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# » Posidonia-Dämmstoff Projekt – AP7 Umweltaspekte, Logistik und Marketing – 7.4. Ökobilanzierung nach DIN «

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# 1 Introduction

This study, Posidonia Life Cycle Assessment (LCA), is a part of the Posidonia-Insulation Project, which consists of evaluating the environmental impact, especially the greenhouse gases (GHG) emissions, of the whole life cycle of an alternative insulation material made of sea grass, called Posidonia Oceanica.

The work plan (WP) of the entire Posidonia-Insulation Project comprises in eight items:

1. Fibre preparation
2. Blowing technology
3. Material development
4. Production of insulating matts
5. Production of fibre component
6. Qualification of the product
7. Environmental aspects, Logistic and Marketing
8. Project management

The Life Cycle Assessment of the posidonia oceanica sea grass takes part in the Work Plan 7 – Environmental aspects, Logistic and Marketing. It consists of the WP 7.4. Life Cycle Assessment according to DIN.

The balance between the resources needed and the emissions to the environment was made based on the Life Cycle Assessment tool. From this analysis is possible to verify the effective environmental performance of the application of posidonia fibres to produce thermal insulation material in Germany.

**All numbers notation are written using a comma to separate the decimal point.**

# 2 Life Cycle Assessment tool

Life Cycle Assessment is an environmental management tool that evaluates and compares the potential environmental impacts of the product analyzed from raw material acquisition, through manufacture, distribution, use, possible reuse/recycling and then final disposal - from "cradle to grave" (ISO 14040, 1997).

The United State Environmental Protection Agency (EPA) defines the Life Cycle Assessment as a tool that evaluates, in holistic form, a product or service through its life cycle (Vigon et al., 1993). Thus, LCA provides a complete overview of the life cycle that allows an environmental assessment of each stage of the process, enabling the optimization of the environmental management and the improvement of the industry-environment interaction.

In each life cycle stage, the inputs (energy, raw materials and resources) and outputs (emissions to air, soil and water) are accounted, analyzed and calculated. The Life Cycle Assessment could also allow a comparison between a single product manufactured from different raw materials. However, as described by McDougall et al. (2001), LCA will not necessarily guarantee the "environmental superiority", but it will allow the trade-offs associated with each option to be assessed.

In 1990, the Society of Environmental Toxicology and Chemistry (SETAC) established a technical standard structure for the Life Cycle Assessment studies. In 1991, the EPA created a LCA inventory, called the Product Life Cycle Assessment: Principles & Guidelines, whose authors are Battelle Franklin & Associates, and this methodology has been standardized globally by the International Organization for Standardization, the ISO 14040ff series on Life Cycle Assessment (CIWMB, 2003). The ISO 14040 series consists in:

1. ISO 14040 Environmental Management – Life Cycle Assessment – Principles and Framework (ISO 14040:1997).

2. ISO 14041 Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Life Cycle Inventory Analysis (ISO 14042:1998). The study purpose, system boundaries, life cycle stages, intended audience and scope of the assessment have to be presented. Also, the functional unit has to be defined to measure the performance of the outputs and for possible comparison.

3. ISO 14042 Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment (ISO 14042:2000). Considers all inputs (energy, raw materials and resources) and outputs (emissions to air, soil and water) across the entire life cycle. Associate them with a particular environmental issues and converts into representative indicators, classifying into specific issues or categories.

4. ISO 14043 Environmental Management – Life Cycle Assessment – Life Cycle Interpretation (ISO 14043:2000). Identifies, qualifies and evaluates the results from the Life Cycle Impact Assessment and balances the importance of different environmental impacts.

## 2.1 Structure of a LCA

The structure of a Life Cycle Assessment study is described below following the international standards of the ISO 14040 series:

1. Phase 1 - Goal and scope definition – definition of the options to be compared; intended use of results; functional unit; intended audience and system boundaries (technical, geographical and time). The scope should be sufficiently well defined to ensure that the breadth, the depth and the details of the study are compatible and sufficient to address the stated goals – ISO 14040 (1997).

2. Phase 2 - Life Cycle Inventory Analysis (LCI) – account for all materials and energy consumed across the whole life cycle (inputs and outputs).

LCI concerns with the data collection and calculation procedures to complete the inventory – ISO 14041 (1998).

3. Phase 3 - Life Cycle Impact Assessment (LCIA) – classification and aggregation of LCI inputs and outputs into specific categories. LCIA aims to examine the product system from an environmental perspective using category indicators, derived from LCI results. LCIA phase also provides information for the interpretation phase – ISO 14042 (2000).

4. Phase 4 - Life Cycle Interpretation – the process of balancing the importance of different effects; no agree scientific method; and requires public debate. This phase is a systematic technique to identify, qualify, check and evaluate information from the results of the LCI analysis and/or LCIA of a product system, and present them in order to meet the requirements of the application as described in the goal and scope of the study – ISO 14043 (2000).

# 3 Phase 1 – Goal and Scope definition

The considerations and assumptions to assess the LCA of the posidonia oceanica fibres are described in this chapter, which consists on Phase 1 - Goal and scope definition – of a LCA study.

## 3.1 Goal and scope definition

The main goal of the study is to evaluate the environmental profile, especially the global warming potential and energy consumption, of the posidonia oceanica fibres, which can be applied as thermal insulation materials in buildings. Each life cycle phase has been checked, from raw material collection, through fibre production by a German company, and its end of life.

The analysis was carried out according to the Life Cycle Assessment (LCA) standards of the series ISO 14040.

The study also analyzed the processes and parameters (inputs and outputs) which cause the main environmental impacts.

## 3.2 Product description

The posidonia oceanica (also known as Neptune Grass or Mediterranean tapeweed) is a sea grass species that is endemic to the Mediterranean Sea. It grows and lives underwater meadows in the sand (at depths of 5-40 meters), in a narrow coastal strip, normally on beds of soft sediment. The motion of the waves aggregates its dead leaves and washes them up to the beach. They can be found on the sands of the beaches during the winter and spring in form of spherical shape, which are round or slightly flattened as kiwis and with size about 2-10 centimeters. Its foliage is formed of a fibrous material that could be used for many industrial applications, such as thermal insulation material, which intends the Posidonia-Insulation Project.

In some countries they are collected as waste material and disposal of in open dumps next to the beach; or they can also be left on the beach. In this study it was considered that the balls are collected right after their appearance on the beach.

## 3.3 Functional unit and Intended audience

The functional unit (F.U.) is defined in the ISO 14040 standards as "the quantified performance of a product system for use as a reference unit in a life cycle assessment study".

In this study the F.U. was defined according to the proposal given by the Council of European Producers of Materials for Construction (CEPMC, 2000), which defined 50 years use phase and R-value of 1 $m^2K/W$:

$$F.U. = R \times \lambda \times \rho \times A$$

Where R is the thermal resistance as 1 $m^2K/W$; $\lambda$ is the thermal conductivity measured as W / (mK); $\rho$ is the density of the insulation product in $kg/m^3$; A is the area as 1 $m^2$; K is temperature in Kelvin; and W is Watt.

This functional unit gives the quantity of insulation material required to perform a certain thermal resistance over the insulation lifetime of the building, concerning only its environmental and insulation properties.

According to the first findings provided by project partners in July 2011 the value of thermal conductivity and density for the posidonia fibres were 0,0490 W/(mK) and 100,0 $kg/m^3$, respectively, because they were at that time still under investigation. In March 2012, these two values were updated to (Fraunhofer IBP, 2012):

Density of dry material $\rho_{(10,dry)} = 72,5\ kg/m^3$

Thermal conductivity at $10^0C$ $\lambda_{(10,dry)} = 0,0422\ W/(mK)$

The amount of posidonia oceanica fibres as insulation material needed to attend the requirements suggested by CEPMC is of:

$$F.U. = 1 \times 0,0422 \times 72,5 \times 1 = 3,06\ kg$$

Hence, this 3,06 kg of posidonia oceanica fibres refers to the functional units necessary to provide a thermal resistance of 1 $m^2K/W$ for a use period of 50 years.

The intended audience of this study is thermal insulation consumers, waste managers (both in public service and private companies), regulators, policymakers and natural fibres product designers. The case study shows how the Life Cycle Assessment results can provide information and data that can be used as a part of the decision making process, either for the use of future improvements of insulation thermal product and waste management associated to this product. From the analysis presented in this study the intended audience will be able to find environmental outcomes for this alternative product. Also, they will gain an understanding of how their actions influence the environment and how they can improve and combine this influence with insulation material production.

## 3.4 Product system and System boundary

A product system is a collection of operations connected by flows of intermediate products. In other words, is subdivided into process units. Each process unit encompasses the activities of a single operation. The system itself lies in a system boundary. The system boundary defines the process units that will be included in the system to be modeled (McDougall et al., 2001).

The product system and the system boundaries were based on the German case study, which includes mass and energy flow (inputs) and emissions to the environment (outputs) from the collection of raw material to its final disposal, following the "cradle to grave" approach, excluding the use phase.

The process units (life-cycle steps/phases) defined for the basic scenario according to the information and data provided by the project partners (NeptuTherm, X-Floc and Fibre Engineering) can be summarized as follows:

- Collection – of the posidonia balls (raw material) on Sousse beach in Tunisia. This work is made without any machine; it is a hand-pick work.

