floorings, Wood polymer composites, SME compatible LCA-tool

1. Introduction

There are various materials commercially available for terrace flooring. Recently, wood-polymer composite (WPC) decks could establish themselves as an alternative besides wooden decking boards.

Besides appearance, technical properties and price, environmental compatibility is to an increasing extend a possible purchase criterion for customers. Utilizing these properties, life cycle assessment (LCA) provides objective decision-making assistance. Accordingly, the LCA at hand compares terraces using four different types of decking boards made of WPC and wood.

2. Materials and Settings

In 2006 tropical wood had a market share of 54 % for terrace deckings, Douglas fir, larch and pressure-impregnated wood together had about 38 % and WPC had about 8 % in Europe [Bru08]. Meanwhile WPC's market share has increased to about 15 % [Nov12].

All compared terraces have the same structural design: The basic foundation is complemented by sand, some plastic pads, a layer of gravel and concrete blocks. Usually a pool liner is laid on the concrete blocks to serve as a barrier to rising water. Then the beams for the subconstruction are installed, the decking boards themselves and edge boards if come on top.

3. Methods

3.1. Methodological Considerations

The methodology of choice is LCA according to ISO 14040/44 to assess the different product systems used for terrace floorings [ISO40, ISO44].

In order to fulfill the criteria – relevance and comprehensibility for customers, transparency of the assessment and results, completeness of the assessment, and scientific acceptance – the following impact categories are examined using the CML assessment method to quantify the potential environmental impacts [Gui02]:

- Global Warming Potential (GWP in kg of CO_{2e}), with a time horizon of 100 years,
- Acidification Potential (AP in kg of SO_{2e}),
- Ozone Depletion Potential (ODP in kg of CFC 11_e),
- Photochemical Ozone Creation Potential (POCP in kg of C_2H_{4e}), and
- Eutrophication Potential (EP in kg of PO_{4e}).
- In addition, the Cumulative Energy Demand (CED) is examined to assess the overall energy consumption of the products.

3.2. Goal, Scope and Functional Unit

The products under consideration are two terrace boards made of WPC and two made of wood. WPC-A is PP based with 70 % of wood, WPC-B is PVC based with 50 % of wood. The wooden alternatives are Bilinga and pressure-impregnated Pine.

The functional unit is defined as: manufacture, 15-year use, and disposal of 1 m^2 of a terrace deck consisting of decking boards and subconstruction. The assumed 15 years of lifespan corresponds, according to experts, to the typical useful life of durable wood deckings such as Bilinga [Dup11]. In reality, the technically possible lifespans of different terraces differ substantially, depending basically on material, design, and local construction situation. So far, the present study does not take into account any differences in weathering resistance or lifespan.Results of the ongoing relevant tests are not yet available.

3.3. System Boundaries and Assumptions

The system boundaries refer to the entire life cycle of the products: acquisition of raw materials, manufacturing processes, use as terrace decks, and disposal (see Fig. 1).

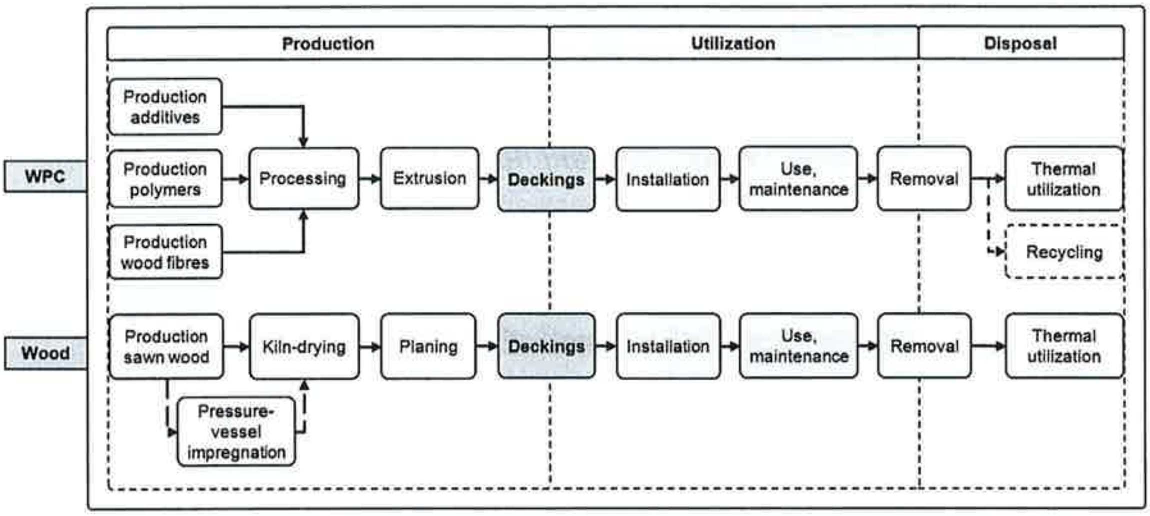

Fig. 1: System boundaries: life cycle phases taken into consideration

Disposal includes the transportation of the WPC to an incinerator and its thermal utilization. Since WPC are fully recyclable, a scenario of material utilization was prepared.

The geographic reference framework of the analysis covers the manufacture, utilization, and disposal of terrace decks in Germany. The tropical wood Bilinga, imported from west/central Africa, is modeled according to [Wag00]. The process data are valid for the time-period between March 2010 and February 2012.

The life cycle inventory analysis (LCI) of the terrace deckings is based on information from three manufacturers of WPC terrace boards and on the authors' measurements and calculations. Background data for the LCI analysis are taken from the Ecoinvent 2.2 database.

4. Inventory Analysis

4.1. Production of WPC Terrace Deckings

Both of the observed WPC terrace deckings differ primarily in the composition of the material employed. The important product features of each of the two types of terraces are listed in Table 1.

