LCA of a PaperShell chair seat

Including a comparison with veneer, PP, GFRP and aluminium

Daniel Böckin, Miljögiraff, 2022-02-21

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Content

Goal and scope

- The goal was to quantify the environmental performance of PaperShell used for a chair seat – based on data provided to Miljögiraff by PaperShell and their suppliers
- A secondary goal was to compare PaperShell with four other materials for the same application
- Functional unit (FU):

  Chair seat during 10 years of use, of size 0,19 m², of a thickness that gives a strength equal to PaperShell of 4 mm thickness.[1]

System description

- Raw materials
  - 70% Kraft paper (pulpwood from 45% spruce, 45% pine, 10% birch)
  - 30% Biobinder
- Manufacturing of impregnated Kraft paper
  - Fuel oil, electricity, steam, propane
  - Ca 8% production waste
- Manufacturing of chair seat
  - Cutting (laser)
  - Pressing
  - CNC milling
- End of Life
  - Incineration

Scenarios for comparison

- Processing steps - Each material is pre-processed and then formed into a chair seat

	PaperShell	Veneer	Polypropylene (PP)	Glass fibre reinforced plastic (GFRP)	Aluminium
Process 1 (pre-processing)	Impregnation of Kraft paper	Approximated with plywood without glue and nails	Injection moulding	Approximated with injection moulding of glass-filled nylon	Sheet rolling of aluminium
Process 2 (blank preparation)	Cutting (laser)	Cutting (knife)	-	Cutting (laser)	Metal cutting
Process 3 (pressing)	Pressing (approx. with thermo-forming of plastic sheets)	Pressing (approx. with thermo-forming of plastic sheets)	-	Pressing (approx. with thermo-forming of plastic sheets)	Pressing (approx. with thermo-forming of plastic sheets)
Process 4 (milling or cutting)	CNC	CNC	-	CNC	Metal cutting
Process 5 (coating)	-	Coating, approx. with TiO2 coating powder	-	Coating, approx. with TiO2 coating powder	-

Scenarios for comparison (cont.)

- Parameters defining the scenarios for each material

	PaperShell	Veneer	PP	GFRP	Aluminium
Thickness to achieve similar strength/ function (mm) [1]	4	9	5	4	2,5
Density (kg/m3)	1340	900	910	2000	2700
Expected life length (years) [2]	10	10	10	10	10
End of life scenario	Incineration	Incineration	Incineration	Incineration	Recycling
Production waste in process 2 [3]	10%	30%	0%	30%	30%
Laser time in process 2 [4]	20 s	-	-	20 s	20 s
Relative energy for process 3 (pressing) [5]	1	1	1	3	0

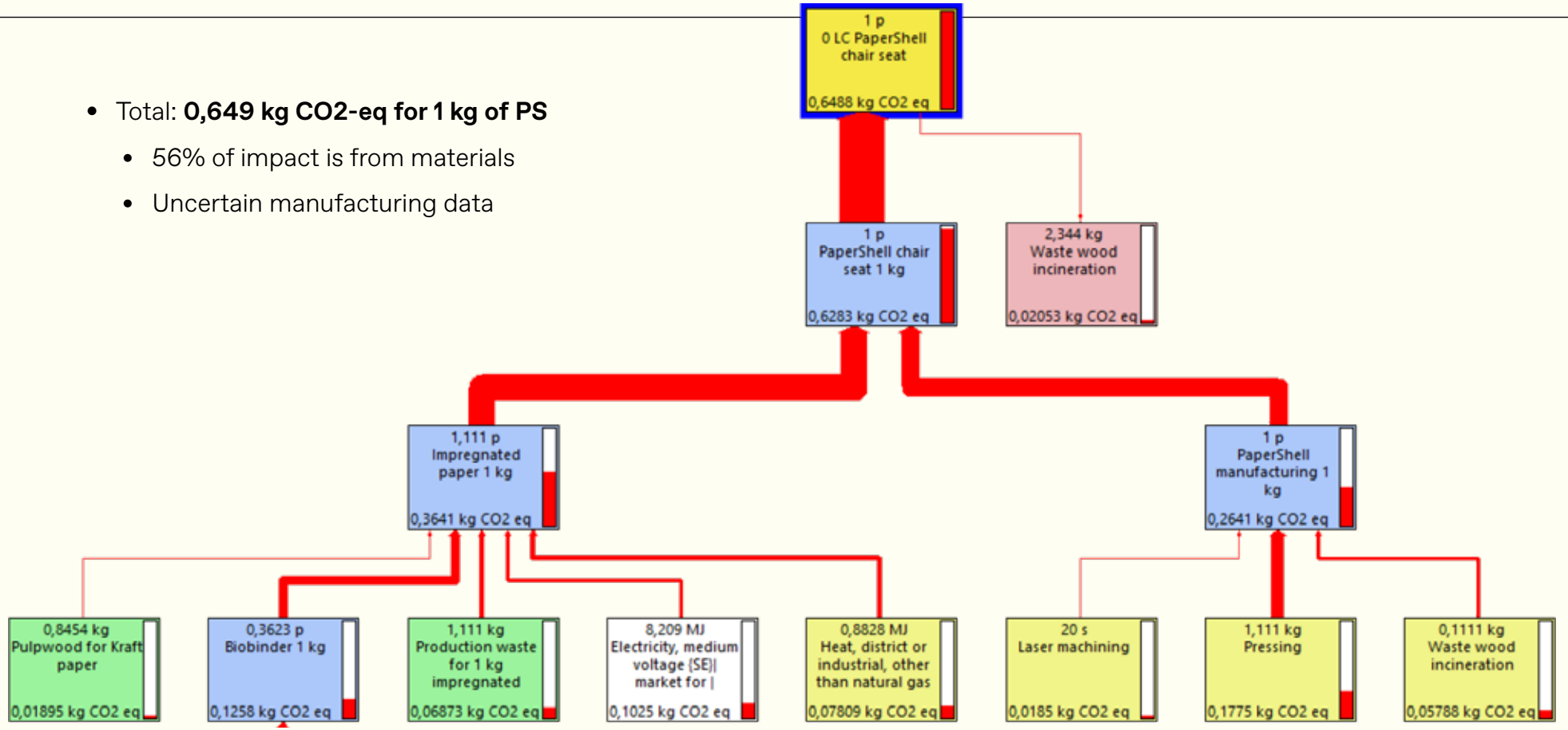
How the materials were compared (calculation of reference flows)

