Life Cycle Assessment of EcoCocon Panel

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Commissioning party

EcoCocon s.r.o.
Záhradnícka 60,
821 08 Bratislava,
Slovakia

Executing party

Hedgehog Company B.V.
Turbinestraat 6,
1062 AV Amsterdam,
The Netherlands

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1. Introduction

1.1 Background

Hedgehog Company. This report was drawn up on 27-09-2022 and meets the requirements of -NEN-EN ISO 14040 [1] and NEN-EN ISO 14044 [2]. There is no Product Category Rule(s) (PCR) applicable for this product, thus NEN-EN ISO 15804+A2:2019 [3] was used as PCR along with the Environmental Performance Assessment Method for Construction Works (hereafter: Assessment Method) [4].

For the LCA calculations Mobius version 0.8.751 is used, a LCA software developed by Ecochain Technologies. The results of the LCA study and resulting Environmental Product Declarations (EPDs) are only comparable if they comply with the same calculation method used in this LCA.

1.2. Product description

This study concerns an average EcoCocon panel, which is always 40 cm depth. The exact dimensions of the EcoCocon panels vary (table 1). This LCA uses the average resources per m2. The average is based on the panel types Standard and Braced. The panel types Inclined, Sill, Lintel and Column are not included. The product is produced in Kybartai, Lithuania by EcoCocon UAB. It consists of a wooden frame with straw filling. The wall panels serve as constructive and insulating elements.

Table 1. The different types of panels and their dimensions. The depth is 0,4m for all panels.

Panel type	Width (m)	Height (m)	Production share
Standard	0,7	2,6	52,5%
Braced	0,8	2,6	17%

1.3. Verification statement

Declaration from the verifier, MSc P.F. Stadhouders 30-9-2022:

“the methodologies and data collection that are described in this report, comply with the requirements that are stated in “Bepalingsmethode Milieuprestatie Bouwwerken” version 1.1, released in March 2022, and the standards that it is based on: ISO 14040, ISO 14044 en NEN-EN 15804.

2. Goal and scope definition

2.1 Goal

This study aims to generate reliable and accurate quantitative environmental data of the EcoCocon Straw Panels and deliver this to the NMD (Nationale Milieudatabase). The data serves as a foundation for construction-related calculations and to generate solutions that cause a low environmental impact. Moreover, this study supplies environmental data that can be used by organisations downstream in the supply chain to calculate the environmental impact of their product. This study measures the direct environmental impact of the panel as a constructive and insulating element.

This leads to the following goal:

- Quantifying the environmental impact of an average EcoCocon Straw Panel.

The target audience of this study consists of customers of EcoCocon and users of the Nationale Milieudatabase. Additionally, the results of this study are relevant for EcoCocon itself as they provide insight into the environmental hot spots of their product.

2.2 Scope

2.2.1. Functional unit

This LCA calculates the environmental impact of 1 m2 of EcoCocon Straw Panel. The panel has a life expectancy of 75 years [5]. The functional unit is defined as: the production, construction and end-of-life of 1 m2 of the EcoCocon Straw Panel with a service life expectancy of 75 years.

2.2.2 System boundaries

The system boundaries of this study are set at the cradle, taking into account the production phase (A1-A3) and the construction stage (A4-A5). Although the use stage is included in the system boundaries, its impact is 0, as no material or energy inputs are required during use. The system ends with the grave; the end-of-life stage (C1-C4). The costs and benefits outside the product system are accounted for in Module D. With these system boundaries, this study conforms to the EN15804+A2 and the Assessment Method.

Table 2. Overview of the LCA stages described in this study.

Production stage			Construction stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundaries
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
x	x	x	x	x	x	x	x	x	x	ND	ND	x	x	x	x	x
Raw material supply	Transport	Production	Transport to site	Construction - installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse- Recovery- Recycling potential

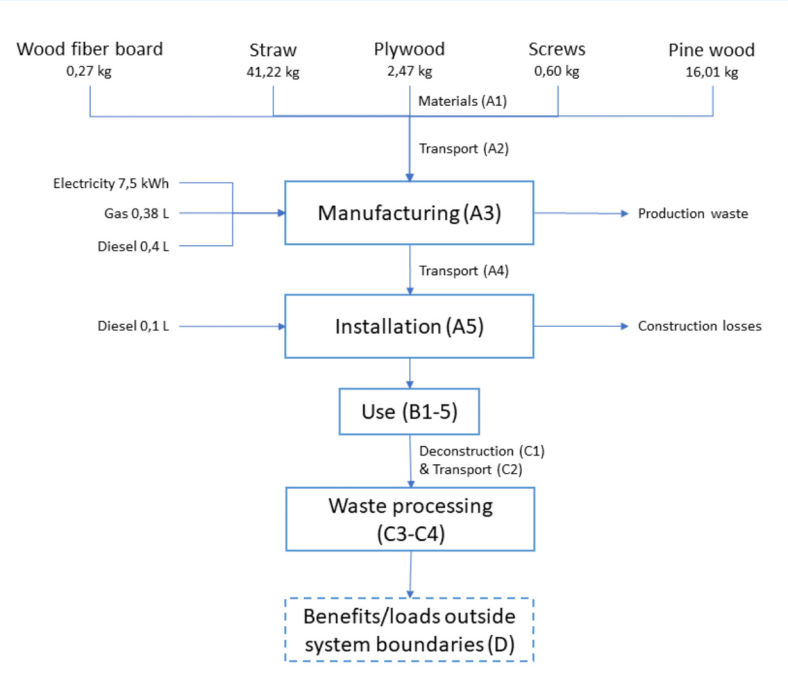

Figure 1. Flowchart of the scope of this LCA

3. Life cycle inventory

The life cycle inventory includes the data collection method and the inventory of the relevant in- and outflows of the product system. This chapter includes an inventory of the energy, material and transport in- and outflows for each step in the production process. The collected data is used to calculate the environmental impact through for example emissions to air, surface, water and resource depletion.

3.1 Data collection method

EcoCocon UAB collects and supplies the foreground data on raw material and energy inputs. Encountered data gaps are supplemented by literature. The collected information forms the basis for the selection of relevant processes of the Ecoinvent (v3.6) database and the Nationale Milieudatabase (v3.3). Section 4.2 describes the selected processes in detail.

3.2 Inventory and allocation

This section describes the different material and energy inputs that are required in all stages of the production process.

3.2.1 Production stage

Material collection (A1)

Table 3 lists the material inputs for 1 m2 panel. This data is obtained from EcoCocon UAB.

Table 3. Bill-of-materials for 1 m2 of EcoCocon panel. The amount of material includes the production waste.

Materials	Unit	Amount
Straw (from wheat)	kg	41,22
Wood Fiber board (684 kg/m3)[1]	kg	0,27
Plywood (birch) (640 kg/m3)[1]	kg	2,47
Pinewood (490 kg/m3)[1]	kg	16,01
Screws (zinc plated, low-alloyed)	kg	0,60
Total panel weight	*kg*	*60,57*
Pine wooden sticks for transportation (490 kg/m3)[1]	kg	1,3a

[1] The wood densities are based on their respective Ecoinvent references (see table 12).

Straw

Straw is a by-product of wheat production. Based on information from EcoCocon regarding recent prices, the environmental impact of the straw was allocated through economical allocation. EcoCocons straw supplier delivered the price of straw and wheat. Table 4 shows the prices and the calculations for economical

allocation. The wheat price is in line with the average price of the EU in September 2021 [6]. The straw supplier also disclosed the production numbers (ton) of straw, but chose to not supply the production numbers of wheat. The average data for Lithuanian wheat production serves as the basis for the production number [7].

