LCA OF A SHORT-FLIGHT BELT CONVEYOR

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This paper presents a parametric Life Cycle Assessment (LCA) of a short-flight belt conveyor (BC) installed on the Bucket Wheel Excavator (BWE) SchRs 1200 x 22 / 2. The primary objective of this study is to identify environmental hotspots linked to the manufacturing and use phases of the BC, introduce potential improvements in design, materials, and energy consumption, and establish a flexible parametric model applicable to various short-flight conveyor systems. The LCA was conducted using SimaPro 8 software, applying the CML-IA baseline method. In most analyzed impact categories, the production of the belting and pulleys exhibits the biggest impact, primarily due to the environmental impact of steel and rubber production. The environmental impact of the impact and return rollers is also noticeable for the same reason. The contribution of the EM is most prominent in the abiotic depletion category due to copper extraction. When the use phase is considered, the impact of electricity consumption for EM operating exhibits the highest impact results primarily because Serbia's electricity is largely generated from lignite combustion. The resulting LCA model provides a robust foundation for decision-making in Ecodesign and sustainability optimization of short-flight belt conveyors.

Keywords*: Life Cycle Assessment (LCA), short-flight belt conveyor, environmental performance, Sustainability*

1. Introduction

LCA is a widely used method for assessing the potential environmental impacts over the life cycles of various products and processes, such as agricultural biomass production [1, 2], forestry biomass chains [3], construction materials (e.g., concrete and steel [4]), food packaging (e.g., PET bottle recycling [5]) and lately for the use of heat pumps under varying energy mixes [6]. However, Life Cycle Assessments specifically for belt conveyors, the most common means of transportation in bulk material handling, remain scarce and often simplified, focusing mostly on single components or specific stages rather than full cradle-to-grave assessments. In this regard, a more comprehensive, parametric Life Cycle Assessment (LCA) of the Bucket Wheel Excavator (BWE) SchRs 1200 × 22/2 [7] belt conveyor (BC) is presented in this paper. This research builds upon earlier studies [8-16], but introduces improvements including refined component modeling, mass-based process definition, inclusion of spare parts and service intervals, and detailed transport data. Most of these LCAs, including the one presented in this paper, were conducted using Ecodesign Assistant (EA) and Ecodesign PILOT (EP) software tools [17, 18]. The foundation of this section is primarily based on the analysis presented in [2], further expanded with more detailed data. The BC model used in this study is more refined and serves as the final preparatory step for conducting a formal LCA using SimaPro 8 software [19], which is covered in this paper. The improvements implemented in the analyzed model, compared to the one presented in [8], include:

- Defining precise boundaries for the hauling distance range;
- Accurately determining the service life of the BC;
- Incorporating spare parts and establishing servicing intervals;
- Expanding the analysis to include additional BC components;
- Refining the modeling approach for idlers;
- Introducing parameter-based modeling of components according to their mass.

The LCA conducted in this paper is parametric, providing a methodological framework for assessing any short-flight BC.

2. Methodology

The LCA model was developed in accordance with ISO 14040 standards [20, 21], following the four fundamental steps of the methodology: (1) Goal and scope definition, (2) Life Cycle Inventory (LCI), (3) Life Cycle Impact Assessment (LCIA), and (4) Interpretation. The analysis is performed using the SimaPro 8 Educational software package with the Ecoinvent 3.1 database. For LCIA phase CML-IA baseline method is applied, since it covers most relevant impact categories for BC such as GWP and AP [22-24]. This method (developed by the Institute of Environmental Sciences (CML) at Leiden University in the Netherlands), provides a well-established, midpoint-oriented framework for quantifying environmental impacts across multiple categories, such as Abiotic depletion (AD), Abiotic depletion-fossil fuels (ADff), Global Warming (GWP), Ozone layer depletion (OD), Human toxicity (HT), Fresh water aquatic ecotoxicity (FET), Marine aquatic ecotoxicity (MET), Terrestrial Ecotoxicity (TET), Photochemical Oxidation (PhO), Acidification (AC) and Eutrophication (ET). Its compatibility with product-based LCAs makes it ideal for assessing and comparing the contributions of individual components and life cycle stages of the BC.