- Transport – of the container by truck with posidonia balls from the beach to Tunis harbor. It is transported by ship from Tunis (Tunisia) to Barcelona harbor (Spain); from Barcelona to Zeebrugge harbor (Belgium); and then from Zeebrugge to Karlsruhe harbor (Germany). From Karlsruhe harbor the container is transported to fibre production industry in Karlsruhe. Diesel and fuel oil are consumed by trucks and ships.

- Production of the fibres – electricity from the power grid is consumed. From this process three waste materials are generated: sand, salt and polypropylene packaging (PP film) of the balls. Sand and salt are sent to disposal of at landfill (*Karlsruher Mülldeponie*) and PP packaging is incinerated in German municipal waste incinerator.

- Transport – of the fibres from production industry to the building. Diesel is consumed by trucks.

- Installation – of the thermal insulation material inside buildings. Electricity is consumed from the power grid by the fibre blowing machine. From this process 25% of the polyethylene packaging (PE film) for the fibres is re-sent to the fibre industry to be re-used and 75% are sent to mechanical recycling industry.

- Transport of waste materials - to landfill (sand and salt), incinerator (PP packaging) or mechanical recycling industry (PE packaging). Diesel is consumed by trucks.

- End-of-Life – of the fibres. After the use phase, the option of re-use them was assumed with assurance of collection of the material during the demolishing process.

The collection of the posidonia balls could also be made on other Mediterranean countries, such as in Italy and Albania. These other alternatives will be discussed on the Scenario Analysis.

Actually, from the fibre production four waste materials are generated: sand, salt, PP film and natural fibres as well. Since the amount of natural fibres observed was very small in comparison to the other residues, its impact was neglected.

Regarding the packaging, it has been assumed in the system boundary the acquisition and production of the PE packaging (to carry the fibres) once each piece has a weight of 300 grams. The acquisition and production of the PP packaging, with weight of only 2 grams, was not included in this study after the verification of its very low impact.

Concerning the installation phase, the posidonia oceanica fibres as thermal insulation material could also be installed by hand which does not require any energy consumption. This will also be discussed in the Scenario Analysis.

The environmental impact of maintenance and use phases was neglected, no data could be provided by the partners up to now.

Due to uncertainty within the End-of-Life phase, it was hard to define how this insulation waste material will be managed 50 years (expected) from now. Posidonia oceanica fibre as thermal insulation material is being testing and, consequently, has also not yet reached its End-of-Life. By the assumption of re-using of insulation waste, consumption of other resources could be avoided and posidonia as $CO_2$-neutral material could be considered as well. In the basic scenario, however, it was decided to include neither positive nor negative environmental impacts from the re-use option. In the Scenario Analysis this topic is discussed in more details and an evaluation of the environmental impact of disposal options (e.g. incineration with energy recovery) is presented.

## 3.5 Life Cycle Assessment Software

The GaBi (*Ganzheitliche Bilanzierung*) Software-System was used as the Life Cycle Assessment program to account all the inputs and outputs of this study. This German LCA software has been developed by the department Life Cycle Engineering at the Chair of Building Physics at the Stuttgart University together with PE Europe GmbH since 1992. The GaBi software is served for greenhouse gas accounting, design for environment, energy resource efficiency, sustainability benchmarking, company ecobalances and total cost accounting (Life Cycle Cost).

Fraunhofer-Institut für Chemische Technologie (ICT) has a permanent license of GaBi 4 software.

## 3.6 Survey of the database for Phase 2

The product system was modeled using information provided by the Posidonia project partners and available in the database of the GaBi software.

The processes chosen from the GaBi databases 2006 for the posidonia case study are presented in Table 1, including those selected for the Scenario

Analysis as well. The data and the assumptions are presenting considering the temporal and spatial aspects.

Table 1. Processes from the GaBi databases 2006 applied in posidonia LCA

| Parameter | Name of database | Reference year of database (last change) | Local of database | Application on this study |
|---|---|---|---|---|
| **Truck-trailer** | Truck-trailer up to 28 t total cap./ 12,4 t payload / Euro 3 (Truck fleet, long-dist., empty return) – PE International | 2010 | Global | Road transport of the container with posidonia balls collected on the beach to the harbor.<br><br>distance = 150 km |
| **Truck** | Truck up to 28 t total cap./ 12,4 t payload / Euro 4 – PE International | 2010 | Global | Road transport from Trieste or Genoa, Italy to Karlsruhe, Germany.<br><br>distance = 790; 669 km |
| **Motor ship** | Motor ship / 1228t payload / upstream – PE International | 2010 | Global | Waterway transport of the container from Tunis to Barcelona harbor, Spain or Genoa, Italy / or from Dürres, Albania to Trieste, Italy.<br><br>distance = 925; 754; 880 km |
| **Bulk commodity carrier** | Bulk commodity carrier/1500 to 20000 dwt /coast - PE International | 2010 | Global | Waterway transport of the container from Barcelona to Zeebrugge harbor, Belgium.<br><br>distance = 3423 km |
| **Ship** | Average ship/1228t payload/canal ELCD/PE-GaBi – ELCD/PE International | 2010 | Global | Waterway transport of the container from Zeebrugge to Karlsruhe harbor, Germany.<br><br>distance = 590 km |
| **Truck-trailer** | Truck-trailer up to 28 t total cap./ 12,4 t payload / Euro 3 (Truck fleet, local, empty return) – PE International | 2010 | Global | Road transport of the container from Karlsruhe harbor to the fibre production industry in Karlsruhe.<br><br>distance = 3 km |
| **Solo truck** | Solo truck up to 7,5 t total cap. / 3,3 t payload / Euro 3 (short-distance) – PE International | 2010 | Global | (i) Road transport of PE packaging from its production industry in Reutlingen, in Germany, to the fibre production industry in Karlsruhe;<br>(ii) Road transport of sand and salt as waste materials from fibre industry to final disposal of at landfill in Karlsruhe;<br>(iii) Road transport of PP packaging as waste material |

| | | | | |
|---|---|---|---|---|
| | | | | from fibre production industry to municipal incinerator.<br><br>distances = 120 km; 3 km ; 100 km, respectively |
| **Truck (local)** | Truck local – technology mix, diesel driven, Euro 3, cargo 14 – 20 t total cap. / 11,4 t payload capacity – PE International | 2010 | Global | Road transport of posidonia fibre from fibre industry to building, in Germany.<br><br>distance = 100 km |
| **Railway** | Rail transport cargo – Electric– PE International | 2010 | Global | Railway transport of the container from Italy to Germany (Scenario Analysis).<br><br>distance = 853 km; 684 km |
| **Diesel** | Diesel at refinery – ELCD/PE International | 2010 | EU-15 | Fuel consumed by truck-trailer, motor ship and average ship (Tunisia-Spain-Belgium-Germany). |
| **Diesel** | Diesel at refinery – PE International | 2010 | Germany (DE) | Fuel consumed by solo truck and truck (local) in Germany. |
| **Fuel oil light** | Fuel oil light at refinery – ELCD/PE International | 2010 | EU-15 | Fuel consumed by bulk commodity carrier from Spain to Belgium. |
| **Power grid mix** | Power grid mix ELCD/PE-GaBi – ELCD/PE International | 2010 | Germany (DE) | Electric power consumed by fibre production industry and installation of thermal material in buildings in Germany.<br><br>Energy needed:<br>1,9 kWh / $m^3$ of posidonia ball (fibre production);<br>6,5 kWh / $m^3$ of posidonia fibres (installation of insulation material) |
| **Power grid mix** | Power grid mix ELCD/PE-GaBi – ELCD/PE International | 2010 | Italy (IT) and Switzerland (CH) | Energy consumed by trains to transport the container (Scenario Analysis). |
| **LDPE film** | Polyethylene film (PE-LD) - PlasticsEurope | 2010 | Europe | LDPE film production for the PE packaging to carry the posidonia fibres. |
| **Landfill (inert material)** | Glass - BUWAL | 2006 | Switzerland (CH) | Disposal of inert material (sand and salt) at landfill. |
| **Landfill (commercial waste)** | Commercial waste for municipal disposal – PE International | 2006 | AT, DE, IT, LU, NL, SE, CH | Disposal of PE waste material at landfill. |
| **Incinerator (PP packaging)** | Polypropylene (PP) incinerated in municipal waste incinerator – PE International | 2010 | Germany (DE) | Incineration of PP packaging after its use to carry posidonia balls. |
| **Mechanical recycling (PE packaging)** | HDPE mechanical recycling – Fraunhofer ICT | 2009 | Germany (DE) | Mechanical recycling of PE packaging after its use to carry posidonia fibres. |
| **Incinerator (posidonia fibre)** | Wood (natural) in municipal waste incinerator – PE International | 2010 | Germany (DE) | Incineration of posidonia fibres after use phase (Scenario Analysis). |

The process EU-15 was assumed for the Tunisia case once Fraunhofer ICT has no diesel process for Tunisia in its GaBi databases.

The transportation distances, calculated by the website EcoTransIT (2001), were based on the logistic possibilities provided by the project partners.

For those transports by truck for which no information was available it was assumed a distance of 100 km (default number of the GaBi processes for road truck).

In Fraunhofer ICT license, there is no dataset for inert material and mechanical recycling of polyethylene for Germany. In order to consider the environmental impact of the disposal of inert materials in Germany the LCI dataset "Glass – Landfill - Switzerland" published by *Bundesamt für Umwelt, Wald und Landschaft* (BUWAL) available in "GaBi Databases 2006" was chosen. The LCI dataset "HDPE mechanical recycling" was assumed in order to take into account the environmental impact of the PE film End-of-Life. This dataset was developed for the RailWaste Project at Fraunhofer ICT in 2009, where the main goal of the project was to develop a railway sleeper made of waste materials, including polyethylene.