Table 1: Specifications of the WPC terraces

	Unit	WPC-A	WPC-B
Material	-	PP (70 % wood)	PVC (50 % wood)
Product design	-	Hollow chamber	Hollow chamber
Weight of the terrace boards	kg/m	2.3	2.5
Width of the terrace boards	mm	140	140
Length of the terrace boards / m²	m	6.7	6.7

(including installation spacing)			
Weight of the subconstruction	kg/m	1.2	1.2
Length of the subconstruction / m²	m	2.8	2.8

4.1.1 Manufacture of Plastics, Wood Fiber and Additives

The data sets in the LCI analysis for the manufacture of PP and PVC that we employed were taken from the Ecoinvent database, which are based on industrial data from the manufacturers' association PlasticsEurope.

No generic background data are available for the production of the wood fibers specifically used in WPC. The base case in this analysis assumes that fresh wood is used, not waste wood.

It is assumed that timber harvesting takes place using a harvester, i.e., a state-of-the-art timber harvesting machine for felling, debranching, and sorting the logs, which are transported to the forest road using a forwarder. The fuel consumption of both machines originates from manufacturers' data. Natural drying reduces the moisture level from about 140 % to about 70 % [Mül11].

Subsequently, the logs are transported to the wood fiber manufacturer. The average transport distance was determined to be 216.5 km based on data for wood-based materials according to [Weg04]. The transport is modeled with data for a truck with a gross vehicle weight rating less than 32 tons (GVWR < 32 tons).

Background data from the Ecoinvent database on the decortication of conifer wood are used to describe decortication. Chaffing is modeled on the basis of energy consumption. Approximately 8 kWh/ton of wood is needed for the comminution of logs according to [Sch11]. At this point, it is necessary to convert volume to mass. A volume of 1 m^3 decorticated conifer logs with a moisture level of 70 % weighs approximately 730 kg according to [Mül11]. The wood chips are dried in kilns until the residual moisture level is 10 %. This process-step is modeled using background data from the Ecoinvent database on chamber desiccation of sawed conifer. Following desiccation the wood chips are comminuted to the desired size in a wood mill by grinding. The process is modeled by its energy consumption (48.5 kWh/ton [Soi95]). The finished wood fibers are then filled in sacks.

The typical levels of additives range from 2 % to 4 % [Vog06]. We assume that the observed products contain 1 % of each of the following additives: adhesion agents, stabilizers and pigments for WPC-A, lubricants, stabilizers and pigments for WPC-B.

Customary market products are taken for these additives and are modeled using the background data from Ecoinvent as shown in Table 3. Pigments are not modeled due to the numerous substances they contain.

Table 3: Additives modeled and data used

Function	Material	Data sets used
Adhesion agent	Maleic anhydride-grafted PP	PP, granulate, at plant Maleic anhydride, at plant
Lubricant	PE wax PP wax Calcium stearate	PE, HDPE, granulate, at plant PP, granulate, at plant Fatty acids, from vegetarian oil, at plant
Thermostabilizer	Sterically hindered phenols	Phenol, at plant
UV stabilizers	Titanium dioxide	Titanium dioxide, chloride process, at plant

4.1.2. Transportation and Packaging of the Materials Used

According to information from manufacturers, raw materials are delivered by truck. Typical distances are 400-500 km for polymers, 100-200 km for wood, and 50-100 km for additives. The transports are modeled using Ecoinvent data for trucks with GVWR < 32 tons. The manufacture and disposal of packaging (flexible intermediate bulk container made of PP) are taken into account.

4.1.3. Preparation and Processing of WPC

This study assumes that the products are processed via compounding and subsequent extrusion. The electricity consumed during the preparation and processing of WPC is the decisive variable for the environmental impact linked to the procedure. As random samples have shown, no direct emissions are to be expected from the processes during regular operation. Values providing an indication of the power consumption during the production of WPC decking boards were determined in a test series. Accordingly, the preparation via compounding and the final shaping via extruding consume about 0.4 kWh per kg processed material.. Background data for the German electricity mix are used.

4.1.4. Packaging and Transport to the Customer

The study considers as packaging material a EUR-pallet made of wood, strapping band made of PP, and PE foil, including its thermal utilization. The transport processes to make the packaging material available are not taken into account.

According to products of the sawmilling industry transports to stores are about 627 km, primarily by truck [Weg04]. The transport is modeled using Ecoinvent data for a truck with GVWR < 32 tons. Transport from stores to customers is considered as a marginal portion of the overall transport distances and is thus disregarded.

4.2. Production of Wood Decking Boards

The main product features of both the wood terraces studied in the project are summarized in Table 4.

Table 4: Specifications of wooden terraces

	Unit	Bilinga	Pine, pressure-impregnated
Material	-	Solid wood Bilinga	Solid wood Pine
Weight of the terrace boards	kg/m	4.1	2.1
Width of terrace boards	mm	140	140
Length of terrace Boards/ m^2 (including installation distance)	m	6.67	6.67
Weight of the subconstruction	kg/m	2.4	1.6
Length of the subconstruction / m^2	m	2.5	2.5

The basis for the preparation of the LCI analysis for wood deckings is the database Ecoinvent 2.2. If a data set is considered to be inappropriate or too imprecise, it is either replaced by appropriate information or manipulated. The important variables, such as material or energy consumption, are determined in order to form the basis of the LCI analysis model. Different sources are evaluated to obtain necessary information, such as the technical fact sheets of care products (manufacturers' data) and the results of further literature searches.

4.2.1. Provision of Logs

Data sets for LCI analysis from the Ecoinvent database are used to describe how Pine is provided by German forestry (data set ‘Round wood, softwood, under bark, u=70 % at forest road’) and Bilinga logs are delivered by ship to Europe from central and west Africa, in each case as ordinary processes. In our study, Bilinga is described by using data for Azobé (data set ‘Logs, Azobé (SFM), debarked, u=30 %, CM, at maritime harbor’). According to [Wag00], Azobé is sufficiently identical to Bilinga with regard to its areas of growth and its technical properties such as density and durability.