The percentage of allocation is obtained by calculating what share of the total revenue is generated by straw. The Ecoinvent reference for 'wheat production, straw [RoW]' already contains an allocation factor for straw (5,1%). It was corrected based on this supplier specific allocation, to 10,2%.

Table 4. Calculation of allocation of straw from wheat.

Material	Price (€/ton)	Production (ton)	Revenue	Allocation	%
Straw	90	300	27000	0,101666196	10,1666196
Wheat	250	954,3	238575	0,898333804	89,8333804

Transport (A2)

This stage includes the transport of (raw) materials to the EcoCocon production location. Table 5 presents an overview of the means of transport and the distance from the supplier to EcoCocon. A courier delivers the screws from Vilnius, using a light commercial vehicle instead of a truck. All suppliers are expected to have enough materials available to meet EcoCocons demand in the near future.

Table 5. Transport distances and transport modes for all materials in the EcoCocon panel.

Material	Supplier	Transport distance (km)	Transportation mode
Straw (from wheat)	Farmers in Kybartai, Lithuania	10	Truck
Wood Fiber board	Hesora ir Ko UAB, Czarnków, Poland	610	Truck
Plywood (birch)	Trukmė UAB, Riga, Latvia	319	Truck
Pinewood	Medzio bitės UAB, Tartu, Estonia	567	Truck
Screws (zinc plated, low-alloyed)	Ottensten UAB, Vilnius, Lithuania	201	Light Commercial Vehicle

Product manufacturing (A3)

This study includes all relevant production processes in module A3, such as production losses. EcoCocon UAB supplied the data for energy usage during production. The data is based on the production of all panel types at EcoCocons facility. It was assumed that the required energy does not differ significantly between panel types Standard and Braced and the other panel types. Table 6 gives an overview of the amount of energy that is required for the production of the Straw Panel. The machines used for the production of the straw panels are electrical. EcoCocon uses the Lithuanian energy mix. Heating is supplied by ovens that burn waste materials. Forklifts at the facility use diesel and natural gas. Figure 2 presents the schematic overview of the production process at the facility of EcoCocon UAB.

Table 6. Energy consumption for the production of 1 m2.

Utility	Amount
Electricity (kWh)	7,5
Gas (L)	0,38
Diesel (L)	0,4

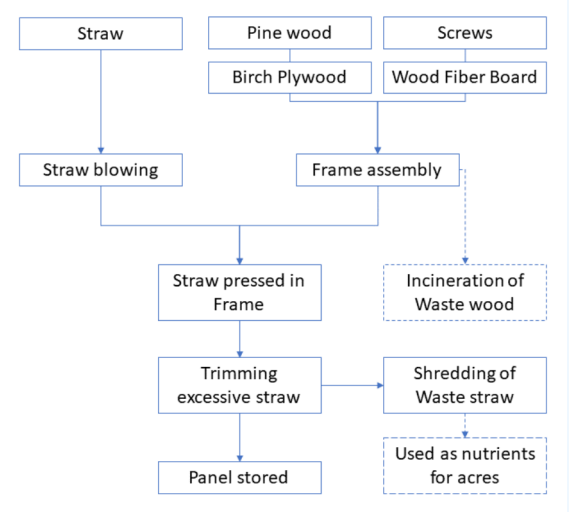

Figure 2. Schematic overview of the production of an EcoCocon panel.

Production waste

Some production waste occurs during the production of the panel. For straw, this is 2,5% of the material used, while for wood and plywood this is 5%. The waste straw returns to the supplier and is reused as soil fertiliser. The benefits from reusing the straw are multiplied by the quality-factor K. EcoCocon provides the straw to the farmers for free. Based on the economic value, the quality-factor is 0. Therefore, no benefits are attributed to this module. The model uses landfill of wood '0245-sto&Stort hout, 'schoon' (o.b.v. Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, untreated, sanitary landfill | Cut-off, U)' to calculate the burdens for this process.

EcoCocon UAB collects the waste wood. They use 99% of the waste wood for incineration in a heating installation at the production site. EcoCocon uses a closed boiler to burn the waste wood. Since no heat is supplied back to the heating grid, it does not deduct

additional heat. No extra environmental benefits are calculated for this in module D. The other 1% of waste wood is lost and assumed to be landfilled.

This module includes the transportation of the straw. The use of facilities like water for sanitary use is outside the scope of this study. There is no production loss of the screws.

3.2.2 Construction stage

Transport (A4)

In line with the Assessment Method, the distance to the construction site is measured to Utrecht, The Netherlands. The distance of 1526 km runs from the production site in Kybartai, Lithuania. The transportation mode is by truck, using the Ecoinvent reference 'market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified [GLO]'. This study reports on the impact of the transportation distance of 1526 km and the impact of transportation per km. The impact per km enables EcoCocon UAB to scale this impact for any transportation distance. This way, EcoCocon can estimate the environmental impact of their product as if it was produced in a different location.

Installation (A5)

Table 7 lists the data for installation machinery which is obtained from EcoCocon UAB. A diesel crane lifts the panel in its place, using 0,1L per m2. The caloric value of diesel is 36 MJ/L, so 0,1L yields 3,6 MJ. The reference '0121-pro&Kraan hydr.tele. band, per uur (o.b.v. 263 kWh Diesel, burned in building machine {GLO}| market for | Cut-off, U)' uses hours as unit. To calculate the hours, the used MJ was converted to kWh and divided by the energy use per hour.

A 200W drill is used for 30 seconds to install the panel with an additional 0,12 kg screws.

Table 7. Inputs for the construction phase of 1 m2 Straw Panel, excluding construction losses.

Input	Unit	Amount
Transportation per km (A4)	ton*km	0,064
Transportation over 1526 km (A4)	ton*km	97,250
Screws (zinc plated, low-alloyed)	kg	0,12
Diesel for crane	hour	0,0038
Electricity for drill	kWh	0,00167

Construction losses

A loss of 3% of the prefab product occurs during the transportation or installation, as described in the Assessment Method. The production, transport and end-of-life of the lost prefab materials is processed according to the standard waste values of the Assessment Method (February 2022).

An extra 3% of EcoCocon panel is calculated in A5. The materials (A1), transport (A2), energy use (A3) and transport to the building site (A4) are considered. Table 8 shows the inputs that are used. Subsequently, the construction losses are transported to the waste facilities (C2) and processed (C3 & C4). Table 9 lists the used end-of-life scenarios. Any burdens and benefits (D) are also taken into account.

Table 8. Construction loss materials, transport, production energy.

Input	Unit	Amount
Straw (from wheat)	kg	1,237
Wood Fiber board	kg	0,008
Plywood (birch)	kg	0,074
Pinewood	kg	0,480
Screws	kg	0,018
Wooden sticks	kg	1,339
Transport A2	ton*km	1,076
Diesel	L	0,012
Electricity	kWh	0,225
Natural gas	L	0,0114
Transport A4	ton*km	4,816

Table 9. End-of-life phase of construction waste.

