

The Circularity of Materials from the Perspective of a Product Life Cycle: A Life Cycle Assessment Case Study of Secondary Fence Boards – Part 1 (Baseline Scenario)

Joanna Kulczycka ¹, Anna Lewandowska ², Katarzyna Joachimiak-Lechman ^{2,*} and Przemysław Kurczewski ³

¹ Mineral and Energy Economy Research Institute, Polish Academy of Sciences, 31-261 Kraków, Poland; kulczycka@meeri.pl

² Institute of Management, Poznan University of Economics and Business, 61-875 Poznań, Poland; anna.lewandowska@ue.poznan.pl

³ Faculty of Civil and Transport Engineering, Poznan University of Technology, 60-965 Poznań, Poland; przemyslaw.kurczewski@put.poznan.pl

* Correspondence: katarzyna.joachimiak-lechman@ue.poznan.pl; Tel.: +48-61-854-31-21

Table S1 Inventory results for life cycle stage Materials – auxiliary materials

MATERIALS - AUXILIARY MATERIALS (wooden fence posts, wood preservative, steel screws, and steel bolts)		
Ecoinvent dataset (https://ecoinvent.org/database/)	Amount	Unit
Inputs		
Sawnwood, beam, softwood, dried (u=10%), planed {Europe without Switzerland} market for sawnwood, beam, softwood, dried (u=10%), planed Cut-off, U	0.004762	m ³
Wood preservative, creosote {RER} market for wood preservative, creosote Cut-off, U	0.037278	kg
Steel, chromium steel 18/8 {GLO} market for Cut-off, U	0.42	kg

Source: own elaboration based in calculations SimaPro software

Table S2 Inventory results for life cycle stage Transport to the installation place

TRANSPORT TO THE INSTALLATION PLACE		
Ecoinvent dataset (https://ecoinvent.org/database/)	Amount	Unit
Inputs		
Transport, freight, lorry 3.5–7.5 metric ton, euro6 {RER} market for transport, freight, lorry 3.5–7.5 metric ton, EURO6 Cut-off, U	8125.5 (Load: 70 kg board + 11.25 kg auxiliary materials Distance: 100 km)	kgkm

Source: own elaboration based in calculations SimaPro software

Table S3 Inventory results for life cycle stage Installation and maintenance (15 years of lifetime)

INSTALATION AND MAINTENANCE (drilling and screwing, maintenance of wooden posts, cleaning)		
Ecoinvent dataset (https://ecoinvent.org/database/)	Amount	Unit
Inputs		
Wood preservative, creosote {RER} market for wood preservative, creosote Cut-off, U	0.104	kg
Tap water {Europe without Switzerland} market for Cut-off, U	56	kg
Electricity, low voltage {PL} market for Cut-off, U	0.058	kWh
Outputs		
Wastewater, unpolluted {RoW} market for wastewater, unpolluted Cut-off, U	56	l

Source: own elaboration based in calculations SimaPro software

Table S4 Inventory results for life cycle stage End of life - auxiliary materials (based on calculations with the CFF formula, $R_{2_wood} = 0.38$, $A_{wood} = 0.8$, $R_{2_steel} = 0.85$, $A_{steel} = 0.2$, the fraction of the waste not sent for recycling is to be disposed of as follows: 99% landfilled and 1% incinerated)

END OF LIFE - AUXILIARY MATERIALS		
Ecoinvent dataset (https://ecoinvent.org/database/)	Amount	Unit
Inputs		
Transport, freight, lorry 7.5–16 metric ton, euro6 {RER} market for transport, freight, lorry 7.5–16 metric ton, EURO6 Cut-off, U	402 (Load: 4.2 kg Distance: 100 km)	kgkm
Sawnwood, beam, softwood, dried (u=10%), planed {Europe without Switzerland} market for sawnwood, beam, softwood, dried (u=10%), planed Cut-off, U (credit)	-0.00036	m3
Steel, chromium steel 18/8 {GLO} market for Cut-off, U (credit)	-0.286	kg
Outputs		
Waste bulk iron, excluding reinforcement {Europe without Switzerland} treatment of waste bulk iron, excluding reinforcement, sorting plant Cut-off, U	0.286	kg
Waste brick {Europe without Switzerland} treatment of waste brick, sorting plant Cut-off, U (used as proxy)	0.274	kg
Waste wood, untreated {RoW} treatment of, sanitary landfill Cut-off, U	2.21	kg
Waste building wood, chrome preserved {RoW} treatment of, municipal incineration Cut-off, U	0.022	kg
Inert waste {Europe without Switzerland} treatment of inert waste, sanitary landfill Cut-off, U	0.062	kg
Scrap steel {Europe without Switzerland} treatment of scrap steel, municipal incineration Cut-off, U	0.001	kg

Source: own elaboration based in calculations SimaPro software

Table S5 Inventory results for life cycle stage End of life – secondary fence board
(based on calculations with the CFF formula, $R_{2_fence_board} = 0.499$, $A_{fence_board} = 0.5$ the fraction of the waste not sent for recycling is to be disposed of as follows: 99% landfilled and 1% incinerated)