4.2.2. Sawing, Planing and Impregnation of Wood

The sawing of Pine and Bilinga logs takes place in a European sawmill powered by the amount of electrical energy needed (data set 'electricity, medium voltage, production DE, at grid [DE]'). The sawing is followed by planing on-site. Planing is referred to as 'planing, softwood, air dried, u=20 %'.

Pressure impregnation is only applied to Pine due to the natural durability of Bilinga. The pressure impregnation of sawn lumber of Pine is done at the processing location. The calculation includes a value for a commercially available product for impregnation [Rüt10], described by data taken from the Ecoinvent database. The active ingredients are based on copper, ammonium, and boron. The required amount is, according to the manufacturer's information, 6.0 kg salt/m^3, applied via an aqueous solution with 3.5 % concentration. The impregnation is applied via pressure vessel (data set 'preservative treatment, sawn timber, pressure vessel').

Fixation is achieved by open-air storage under a roof, where the material stays until the desired degree of moisture is achieved for external use.

4.2.3. Packaging and Transport to Customers

The study considers packaging as well as transports to be identical to WPC (see above).

For Bilinga, additional shipping to Germany is considered by ship (data set 'transport, transoceanic freight ship [OCE]') for a distance of 9,100 km and by truck (data set 'transport, lorry >32 t, EURO5 [RER]') for 283 km. Transport from stores to customers are disregarded.

4.3. Use Phase

The use phase encompasses maintenance over the entire period of use. To gain relevant information 139 owners of wood and WPC terraces were questioned in order to define how frequently users apply cleaning or maintenance products: WPC terraces are treated 0.15 times a year, and wood terraces 0.43 times a year (assumption: no treatments in the years of installation and removal).

Various cleaning or maintenance products are available for decking boards made of wood and also made of WPC. For the LCA, several products for wood are studied (see [osm11], [Kor10]). The mean applied quantity is 59.2 g/m^2. The use of fungicidal preservatives is not considered since it is not necessary for the wood assessed.

According to the manufacturers' specifications, no special maintenance is necessary for WPC and cleaning is done with water only, which is not taken into account.

4.4. Disposal

Disposal covers all of the decking boards and the specific subconstruction as well as side products of the manufacturing process (sawdust and packaging material), that is not accompanied by a credit note or by additional utility such as heat.

Under today's conditions, disposal normally takes place through incineration. In the base case material utilization of WPC is not considered since it is not done yet. Furthermore, the influences of dampness, UV radiation, or fungal infestation on the recyclate properties are not yet determined. However, the potential of material recycling is taken into account in a scenario. The impregnation impedes the inclusion of Pine wood in many types of material utilization of old wood, and the separate consideration of all of the versions of utilization is hardly assessable.

For these reasons, disposal is modeled in the base case as incineration in a waste incineration plant. Such incineration is modeled using data sets from the Ecoinvent database. The sets make it possible to consider each material separately, i.e., the study takes into consideration the proportion of wood or plastic in WPC, the type of incinerated plastic (PP, PE, or PVC), and the wood treatment.

Transportation from customer to collection center is not taken into consideration because of variable conditions and the relatively short distances. The distance from the collection center to the incinerator is taken from [Weg04]. It amounts to 285 km on average and is analyzed as being transported by a truck with GVWR > 32 tons.

5. Results and Discussion

Under the described conditions, Table 5 gives the LCIA results per square meter of terrace of the two WPC systems studied. The PVC-based WPC, primarily due to the lower wood content, is disadvantageous in all impact categories.

Table 5: LCIA results of the two WPC terraces per m²

	GWP [kg CO_{2e}]	ODP [kg $R11_e$]	POCP [kg C_2H_{4e}]	AP [kg SO_{2e}]	EP [kg PO_{4e}]	CED [MJ]
PE (70 % wood), hollow chamber	4,7E+01	1,5E-06	6,0E-03	9,6E-02	1,1E-01	1,1E+03
PVC (50 % wood), hollow chamber	6,6E+01	1,6E-06	6,9E-03	1,2E-01	1,2E-01	1,5E+03

By showing the contribution of each life cycle phase Fig. 2 gives a more detailed view on the two WPC terraces. The production of a terrace (raw materials and manufacture) is the dominant phase. The use of a larger proportion of wood leads to lower values for the raw materials (except ODP) while it has only little influence on the emissions from manufacture. The second significant phase is thermal combustion at the end of the life cycle, where higher share of wood reduces results. Logistics of raw materials and distribution only show significance for the ODP. Maintenance during the use phase is negligible.

To compare WPC decks to wood decks a lower level of detail is appropriate. In Fig. 3 life cycle phases are subsumed according to Fig. 1. The terrace made of Pine wood is advantageous in all impact categories. Under the assumption of 15 years of lifetime for all assessed alternatives, WPC terraces show advantages to those made of tropical wood. Exceptions are the impact categories GWP and EP.

Results of the recycling scenario are shown in Fig. 3 by the error indicator under the assumption that 50 % of the dismantled WPC is incinerated and 50 % substitute virgin material (less 5 % decrease in production).