Input	Unit	Landfill	Incineration	Recycling	Reuse
Transportation of waste	ton*km	0,005	0,153	0,010	0
Straw	kg	0,062	1,175	0	0
Wood Fiber board	kg	4,08E-04	6,94E-03	8,16E-04	0
Plywood (birch)	kg	0,004	0,063	0,007	0
Pinewood	kg	0,024	0,384	0,048	0,024
Screws	kg	1,79E-04	0	0,018	0
Wooden sticks	kg	0,067	1,071	0,134	0,067

Inputs benefits & burdens construction loss	Unit	Amount
Prevented energy production	MJ	23,73
Prevented production steel	kg	0,01
Prevented production wooden beams	kg	0,02
Prevented production wood chips	kg	0,06
Prevented production zinc	kg	2,49E-04
Loss of secondary steel	kg	8,51E-05

3.2.3 Use stage (B1-5)

The wall element has no emissions during use. It does not need maintenance, repair, replacement or refurbishment during its expected service life. The environmental impact of these modules is therefore non-existent.

3.2.4 End-of-life stage (C1-4)

After use, the panels are deconstructed and removed from the building. It is assumed that the machinery for deconstruction uses the same amount of diesel and electricity as for installation (Table 8). Then, the materials are transported and processed according to the standard values of the Assessment Method. In Table 10, the used standard values are displayed.

Table 10. Standard values from the Assessment Method.

Transportation distance (in km)	*50*	*100*	*50*	*0*
Material	**Landfill**	**Incineration**	**Recycling**	**Reuse**
Straw (*organisch, overig o.a. isolatie*)	5%	95%	0%	0%
Wood fiber board (*plaatmateriaal 'schoon'*)	5%	85%	10%	0%
Plywood (*plaatmateriaal 'schoon'*)	5%	85%	10%	0%
Pinewood (*hout 'schoon', o.a. balken, planken*)	5%	80%	10%	5%
Screws (*staal, bevestigingsmiddelen*)	1%	0%	99%	0%

3.2.5 Module D

After waste processing, certain benefits or burdens can occur outside the product's system boundaries. These effects depend on the waste processing step, and include materials saved by recycling a material, prevented energy production and lost secondary materials. The costs or benefits that follow the end-of-life stage are included in Module D and are discussed in this section.

Recycling and reuse

When a material is recycled, it prevents the production of its raw material equivalent. When a material is reused, it prevents the production of this product. These benefits are displayed in Table 11. They are calculated as follows:

- The wood chips: from wood recycling.
- The wood: from wood reuse.
- Steel: from recycling steel screws. The share of secondary steel (43,3%) was subtracted from the amount of steel to be recycled (99%) (as described in the Assessment Method). The benefits of prevented steel production are calculated over this amount.
- There is also loss of secondary steel, through landfill. 1% of the steel screws is lost. Of this 1%, a share of 43,3% is secondary steel. This burden is calculated in module D as well.
- Zinc: from recycled screw coating.

Energy from incineration

The materials that are incinerated produce energy (Table 11). This benefit is calculated as follows:

- The prevented energy production: The wood for incineration is multiplied by the Lower Heating Value of 13,99 MJ/kg. The straw for incineration is multiplied by the LHV of 14,79 MJ/kg [10].

Table 11. Benefits and burdens in Module D.

Benefits: Prevented production	**Unit**	**Amount**
Energy	MJ	790,988
Wood chips	kg	1,876
Wood	kg	0,800
Steel	kg	0,334
Zinc	kg	0,008
Burdens: Loss of secondary material	**Unit**	**Amount**
Steel	kg	0,003

4. Data collection

4.1 Data quality, representativeness and consistency check

The data quality of the information from the processes at the producer is higher than that of the other used processes. Furthermore, the economic flows approach reality as closely as possible within practically feasible limits for the LCA practitioner. The data quality is evaluated with the data quality system of the Verification protocol appendix D [11] and instructions from Stichting NMD.

The used references are recent (<2 years). The quality was therefore assessed to be pedigree score 1, on a scale of 1-5 where 1 is the highest.

The geographical coverage of this study is representative of the geographical scope of the production process. Where possible, specific country specific references are selected. Where this is not possible, region-specific references are selected.

The technological coverage of this study is representative as specific business, product and process data of the year 2021 are used to model the product system. Therefore, this data is representative of the state-of-the-art production technology.

All identified environmental interventions have been translated into environmental effects. Direct emissions from the inventory are all characterised via the characterization factors of CML. The used database references for the production process are selected from Ecoinvent v3.6 and Nationale Milieudatabase v3.3 (Dutch). This ensures that all relevant environmental interventions are characterised.

4.2 Qualitative and quantitative description of processes, scenarios and sources

This paragraph describes all background processes that are used to perform this LCA. Table 12 describes which references are selected for each emission source, from which database this reference is collected and why this reference is selected.

Table 12. Inventory and used references of all materials and processes in this LCA.

	Source	Reference	Database	Argumentation
A1	Plywood production	plywood production, for indoor use | plywood, for indoor use [RER]	Ecoinvent v3.6	Most representative reference.
	Pinewood production	planing, beam, softwood, u=10% | sawnwood, beam, softwood, dried (u=10%), planed [RoW]	Ecoinvent v3.6	Most representative reference for dried pine beams.
	Wood fiber board production	medium density fibre board production, uncoated | medium density fibreboard [RER]	Ecoinvent v3.6	Most representative reference.
	Screws production	0416-fab&Staal, laaggelegeerd, verzinkt (o.b.v. 98,6% Steel, low-alloyed {GLO}| market for | Cut-off, U + Wire drawing; 1,4% Zinc {GLO}| market for | Cut-off, U + Zinc coat, coils)	Nationale Milieudatabase v3.3	Most representative reference.
		metal working, average for steel product manufacturing | metal working, average for steel product manufacturing [RER]	Ecoinvent v3.6	Most representative reference for forming metal into screws.
	Straw production	wheat production | straw [RoW]	Ecoinvent v3.6	Most representative reference, corrected as described in 3.2.1.
A2	Transport A2, wood elements and straw	market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, U [GLO]	Ecoinvent v3.6	Reference as required by the Assessment method.
	Transport A2, screws	market for transport, freight, light commercial vehicle | transport, freight, light commercial vehicle [Europe without Switzerland]	Ecoinvent v3.6	Most representative reference.