Material for chair shell	Amount needed for 0,187 m2 (FU)	Amount needed for 0,327 m2 (chair seat)	Calculation to find amount (area*thickness*density, see parameters below)	End of life	Comment
PaperShell	1 kg	1,75 kg	FU_area*thickness_PS*density_PS* (FU_period/lifetime_PS)	Incineration	4 mm thickness
Veneer	1,7 kg	2,65 kg	FU_area*thickness_V*density_V* (FU_period/lifetime_V)	Incineration	9 mm thickness vs 4 mm for PaperShell of corresponding strength
PP	0,86 kg	1,49 kg	FU_area*thickness_PP*density_PP* (FU_period/lifetime_PP)	Incineration	5 mm thickness vs 4 mm for PaperShell of corresponding strength.
GFRP	1,5 kg	2,39 kg	FU_area*thickness_GFRP*density_GFRP* (FU_period/lifetime_GFRP)	Incineration	4 mm thickness vs 4 mm for PaperShell of corresponding strength
Aluminium	0,625 kg	2,21 kg	FU_area*thickness_Alu*density_Alu* (FU_period/lifetime_Alu)	Recycling	2,5 mm thickness vs 4 mm for PaperShell of corresponding strength

Parameter	Value	Parameter	Value	Parameter	Value
FU_area	0,187 m2	FU_period	10 years		
thickness_PS	4 mm	Lifetime_PS	10 years	density_PS	1340 kg/m³
thickness_V	9 mm	Lifetime_V	10 years	density_V	900 kg/m³
thickness_PP	5 mm	Lifetime_PP	10 years	density_PP	910 kg/m³
thickness_GFRP	4 mm	Lifetime_GFRP	10 years	density_GFRP	1875 kg/m³
thickness_Alu	2,5 mm	Lifetime_Alu	10 years	density_Alu	2700 kg/m³

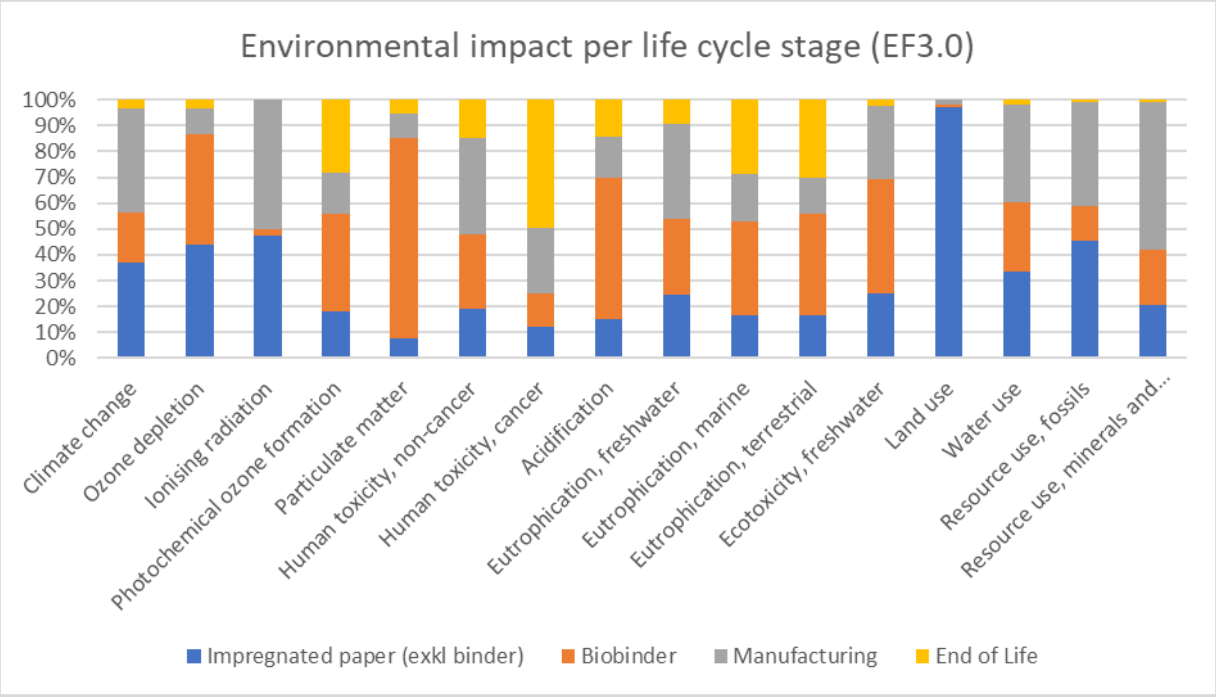
Climate impact per FU of PaperShell (EF3.0)

- Total: **0,649 kg CO2-eq for 1 kg of PS**
  - 56% of impact is from materials
  - Uncertain manufacturing data