## 3.7 Allocation

There is no by-product from the production of the insulation fibres in the basic scenario and allocation was not necessary.

In the Scenario Analysis, it was considered that a thermal processing of fibres in their end of life occurs in a municipal incinerator / power plant. The allocation of energy credits for electricity and heat produced from the German electricity mix were based on the heating value of the input.

# 4 Phase 2 – Life Cycle Inventory (LCI)

This phase, called Life Cycle Inventory Analysis (LCI), is the compilation and quantification of the inputs and outputs across the whole life cycle of the posidonia oceanica for the German case. An overview of the basic scenario described in 3.4 is presented in Figure 1.

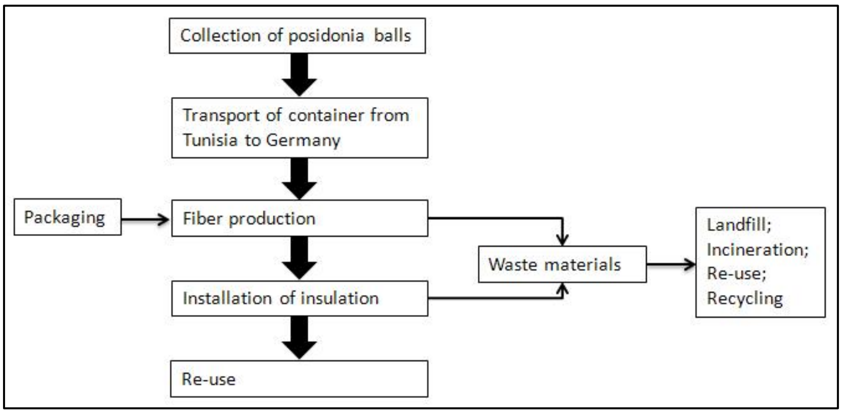


Figure 1. Flow diagram of basic scenario (from Tunisia to Germany)

The size of the container is 76 $m^3$ and the density of posidonia ball is about 146 kg / $m^3$. Outcomes show that the total emission from the entire life cycle of the 11.121 kg of posidonia balls or 1 container is of 6.983 kg, being 6.939 kg to air emissions, 44 kg to water emissions and 0,1 kg to industrial soil emissions.

The main results of the Life Cycle Inventory of the posidonia oceanica balls per container, 1 kg of material and functional unit are presented in Table 2.

Table 2. Life Cycle Inventory results for posidonia

| Parameters | Unit | Total per container | Total per kg posidonia | Total per F.U. (3,06 kg) |
|---|---|---|---|---|
| **RESOURCES** | | | | |
| **Energy resources** | MJ | 27.695,5 | 2,49 | 7,62 |
| Non-renewable energy resources | MJ | 27.065,4 | 2,43 | 7,45 |
| Renewable energy resources | MJ | 630,1 | 0,06 | 0,17 |
| **Material resources** | MJ | 0,4 | 0,00 | 0,00 |
| **WATER CONSUMPTION** | | | | |
| Water | kg | 2.167,3 | 0,19 | 0,60 |
| **EMISSIONS TO AIR** | | | | |
| Carbon dioxide | g | 1.738.836,8 | 0,16 | 0,48 |
| Carbon dioxide (biotic) | g | 31.810,0 | 0,00 | 0,01 |
| Carbon monoxide | g | 3.281,0 | 0,00 | 0,00 |
| Sulphur dioxide | g | 6.109,0 | 0,00 | 0,00 |
| Nitrogen oxides | g | 15.990,7 | 0,00 | 0,00 |
| Nitrogen dioxide | g | 264,1 | 0,00 | 0,00 |
| Methane | g | 3.067,8 | 0,00 | 0,00 |
| Hydrogen fluoride | g | 1,8 | 0,00 | 0,00 |
| Hydrogen chloride | g | 13,4 | 0,00 | 0,00 |
| Hydrocarbons (except CH4) | g | 238,9 | 0,00 | 0,00 |
| Ammonia | g | 8,2 | 0,00 | 0,00 |
| Organic emissions (VOC) | g | 5.426,3 | 0,00 | 0,00 |
| Particles | g | 651,0 | 0,00 | 0,00 |
| Heavy metals | g | 1,5 | 0,00 | 0,00 |
| Steam | g | 1.827.996 | 0,16 | 0,50 |
| Exhaust | g | 2.913.060 | 0,26 | 0,80 |

| EMISSIONS TO WASTE WATER | | | | |
|---|---|---|---|---|
| Biological oxygen demand (BOD) | g | 4,5 | 0,00 | 0,00 |
| Chemical oxygen demand (COD) | g | 243,8 | 0,00 | 0,00 |
| Solids (dissolved) | g | 12,5 | 0,00 | 0,00 |
| Solids (suspended) | g | 921,1 | 0,00 | 0,00 |
| Nitrogen | g | 1,3 | 0,00 | 0,00 |
| Nitrogen organic bounded | g | 3,7 | 0,00 | 0,00 |
| Phosphate | g | 0,4 | 0,00 | 0,00 |
| Organic compounds (dissolved) | g | 0,6 | 0,00 | 0,00 |
| Sodium (+I) | g | 547,4 | 0,00 | 0,00 |
| Sulphate | g | 18.058,3 | 0,00 | 0,00 |
| **SOLID WASTE** | | | | |
| Waste materials | kg | 2.249,3 | 0,20 | 0,62 |

# 5 Phase 3 - Life Cycle Impact Assessment (LCIA)

In the phase Life Cycle Impact Assessment (LCIA) the inputs and outputs were aggregated and translated into potential environmental impacts.

In this study it was conducted the mandatory steps: Selection, Classification and Characterization of the inventory flows.

In Classification, the inventory flows of the LCI were assigned to the impact categories selected for this study. Some data may belong to more than one category (e.g NOx influences greenhouse and acidification effects). In Characterization, these contributors (aggregated data of the inventory results) were converted into a common indicator for each category (e.g. $CO_2$ equivalent).

The Weighting, which consist the process of converting these indicators from Characterization step into scores by using numerical factors, was not contemplate in this study once this is the most subjective step of a LCA based on value judgments, which could vary from different organisations (McDougall et al., 2001).

The contribution to the following environmental impacts has been assessed.

i. *<u>Global warming potential</u>* (kg$CO_2$-equivalents) (output) – aggregate loading of greenhouse gases (e.g. $CO_2$, $CH_4$, CFCs, HCFCs) expressed as $CO_2$ equivalents that contribute to increase in average global temperature.

The carbon dioxide is the largest contributor for the global warming potential, responding for 89% of the total GHG emission. The methane contribution is of 3% of this emission.

The journey of about 5.000 km to transport the posidonia balls from Tunisia to Germany has presented the highest greenhouse gases (GHG) emissions (56%) due to diesel consumption by ships and trucks. Electricity consumption accounts for 35% of the GHG emissions, being 30% from installation of the fibres in the buildings and 5% from fibre production industry. The polyethylene packaging production to carry the posidonia fibres from the industry to the buildings is responsible for 1% of the GHG emissions attributed to the amount of non-renewable raw material needed to produce them. Each packaging that carries 22 kg of fibres weights 300 grams. The assumption that 75% of these polyethylene packaging will be collected and forwarded to the mechanical recycling contributes with 5% for the GHG emissions due basically to the electricity needed to reprocess this waste material.

It is worth to be mentioned that has been considered in the basic scenario that 25% are re-sent to the fibre production industry to be re-used and that the PE packaging waste, as secondary/recycled material (PE film), supplies 75% of the material needed to produce the polyethylene packaging. In other words, if no re-use or recycling was assumed, the PE packaging industry would contribute with a higher GHG emission due to the highest amount of non-renewable raw material and, in consequence, also of energy resources needed to produce them. Therefore this would increase the total warming potential as well. Hence, the replacement of non-renewable material from recycled one explains the reason of the higher contribution in terms of GHG emissions from the recycling industry in comparison with the PE packaging industry.

The disposal of waste materials along the life cycle of the posidonia balls (End-of-Life phase) accounts for 2% of the greenhouse gases emissions. This emission refers mainly to the disposal of sand, salt and 6% of the PE packaging at landfill[1] and the PP packaging burned in municipal incinerator. The electric power generated from these landfills was also taken into account to supply a part of the electricity consumed by the fibre production industry and PE recycling plant.

One container with 11.121 kg of posidonia balls emits 1.857 kg$CO_2$e. Hence, the greenhouse gases emissions of one kilogram of posidonia material is of 167 g$CO_2$e (or 12.107 g$CO_2$e / $m^3$; 511 g$CO_2$e / F.U.).

In Figure 2 is presenting the sharing of greenhouse gases emissions within posidonia life cycle.

[1] The 6% of PE packaging refers to the residue from the recycling industry; or the waste material that was not able to be recycled.