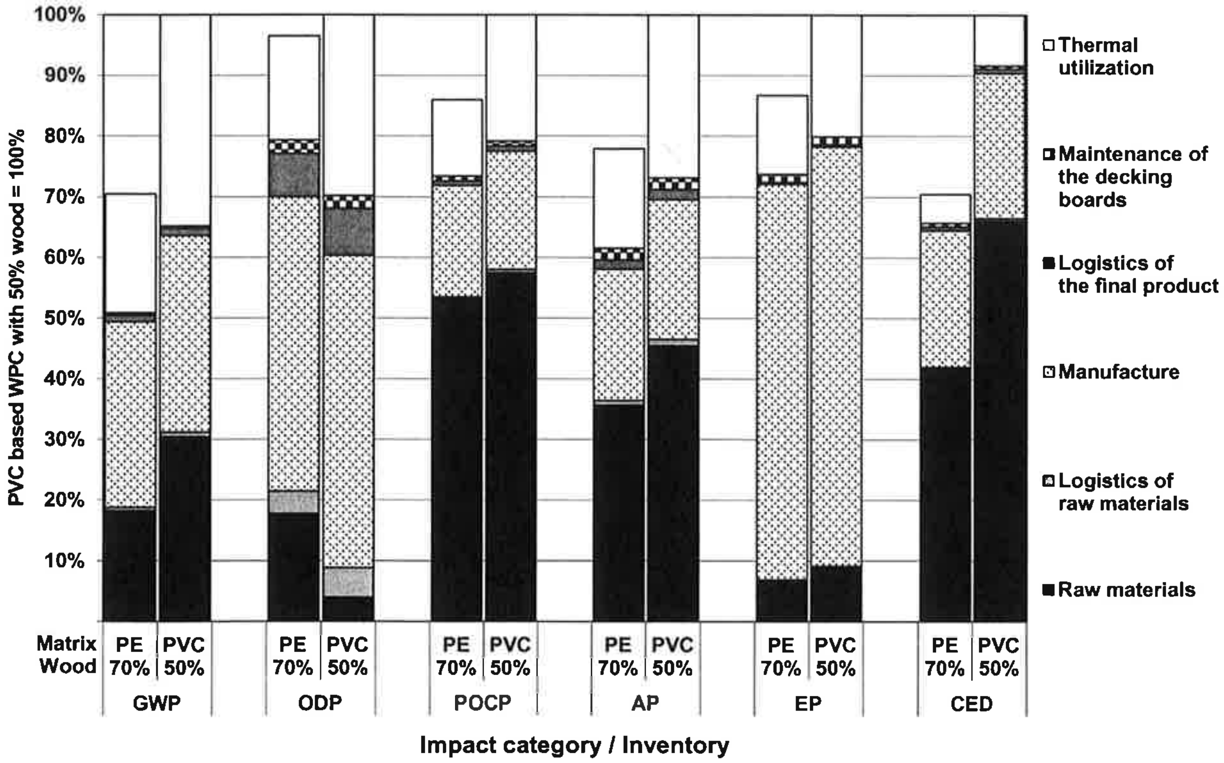

Fig 2: LCIA results, contribution per life cycle phase of the two WPC terraces

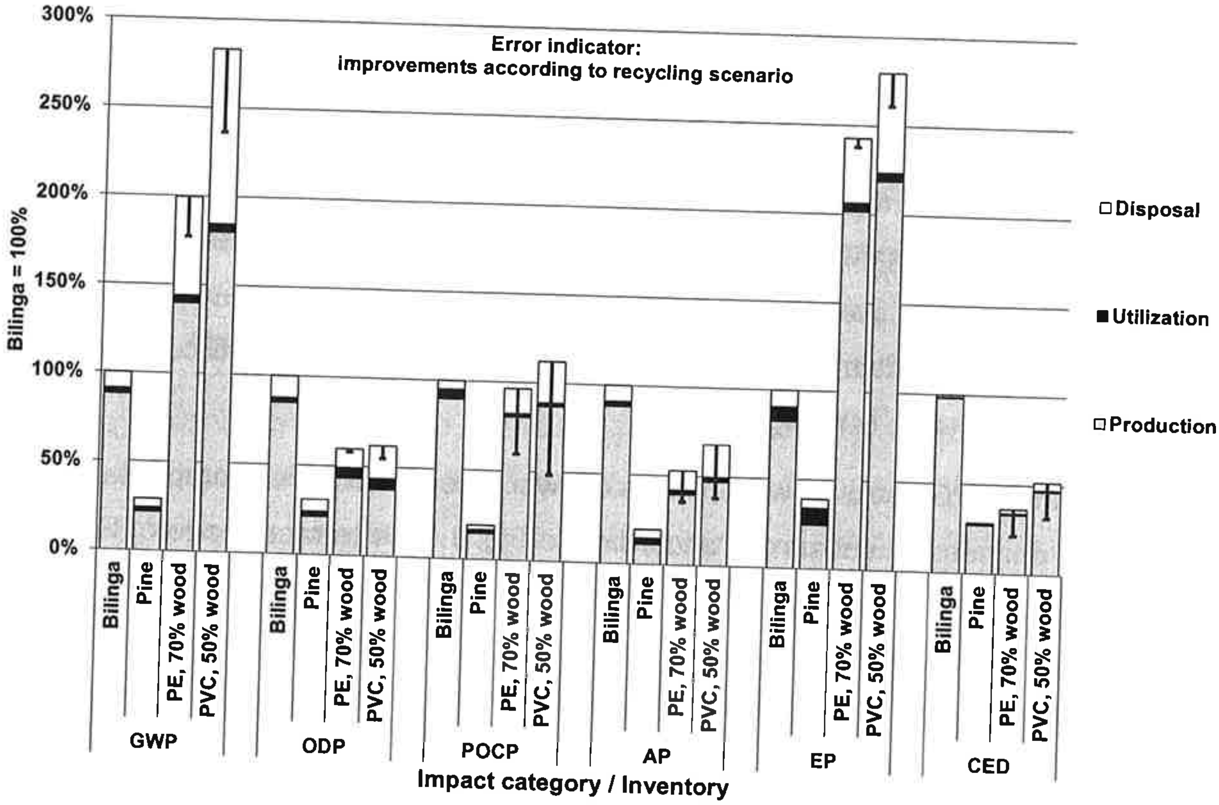

Fig 3: Benchmarking for WPC and wood terraces

6. Conclusion

For manufacturers and processors of WPC it is crucial to know their products' environmental impact to be able to make scientifically sound statements in regard to the product sustainability. To support them in this task the life cycle management tool *Elwood 2* was created in the project at hand. It enables them to compare the material compositions of different WPC decking boards with one another and with wood products.