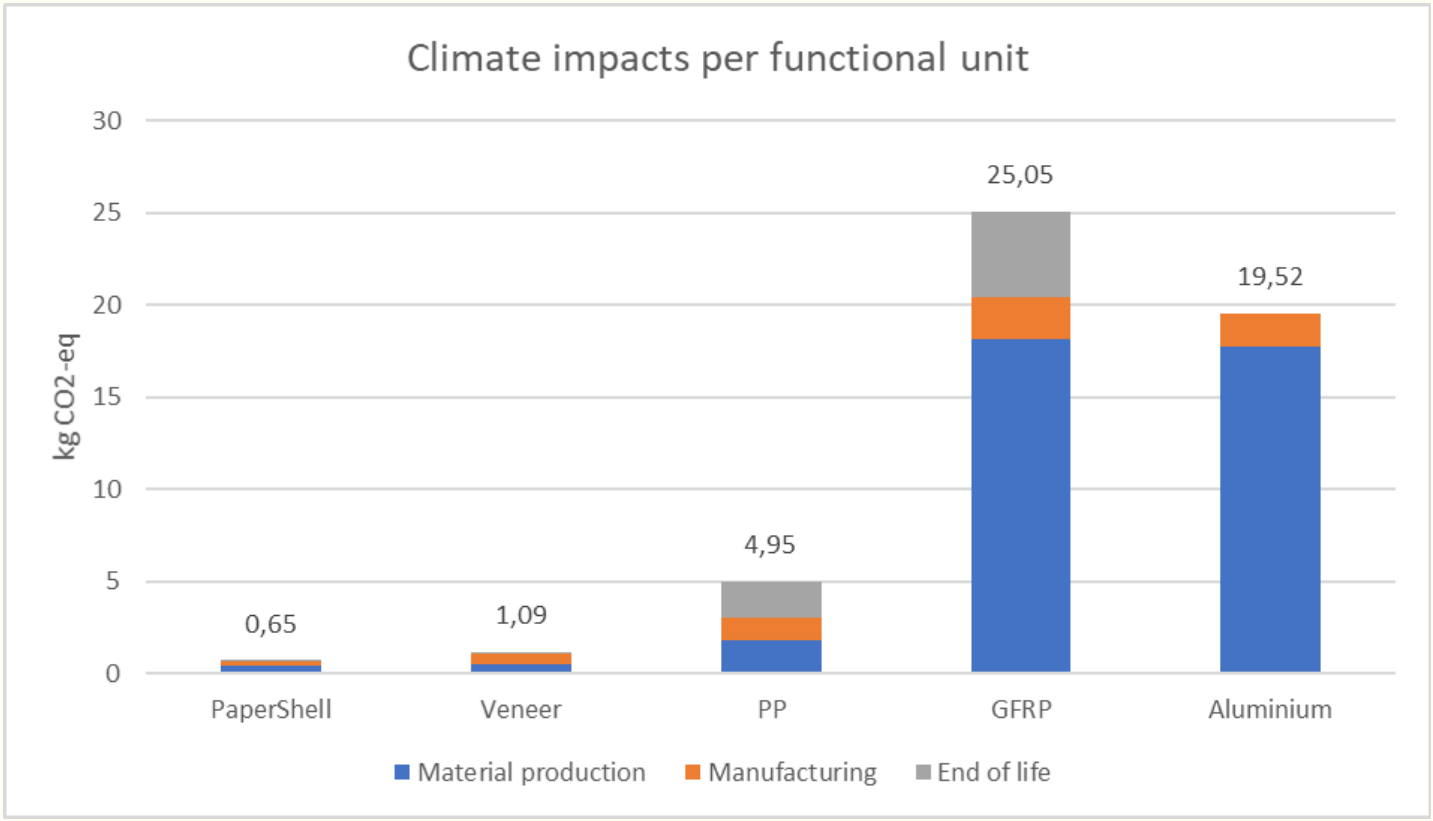
Sankey diagram: (Thickness of arrows represents amount of emission. Excludes the boxes for processes that contribute less than 2% of the total)