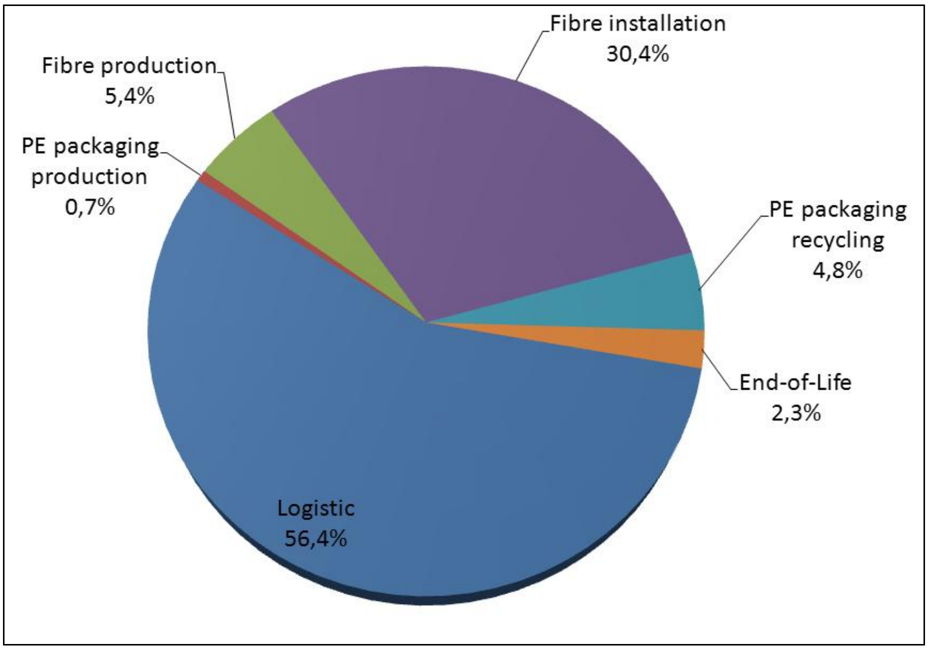


Figure 2. Sharing of GHG emissions in the posidonia life cycle

ii. *Acidification potential* (kg$SO_2$-equivalents) (output) – aggregate loading of all atmospheric and aquatic emissions expressed as acidification potential, such as acids and substances possibly converted to acids (e.g. HCl, $SO_2$, $NO_x$) that contribute for loss of aquatic life as pH of receiving waters decreases.

From the total acidification impact, the highest emissions are of nitrogen oxides (62%) and sulphur dioxide (36%).

The major contribution for the acidification comes again from the logistic phase, being 43% from fuel oil consumption by ship to transport the container from Barcelona to Zeebrugge; 18% from diesel consumption by ship from Tunis to Barcelona; 12% from diesel consumption by ship from Zeebrugge to Karlsruhe; and 6% from diesel consumption by truck from Sousse beach to Tunis harbor. The remaining contributions are attributed to the production of polyethylene packaging production (8%) and electricity consumption during the insulation material installation phase (4%).

iii. *Eutrophication potential* (kg$PO_4^{3-}$-equivalents) (output) – loading of nutrient substances, which may decrease dissolved oxygen during mineralization such as phosphorous and nitrogen, that contribute for loss of aquatic life and deterioration of water quality as dissolved oxygen levels in receiving waters decrease.

Concerning the total eutrophication impact, the nitrogen oxides emission contributes alone with 96%.

The logistic phase is once again the main responsible for the eutrophication impact, being 32% from fuel oil consumption by ship to transport the container from Barcelona to Zeebrugge; 27% from diesel consumption by ship from Tunis to Barcelona; 17% from diesel consumption by ship from Zeebrugge to Karlsruhe; and 13% from diesel consumption by the trucks.

iv. *Photochemical ozone creation potential* ($kgC_2H_4$-equivalents) (or summer smog) (output) – loading of Volatile Organic Compounds (VOCs) and nitrogen oxides ($NO_x$, a common pollutant) in the presence of radiation from the sun can create ozone. In the low atmosphere, ozone impacts human health (e.g. breathing difficulties) and crops damage.

The main outputs that impact the photochemical ozone creation impact are the group NMVOC (35%), nitrogen oxides (30%) and sulphur dioxide (21%).

The logistic phase accounts for 78% of the emissions. From this total, 30% of the emissions occur during the transportation of the container by ship from Barcelona to Zeebrugge; 20% are emitted by ship from Tunis to Barcelona and 13% from Zeebrugge to Karlsruhe. The production of polyethylene is responsible for 12% of the emissions and the disposal of inert material at landfill contributes with 6% of the emissions to this environmental impact.

v. *Energy consumption* (MJ) (input) – accounts for renewable and fossil fuel feedstock and energy consumed.

It was assumed that the electricity needed during the production phase is of 0,01305 kWh per kg of material (or 522 MJ / container) and for the installation of the posidonia fibres as insulation material in buildings is of 6,5 kWh / $m^3$ (or 2.872 MJ / container; density of 72,5 kg/$m^3$), according to information provided by the project partners.

However, the energy consumption during the whole life cycle of the posidonia has been assessed by looking at primary energy demand from renewable and non-renewable resources. Results show that the energy demand accounted for 2,5 MJ per kg of material, being 98% of non-renewable material resources. This is basically due to the diesel (produced in Europe) consumed during the logistic phase (52%); the electricity consumed from the German power grid mix during the building's installation of the posidonia fibres (33%), fibre production industry (6%) and recycling industry (5%).

The non-renewable energy resources required to produce posidonia fibre as insulation material shows that the main primary energy accounts for crude oil (53%), followed by uranium (18%), lignite (11%), hard coal (10%) and natural gas (8%) (see Figure 3).

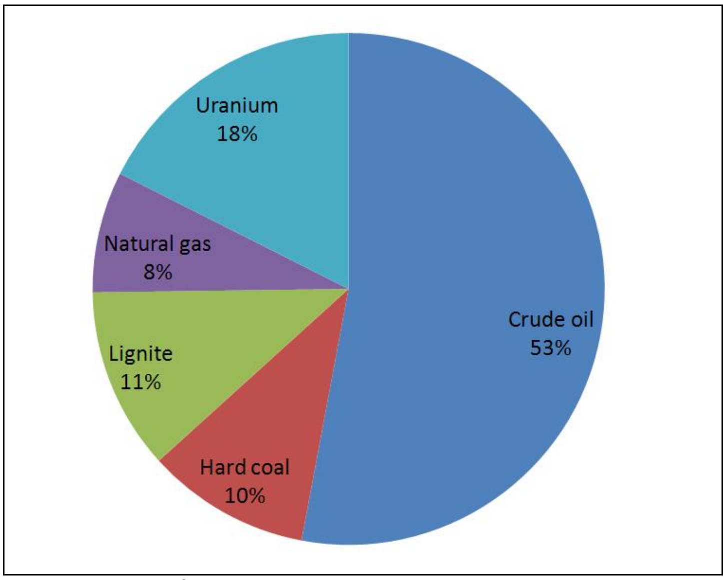


Figure 3. Sharing of non-renewable energy resources required

The assumption of thermal recovery of the posidonia fibres after the use phase with steam and electricity production at a German municipal incinerator will be approached in the Scenario Analysis. This results in an energy credit by the substitution of non-renewable primary energy resources at German power grid mix for the thermal recycling of natural fibres.

vi. *Water consumption* (kg) (input) –

The water consumed through the whole life cycle of the posidonia ball is of 0,2 kg per kg of material. The highest consumptions occur during the installation of the fibres in buildings (61%). The electricity consumed from the German power grid is responsible for the water consumption, which is one of the renewable material resources identified within its Life Cycle Inventory available in the GaBi dataset.

vii. *Generation of solid waste* (g) (output) –

The total solid waste generated is of about 202 gram per kilogram of material.

From the production of posidonia fibres for insulation material residues are generated, such as sand and salt, which are disposal of at landfill in Karlsruhe. Each kilogram of posidonia balls contents in average 200 g of these inert materials. Other solid waste materials generated during the posidonia life cycle are the polypropylene packaging (2,5 kg / container) - used during the logistic phase to carry the posidonia balls -, and the polyethylene packaging (91 kg / container) - used to carry the fibres. The first one was considered to be sent to waste incinerator and the second one to re-use, recycling plant and landfilling.

For the LCA calculation, the unit processes can roughly be divided into 6 stages: logistic, PE packaging production, fibre production, fibre installation, PE packaging recycling and landfill. The results (total and for each phase) for 1 kg of raw material are summarized in Table 3.

Table 3: Environmental categories impact in each process unit

| Environmental categories / 1 kg posidonia | TOTAL | Logistic | PE packaging production | Fibre production | Fibre installation | PE packaging recycling | End-of-Life |
|---|---|---|---|---|---|---|---|
| Global warming potential ($gCO_2e$) | **167,00** | 94,2 (56%) | 1,2 (1%) | 9,1 (5%) | 50,7 (30%) | 8,0 (5%) | 3,8 (2%) |
| Acidification potential ($gSO_2e$) | **1,61** | 1,4 (86%) | 0,1 (8%) | 0,0 (1%) | 0,1 (4%) | 0,0 (0%) | 0,0 (0%) |
| Eutrophication potential ($gPO_4^{3-}e$) | **0,19** | 0,2 (91%) | 0,0 (4%) | 0,0 (1%) | 0,0 (2%) | 0,0 (0%) | 0,0 (3%) |
| Photochemical ozone creation potential ($gC_2H_4e$) | **0,13** | 0,1 (78%) | 0,0 (12%) | 0, (1%) | 0,0 (3%) | 0,0 (0%) | 0,0 (6%) |
| Energy consumption (MJ) | **2,49** | 1,3 (52%) | 0,0 (2%) | 0,1 (6%) | 0,8 (33%) | 0,1 (5%) | 0,0 (1%) |
| Water consumption (kg) | **0,19** | 0,0 (5%) | 0,0 (12%) | 0,0 (11%) | 0,1 (61%) | 0,0 (10%) | 0,0 (1%) |

In Figure 4 can be seen the relative contributions of each of these 6 stages to the environmental categories examined.