A3	Diesel	diesel, burned in building machine | diesel, burned in building machine [GLO]	Ecoinvent v3.6	Most representative reference.
	Electricity from LT mix	market for electricity, low voltage | electricity, low voltage | Cutoff, U [LT]	Ecoinvent v3.6	Most representative reference.
	Natural gas	heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas [Europe without Switzerland]	Ecoinvent v3.6	Most representative reference.
	Transport of production losses	market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, U [GLO]	Ecoinvent v3.6	Reference as required by the Assessment method.
	Production loss processing	0262-avC&Verbranden hout, 'schoon' (13,99 MJ/kg) (o.b.v. Waste wood, untreated {CH}| treatment of, municipal incineration	Nationale Milieudatabase v3.3	Most representative reference for incineration of wood.
		0245-sto&Stort hout, 'schoon' (o.b.v. Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, untreated, sanitary landfill	Nationale Milieudatabase v3.3	Most representative reference for landfill of wood.
		0294-reC&Composteren, per kg te composteren materiaal (o.b.v. Biowaste {RoW}| treatment of biowaste, industrial composting	Nationale Milieudatabase v3.3	Most representative reference for composting of straw.
		heat and power co-generation, wood chips, 6667 kW | heat, district or industrial, other than natural gas | Cutoff, U [LT]	Ecoinvent v3.6	Most representative reference for heat production from wood.
A4	Transport A4	market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, U [GLO]	Ecoinvent v3.6	Reference as required by the Assessment method.
A5	Construction, crane	0121-pro&Kraan hydr.tele. band, per uur (o.b.v. 263 kWh Diesel, burned in building machine {GLO}| market for | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference.
	Construction, drill	market for electricity, low voltage | electricity, low voltage [NL]	Ecoinvent v3.6	Most representative reference.
	Loss of 3% prefab elements	plywood production, for indoor use | plywood, for indoor use [RER]	Ecoinvent v3.6	Most representative reference for 3% extra production.
		planing, beam, softwood, u=10% | sawnwood, beam, softwood, dried (u=10%), planed [RoW]	Ecoinvent v3.6	Most representative reference for 3% extra production.
		medium density fibre board production, uncoated | medium density fibreboard [RER]	Ecoinvent v3.6	Most representative reference for 3% extra production.
		0416-fab&Staal, laaggelegeerd, verzinkt (o.b.v. 98,6% Steel, low-alloyed {GLO}| market for | Cut-off, U + Wire drawing; 1,4% Zinc {GLO}| market for | Cut-off, U + Zinc coat, coils)	Nationale Milieudatabase v3.3	Most representative reference for 3% extra production.
		metal working, average for steel product manufacturing | metal working, average for steel product manufacturing [RER]	Ecoinvent v3.6	Most representative reference for forming metal into screws.
		wheat production | straw [RoW]	Ecoinvent v3.6	Most representative reference for 3% extra production.
		market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, U [GLO]	Ecoinvent v3.6	Reference as required by the Assessment method for transport A2.
		market for transport, freight, light commercial vehicle | transport, freight, light commercial vehicle [Europe without Switzerland]	Ecoinvent v3.6	Most representative reference for transport of screws.
		diesel, burned in building machine | diesel, burned in building machine [GLO]	Ecoinvent v3.6	Most representative reference for 3% extra energy for production..
		market for electricity, low voltage | electricity, low voltage | Cutoff, U [LT]	Ecoinvent v3.6	Most representative reference for 3% extra energy for production..
		heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas [Europe without Switzerland]	Ecoinvent v3.6	Most representative reference for 3% extra energy for production..
		0001-tra&Transport, vrachtwagen (o.b.v. Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for transport in NL.
		0262-avC&Verbranden hout, 'schoon' (13,99 MJ/kg) (o.b.v. Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for incineration of wood elements and straw.
		0245-sto&Stort hout, 'schoon' (o.b.v. Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, untreated, sanitary landfill | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for landfill of wood elements.
		0284-reC&Verspanen hout (o.b.v. Wood chipping, industrial residual wood, stationary electric chipper {GLO}| market for | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for recycling of wood elements.
		0253-sto&Stort staal (o.b.v. Scrap steel {Europe without Switzerland}| treatment of scrap steel, inert material landfill | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for landfill of steel.
		0315-reC&Sorteren en persen oud ijzer (o.b.v. Iron scrap, sorted, pressed {RER}| sorting and pressing of iron scrap | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for recycling of steel.
		0294-reC&Composteren, per kg te composteren materiaal (o.b.v. Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for composting of straw.
		0268-avD&Vermeden energieproductie AVI, o.b.v. HERNIEUWBARE grondstoffen, 18% elektrisch en 31% thermisch (per MJ LHV)	Nationale Milieudatabase v3.3	Most representative reference for prevented energy production from renewable materials.
		0276-reD&Module D, houtspaanders, per kg NETTO geleverd (o.b.v. Wood chips, dry, measured as dry mass {RER}| three layered laminated board production | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for prevented production of wood chips.
		0275-reD&Module D, houten balk, per kg NETTO geleverd (o.b.v. Sawnwood, beam, softwood, dried (u=10%), planed {RoW}| planing, beam, softwood, u=10% | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for prevented production of wooden beams.
		0282-reD&Module D, staal, per kg NETTO geleverd ongelegeerd schroot (World Steel methode obv Steel, low-alloyed {RER&RoW}| steel production, electric, low-alloyed | Cut-off, U - Steel, unalloyed {RER&RoW}| steel production, converter, unalloyed | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for prevented production of steel.
		0283-reD&Module D, zink, per kg NETTO geleverd schroot (vermeden: Zinc {RoW}| primary production from concentrate | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for prevented production of zinc.

C1	Deconstruction, crane	0121-pro&Kraan hydr.tele. band, per uur (o.b.v. 263 kWh Diesel, burned in building machine {GLO}| market for | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference.
	Deconstruction, drill	market for electricity, low voltage | electricity, low voltage [NL]	Ecoinvent v3.6	Most representative reference.
C2	Transport to waste processing sites	0001-tra&Transport, vrachtwagen (o.b.v. Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for transport in NL.
C3, C4 & D	Processing of wooden elements	0262-avC&Verbranden hout, 'schoon' (13,99 MJ/kg) (o.b.v. Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for incineration of plywood, wood fiber board and pinewood.
		0245-sto&Stort hout, 'schoon' (o.b.v. Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, untreated, sanitary landfill | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for landfill of plywood, wood fiber board and pinewood.
		0284-reC&Verspanen hout (o.b.v. Wood chipping, industrial residual wood, stationary electric chipper {GLO}| market for | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for recycling plywood, wood fiber board and pinewood.
		0275-reD&Module D, houten balk, per kg NETTO geleverd (o.b.v. Sawnwood, beam, softwood, dried (u=10%), planed {RoW}| planing, beam, softwood, u=10% | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for benefits from reusing pinewood.
		0276-reD&Module D, houtspaanders, per kg NETTO geleverd (o.b.v. Wood chips, dry, measured as dry mass {RER}| three layered laminated board production | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for benefits from recycling plywood, wood fiber board and pinewood.
		0268-avD&Vermeden energieproductie AVI, o.b.v. HERNIEUWBARE grondstoffen, 18% elektrisch en 31% thermisch (per MJ LHV)	Nationale Milieudatabase v3.3	Most representative reference for energy production from renewable sources.
	Processing of steel	0253-sto&Stort staal (o.b.v. Scrap steel {Europe without Switzerland}| treatment of scrap steel, inert material landfill | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for landfill of steel.
		0315-reC&Sorteren en persen oud ijzer (o.b.v. Iron scrap, sorted, pressed {RER}| sorting and pressing of iron scrap | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for recycling of steel.
		0282-reD&Module D, staal, per kg NETTO geleverd ongelegeerd schroot (World Steel methode obv Steel, low-alloyed {RER&RoW}| steel production, electric, low-alloyed | Cut-off, U - Steel, unalloyed {RER&RoW}| steel production, converter, unalloyed | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for prevented production of steel.
		0283-reD&Module D, zink, per kg NETTO geleverd schroot (vermeden: Zinc {RoW}| primary production from concentrate | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for prevented production of zinc.
	Processing of straw	0262-avC&Verbranden hout, 'schoon' (13,99 MJ/kg) (o.b.v. Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for incineration of straw.
		0294-reC&Composteren, per kg te composteren materiaal (o.b.v. Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U)	Nationale Milieudatabase v3.3	Most representative reference for composting of straw.
		0268-avD&Vermeden energieproductie AVI, o.b.v. HERNIEUWBARE grondstoffen, 18% elektrisch en 31% thermisch (per MJ LHV)	Nationale Milieudatabase v3.3	Most representative reference for energy production from renewable sources.

5. Life Cycle Impact Assessment

This chapter shows the results of the LCA calculation.

5.1 Environmental profile

Several environmental profiles show the environmental impact results (table 13). The first is set 1, which is based on EN15804+A1:2013 and is supplemented with characterization factors as described in the Assessment method. Set 2, based on EN15804+A2:2019, elaborates on set 1. The results from set 1, set 2 and the additional characterization factors describe the full environmental profile of the EcoCocon panel. Table 14 shows the biogenic carbon content.