Overall environmental impact per FU of PaperShell

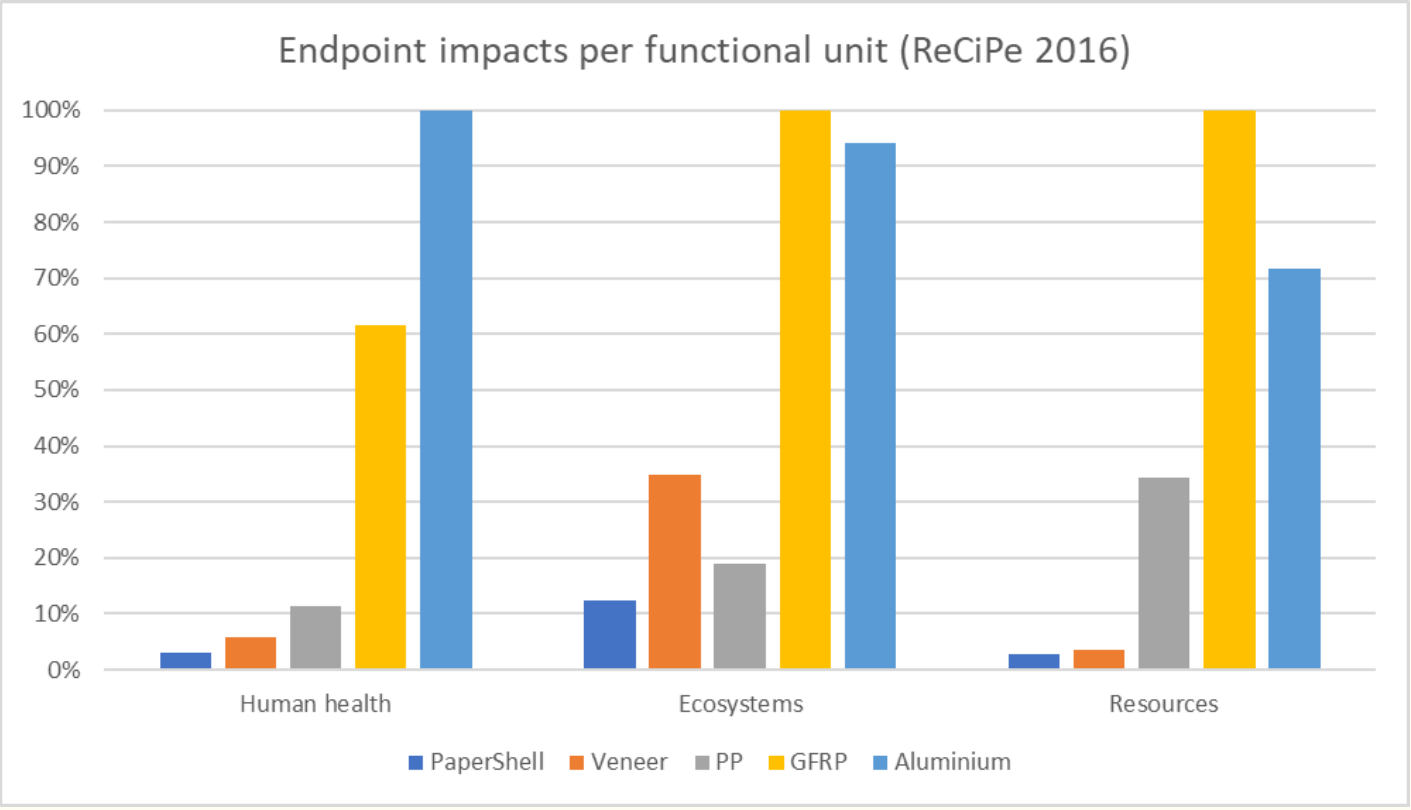


Impact category	Unit	Total	Impr. paper	Bio-binder	Manuf.	End of life.
Climate change	kg CO2 eq	0,65	0,24	0,13	0,26	0,02
Ozone depletion	kg CFC11 eq	7,3E-08	3,2E-08	3,1E-08	7,2E-09	2,3E-09
Ionising radiation	kBq U-235 eq	1,11	0,53	0,03	0,56	7,8E-04
Photochemical ozone formation	kg NM-VOC eq	3,4E-03	6,1E-04	1,3E-03	5,4E-04	9,5E-04
Particulate matter	disease inc.	9,7E-08	7,5E-09	7,5E-08	9,0E-09	5,4E-09
Human toxicity, non- cancer	CTUh	1,3E-08	2,4E-09	3,6E-09	4,7E-09	1,9E-09
Human toxicity, cancer	CTUh	1,3E-09	1,6E-10	1,6E-10	3,3E-10	6,5E-10
Acidification	mol H+ eq	4,6E-03	7,0E-04	2,5E-03	7,2E-04	6,7E-04
Eutrophication, freshwater	kg P eq	1,4E-04	3,5E-05	4,1E-05	5,2E-05	1,3E-05
Eutrophication, marine	kg N eq	1,2E-03	1,9E-04	4,2E-04	2,2E-04	3,3E-04
Eutrophication, terrestrial	mol N eq	1,2E-02	2,0E-03	4,7E-03	1,7E-03	3,6E-03
Ecotoxicity, freshwater	CTUe	17,90	4,51	7,90	5,03	0,46
Land use	Pt	106,33	103,14	0,95	2,18	0,06
Water use	m3 depriv.	0,32	0,11	0,08	0,12	6,3E-03
Resource use, fossils	MJ	21,04	9,52	2,90	8,42	0,20
Resource use, minerals and metals	kg Sb eq	6,8E-06	1,4E-06	1,5E-06	3,9E-06	7,2E-08

Comparison – climate impacts per chair seat (EF3.0)

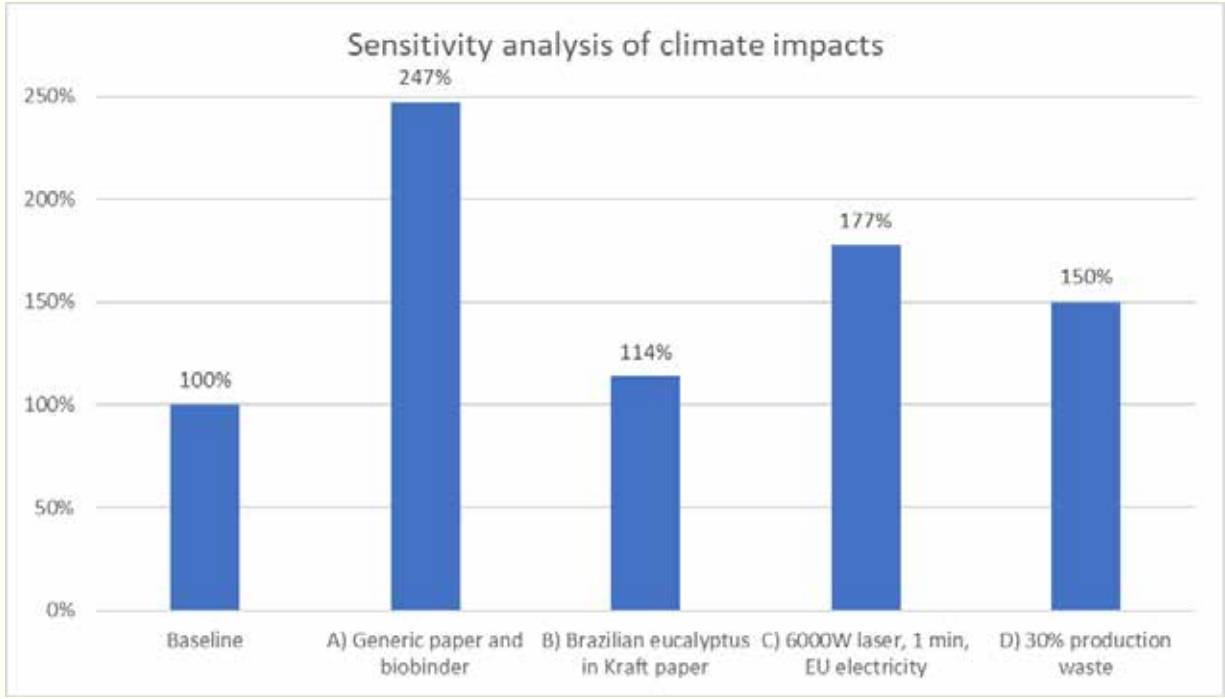


Comparison – impacts per chair seat for each area of protection



Sensitivity and scenario analysis

	Baseline	Alternative scenario
A	Specific data for Kraft paper and binder	Generic data for Kraft paper and binder
B	Material input for Kraft paper is Swedish spruce, pine, birch	Material input for Kraft paper is Brazilian eucalyptus [2]
C	2000 W laser for 20 s with Swedish electricity in manu-facturing	6000 W laser for 1 minute with EU electricity in manu-facturing
D	10% production waste	30% production waste