2.1. Goal, scope and system boundaries

The goal of the study is to analyze the environmental impacts of the short-flight belt conveyor (BC) and develop the model for its parameterized LCA. Based on the findings of the results, potential solutions for improving energy efficiency, reducing energy consumption, and incorporating alternative technologies or techniques are proposed.

The system boundaries include the BC manufacturing and use phases, while the end-of-life (EoL) phase, (i.e., waste scenarios and waste flows) is omitted, as both the current study's own sensitivity analysis [8] demonstrated it contributes negligibly to the overall environmental impact. Given the defined system boundaries, the study follows a "cradle-to-grave" approach.

2.2. Functional unit

The functional unit for the analyzed BC is "Transportation of 3,465 m^3 of brown coal per hour" [8]. The service life of the belt conveyor (BC), i.e., its operational lifespan, can reach up to 30 years [25, 26]. In this study, the calculations are based on one year of BC operation. Assuming 296 working days of BC per year and the actual operating time of 18 hours per day [27, 28], this results in a total annual operating time of 5,328 hours.

2.3. Inventory

2.3.1. Production – Raw materials and manufacture

As stated in previous research [8], the BC consists of five main groups of components:

1. Rollers
2. Pulleys
3. Belting
4. Electric Motor (EM) and
5. Other.

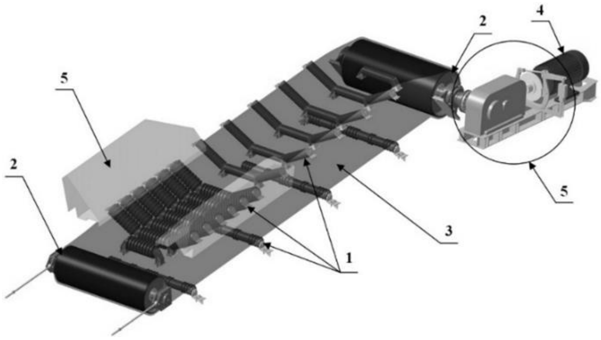

Figure 1. Main groups of BC components

The components classified under "other" include parts of the BC drive mechanism (excluding the EM) and various accessories, which are analyzed separately. For the purpose of this research, these five main components are further divided into individual products and associated processes within the SimaPro software: Roller (carrying), Roller (impact), Roller (return), Pulleys, Electric motor (EM), Belting, Gearbox (other parts), Coupling (other parts), Drum brake (other parts), Chute (other parts). Ball bearing 6310 C3 (BB) and roller Bearing 22240 CCK/W33 (RB) are treated as subcomponents, i.e., subprocesses, within the manufacturing process models for rollers and pulleys. Scrap generated during the manufacturing processes is included in the mass flow for each material used. For transportation, the calculations were based on the distance between the supplier factories and the open-pit mine. Packaging is not considered in this analysis, except for ball and roller bearings. Detailed inventory of each component is shown in Table 1 and described below. Most of the calculations were done in accordance with [8], using [29-31].

Table 1. BC production Inventory

Item/proces	Total No of pieces in BC	Weight per piece Kg	Main components and units	SimaPro Process used
Roller (carrying)	16	27.2	SR1+2×BB	See Table 2 and BB below
Roller (impact)	19	18.2	SR1+9×RD+2×BB	See Table 2 and RD and BB below
Roller (return)	4	55.8	SR2+16×RD+4×RR+2×BB	See Table 2 and RD, RR and BB below
Pulleys	1.5	2,160.6	Steel parts: 1,167 kg+10% scrap High Alloy parts: 751.3kg+10% scrap Rubber parts: 156.8 kg+10% scrap	Steel, low-alloyed {GLO}| market for | Alloc Def, U Steel, chromium steel 18/8, hot rolled {RER}| production | Alloc Def, U