Table 15 displays the impact in A4 per km. The environmental profile can be calculated for different transportation distances in combination with the total impact without A4.

Table 13. Environmental profile of 1 m2 EcoCocon panel. In this table, set 1 and 2 from the Assessment Method are listed, as well as the values for use of resources, waste categories and outputs.

Set 1	**A1**	**A2**	**A3**	**A4**	**A5**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
Environmental Cost Indicator (ECI)	**1,82**	**0,21**	**0,35**	**1,57**	**0,22**	**0,04**	**0,09**	**0,24**	**0,02**	**-1,34**	**3,21**
Abiotic depletion, non fuel (ADPE) (kg Sb eq)	2,87E-03	4,34E-05	2,96E-05	3,33E-04	5,96E-04	5,22E-07	1,95E-05	3,93E-06	3,41E-07	-8,26E-04	3,07E-03
Abiotic depletion, fuel (ADPF) (kg Sb eq)	5,77E-02	1,26E-02	2,24E-02	9,57E-02	8,26E-03	2,19E-03	5,61E-03	2,94E-03	3,66E-04	-2,44E-02	1,83E-01
Global warming (GWP) (kg CO2 eq)	9,47E+00	1,72E+00	3,16E+00	1,30E+01	1,23E+00	3,31E-01	7,63E-01	5,12E-01	2,26E-01	-4,07E+00	2,64E+01
Ozone layer depletion (ODP) (kg CFC-11 eq)	8,34E-07	3,03E-07	4,58E-07	2,31E-06	1,29E-07	5,68E-08	1,35E-07	5,88E-08	7,87E-09	-1,00E-06	3,29E-06
Photochemical oxidation (POCP) (kg C2H4 eq)	8,90E-03	1,11E-03	1,56E-03	7,85E-03	7,56E-04	3,33E-04	4,61E-04	2,23E-03	7,08E-05	-1,21E-02	1,11E-02
Acidification (AP) (kg SO2 eq)	6,54E-02	7,57E-03	1,62E-02	5,72E-02	6,29E-03	2,47E-03	3,36E-03	1,17E-02	2,10E-04	-7,20E-02	9,84E-02
Eutrophication (EP) (kg PO4--- eq)	3,08E-02	1,46E-03	2,45E-03	1,12E-02	1,40E-03	5,62E-04	6,59E-04	3,02E-03	8,64E-05	-2,33E-02	2,84E-02
Human toxicity (HT) (kg 1,4-DB eq)	8,02E+00	7,11E-01	9,61E-01	5,48E+00	1,20E+00	1,21E-01	3,21E-01	1,40E+00	1,96E-02	-6,39E+00	1,19E+01
Ecotoxicity, fresh water (FAETP) (kg 1,4-DB eq)	5,43E-01	2,04E-02	3,54E-02	1,60E-01	2,72E-02	1,70E-03	9,38E-03	1,11E-02	3,19E-04	-1,25E-01	6,84E-01
Ecotoxicity, marine water (MAETP) (kg 1,4-DB eq)	3,29E+02	7,31E+01	8,22E+01	5,75E+02	3,91E+01	5,91E+00	3,37E+01	2,92E+01	1,31E+00	-1,74E+02	9,94E+02
Ecotoxicity, terrestric (TETP) (kg 1,4-DB eq)	2,20E-01	2,62E-03	3,05E-02	1,94E-02	1,43E-02	2,19E-04	1,14E-03	1,49E-03	6,37E-05	-1,13E-02	2,79E-01
Resource use	**A1**	**A2**	**A3**	**A4**	**A5**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
Energy, primary, renewable, excluding materials (PERE) (MJ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Energy, primary, renewable, materials (PERM) (MJ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Energy, primary, renewable (PERT) (MJ)	7,78E+02	3,74E-01	6,08E+01	2,48E+00	-1,69E+01	3,01E-02	1,45E-01	3,00E-01	1,32E-02	-9,06E+02	-8,11E+01
Energy, primary, non-renewable, excluding materials (PENRE) (MJ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Energy, primary, non-renewable, materials (PENRM) (MJ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Energy, primary, non-renewable (PENRT) (MJ)	1,21E+02	2,77E+01	5,96E+01	2,10E+02	1,79E+01	4,88E+00	1,23E+01	5,94E+00	8,00E-01	-5,08E+01	4,10E+02
Secondary material (SM) (kg)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Secondary fuel, renewable (RSF) (MJ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Secondary fuel, non-renewable (NRSF) (MJ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Water, fresh water use (FW) (m3)	1,17E+00	3,34E-03	6,72E-02	2,41E-02	4,39E-02	2,65E-04	1,41E-03	2,67E-02	7,86E-04	-1,53E-02	1,32E+00
Waste categories	**A1**	**A2**	**A3**	**A4**	**A5**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
Waste, hazardous (HWD) (kg)	6,39E-04	1,22E-04	5,71E-05	5,02E-04	1,16E-04	1,24E-05	2,94E-05	1,48E-05	1,16E-06	-3,21E-04	1,17E-03
Waste, non hazardous (NHWD) (kg)	2,22E+00	1,54E+00	-7,19E-01	1,26E+01	2,23E-01	5,32E-03	7,36E-01	3,57E-01	-2,98E+00	-1,32E+00	1,26E+01
Waste, radioactive (RWD) (kg)	4,84E-04	1,72E-04	3,57E-04	1,30E-03	8,84E-05	3,17E-05	7,62E-05	1,77E-05	4,48E-06	-2,74E-04	2,26E-03
Output flows	**A1**	**A2**	**A3**	**A4**	**A5**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
Components for re-use (CRU) (kg)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Materials for recycling (MFR) (kg)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Materials for energy recovery (MER) (kg)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Exported energy	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Set 2	**A1**	**A2**	**A3**	**A4**	**A5**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
Climate change (kg CO2 eq)	-1,13E+02	1,74E+00	1,99E+00	1,31E+01	1,84E+00	3,34E-01	7,70E-01	7,98E+01	3,34E-01	-1,03E+00	-1,37E+01
Climate change - Fossil (kg CO2 eq)	9,67E+00	1,73E+00	3,09E+00	1,31E+01	1,23E+00	3,34E-01	7,70E-01	5,20E-01	3,24E-02	-4,16E+00	2,64E+01
Climate change - Biogenic (kg CO2 eq)	-1,22E+02	1,16E-03	-1,13E+00	6,06E-03	6,07E-01	1,35E-04	3,55E-04	7,93E+01	3,02E-01	3,17E+00	-4,01E+01
Climate change - Land use and LU change (kg CO2 eq)	4,48E-02	6,89E-04	3,29E-02	4,81E-03	2,00E-03	2,72E-05	2,82E-04	1,94E-04	1,56E-05	-3,94E-02	4,63E-02
Ozone depletion (kg CFC11 eq)	9,26E-07	3,80E-07	4,68E-07	2,90E-06	1,56E-07	7,15E-08	1,70E-07	6,47E-08	9,85E-09	-1,02E-06	4,13E-06
Acidification (mol H+ eq)	9,63E-02	1,00E-02	2,01E-02	7,61E-02	8,77E-03	3,46E-03	4,46E-03	1,73E-02	2,76E-04	-1,12E-01	1,25E-01
Eutrophication, freshwater (kg P eq)	2,66E-03	1,90E-05	1,60E-04	1,32E-04	1,05E-04	1,42E-06	7,76E-06	1,25E-05	6,65E-07	-3,82E-04	2,72E-03
Eutrophication, marine (kg N eq)	3,73E-02	3,46E-03	4,09E-03	2,68E-02	2,45E-03	1,53E-03	1,57E-03	7,96E-03	1,79E-04	-3,26E-02	5,28E-02
Eutrophication, terrestrial (mol N eq)	3,49E-01	3,82E-02	4,54E-02	2,96E-01	2,92E-02	1,68E-02	1,73E-02	9,13E-02	1,02E-03	-5,31E-01	3,52E-01
Photochemical ozone formation (kg NMVOC eq)	5,09E-02	1,11E-02	1,15E-02	8,44E-02	5,83E-03	4,61E-03	4,95E-03	2,39E-02	3,65E-04	-9,61E-02	1,01E-01
Resource use, minerals and metals (kg Sb eq)	2,87E-03	4,34E-05	2,96E-05	3,33E-04	5,96E-04	5,22E-07	1,95E-05	3,93E-06	3,41E-07	-8,26E-04	3,07E-03
Resource use, fossils (MJ)	1,13E+02	2,61E+01	5,61E+01	1,98E+02	1,68E+01	4,60E+00	1,16E+01	5,52E+00	7,53E-01	-4,79E+01	3,85E+02
Water use (m3 depriv.)	4,45E+01	9,55E-02	1,66E+00	7,08E-01	1,59E+00	6,48E-03	4,15E-02	1,81E-01	3,23E-02	-5,35E-01	4,83E+01
Particulate matter (disease inc.)	2,31E-06	1,58E-07	2,47E-07	1,18E-06	1,16E-07	9,14E-08	6,91E-08	1,40E-07	5,22E-09	-1,57E-06	2,74E-06
Ionising radiation (kBq U-235 eq)	4,68E-01	1,11E-01	6,21E-01	8,29E-01	8,17E-02	1,96E-02	4,86E-02	1,55E-02	2,95E-03	-1,78E-01	2,02E+00
Ecotoxicity, freshwater (CTUe)	4,54E+02	2,40E+01	5,41E+01	1,77E+02	-4,79E+00	2,79E+00	1,04E+01	1,37E+01	7,55E-01	-1,08E+03	-3,49E+02
Human toxicity, cancer (CTUh)	3,31E-08	1,02E-09	3,37E-09	5,72E-09	4,06E-09	9,67E-11	3,36E-10	1,61E-08	2,08E-11	-1,24E-08	5,14E-08
Human toxicity, non-cancer (CTUh)	4,60E-07	2,68E-08	4,37E-08	1,93E-07	3,86E-08	2,38E-09	1,13E-08	5,21E-08	8,08E-10	-3,37E-07	4,92E-07
Land use (Pt)	4,72E+03	2,13E+01	2,53E+02	1,72E+02	-5,70E+01	5,92E-01	1,01E+01	2,11E+00	3,21E-01	-4,40E+03	7,26E+02