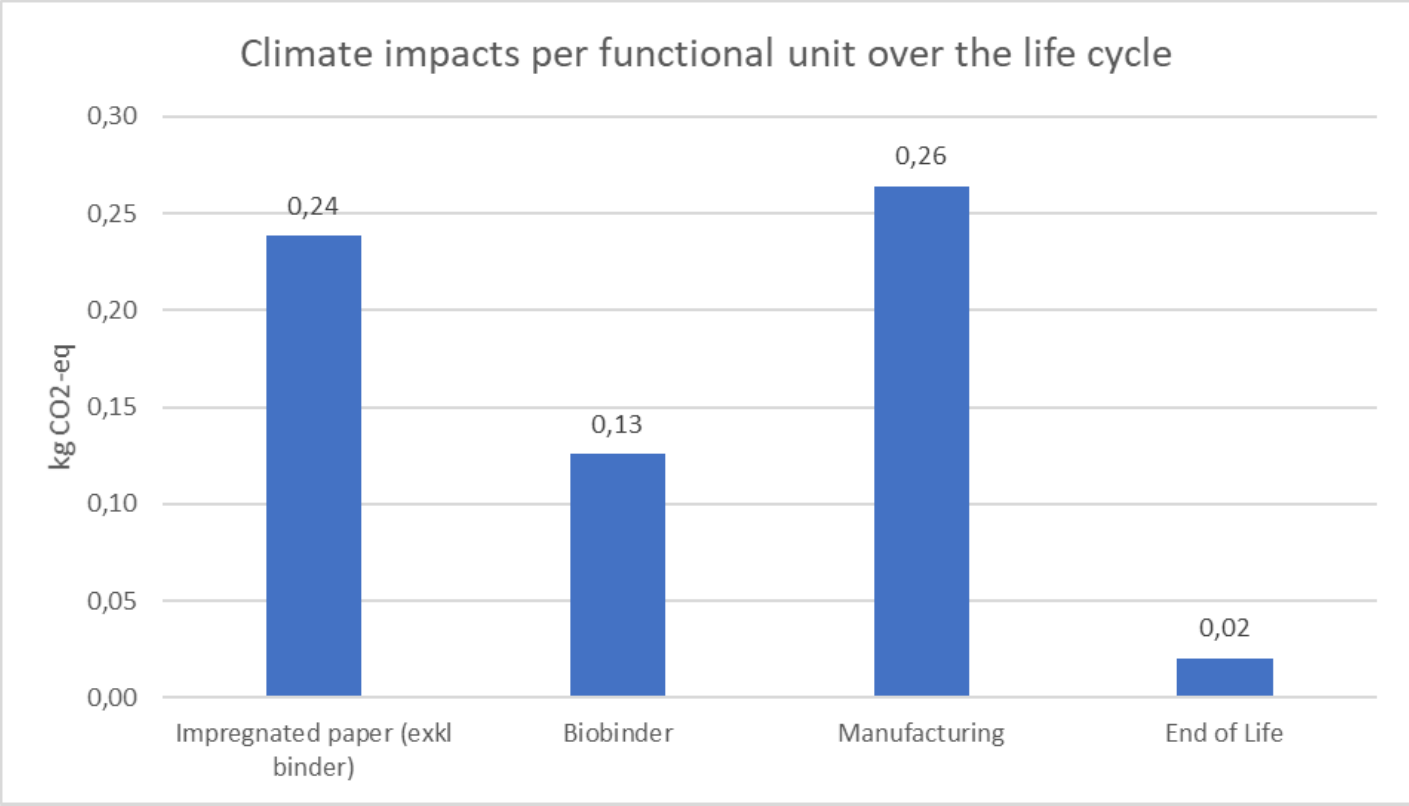
Summary of key results

- **Most impacts are from:**
  - Climate change and fossil resource use
    - 56% from material production (mostly from fossil-based fuels)
    - 40% from manufacturing (uncertain data)
  - Particulate matter
    - For steam in biobinder production
- **Key parameters influencing the results:**
  - Thicknesses for comparison
  - Production waste
  - Lifetimes

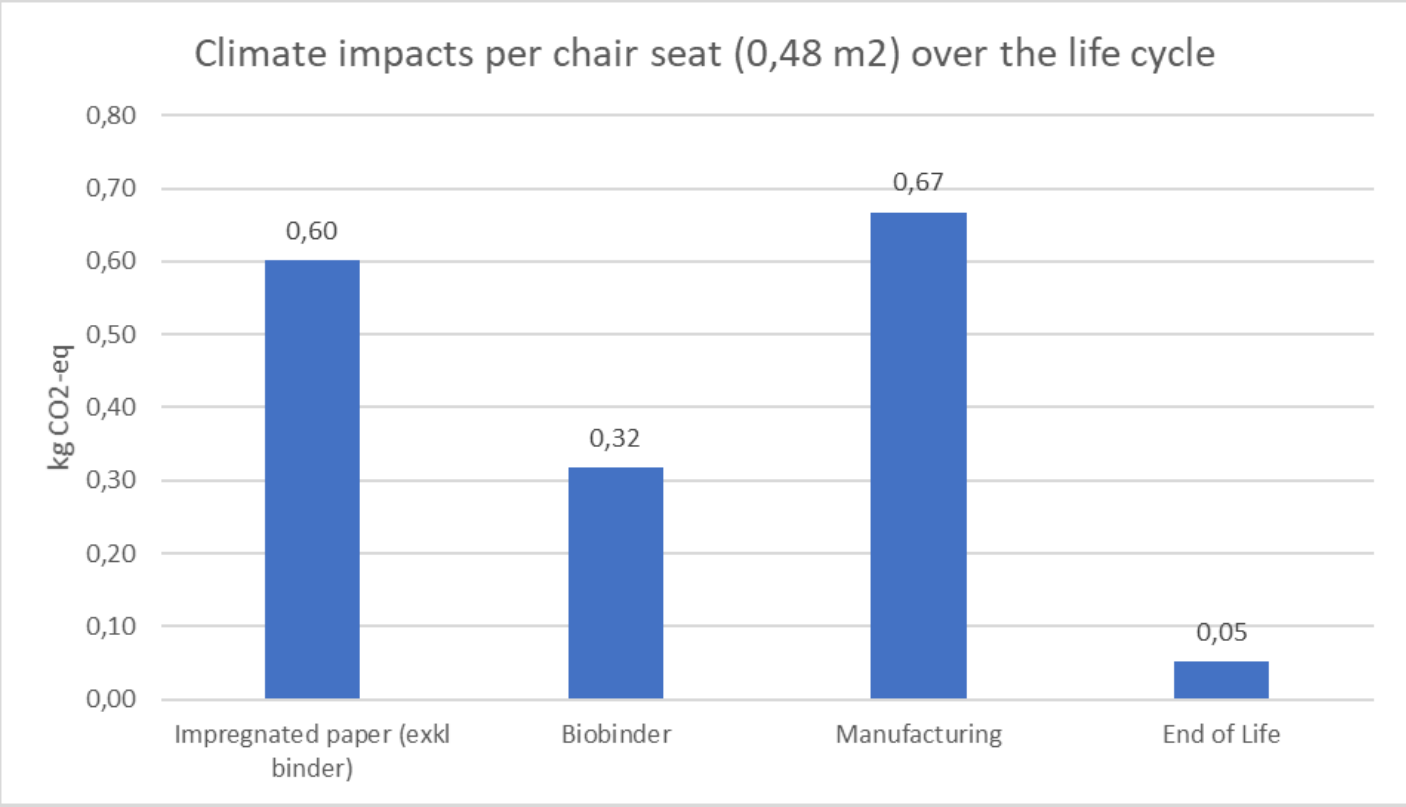
Take aways

1. Reduce fossil-based fuels in production
2. Reduce emission of particulates from combustion throughout life cycle (of fossil and renewable fuels)
3. Supplier choice matters
    - Specific data for impregnated paper showed favourable results compared to generic data
4. Improve data for biobinder in future
    - Based on old model, increased uncertainty
5. When possible, collect specific data on manufacturing
    - Uncertain manufacturing data has potentially large effects on results