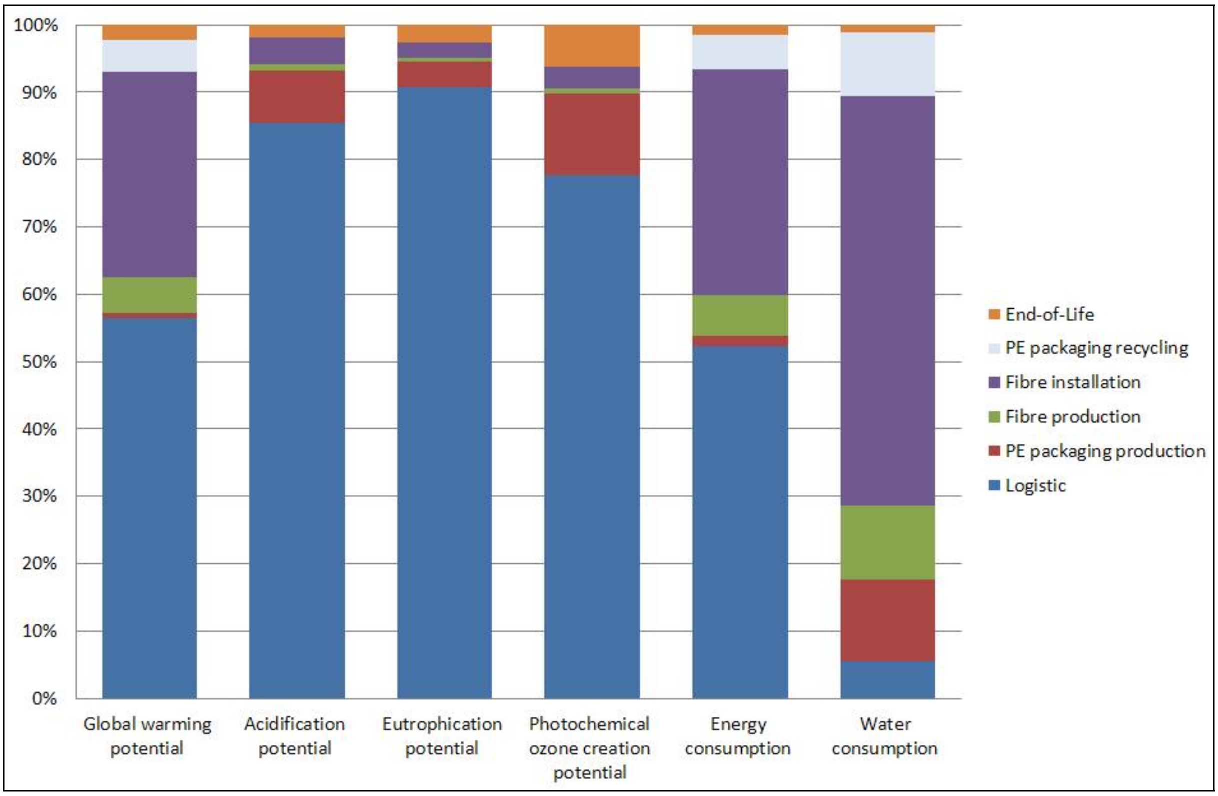


Figure 4. Relative contributions to the environmental effects of 1 kg of posidonia

In Table 4 is also presented the results per functional unit and cubic meter of posidonia oceanica material needed to produce insulation material.

Table 4. Environmental categories impact per F.U and $m^3$ of posidonia

| Environmental categories impact | Per Functional Unit (3,6 kg) | Per $m^3$ posidonia |
|---|---|---|
| Global warming potential ($gCO_2e$) | 511,02 | 12.107,42 |
| Acidification potential ($gSO_2e$) | 4,92 | 116,53 |
| Eutrophication potential ($gPO_4^{3-}e$) | 0,59 | 13,89 |
| Photochemical ozone creation potential ($gC_2H_4e$) | 0,40 | 9,49 |
| Energy consumption (MJ) | 7,62 | 180,55 |
| Water consumption (kg) | 0,60 | 14,13 |

Impacts on local ecosystems and the general population; costs analysis; and human and health aspects were not accounted in this study.

# 6 LCA studies for thermal insulation materials

**Disclaimer**

**The comparison made in this chapter, between the environmental impacts of different materials when used as insulation material, was made uniquely by request of the project partners. They were duly informed, however, that in order to make such comparison possible, LCA studies of these materials should have been performed using the same software, assumptions and dataset, which was not done in this work. On the contrary, different LCA software, assumptions (e.g. system boundary) and dataset were employed in the analysis of said materials in the different studies and by the different authors referred herein. Therefore, the comparison presented in this chapter is to be considered only for internal reference by the project partners, and was not made following the correct scientific methodology.**

The major materials used in Europe of insulating materials are mineral wool - glass and stone wool -, and organic foamy ones - expanded polystyrene (EPS), extruded polystyrene (XPS) and polyurethane (PUR). However, numerous alternatives have come into the market, such as flax and paper wool. Some outcomes of the LCA studies for these materials are presented below.

In Papadopoulos & Giama (2007) two insulation materials, stone wool and extruded polystyrene (XPS), were compared in terms of their environmental performance using GEMIS model (GEMIS, 2011). In this study was verified that the electricity consumption during the production phase of the insulation material was a significant parameter. The energy consumed during the production process of both materials were 0,3 kWh / kg of stone wool and 0,86 kWh / kg of XPS. Analyzing different environmental categories, the greenhouse effect arisen as the most relevant environmental impact of the production of insulation materials, resulting in an emission of 0,4 $kgCO_2e$ / kg of stone wool insulation material and 1,18 $kgCO_2e$ / kg of XPS insulation material. Moreover, concerning the energy consumption needed by taking stone wool as insulation material (0,6 kWh / $m^2$) and XPS (1,3 kWh / $m^2$) during the use phase, the greenhouse gases emissions of 1 $m^2$ insulated by stone-wool was 0,8 $kgCO_2e$ and by XPS was 1,8 $kgCO_2e$[2]. Other two indicators analyzed in this study were packaging material needed and solid wastes generated. The amount of material used to produce packaging for the insulation materials, made of low-density polyethylene (LDPE), was 12,5 kg LDPE / kg of stone wool and 18 kg LDPE / kg of XPS. The quantity of solid wastes generated was quite similar for both materials, 0,09 kg / kg of stone wool insulation material and 0,08 kg / kg of XPS insulation material.

The study presented in two parts by Schmidt et al. (2004) made a LCA comparison of three building insulation products: stone wool, paper wool and flax. From the results could be verified that the flax had the highest global and regional environmental impacts, followed by stone wool and paper wool. However, it was addressed that the stone wool presented the lowest total energy consumed in the whole life cycle in comparison to the other products, with the paper wool falling in between and flax with the highest consumption. The system boundary defined was based on the Western European market and included all processes from the acquisition of the raw materials until the final disposal phase.

In Schmidt et al. (2004) is also presented the functional unit for stone wool batts (1,184 kg), paper wool granulate (1,28 kg) and flax rolls (1,26 kg). These lower values are referred to their lower density: 32, 32 and 30 kg/$m^3$, respectively. In Ardente et al. (2008) the functional unit of kenaf (Hibiscus cannabinus) corresponds to an insulation panel of 1,52 kg (with density of 40 kg/$m^3$).

More detailed results from these studies can be seen in item 6.1.

## 6.1 Comparison with other insulation materials

The environmental impacts of the posidonia oceanica life cycle have been compared to the performances of others raw materials for thermal insulation product. The comparison has included various materials such as mineral, synthetic and natural fibre, as following described:

- Stone wool: natural minerals mixed with recycled post-production waste materials with addition of binder and impregnation oil (Schmidt et al., 2004).

[2] Papadopoulos & Giama (2007) considered the GHG emissions of the data given from GEMIS's software for Greek to calculate the emissions during the use phase and production of the insulation material.

- Paper wool: shredded newspaper with addition of aluminium hydroxide, borax and/or boric acid (Schmidt et al., 2004).

- Flax: flax with addition of polyester, diammonium hydrogen phosphate and borax. Growing flax requires artificial fertilizes (Schmidt et al., 2004).

- Kenaf: vegetable fibres incorporated in a polyester matrix (fibre reinforced composite) (Ardente et al., 2008).

- Glass wool: low-density insulation derived from waste glass mixed with other minerals and organic resins and melted in electrical furnaces (Ardente et al., 2008).

- Polyurethane: rigid foam blown with CFC-free gas (Ardente et al., 2008).

The results from posidonia study were compared to these other 6 insulation materials considering their functional unit (Table 5) and the total per kg of material (Table 6). The number in parenthesis means the F.U. calculated for each material.

For example, in Schmidt et al. (2004) it was considered that 100% of stone wool / paper wool / flax are recycled in low grade application after the use phase. In this study is not mentioned the consideration of the packaging production and its use within the system boundary. Also, it was used the GEMIS database (Global Emission Model for Integrated Systems) and the work was published in 2004.