Table 14. Biogenic carbon content and carbon dioxide removal by the different panel parts and by the total panel.

Panel part	Carbon content (wt%)	kg carbon* per m2
Straw [10]	40,89	16,855
Woodfibre board [12]	48,49	0,132
Pine Wood [13]	47,22	7,560
Birch Plywood [14]	48,69	1,205
Total	-	*25,752*
Packaging: Wooden sticks	47,22	0,61386

** 1 kg biogenic carbon is equivalent to 44/12 kg of CO_2*

Table 15. Impact categories from set 1 and 2 for A4 per km. The table also shows the total impact of without A4.

Set 1	**A4 per km**	**Total without A4**
Abiotic depletion, non fuel (ADPE) (kg Sb eq)	3,42E-06	2,74E-03
Abiotic depletion, fuel (ADPF) (kg Sb eq)	9,84E-04	8,75E-02
Global warming (GWP) (kg CO2 eq)	1,34E-01	1,33E+01
Ozone layer depletion (ODP) (kg CFC-11 eq)	2,37E-08	9,81E-07
Photochemical oxidation (POCP) (kg C2H4 eq)	8,07E-05	3,29E-03
Acidification (AP) (kg SO2 eq)	5,88E-04	4,11E-02
Eutrophication (EP) (kg PO4--- eq)	1,16E-04	1,72E-02
Human toxicity (HT) (kg 1,4-DB eq)	5,63E-02	6,37E+00
Ecotoxicity, fresh water (FAETP) (kg 1,4-DB eq)	1,64E-03	5,24E-01
Ecotoxicity, marine water (MAETP) (kg 1,4-DB eq)	5,92E+00	4,19E+02
Ecotoxicity, terrestric (TETP) (kg 1,4-DB eq)	1,99E-04	2,59E-01
Resource use	**A4 per km**	**Total without A4**
Energy, primary, renewable, excluding materials (PERE) (MJ)	0,00E+00	0,00E+00
Energy, primary, renewable, materials (PERM) (MJ)	0,00E+00	0,00E+00
Energy, primary, renewable (PERT) (MJ)	2,55E-02	-8,36E+01
Energy, primary, non-renewable, excluding materials (PENRE) (MJ)	0,00E+00	0,00E+00
Energy, primary, non-renewable, materials (PENRM) (MJ)	0,00E+00	0,00E+00
Energy, primary, non-renewable (PENRT) (MJ)	2,16E+00	2,00E+02
Secondary material (SM) (kg)	0,00E+00	0,00E+00
Secondary fuel, renewable (RSF) (MJ)	0,00E+00	0,00E+00
Secondary fuel, non-renewable (NRSF) (MJ)	0,00E+00	0,00E+00
Water, fresh water use (FW) (m3)	2,48E-04	1,30E+00
Waste categories	**A4 per km**	**Total without A4**
Waste, hazardous (HWD) (kg)	5,16E-06	6,72E-04
Waste, non hazardous (NHWD) (kg)	1,29E-01	6,61E-02
Waste, radioactive (RWD) (kg)	1,34E-05	9,58E-04
Output flows	**A4 per km**	**Total without A4**
Components for re-use (CRU) (kg)	0,00E+00	0,00E+00
Materials for recycling (MFR) (kg)	0,00E+00	0,00E+00
Materials for energy recovery (MER) (kg)	0,00E+00	0,00E+00
Exported energy	0,00E+00	0,00E+00
Set 2	**A4 per km**	**Total without A4**
Climate change (kg CO2 eq)	1,35E-01	-2,68E+01
Climate change - Fossil (kg CO2 eq)	1,35E-01	1,32E+01
Climate change - Biogenic (kg CO2 eq)	6,23E-05	-4,01E+01
Climate change - Land use and LU change (kg CO2 eq)	4,95E-05	4,15E-02
Ozone depletion (kg CFC11 eq)	2,98E-08	1,23E-06
Acidification (mol H+ eq)	7,83E-04	4,85E-02
Eutrophication, freshwater (kg P eq)	1,36E-06	2,58E-03
Eutrophication, marine (kg N eq)	2,76E-04	2,59E-02
Eutrophication, terrestrial (mol N eq)	3,04E-03	5,68E-02
Photochemical ozone formation (kg NMVOC eq)	8,68E-04	1,70E-02
Resource use, minerals and metals (kg Sb eq)	3,42E-06	2,73E-03
Resource use, fossils (MJ)	2,04E+00	1,87E+02
Water use (m3 depriv.)	7,28E-03	4,76E+01
Particulate matter (disease inc.)	1,21E-08	1,57E-06
Ionising radiation (kBq U-235 eq)	8,53E-03	1,19E+00
Ecotoxicity, freshwater (CTUe)	1,81E+00	-5,25E+02
Human toxicity, cancer (CTUh)	5,89E-11	4,56E-08
Human toxicity, non-cancer (CTUh)	1,99E-09	2,99E-07
Land use (Pt)	1,77E+00	5,55E+02

5.2 Environmental costs indicator

The environmental costs indicator (ECI) - as presented in table 13 - is an indicator that summarises several impact categories and their effects. All categories of set 1 have a weighting factor which represents the costs needed to mitigate the environmental damage on society, so called shadow costs. The factor is therefore in €/unit.