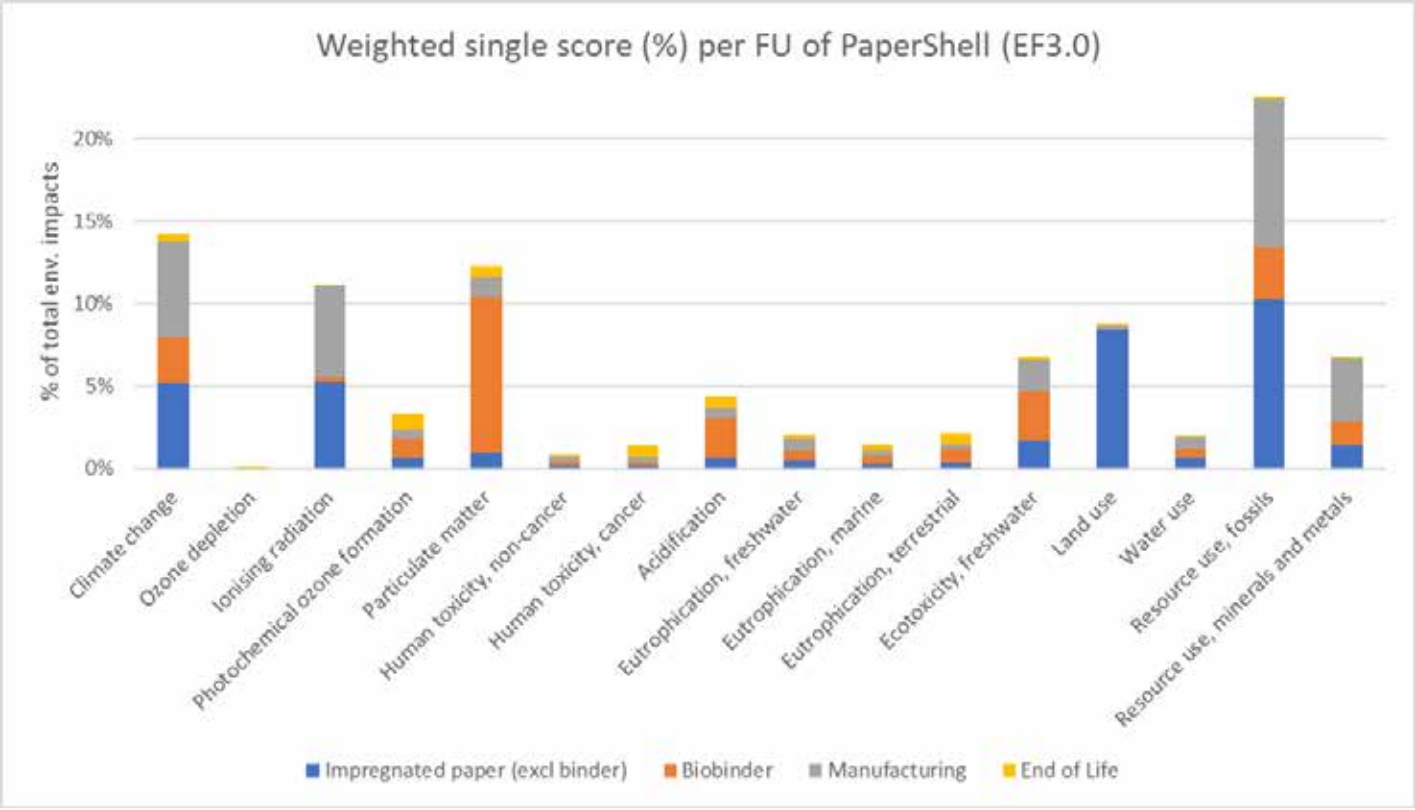
Climate impact per PaperShell chair seat (0,19 m², 1 kg)



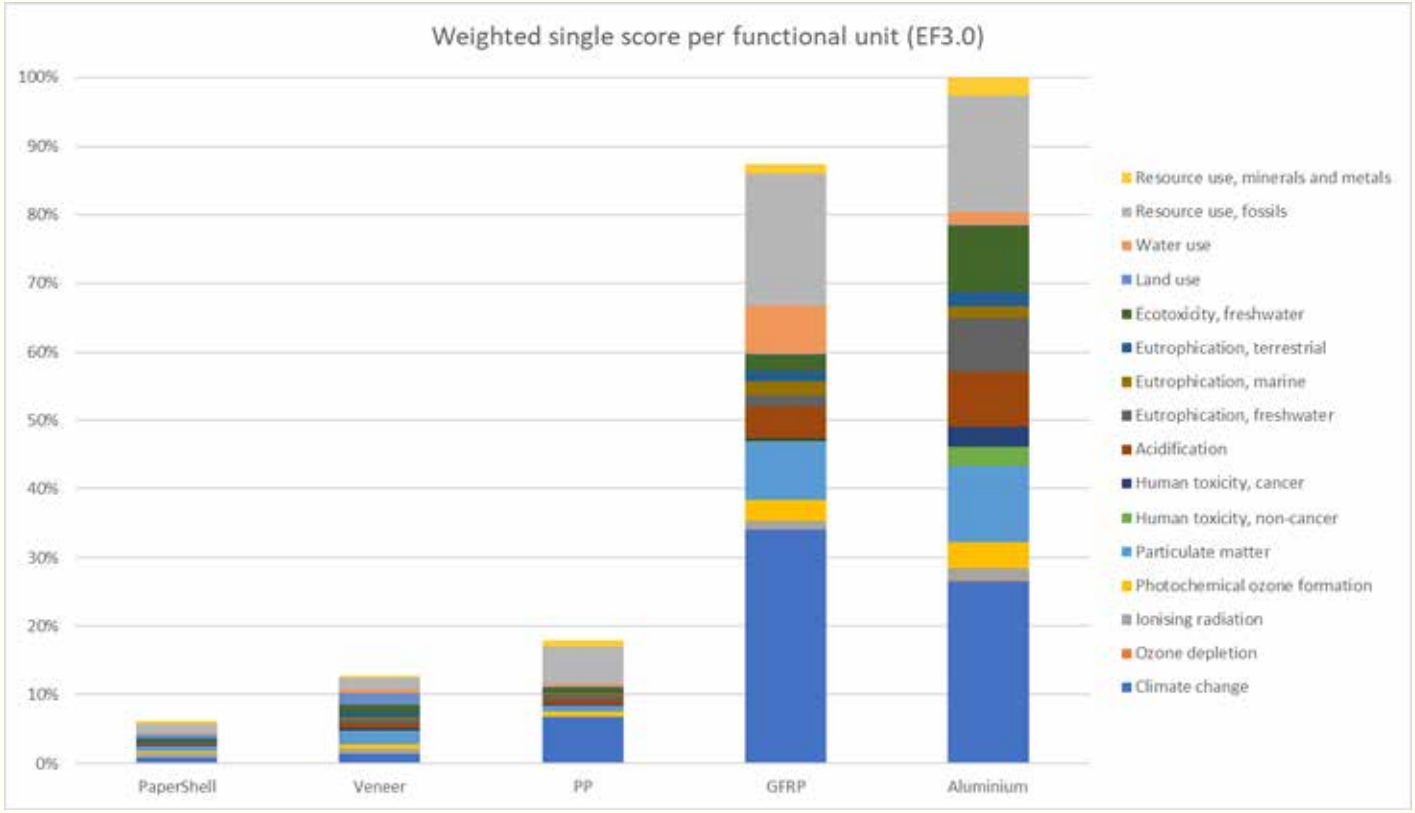
Climate impact per PaperShell chair seat (0,48 m², 2,53 kg)