Compared to terrace boards made of tropical wood, WPC terrace boards are already an ecologically tenable alternative. In contrast to the wooden terraces, there is still potential for optimizing WPC. For example, the environmental impact can be reduced by up to 30 % through material recycling. Also promising is a further improvement of WPC durability, particularly in outdoor uses. With a lifespan 1.8 times as long as Bilinga terrace, hollow chamber profile WPC terrace would be advantageous in all impact categories. The WPC terrace would then even be equivalent to the Pine terrace in the impact categories ODP, AP, and CED.

In summary, the principal tasks currently are to set up functioning recycling programs and to intensify research activities on weatherability to further extend the lifespan of WPC products.

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Life Cycle Management for WPC producers and manufacturers

Oliver Stübs

Biarritz, September 24th 2013

Contents

- **Life Cycle Assessment of WPC (terrace deckings)**
    - General Framework
    - Results („Impact Assessment“)
- **Conducting a Life Cycle Assessment**
    - Life Cycle Management using the software *Elwood*
- **Summary**

Motivation

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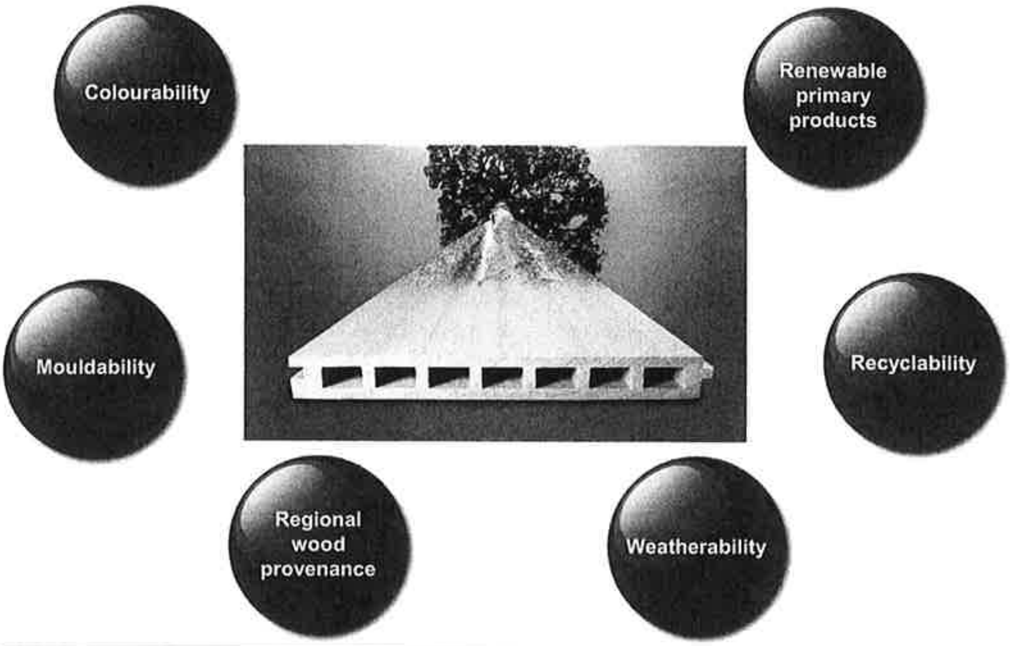
WPC: A promising material for sustainable products



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Life Cycle Assessment of WPC

General Framework

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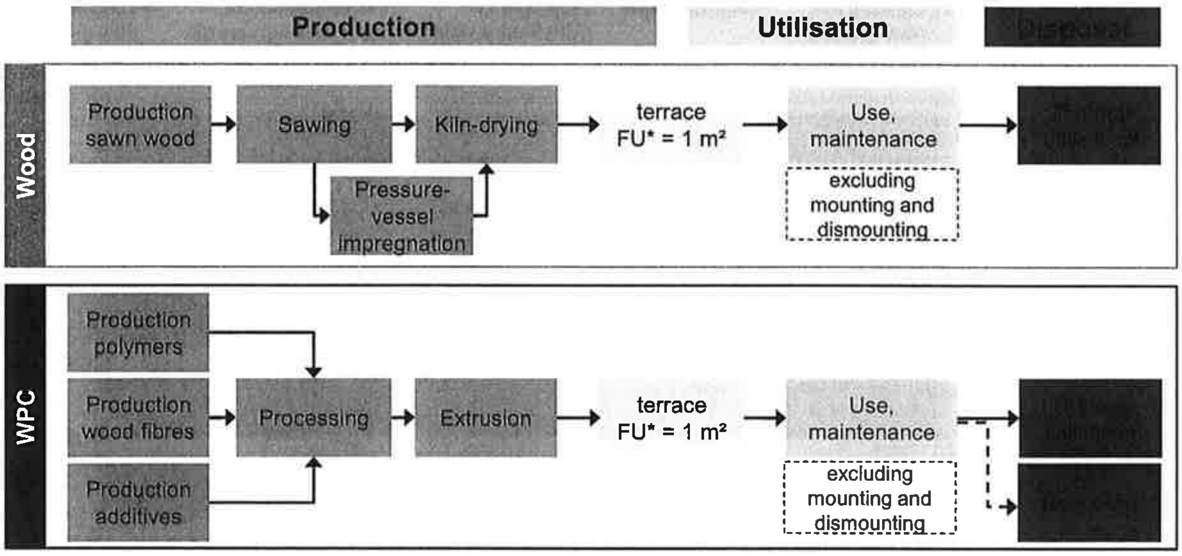
Production System and System Boundaries