By expressing the ECI in euros, the environmental effects become palpable and easier to compare between products. For the calculation of the Environmental Costs Indicator, the methodology of the Assessment method is followed.

Table 16 shows the weighting factors for each impact category of set 1. The 'Environmental Prices Handbook' from CE Delft [15] and 'Toxiciteit heeft z'n prijs' from TNO (Dutch) [16] justify the weighting factors.

Table 16. Impact categories of the ECI, with the unit and weighting factor in euros per unit.

Impact category	Unit	ECI Weighting factor (€/unit)
Abiotic depletion, non fuel	kg Sb-eq	0,16
Abiotic depletion, fuel	kg Sb-eq	0,16
Global warming	kg CO2-eq	0,05
Ozone layer depletion	kg CFC-11-eq	30
Photochemical oxidant creation	kg ethene-eq	2
Acidification	kg SO2-eq	4
Eutrophication	kg PO4 3−-eq	9
Human toxicity	kg 1,4-DB-eq	0,09
Ecotoxicity, fresh water	kg 1,4-DB-eq	0,03
Ecotoxicity, marine water	kg 1,4-DB-eq	0,0001
Ecotoxicity, terrestric	kg 1,4-DB-eq	0,06

6. Interpretation

In this chapter, the results of the LCA are further analysed with a contribution analysis in section 6.1. Additionally in section 6.2, a sensitivity analysis is performed.

6.1 Contribution analysis

In order to get a better understanding of which processes cause the environmental emissions, a contribution analysis is performed. By tracing the emissions back to the emissions source, it is possible to get a better understanding of the hot spots in the life cycle of the product system.

Figure 3 points out that the production stage (A1-A3) contributes most to the total ECI. Module A1, raw material supply, is the biggest contributor within the production stage, but also within the entire LCA. However, through the benefits and loads beyond the system boundaries this impact is partially mitigated.

The second biggest contributor is the transportation to the installation site (A4). With a total of €1,57 and no mitigating circumstances, this module is the source of 49% of the product's total ECI score.

Figure 4 focusses on module A1, the raw material supply. The raw materials cause €1,82 or 57% of the total impact. This figure shows the environmental impact per material. The screws, from low-alloyed steel with zinc coating, are the biggest contributor. However, the steel will be recycled for 99%, which mitigates the total impact. The second biggest contributor is straw. This is not surprising since straw makes up the largest part of the product. It should be noted that this figure only shows the impact of the materials, i.e. excluding transportation to the production facility.

Figure 5 shows the contribution to module A5, the installation. The construction loss contributes €0,04 to this module. This includes the materials, transport to factory,

manufacturing and transport to production site. It also includes the transport to the waste treatment facilities, the waste treatment itself and any benefits and burdens outside the system boundaries. The screws needed for installation contribute €0,13 to this module. The installation with the crane contributes €0,04. The use of the electric drill has a small impact. The ECI of the drill rounds down to €0,00.

Figure 6 depicts the contribution to module D, the benefits and burdens outside the system boundaries. It shows that the prevented energy production contributes -€1,24. This is 93% of the total -€1,34. The prevented production by recycling steel, beams, wood chips and zinc contribute -€0,07, -€0,02, -€0,01, -€0,01 respectively. The burden of loss of secondary steel has some impact, but the ECI is rounded down to €0,00.

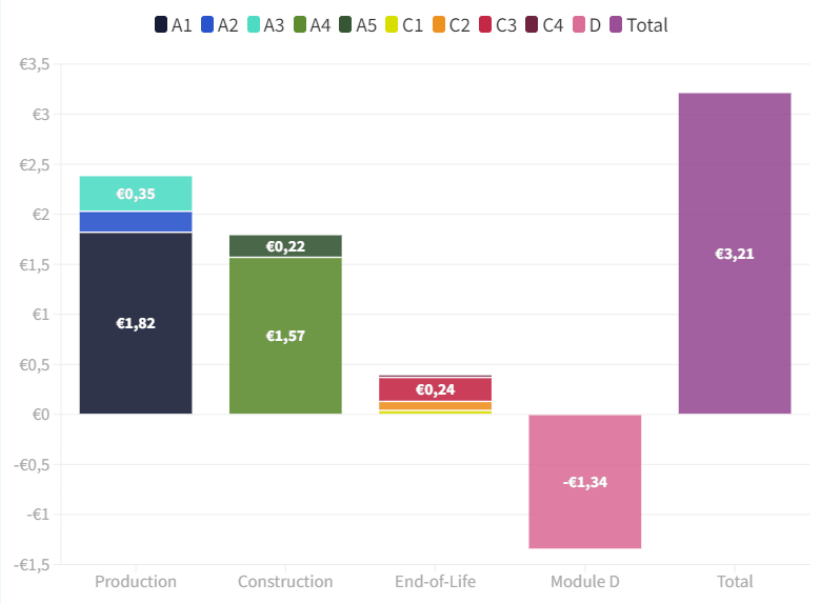

Figure 3. Contribution to the ECI per LCA module and in total.

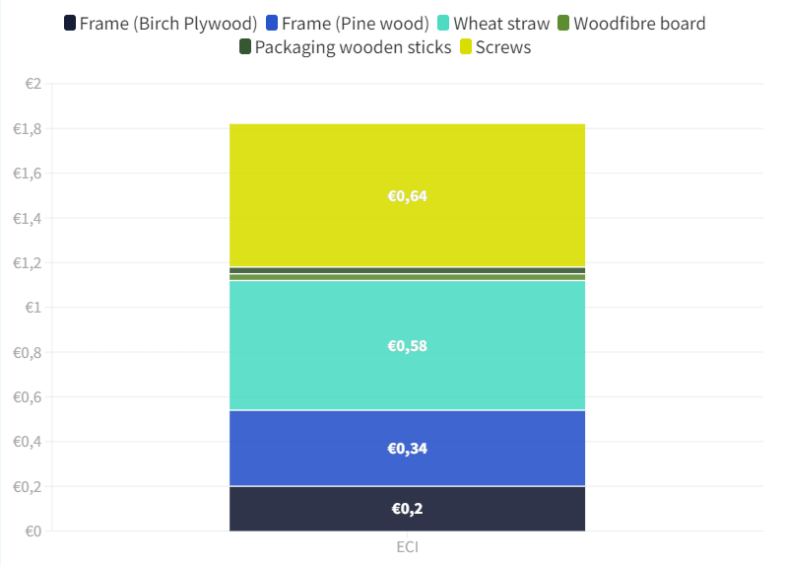

Figure 4. Contribution to the ECI in the module A1, raw material supply. This figure shows the contribution of each material used in the panel.