Table 5. Comparison of different insulation material (per functional unit) with Schmidt et al. (2004) and Ardente et al. (2008)

| Per F.U. | Posidonia oceanica (3,06) | Stone wool (1,18)[1] | Paper wool (1,28)[1] | Flax (1,26)[1] | Kenaf (1,52)[2] | Glass wool (1,00)[2] | Polyurethane (0,84)[2] |
|---|---|---|---|---|---|---|---|
| Global Warming Potential ($gCO_2e$) | 511,02 | 1.449,00 | 819,00 | 2.357,00 | 3.170,00 | 2.200,00 | 3.200,00 |
| Acidification potential ($gSO_2e$) | 4,92 | 12,30 | 5,50 | 16,80 | 27,40 | 8,40 | 27,90 |
| Eutrophication potential ($gPO_4^{3-}e$) | 0,59 | 1,20 | 0,70 | 1,20 | 2,40 | 1,30 | 2,94 |
| Photochemical ozone creation potential ($gC_2H_4e$) | 0,40 | 4,60 | 0,20 | 0,50 | 2,20 | 2,50 | 1,40 |
| Energy consumption (MJ) | 7,62 | 20,80 | 26,20 | 49,70 | 59,37 | 47,30 | 93,60 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Water consumption (kg) | 1,01 | 3,91 | 0,82 | 5,77 | 10,70 | 27,00 | 297,70 |
| Total waste (kg) | 0,01 | 0,05 | 0,03 | 0,16 | 2,00 | 6,60 | 0,32 |

Source: [1]Schmidt et al. 2004; [2]Ardente et al. 2008

Table 6. Comparison of different insulation material (per kg of material) with Schmidt et al. (2004) and Ardente et al. (2008)

| Per kg posidonia | Posidonia oceanica | Stone wool[1] | Paper wool[1] | Flax[1] | Kenaf[2] | Glass wool[2] | Polyurethane[2] |
|---|---|---|---|---|---|---|---|
| Global Warming Potential ($gCO_2e$) | 167,00 | 1.223,82 | 639,84 | 2.969,82 | 4.818,40 | 2.200,00 | 2.688,00 |
| Acidification potential ($gSO_2e$) | 1,61 | 10,39 | 4,30 | 21,17 | 41,65 | 8,40 | 23,44 |
| Eutrophication potential ($gPO_4^{3-}e$) | 0,19 | 1,01 | 0,55 | 1,51 | 3,65 | 1,30 | 2,47 |
| Photochemical ozone creation potential ($gC_2H_4e$) | 0,13 | 3,89 | 0,16 | 0,63 | 3,34 | 2,50 | 1,18 |
| Energy consumption (MJ) | 2,49 | 17,57 | 20,47 | 62,62 | 90,24 | 47,30 | 78,62 |
| Water consumption (kg) | 0,19 | 3,30 | 0,64 | 7,27 | 16,26 | 27,00 | 250,07 |
| Total waste (kg) | 0,00 | 0,05 | 0,02 | 0,20 | 3,04 | 6,60 | 0,27 |

Source: [1]Schmidt et al. 2004; [2]Ardente et al. 2008

The German Institute Construction and Environmental (*Institut Bauen und Umwelt* – IBU) published since 2008 some studies concerning the Life Cycle Assessment for insulation materials. The one about wood fibres panel (IBU, 2009) took into account the packaging of raw material and final product. The system boundary was defined from material extraction to packaged insulation product and then the incinerator plant. The installation phase was left out. Also, it was contemplated the credits of the thermal recovery from burning the wastes from production phase and residues packaging.

In the study for Extruder polystyrene foam (XPS) (IBU, 2010), the system boundary was the same but it was considered two scenarios for disposal materials (50% and 90% of thermal recovery).

For polyurethane panel (IBU, 2010a), the system boundary includes raw material preparation, product manufacture and thermal recovery, but only for packaging and not for all waste material.

In the studies for stone wool panel (IBU, 2008) and for glass wool (IBU, 2008a), however, the system boundary defined include the analysis from cradle to gate (from raw material preparation to insulation production), leaving out the disposal of the waste materials once the long life of these insulation products is not sufficiently quantifiable.

The comparison of posidonia study to these published by the IBU is shown in Table 7 (per kg of material) and Table 8 (per $m^3$ of material) and the products description is as follow:

- Wood fibre panel: made of pine wood (minimum of 80%), certified by PEFC (Programme for the Endorsement of Forest Certification Schemes) with addition of binder fibre (8%) and ammonium phosphate (n.a.) (IBU, 2009).

- Stone wool panel: made basically of dolomite stone, shard and sand, each with 20-30% (mass) of iron oxid and 5-15% (mass) of cement. It is a no laminate mineral wool, which uses organic binder that decomposes at temperatures above ca. 200°C (IBU, 2008).

- Extruder polystyrene foam: polystyrene is used as main raw material, with 90-95% mass), which is foamed using blowing agent, such as carbon dioxide and halogen free Co-propellant (5-8% mass), hexabromocyclododecane (0,5-3% mass) and additives (less than 1%) (IBU, 2010).

- Glass wool panel: main raw material is shard glass (50-70% mass), sand (10-20% mass), soda (5-15% mass) and borax (5-10%). It is a no laminate product (IBU, 2008a).

- Polyurethane panel: made of polyurethane foam produced by chemical reaction of MDI (ca. 55-65%) and polyol (20-30%) with addition of blowing agents (4-5%). Fire retardant foams contain partially fluorinated hydrocarbons without ozone depletion potential. The logs are without facings (IBU, 2010a).

Table 7. Comparison of different insulation material (per kg of material) with Institut Bauen und Umwelt

| Per kg posidonia | Posidonia oceanica | Wood fibre panel[1] | Stone wool panel[2] | Extruder polystyrene foam (XPS)[3] | Glass wool panel[4] | Polyurethane panel[5] |
|---|---|---|---|---|---|---|
| Global Warming Potential ($gCO_2e$) | 167,00 | 16,36 | 1.610,00 | 5.354,12 | 1.770,00 | 5.633,53 |
| Acidification potential ($gSO_2e$) | 1,61 | 2,36 | 4,40 | 13,82 | 6,70 | 12,60 |
| Eutrophication potential ($gPO_4^{3-}e$) | 0,19 | 0,24 | 0,50 | 1,18 | 1,10 | 1,59 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Photochemical ozone creation potential ($gC_2H_4e$) | 0,13 | 18,55 | 0,36 | 15,00 | 0,34 | 2,09 |
| Energy consumption (MJ) | 2,49 | 34,51 | 26,38 | 85,33 | 30,10 | 68,01 |
| Water consumption (kg) | 0,19 | - | - | 14,67 | - | 184,00 |
| Total waste (kg) | 0,00 | 0,83 | 4,87 | 0,12 | 3,95 | 2,58 |

Source: [1]IBU 2009; [2]IBU 2008; [3]IBU 2010; [4]IBU IBU 2008a; [5]IBU 2010a

Table 8. Comparison of different insulation material (per $m^3$ of material) with Institut Bauen und Umwelt

| Per $m^3$ posidonia | Posidonia oceanica | Wood fibre panel[1] | Stone wool panel[2] | Extruder polystyrene foam (XPS)[3] | Glass wool[4] | Polyurethane panel[5] |
|---|---|---|---|---|---|---|
| Global Warming Potential ($gCO_2e$) | 12.107,42 | 900,00 | 181.125,00 | 182.040,00 | 100.005,00 | 191.540,00 |
| Acidification potential ($gSO_2e$) | 116,53 | 130,00 | 495,00 | 470,00 | 378,55 | 428,40 |
| Eutrophication potential ($gPO_4^{3-}e$) | 13,89 | 13,00 | 56,70 | 40,00 | 62,15 | 54,00 |
| Photochemical ozone creation potential ($gC_2H_4e$) | 9,49 | 1.020,00 | 40,50 | 510,00 | 19,21 | 71,00 |
| Energy consumption (MJ) | 180,55 | 1.898,00 | 2.967,75 | 2.901,38 | 1.700,65 | 2.312,27 |
| Water consumption (kg) | 14,13 | - | - | 498,63 | - | 6.256,00 |
| Total waste (kg) | 0,15 | 45,73 | 547,88 | 4,00 | 223,18 | 87,86 |

Source: [1]IBU 2009; [2]IBU 2008; [3]IBU 2010; [4]IBU IBU 2008a; [5]IBU 2010a

# 7 Phase 4 - Interpretation

In this last phase, all assumptions and information from the results of the LCA and LCIA were reviewed, identified, checked and evaluated according to definitions in phase 1.

Once the significant assumptions and results in the phase 2 and 3 were identified, a Scenario Analysis and a Sensitivity Analysis were done in order to investigate the significant influences on the results.

## 7.1 Scenario Analysis

The Scenario Analysis includes studying the impact of parameters and different product systems and system boundaries on the environmental categories results.

The overall impacts are dominated by the logistic phase. The inventory analysis has shown the large impacts in terms of greenhouse gases emissions and energy consumption. According to the European Platform on Life Cycle Assessment, of the European Commission, the carbon footprint (the measurement of GHG emissions caused by a product or a service) is a subset of the data covered by a LCA and, in a policy context, this indicator is one of the most important currently being used in decision making in terms of sustainable consumption and production (EU, 2007).

In this way, a Scenario Analysis was applied in order to examine the changes that can be observed for different assumption on the logistic, insulation material installation and final disposal aspects. These scenarios provide an indication of which option is most favorable from the GHG emission point of view.