END OF LIFE – SECONDARY FENCE BOARD – BASELINE SCENARIO 1A		
(no recycling at the EoL)		
Ecoinvent dataset (https://ecoinvent.org/database/)	Amount	Unit
<i>Inputs</i>		
Transport, freight, lorry 7.5–16 metric ton, euro6 {RER} market for transport, freight, lorry 7.5–16 metric ton, EURO6 Cut-off, U	2502 (Load: 25.025 kg Distance: 100 km)	kgkm
<i>Outputs</i>		
Waste polyethylene {RoW} treatment of waste polyethylene, sanitary landfill Cut-off, U	7.45	kg
Waste polyethylene {RoW} treatment of waste polyethylene, municipal incineration Cut-off, U	0.05	kg
Waste polypropylene {RoW} treatment of waste polypropylene, sanitary landfill Cut-off, U	7.45	kg
Waste polypropylene {RoW} treatment of waste polypropylene, municipal incineration Cut-off, U	0.05	kg
Waste plastic, mixture {RoW} treatment of waste plastic, mixture, sanitary landfill Cut-off, U	2.483	kg
Waste plastic, mixture {RoW} treatment of waste plastic, mixture, municipal incineration Cut-off, U	0.017	kg
Waste plastic, mixture {RoW} treatment of waste plastic, mixture, sanitary landfill Cut-off, U	2.483	kg
Waste plastic, mixture {RoW} treatment of waste plastic, mixture, municipal incineration Cut-off, U	0.017	kg
Waste plastic, mixture {RoW} treatment of waste plastic, mixture, sanitary landfill Cut-off, U	2.483	kg
Waste plastic, mixture {RoW} treatment of waste plastic, mixture, municipal incineration Cut-off, U	0.017	kg
Waste aluminium {RoW} treatment of, sanitary landfill Cut-off, U	2.483	kg
Scrap aluminium {Europe without Switzerland} treatment of scrap aluminium, municipal incineration Cut-off, U	0.017	kg
<i>Total landfilling:</i>	24.75	kg
<i>Total incineration:</i>	0.245	kg

Source: own elaboration based in calculations SimaPro software

Table S6 The results of identification of the most relevant processes in the life cycle of secondary fence board (for the other most relevant impact categories)

The most relevant impact categories	The most relevant processes (only processes with the highest contribution listed)	
	Ecoinvent dataset (https://ecoinvent.org/database/)	Share (based on characterised results, recalculated by considering absolute values)
Ecotoxicity, freshwater	Waste aluminium {RoW} treatment of, sanitary landfill Cut-off, U	54%
	Blasting {RoW} processing Cut-off, U	13%
	Blasting {RER} processing Cut-off, U	7%
	Hard coal {CN} hard coal mine operation and hard coal preparation Cut-off, U	5%
	Polycarbonate {RoW} production Cut-off, U	5%
Eutrophication, freshwater	Spoil from lignite mining {GLO} treatment of, in surface landfill Cut-off, U	61%
	Spoil from hard coal mining {GLO} treatment of, in surface landfill Cut-off, U	33%
Particulate matter	Polycarbonate {RoW} production Cut-off, U	15%
	Electricity, high voltage, for internal use in coal mining {CN} electricity production, hard coal, at coal mine power plant Cut-off, U	12%
	Nylon 6-6 {RER} production Cut-off, U	9%
	Polycarbonate {RER} production Cut-off, U	7%
	Heat, district or industrial, other than natural gas {RoW} heat production, at hard coal industrial furnace 1–10 MW Cut-off, U	6%
	Aluminium, primary, liquid {RoW} aluminium production, primary, liquid, prebake Cut-off, U	4%
	Ethylene {RoW} ethylene production, average Cut-off, U	4%
	Acrylonitrile-butadiene-styrene copolymer {RoW} production Cut-off, U	4%
	Propylene {RoW} production Cut-off, U	4%
	+ 10 other processes with low individual contribution (1–3%)	
Acidification	Electricity, high voltage {PL} heat and power co-generation, hard coal Cut-off, U	16%
	Electricity, high voltage {RoW} electricity production, hard coal Cut-off, U	11%
	Electricity, high voltage {PL} heat and power co-generation, lignite Cut-off, U	11%

	Nylon 6-6 {RER} production Cut-off, U	8%
	Polycarbonate {RoW} production Cut-off, U	4%
	Heat, district or industrial, other than natural gas {RoW} heat production, at hard coal industrial furnace 1–10 MW Cut-off, U	4%
	Ethylene {RoW} ethylene production, average Cut-off, U	3%
	Propylene {RoW} production Cut-off, U	2%
	Polycarbonate {RER} production Cut-off, U	2%
	Acrylonitrile-butadiene-styrene copolymer {RoW} production Cut-off, U	2%
	+ 21 other processes with very low individual contribution (0.4–2%)	

Source: own elaboration based on calculations in SimaPro 9.5. software