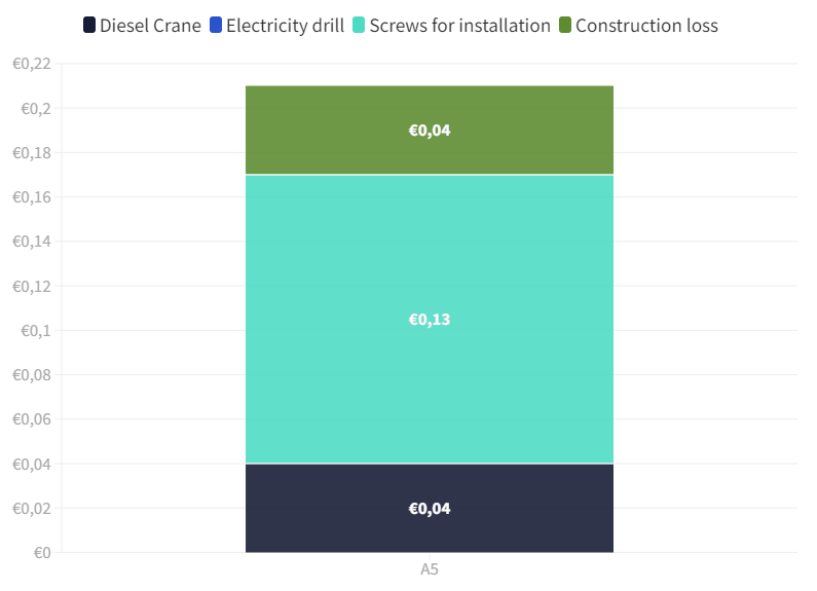

Figure 5. Contribution of installation processes in module A5.

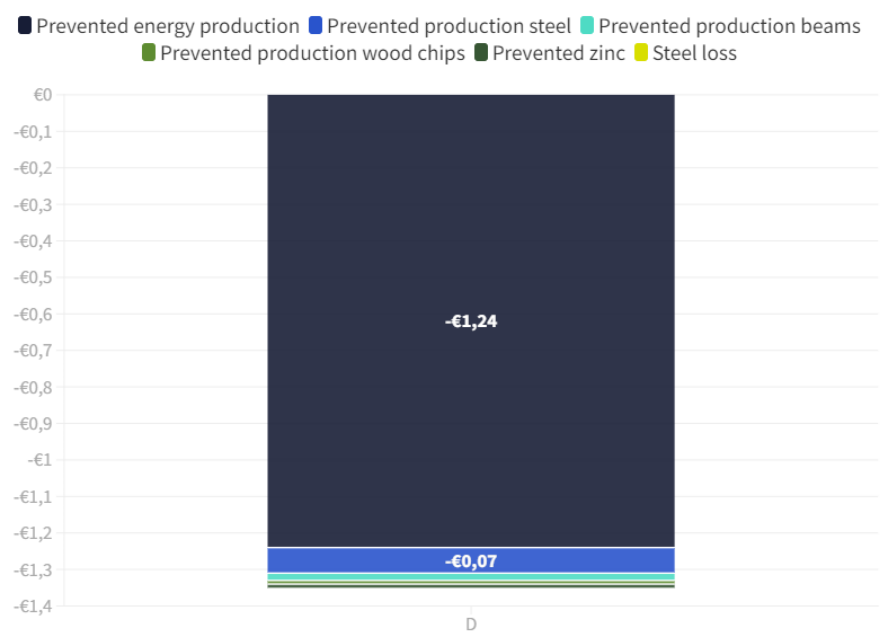

Figure 6. Contribution in module D. The figure depicts benefits in negative values and burdens in positive values.

6.2 Sensitivity analysis

The sensitivity analysis identifies the biggest uncertainties in the study and tests whether the results are robust. The first uncertainty is the difference in material composition between the panels. This section compares the results in set 1 for the 'Standard' and 'Braced' panel to the average composition that was used to obtain the results in table 13. The table below shows the outcome of the sensitivity analysis, along with the percentage change.

The price of wheat changes continuously and is subject to external factors like politics, climate, gas prices etc. The wheat price is identified as one of the biggest uncertainties, partially because of an immense change in international politics while this study was performed.

For the sensitivity analysis, the price of wheat increases by 32,6%. This is the annual change of wheat price between February 2021 and February 2022, according to the price dashboard by the European Commission [17]. The price of straw is kept the same. The price increase influences the allocation between wheat and straw production. The results of the sensitivity analysis are displayed per impact category, in table 18, along with the percentage change. The impact is <20% in all categories. Thus, the uncertainty is not high enough to instigate a split into different environmental profiles.

Table 17. Sensitivity analysis of the panel compositions.

Impact category name	Reference unit	Average	Braced	% change	Standard	% change
Abiotic depletion, non fuel (ADPE)	kg Sb eq	3,07E-03	3,04E-03	-1%	3,06E-03	0%
Abiotic depletion, fuel (ADPF)	kg Sb eq	1,83E-01	1,86E-01	2%	1,79E-01	-2%
Global warming (GWP)	kg CO2 eq	2,64E+01	2,67E+01	1%	2,57E+01	-2%
Ozone layer depletion (ODP)	kg CFC-11 eq	3,29E-06	3,33E-06	1%	3,20E-06	-3%
Photochemical oxidation (POCP)	kg C2H4 eq	1,11E-02	1,13E-02	1%	1,08E-02	-3%
Acidification (AP)	kg SO2 eq	9,84E-02	9,90E-02	1%	9,63E-02	-2%
Eutrophication (EP)	kg PO4--- eq	2,84E-02	2,81E-02	-1%	2,82E-02	-1%
Human toxicity (HT)	kg 1,4-DB eq	1,19E+01	1,19E+01	0%	1,17E+01	-1%
Ecotoxicity, fresh water (FAETP)	kg 1,4-DB eq	6,84E-01	6,78E-01	-1%	6,81E-01	0%
Ecotoxicity, marine water (MAETP)	kg 1,4-DB eq	9,94E+02	1,01E+03	2%	9,73E+02	-2%
Ecotoxicity, terrestric (TETP)	kg 1,4-DB eq	2,79E-01	2,75E-01	-1%	2,79E-01	0%

Table 18. Results of the sensitivity analysis.

Impact category name	Reference unit	Current results (price 2021)	Sensitivity analysis (price 2022)	% change
Abiotic depletion, non fuel (ADPE)	kg Sb eq	3,07E-03	3,05E-03	-0,79%
Abiotic depletion, fuel (ADPF)	kg Sb eq	1,83E-01	1,81E-01	-1,22%
Global warming (GWP)	kg CO2 eq	2,64E+01	2,57E+01	-2,53%
Ozone layer depletion (ODP)	kg CFC-11 eq	3,29E-06	3,25E-06	-1,35%
Photochemical oxidation (POCP)	kg C2H4 eq	1,11E-02	1,09E-02	-1,97%
Acidification (AP)	kg SO2 eq	9,84E-02	9,25E-02	-5,99%
Eutrophication (EP)	kg PO4--- eq	2,84E-02	2,30E-02	-18,85%
Human toxicity (HT)	kg 1,4-DB eq	1,19E+01	1,16E+01	-2,29%
Ecotoxicity, fresh water (FAETP)	kg 1,4-DB eq	6,84E-01	5,84E-01	-14,51%
Ecotoxicity, marine water (MAETP)	kg 1,4-DB eq	9,94E+02	9,76E+02	-1,83%
Ecotoxicity, terrestric (TETP)	kg 1,4-DB eq	2,79E-01	2,39E-01	-14,05%

Referenties

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[16] Van Harmelen, A.K., Korenromp, R.H.J., Ligthart, T.N., Van Leeuwen, S.M.H., Van Gijlswijk, R.N. (2004) "Toxiciteit heeft z'n prijs. Schaduwprijzen voor (eco-)toxiciteit en uitputting van abiotische grondstoffen binnen DuboCalc", TNO.

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