*** Functional Unit (FU):**
Production, 15-year use und thermal utilisation of 1m² of terrace deckings

Impact Assessment

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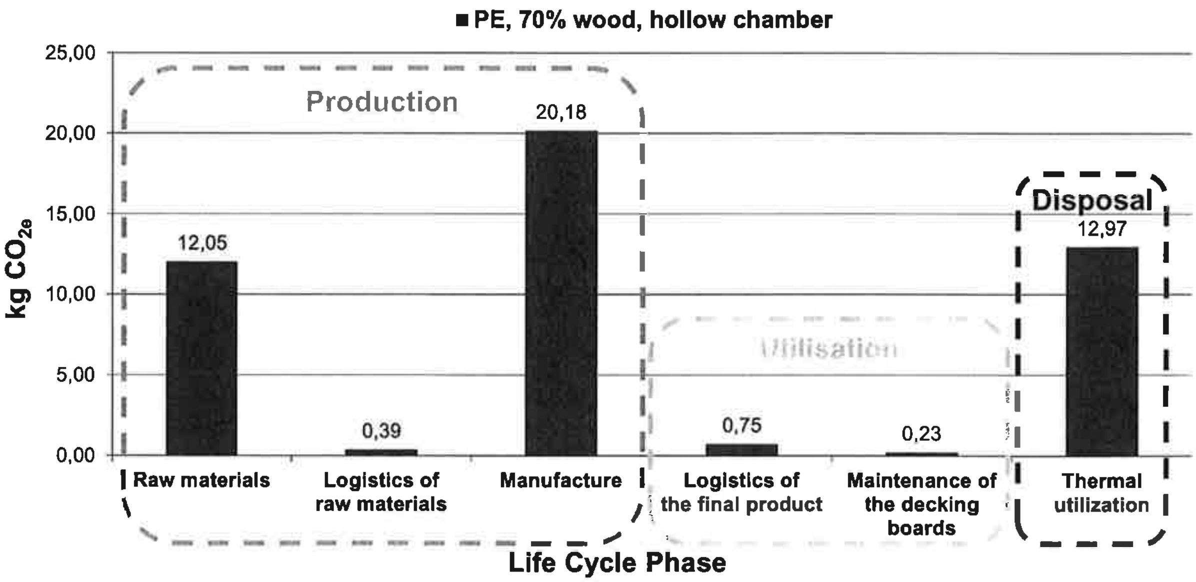
1 m² terrace deckings, PE with 70% wood, hollow chamber profile
15 years lifespan

Global Warming Potential per Life Cycle Phase



Impact Assessment

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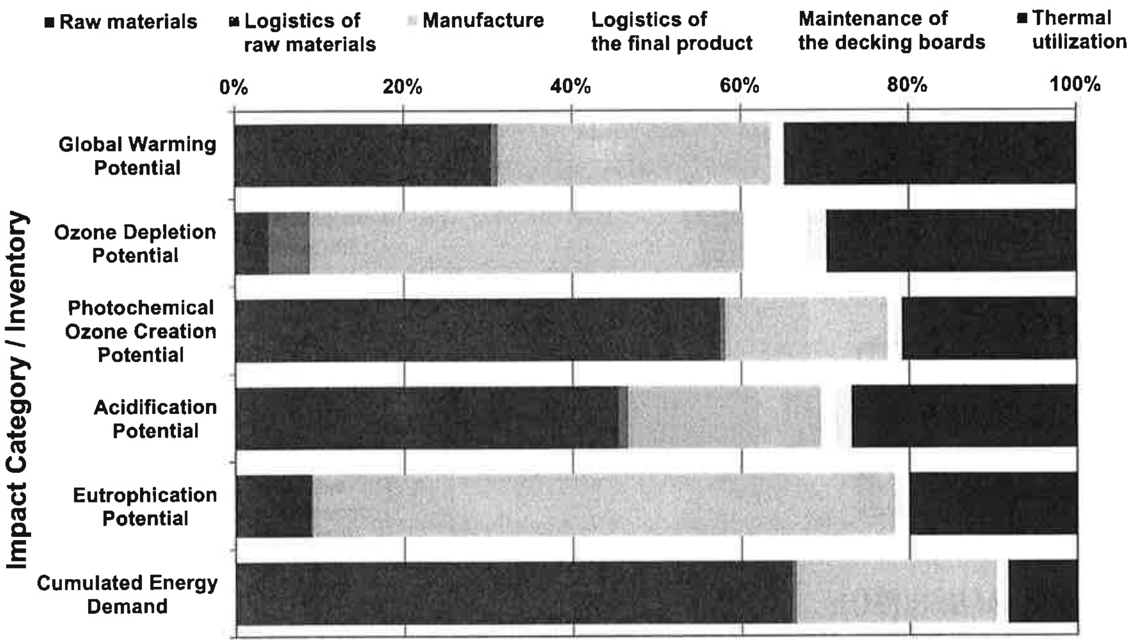
WPC (PE, 70% wood, hollow chamber profile): Life Cycle Phases