The following scenarios were investigated according to the project partners' information.

***Scenario 1- Logistic***

Concerning the logistic phase, four other routes to transport the posidonia balls from Mediterranean See to Karlsruhe, Germany were investigated (see Table 9):

(i) *Barcelona* (Basic scenario) - Posidonia collection in Tunis, Tunisia – transport from Tunis to Barcelona, from Barcelona to Zeebrugge, from Zeebrugge to Karlsruhe, by ship;

(ii) *Livorno* - Posidonia collection in Livorno, Italy - transport from Livorno to Karlsruhe, Germany, by train;

(iii) *Dürres* - Posidonia collection in Durrës, Albania - transport from Dürres to Trieste, Italy, by ship and then to Karlsruhe by truck;

(iv) *Genoa (train)* - Posidonia collection in Tunis, Tunisia – transport from Tunis to Genoa, Italy, by ship and then to Karlsruhe by train.

(v) *Genoa (truck)* - Posidonia collection in Tunis, Tunisia – transport from Tunis to Genoa by ship and then to Karlsruhe by truck.

The alternatives to transport the container with the posidonia balls from Tunisia or Albania to Germany by ship and truck have a high fuel consumption influencing the greenhouse gases effect, mainly due to the carbon dioxide emission. The scenario where the balls were collected in Livorno and then transport by train to Karlsruhe presented the lowest GHG emissions.

Other environmental impacts were verified due to the large contribution of the logistic phase to the categories analyzed, such as acidification, eutrophication, photochemical ozone creation (see Figure 5) and primary energy demand (see Figure 6).

The Barcelona Scenario had showed the highest acidification potential, owing to the inorganic emissions to the air of nitrogen oxides and sulphur dioxide from the ship and truck transport.

Table 9. Logistic scenario

| Scenario | Barcelona (Basic scenario) | Livorno | Dürres | Genoa (train) | Genoa (truck) |
|---|---|---|---|---|---|
| Collection of Posidonia balls | Tunis, Tunisia | Livorno, Italy | Dürres, Albania | Tunis, Tunisia | Tunis, Tunisia |
| Transport route | Tunis, Tunisia ↓ (*ship*) Barcelona, Spain ↓ (*ship*) Zeebrugge, Belgium ↓ (*ship*) Karlsruhe, Germany | Livorno, Italy ↓ (*train*) Karlsruhe, Germany | Dürres, Albania ↓ (*ship*) Trieste, Italy ↓ (*truck*) Karlsruhe, Germany | Tunis, Tunisia ↓ (*ship*) Genoa, Italy ↓ (*train*) Karlsruhe, Germany | Tunis, Tunisia ↓ (*ship*) Genoa, Italy ↓ (*truck*) Karlsruhe, Germany |
| GHG emissions (gCO2e/kg of posidonia) | 167,0 | 116,14 | 168,59 | 133,97 | 163,73 |

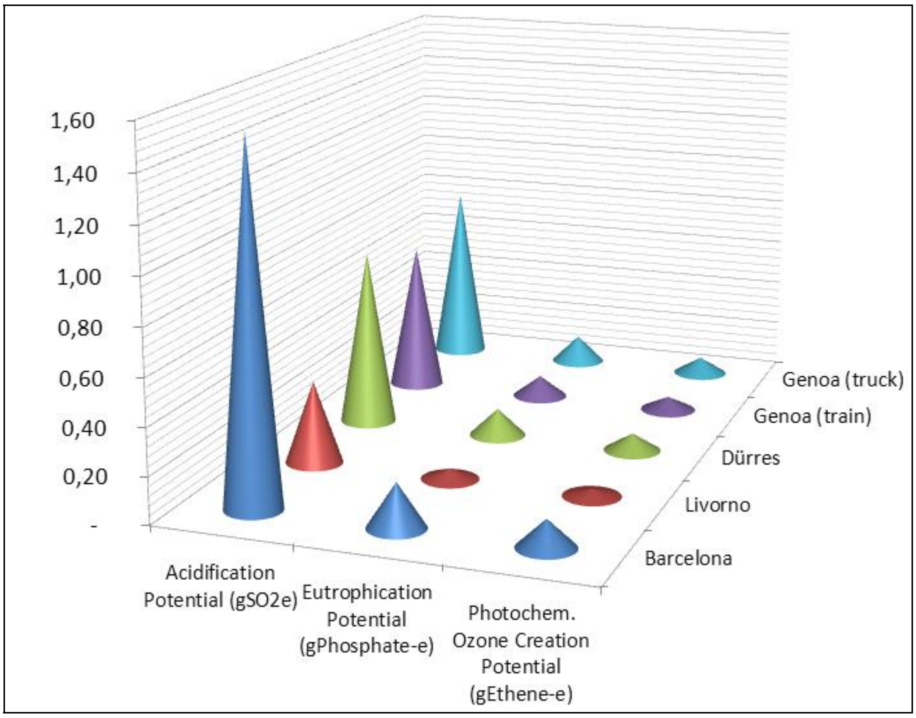


Figure 5. Impact of Scenario 1 – Logistic to the environmental categories (per kg of posidonia)

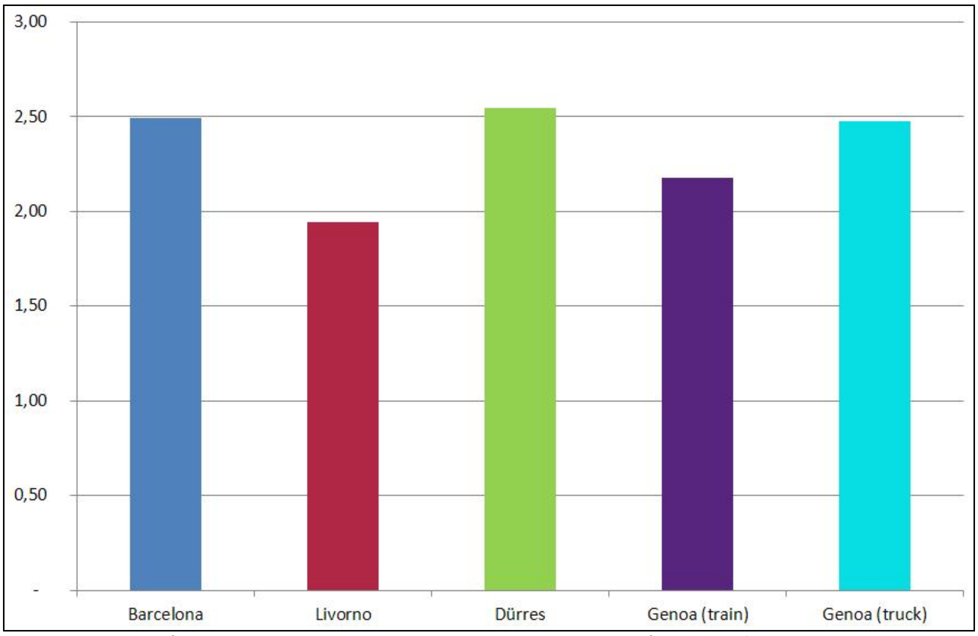


Figure 6. Impact of Scenario 1 – Primary energy demand (MJ / per kg of posidonia)

The alternative route from Livorno (Italy) is the most favorable in the 5 environmental categories analyzed. The Dürres alternative in comparison to Barcelona route has a low impact to acidification, eutrophication and photochemical ozone creation potential but it has a high impact to global warming potential and primary energy demand resources. This is due to the difference between the types of transportation. From Tunis to Karlsruhe, the total journey by ship is almost 5.000 km and by truck is 153 km. From Dürres to Karlsruhe, the total distance cover by ship is 754 km and by truck is 940 km. So, the highest GHG emission and energy demand from Dürres scenario are explained by the highest emission of carbon dioxide from each kilometer cover by truck in comparison to the ship.

***Scenario 2 - Installation***

Regarding the electricity needed during the different phases of the life cycle of posidonia fibres, it was observed the impact of no use of fibre blowing machine during the installation of the thermal insulation material, doing it by hand, once the energy needed at the fibre industry in Karlsruhe for the production of posidonia fibres for insulation material is not very demanding in terms of energy consumption.

In this case, 30% of the greenhouse gases could be reduced due to the avoidance of the blowing machine during the installation of the insulation material, which consumes only electricity. Hence, the total emission of GHG would be of 116 $gCO_2e$ per kilogram of posidonia. This less energy consumption from the German power grid mix also reduced the water use by 61%.

***Scenario 3 – Fibres End-of-Life***

Regarding the final destination of the posidonia fibres after the use phase, it was evaluated the consideration of sending them to a municipal waste incinerator. This option is already a practice for other natural fibre according to the KNR (2011) and Ardente et al. (2008). The posidonia oceanica fibres were regarded as carbon-neutral material since the amount of $CO_2$ emitted during the combustion phase was assumed to be equivalent to the amount of $CO_2$ captured during its growth. So, this means that the carbon dioxide emissions from the combustion of the fibres have been not taken into account. According to the project partners, the energy content of the posidonia fibres is of 15,4 MJ / kg of material.

Since there was no dataset available for incineration of posidonia fibres in a municipal incinerator, the GaBi - LCI dataset "Wood (natural) in municipal waste incinerator" was assumed.