Weighted single score



Weighted single score comparison



Comparison of overall environmental impact (per chair seat, FU)

Impact category	Unit	0 PaperShell	1 Veneer	2 PP	3 GFRP	4 Aluminium
Climate change	kg CO2 eq	0,65	1,09	4,95	25,05	19,52
Ozone depletion	kg CFC11 eq	7,3E-08	8,0E-08	1,4E-07	3,8E-07	1,5E-06
Ionising radiation	kBq U-235 eq	1,11	0,96	0,35	2,10	3,05
Photochemical ozone formation	kg NMVOC eq	3,4E-03	0,01	0,01	0,05	0,06
Particulate matter	disease inc.	9,7E-08	2,3E-07	9,8E-08	1,1E-06	1,4E-06
Human toxicity, non-cancer	CTUh	1,3E-08	2,8E-08	2,3E-08	7,5E-08	6,6E-07
Human toxicity, cancer	CTUh	1,3E-09	6,5E-09	1,2E-09	5,2E-09	4,5E-08
Acidification	mol H+ eq	4,6E-03	0,01	0,01	0,08	0,14
Eutrophication, freshwater	kg P eq	1,4E-04	6,7E-04	8,5E-04	1,8E-03	8,8E-03
Eutrophication, marine	kg N eq	1,2E-03	4,1E-03	2,3E-03	0,03	1,9E-02
Eutrophication, terrestrial	mol N eq	1,2E-02	0,04	0,02	0,14	0,19
Ecotoxicity, freshwater	CTUe	17,90	50,63	29,48	96,59	417,12
Land use	Pt	106,33	335,21	8,72	28,01	28,62
Water use	m3 depriv.	0,32	1,52	1,14	17,81	4,60

Impact category	Unit	0 PaperShell	1 Veneer	2 PP	3 GFRP	4 Aluminium
Resource use, fossils	MJ	21,04	24,82	81,18	288,71	253,37
Resource use, minerals and metals	kg Sb eq	6,8E-06	4,7E-06	1,4E-05	2,4E-05	4,3E-05
Climate change - Fossil	kg CO2 eq	0,63	1,07	4,95	25,00	19,11
Climate change - Biogenic	kg CO2 eq	3,5E-03	0,01	0,01	0,03	0,09
Climate change - Land use and LU change	kg CO2 eq	1,1E-02	0,01	0,00	0,02	0,31
Human toxicity, non- cancer - organics	CTUh	2,8E-10	4,7E-10	1,3E-09	5,4E-09	3,4E-09
Human toxicity, non- cancer - inorganics	CTUh	2,2E-09	1,3E-08	4,1E-09	2,5E-08	2,0E-07
Human toxicity, non- cancer - metals	CTUh	1,0E-08	2,0E-08	1,8E-08	4,8E-08	4,6E-07
Human toxicity, cancer - organics	CTUh	8,1E-10	5,8E-09	4,9E-10	1,5E-09	2,1E-08
Human toxicity, cancer - inorganics	CTUh	x	x	x	x	x
Human toxicity, cancer - metals	CTUh	4,9E-10	6,9E-10	7,2E-10	3,7E-09	2,4E-08
Ecotoxicity, freshwater - organics	CTUe	0,22	0,85	0,42	1,73	6,11
Ecotoxicity, freshwater - inorganics	CTUe	1,78	2,40	4,64	31,92	16,64
Ecotoxicity, freshwater - metals	CTUe	15,90	47,38	24,42	62,94	394,37

Manufacturing of 1 kg of PaperShell chair seat

Processes	Amount or parameter	Unit	Comments
Inputs			
Impregnated paper	1/yield_PaperShell	kg	
Laser machining, metal, with CO2-laser, 2000W power {RER}| laser machining, metal, with CO2-laser, 2000W power | Cut-off, U	laser_time	s	Proxy for laser cutting (process 2). 2000W and 20 seconds for 0,48 m2 surface assumed (https://eagle-group.eu/en/example- calculation). Zero yield assumed, since waste fed back into process.
Thermoforming of plastic sheets {FR}| processing | Cut-off, U (with SE mix)	relative_press_cycle_time_PS/ yield_PaperShell	kg	Proxy for pressing (process 3)
electricity, medium voltage {SE}| market for | Cut-off, U	0,229	kWh	Proxy for CNC cutting (process 4). Number approximated from aluminium-process: "Aluminium removed by drilling, computer numerical controlled {RER}| aluminium drilling, computer numerical controlled | Cut-off, U"
Outputs			
Municipal solid waste {SE}| treatment of, incineration | Cut-off, U	(1/yield_PaperShell)-1	kg	
Parameters			
yield_PaperShell	0,9		
relative_press_cycle_time_PS	1		
laser_time	20	s	

Production of 1 kg of impregnated paper

Processes	Amount or parameter	Unit	Comments
Inputs			
Pulpwood, softwood, measured as solid wood under bark {SE}| softwood forestry, spruce, sustainable forest management | Cut-off, U	share_spruce*share_Kraft/ density_spruce/yield	m3	45% spruce. Assumes a (dry) density for spruce of 430 kg/m3, according to the ecoinvent- documentation
Pulpwood, softwood, measured as solid wood under bark {SE}| softwood forestry, pine, sustainable forest management | Cut-off, U	share_pine*share_Kraft/ density_pine/yield	m3	45% pine. Assumes a (dry) density for pine of 490 kg/m3, according to the ecoinvent-documentation
Pulpwood, hardwood, measured as solid wood under bark {SE}| hardwood forestry, birch, sustainable forest management | Cut-off, U	share_birch*share_Kraft/ density_birch/yield	m3	10% birch. Assumes a (dry) density for birch of 640 kg/m3, according to the ecoinvent-documentation
Biobinder (confidential)	share_binder/yield	ton	Built based on model by Elisabeth Keijzer
Heavy fuel oil {Europe without Switzerland}| market for | Cut-off, U	22,64	kg	Fuel oil for steam. 33 dm3/ton pulp = 23,1 dm3/ton paper = 22,64 kg oil/ton paper. Assuming a density of 0,98 ton/m3 (https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html)
Electricity, medium voltage {SE}| market for | Cut-off, U	1314,5*0,75	kWh	485 kWh/ton pulp (=339,5 kWh/ton paper) + 975 kWh/ton paper. 339,5 + 975 = 1314,5 kWh/ton paper. 75% from grid, 25% from own renewable production
Electricity, renewable fraction, high voltage {SE}| market for | Cut-off, U	1314,5*0,25	kWh	485 kWh/ton pulp (=339,5 kWh/ton paper) + 975 kWh/ton paper. 339,5 + 975 = 1314,5 kWh/ton paper. 75% from grid, 25% from own renewable production
Heat, from steam, in chemical industry {RoW}| steam production, as energy carrier, in chemical industry | Cut-off, U (adapted)	13354	MJ	Approximation for steam, ecoinvent process adapted to have no energy input, since it is from forestry waste (there is some fuel oil used, modelled separately above). Ecoinvent process assumes energy content of 2,75 MJ/kg, which corresponds to a temperature of ca 150 degrees C when looking at an enthalpy chart (e.g.: https://www.researchgate.net/publication/ 292947231_The_Lassen_hydrothermal_system)
Heat, district or industrial, other than natural gas {SE}| heat production, propane, at industrial furnace >100kW | Cut-off, U	18*LHV_propane	MJ	18 kg gasol (propane) per ton paper. 44,14 MJ per kg propane