Impact Assessment

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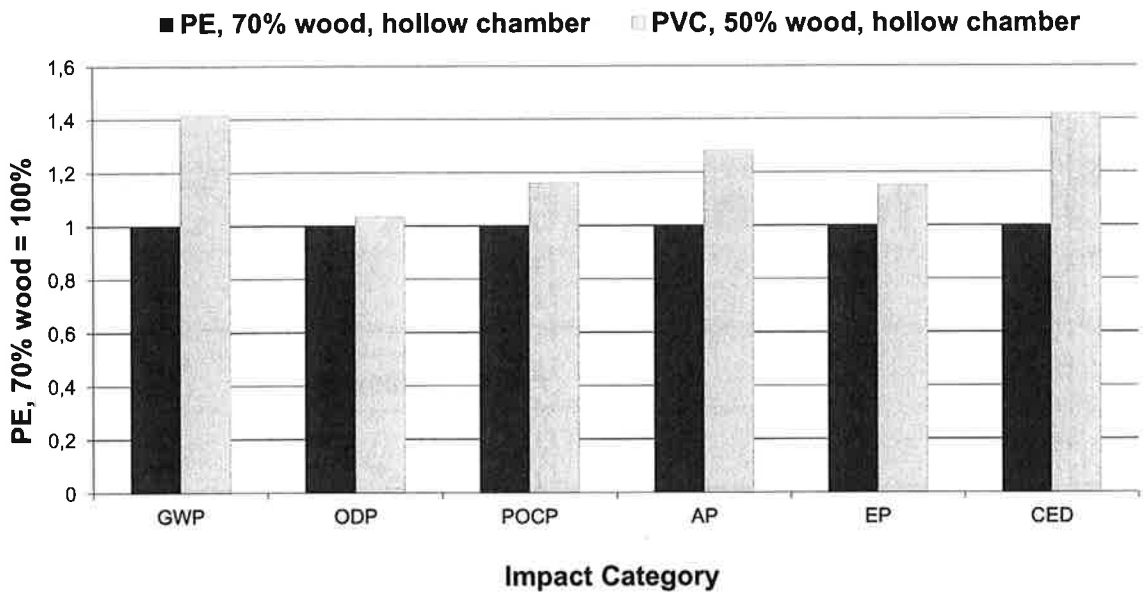
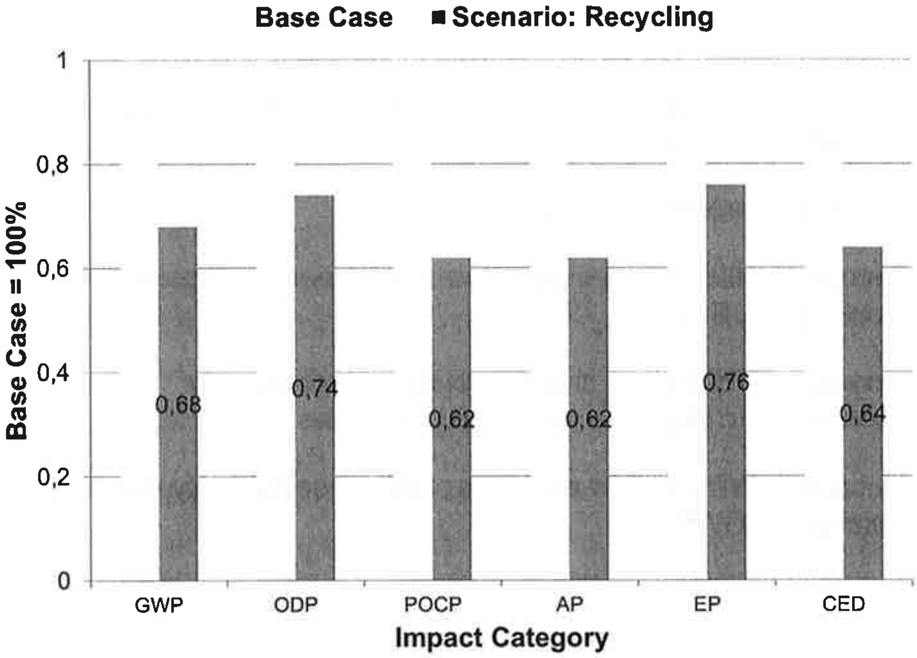
Comparison of different compositions



Impact Assessment

Scenario: What is the impact of recycling?

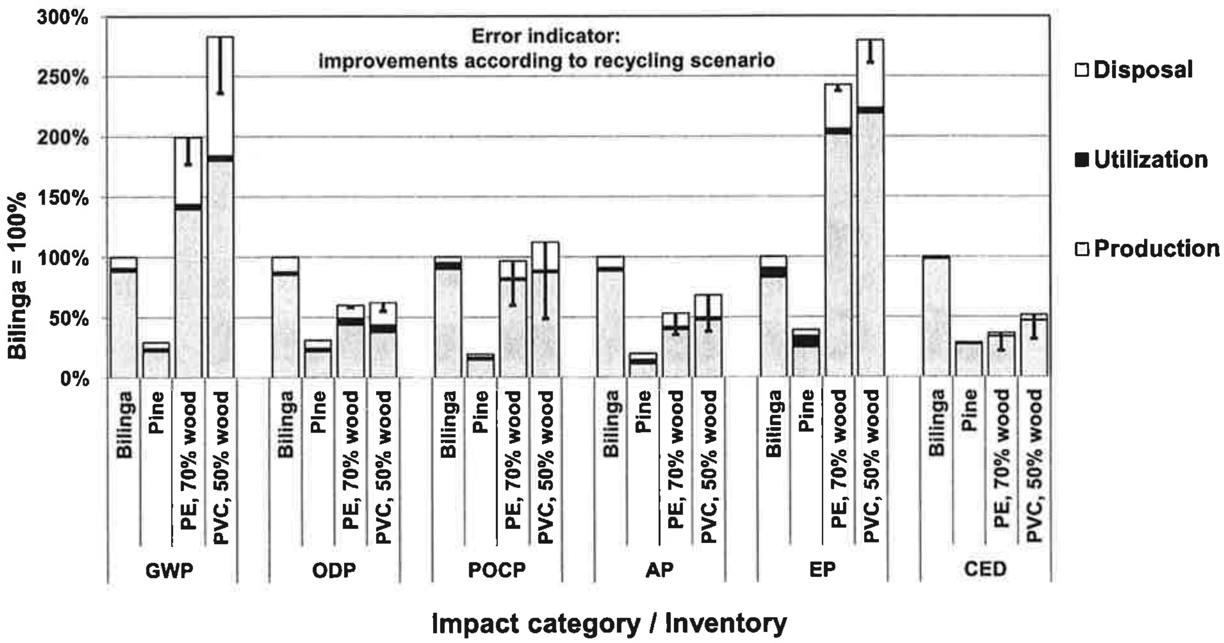


Scenario assumptions:

- **50 % recycled, 50 % incinerated**
- **600 km transport to producer** (return system)
- **0,5 kWh/kg processing** (e.g. grinding and compounding)
- **virgin material substituted by recycled material** (primary material saving is credited)