In this scenario can be seen the influence of the incineration of posidonia oceanica fibres in comparison to the basic scenario where their re-use was assumed after the use phase. Even with the assumption of posidonia oceanica as carbon-neutral material, the GHG emissions have presented an increase of 170 $gCO_2e$ / kg of posidonia. This is due to the accounting of the German process for the "Wood in municipal waste incinerator" provided in the dataset of the GaBi software, which presents a high primary energy demand from non-renewable energy resources. Therefore, in this Life Cycle Inventory the GHG emission of only 1 kilogram of incineration good is of 1,87 $kgCO_2e$.

***Scenario 4 – PE packaging End-of-Life***

Since the alternative of using posidonia fibres as thermal insulation material in buildings is still in its developing and testing phases, the decision for the final destination of the polyethylene packaging after their installation is not yet defined and standardized. So, besides the consideration of 25% of PE packaging being re-sent to the fibre industry, it was analyzed two other possibilities, 50%-75% re-use / 50%-25% mechanical recycling:

(i) 25% re-use (30 kg PE packaging) / 75% recycling (91 kg PE packaging)

(ii) 50% re-use (61 kg PE packaging) / 50% recycling (61 kg PE packaging)

(iii) 75% re-use (91 kg PE packaging) / 25% recycling (30 kg PE packaging)

This parameter variation influences mainly the greenhouse gases emissions. It was observed that decreasing the amount of PE packaging waste sent to the recycling plant increases or increasing the amount sent to be re-used by the fibre industry the contribution for the GHG emissions decreases. As expected, the lowest emission is from the assumption of re-using 75% of the PE packaging and sending 25% to mechanical recycling in Germany. Tthe environmental benefit from re-using the waste packaging could present a maximum reduction potential of 6,4 $gCO_2e$ per kg of material.

In the basic scenario (Barcelona) has been considered that 25% are re-sent to the fibre production industry to be re-used and that the PE packaging waste, as secondary/recycled material (PE film), supplies 75% of the material needed to produce the polyethylene packaging. In other words, if no re-use or recycling was assumed, the PE packaging industry would contribute with a higher GHG emission due to the highest amount of non-renewable raw material and, in consequence, also of energy resources needed to produce them. Therefore this would increase the total warming potential as well.

***Summary***

The results are summarized in Table 10. The column "Phase" accounts for the GHG emission only during the phase analyzed, and the column "Total" means the impact in the whole posidonia LCA. The percentage in parenthesis means the contribution of the phase analyzed in the total impact.

Table 10. Scenario Analysis for GHG emissions

| Scenario | Description | Greenhouse gases emissions ($gCO_2e$/kg of posidonia) | |
|---|---|---|---|
| | | Phase | Total |
| Scenario 1 – Logistic | Barcelona | 94,23 (56%) | 167,0 |
| | Livorno | 43,38 (37%) | 116,14 |
| | Dürres | 95,82 (57%) | 168,59 |
| | Genoa (ship) | 61,21 (46%) | 133,97 |
| | Genoa (truck) | 90,97 (56%) | 163,73 |
| Scenario 2 - Installation | Machine | 50,69 (30%) | 167,0 |
| | By hand | 0,00 (0%) | 116,31 |
| Scenario 3 – Fibres EoL | Re-use | 0,00 (0%) | 167,0 |
| | Incineration | 324,82 (96%) | 337,24 |
| Scenario 4 – PE packaging EoL | 25% re-use / 75% recycling | 9,56 (6%) | 167,0 |

| | | | |
|---|---|---|---|
| | 50% re-use / 50% recycling | 6,21 (4%) | 163,65 |
| | 75% re-use / 25% recycling | 3,20 (2%) | 160,63 |

## 7.2 Sensitivity Analysis

The Sensitivity Analysis provides information on how sensitive the outputs, in this study the environmental categories analyzed, are in relation to the variation (uncertainty) in the inputs.

As mentioned some times, the project is still in its development stage during the performance of this LCA study. Due to the lack of precise available information because they are under investigation, this analysis was performed for energy required by the blowing machine during the installation phase and functional unit.

For the energy used in the installation of the posidonia fibres in the building, 0,065 kWh/kg of material, a standard deviation of 20% and 50% was considered in order to verify the impact on the greenhouse gases emissions.

From the results of 20% deviation, the greenhouse gases emissions can vary between 154,46 and 179,54 $gCO_2e$ / kg posidonia. For 50%, the GHG emissions vary from 135,60 to 198,39 $gCO_2e$ (see Figure 7).

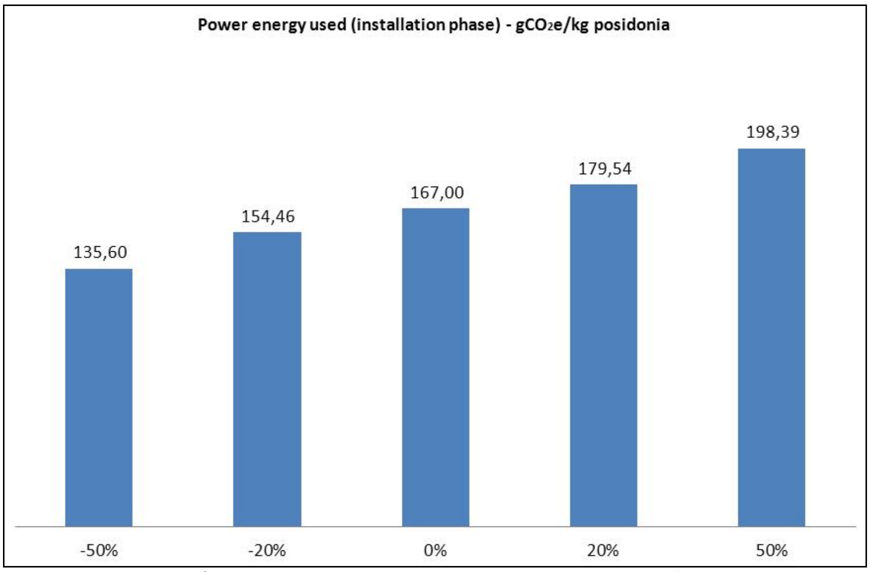

Figure 7. Impacting of energy used on GHG emissions (standard deviation)

The functional unit for insulation material was defined based on the thermal resistance, thermal conductivity, density of the insulation product and area. Once the thermal conductivity and density of posidonia fibre are still under investigation, and were assumed the value available until the performance of this LCA, a sensitivity analysis was done for 50% of deviation of F.U.

The functional unit variation is from 1,53 to 5,63 kg of material needed to attend the CEPMC proposal for the insulation function in buildings. The results are presented in Table 11 based on Table 5 structure and data.

Table 11. Comparison of different insulation material (per functional unit) – Sensitivity Analysis

| Per F.U. | Posidonia oceanica (1,53-5,63) |
|---|---|
| Global Warming Potential ($gCO_2e$) | 255,5 – 940,2 |
| Acidification potential ($gSO_2e$) | 2,5 – 9,0 |
| Eutrophication potential ($gPO_4^{3-}e$) | 0,3 – 1,1 |
| Photochemical ozone creation potential ($gC_2H_4e$) | 0,2 – 0,7 |
| Energy consumption (MJ) | 0,3 – 1,1 |

## 7.3 Conclusions

In this study an eco-profile based on a Life Cycle Assessment approach for the posidonia oceanica balls for the production of insulation material has been defined. The environmental benefits and energy drawbacks during its whole life time have been assessed.

From the Life Cycle Inventory could be observed that the logistic phase is the most responsible process unit for the emissions to the air, affecting the environmental categories analyzed. Also, the electricity required for the blowing machine during the installation of the thermal insulation material is significant parameter for the environmental impact.

In the other hand, the low electric power consumption for the production and preparation of the posidonia fibres is not so remarkable, as well as the PE packaging production and disposal of waste materials at landfill.

Besides the basic scenario, the Scenario Analysis demonstrated that the transportation via Italy, from Livorno to Karlsruhe by train, indicates the best alternative route in terms of the environmental aspects analyzed.

The verification of the use or not of the fibre blowing machine during the installation phase at buildings showed the significant influence of this phase to GHG emissions and water consumption.

The discussion about the final destination of the posidonia fibres after their use phase presented the impact of incineration on the global warming potential category. The GHG emissions could increase 170 $gCO_2e$ per kilogram of posidonia even with the consideration of posidonia fibres as carbon neutral material, which annuls the emissions of carbon dioxide captured during the growth of the natural fibres with its burning at incinerators.

The analysis of the two options of final destination for the polyethylene packaging, mechanical recycling or re-use, showed the range of impact for a parameter that is not yet defined into the project. Regarding the GHG emissions, the maximum contribution between the three alternatives defined would be of 6 g$CO_2$e per kilogram of posidonia.

The Sensitivity Analysis confirmed that the availability of more precise data, such as the energy needed for the blowing machine, thermal conductivity, density and energy content of posidonia fibre are important for the verification of the environmental performance of posidonia balls.

Therefore, the review of the thermal conductivity and the density will influence the results per kilogram of material and functional unit (as is the case of this updated report). Also, the review of the calorific value of posidonia fibres will affect the Scenario 3.

Due to the development stage of the project other types of impacts not addressed in this study could also be remarkable as well. For example, some Mediterranean countries leave the posidonia balls at the beaches and others collect them as waste material, disposing at landfill or open dumps, which impact differently the GHG emissions.

Hence, whether this change will provide or not a real benefit for the environmental is questionable and has to be reviewed.

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# 9 Annex

## Annex 1. GaBi 4 process plan