Production of 1000 kg of impregnated paper (cont.)

Processes	Amount or parameter	Unit	Comments
Outputs			
Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U	share_binder/yield_Kraft -share_binder	ton	
Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U *	share_spruce*share_Kraft/yield_Kraft -share_spruce*share_Kraft	ton	
Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U *	share_pine*share_Kraft/yield_Kraft -share_pine*share_Kraft	ton	
Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U *	share_birch*share_Kraft/yield_Kraft -share_birch*share_Kraft	ton	
Parameters			
yield	0,92		ca 8% waste
share_Kraft	0,7		70%
density_spruce	430	kg/m3	
density_pine	490	kg/m3	
density_birch	640	kg/m3	
share_spruce	0,45		45% tall
share_pine	0,45		45% tall
share_birch	0,1		10% björk
LHV_propane	44,14	MJ/kg	
share_binder	1-share_Kraft		

Manufacturing of 1 kg of veneer chair shell

Processes	Amount or parameter	Unit	Comments
Inputs			
Plywood {RER}| plywood production | Cut-off, U *	(1-share_coat)/yield_veneer	kg	Proxy for veneer
Coating powder {RER}| market for coating powder | Cut-off, U	share_coat	kg	Proxy for coating (process 5) - coat approximated by 1%
Thermoforming of plastic sheets {FR}| processing | Cut-off, U (with SE mix)	relative_press_energy_V*(1- share_coat)	kg	Proxy for pressing (process 3)
electricity, medium voltage {SE}| market for | Cut-off, U	0,229	kWh	Proxy for CNC machining (process 4) (same as for PaperShell)
Outputs			
Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U *	(1-share_coat)/ yield_veneer-1	kg	Production waste from cutting. Process corrected to adjust for 10% water content.
Parameters			
yield_veneer	0,7		30% waste in cutting
relative_press_energy_V	1		Standard, 6 times higher than PS
share_coat	0,01		1% coat for veneer and GFRP

Manufacturing of 1 kg of polypropylene chair shell

Processes	Amount or parameter	Unit	Comments
Inputs			
Polypropylene, granulate {GLO}| market for | Cut-off, U	1/yield_PP	kg	
Injection moulding {RER}| processing | Cut-off, U	1/yield_PP	kg	Process 1 according to the scenario-definition. Waste is assumed to be recycled and thus set to zero
electricity, medium voltage {SE}| market for | Cut-off, U	0,229	kWh	Proxy for CNC machining (process 4) (same as for PaperShell)
Outputs			
Waste polypropylene {CH}| treatment of, municipal incineration | Cut-off, U	1/yield_PP-1	kg	Production waste from cutting
Parameters			
yield_PP	1		30% waste in cutting

Manufacturing of 1 kg of GFRP chair shell

Processes	Amount or parameter	Unit	Comments
Inputs			
Glass fibre reinforced plastic, polyamide, injection moulded {GLO}| market for | Cut-off, U	(1-share_coat)/yield_GFRP	kg	Raw material approximated with glass-filled nylon
Coating powder {RER}| market for coating powder | Cut-off, U	share_coat	kg	Proxy for coating (process 5) - coat approximated by 1%
Laser machining, metal, with CO2-laser, 2000W power {RER}| laser machining, metal, with CO2-laser, 2000W power | Cut-off, U	laser_time	s	Proxy for laser cutting (process 2). 2000W and 20 second run time assumed for a chair surface of 0,48 m2
Thermoforming of plastic sheets {FR}| processing | Cut-off, U (with SE mix)	relative_press_energy_GFRP *(1-share_coat)	kg	Proxy for pressing (process 3)
electricity, medium voltage {SE}| market for | Cut-off, U	0,229	kWh	Proxy for CNC machining (process 4) (same as for PaperShell)
Outputs			
Waste plastic, mixture {CH}| treatment of, municipal incineration with fly ash extraction | Cut-off, U	(1-share_coat)/yield_GFRP-1	kg	Proxy for incineration of GFRP
Parameters			
yield_GFRP	0,7		30% waste in cutting
relative_press_energy_GFRP	3		Standard, 6 times higher than PS
share_coat	0,01		1% coat for veneer and GFRP

Manufacturing of 1 kg of aluminium chair shell

Processes	Amount or parameter	Unit	Comments
Inputs			
Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| market for | Cut-off, U	1/yield_alu	kg	
Sheet rolling, aluminium {RER}| processing | Cut-off, U	1	kg	Proxy for rolling and pressing (process 1 and 3)
Energy and auxilliary inputs, metal working machine {RER}| market for energy and auxilliary inputs, metal working machine | Cut-off, U	1	kg	Proxy for rolling and pressing (process 1 and 3)
Laser machining, metal, with CO2-laser, 2000W power {RER}| laser machining, metal, with CO2-laser, 2000W power | Cut-off, U	laser_time	s	Proxy for laser cutting (process 2). 2000W and 20 second run time assumed for a chair surface of 0,48 m2
electricity, medium voltage {SE}| market for | Cut-off, U	0,229	kWh	Proxy for CNC machining (process 4) (same as for PaperShell)
Outputs			
Aluminium (waste treatment) {GLO}| recycling of aluminium | Cut-off, U	1/yield_alu-1	kg	Production waste from cutting
Parameters			
yield_alu	0,7		30% waste in cutting