Impact Assessment

FU = 1 m² terrace deckings, lifespan 15 years, WPC: PE with 70% wood



1,0	23,3 kg CO_{2e}	2,5E-06 kg $FCKW11_e$	6,2E-03 kg C_2H_{4e}	0,18 kg SO_{2e}	4,4E-02 kg $PO_4^{3-}{}_e$	2,9E03 MJ

Interpretation

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1. Environmental Impacts dominated by production stage
2. Use and Maintenance not relevant
3. Thermal utilisation is of secondary importance (exception: GWP), recycling can contribute to an optimisation of environmental impacts
4. Pine wood performs favourable in all impact categories
5. WPC hollow chamber profiles are ecologically advantageous compared to Bilinga (exceptions: GWP, EP)
6. 80% lifespan increase: WPC hollow chamber profile is ecologically advantageous compared to Bilinga in all impact categories
7. 100% lifespan increase: WPC hollow chamber profile is ecologically comparable to Pine wood (exception: GWP)

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Conducting a Life Cycle Assessment

Life Cycle Management for WPC

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What is Life Cycle Management (LCM)?

UNEP-SETAC Life Cycle Initiative:

- *„target, organize, analyze and manage product-related information and activities towards continuous improvement along the life cycle."*
- LCM *„is about making life cycle thinking and product sustainability operational for businesses"*

➔ Goals of the Project „Life Cycle Management for WPC"

- **Development of a LCM tool for WPC products**
- **Feasible start into LCM for plastics-processing SME**
- **Independent assessment of products and processes**
- **Identification of relevant parameters for more sustainable products**
- **Sustainability-Benchmarking: comparison to wood-based products**

Life Cycle Management for WPC

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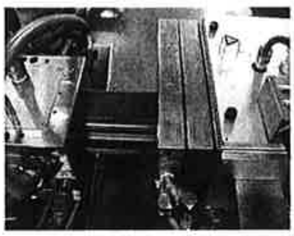
Assessment tool Elwood

Elwood

- **Methods:** Life Cycle Costing and Life Cycle Assessment
- **Main Focus:** LCM tool for WPC, using the example of terrace deckings
- **Realisation:** Comparison of alternative products or processes with a reference product and reference process
- **Application:** Production, utilisation and disposal of WPC terrace deckings
- **Results:** Environmental impacts and costs (calculation based on user inputs and default data provided by the programme)



Life Cycle Management for WPC

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Elwood

Question:

- **How do WPCs differ in Life Cycle Assessment?**
  - different polymer and wood composition
  - solid profile and hollow chamber profile
- **What are the sustainability advantages of WPC compared to wood?**

Approach in Elwood :

- **Freely configurable comparison of WPC profiles**
- **Benchmarking with two wood alternatives** (Pine / Bilinga)

Life Cycle Management for WPC

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Elwood

Data Input in Elwood (example)

Elwood 2

Decking1 | Decking2 | gespeichertes Projekt öffnen

Dimensionen | Zusammensetzung | Transport | Fertigung | Reinigung | Kosten |

WPC-Decking

	Decking1		Decking2	
Gewicht laufender Meter		kg		kg
Breite Decking		cm		cm
Standardlänge Decking		m		m
Mindestabstand zwischen zwei Deckings		cm		cm

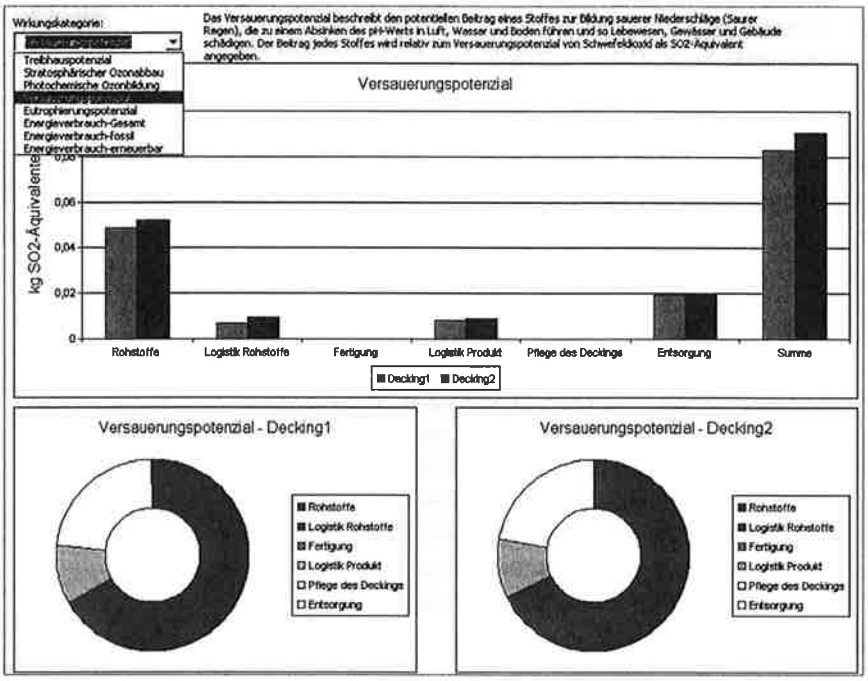
Unterkonstruktion

Konstruktionsbalken

	Decking1		Decking2	
Gewicht laufender Meter		kg		kg
Länge pro qm Terrasse		m		m

Life Cycle Management for WPC

Analysis in Elwood (example)



Summary

Life Cycle Assessment

- Comparison of WPC and wood gives no clear-cut result
- WPC: potential to increase sustainability, in particular through
  - → Recycling
  - → Increased Lifespan

Life Cycle Management for WPC

- Efficient Tool:
  - Identify improvement potentials
  - Evaluate improvements
  - Prepare for future requirements

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Karlsruher Institut für Technologie

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Thank you!

SKZ