			Roller Bearing×2: 42.5 kg×2 Electricity used: 9,196 MJ	Rubber (NR+SR)[1], (see Table 3) Roller Bearing 22240 CCK/W33[2] Electricity, medium voltage {RS}| market for | Alloc Rec, S
Electric motor (EM)	1	630	Winding and bars (copper): 126 kg+10% scrap Housing (Cast iron): 189 kg+10% scrap Steel parts: 315 kg+10% scrap Electricity used: 945 MJ Transport by truck, from Subotica: L=250 km	Copper {GLO}| market for | Alloc Def, U Cast iron {RER}| production | Alloc Def, U Steel, low-alloyed {GLO}| market for | Alloc Def, U Electricity, medium voltage {RS}| market for | Alloc Def, U Transport, truck >20t, EURO3, 20%LF, empty return/GLO Mass
Belting (1 m length)	16	35.24 per 1 m	Rubber: 28.2 kg Nylon: 7.04 kg (import from DE) Electricity consumed in DE: 40.9 kWh Electricity consumed in RS: 11.3 kWh Coal burned for calendering: 338 MJ Transport by trucks from DE (Leona) to RS manufacturer (Kolubara): Total length, L=1,320 km	Rubber (NR+SR) (Table 3) Nylon Electricity, medium voltage {DE}| market for | Alloc Def, U Electricity, medium voltage {RS}| market for | Alloc Def, U Coal Transport, truck >20t, EURO3, 20%LF, default/GLO Mass Transport, truck >20t, EURO4, 100%LF, empty return/GLO Mass
Gearbox (other parts)	1	561.5	Iron parts: 450 k +10% scrap High Alloy parts: 74 kg+10% scrap, Steel parts: 37.6 kg+10% scrap Lubricating oil: 50 l Transportation distance: L=75 kg Electricity used: 2,230 MJ (casting, machining and forging)	Cast iron {GLO}| market for | Alloc Def, U Steel, chromium steel 18/8 {GLO}| market for | Alloc Def, U Steel, low-alloyed {GLO}| market for | Alloc Def, U Lubricant oil (1) Transport, truck >20t, EURO3, 20%LF, default/GLO Mass Electricity, medium voltage {RS}| market for | Alloc Def, U
Coupling (other parts)	1	20	Steel parts: 30 kg Transport, Coupling is produced by "Kolubara metal", distance is 20 km Electricity used: 76 MJ	Steel, low-alloyed {GLO}| market for | Alloc Def, U Transport, truck >20t, EURO3, 20%LF, default/GLO Mass Electricity, medium voltage {RS}| market for | Alloc Def, U
Drum brake (other parts)	1	120	Steel parts: 120 kg +10% Scrap Transport by truck, distance from Germany: L=approx. 1,500 km Electricity used: 76 MJ	Steel, low-alloyed {GLO}| market for | Alloc Def, U Transport, truck >20t, EURO3, 20%LF, default/GLO Mass Electricity, medium voltage {RS}| market for | Alloc Def, U
Chute (other parts)	1	1,950	Steel parts: 1,950 kg +10% Scrap Transport by truck, Chute is produced by "Kolubara metal", distance is 20 km Electricity used: 1,482 MJ	Steel, low-alloyed {GLO}| market for | Alloc Def, U Transport, truck >20t, EURO3, 20%LF, default/GLO Mass Electricity, medium voltage {RS}| market for | Alloc Def, U
Sub_Ball Bearing (BB)	78	1.05	Steel parts: 1 kg Kerosene: 0.11 kg Chromium steel (machining): 0.43 kg Chromium steel (grinding): 0.29 kg	Steel, chromium steel 18/8, hot rolled {GLO}| market for | Alloc Def, U Kerosene {Europe without Switzerland} | market for | Alloc Def, U Chromium steel removed by turning, average, conventional {GLO}| market for | Alloc Def, U Chromium steel removed by milling, average {GLO}| market for | Alloc Def, U

[1] New process created in SimaPro

[2] Ibid

			Steel wire cutting and die-punching processes are replaced by forging, 1.34 kg Laser making - duration 5 s = 5/3,600 h = 0.0014h - the last power laser Lubricating oil: 0.21 kg Packaging material: - Corrugated board box: 0.05 kg - Carton board box: 0.29 kg Transport by freight, lorry: distance, L=500 km Electricity used: 0.376 kWh	Forging, steel {GLO}| market for | Alloc Def, U Laser machining, metal, with YAG-laser, 30W power {CA-QC}| laser machining, metal, with YAG-laser, 30W power | Alloc Def, U Lubricating oil {GLO}| market for | Alloc Def, U Corrugated board box {GLO}| market for corrugated board box | Alloc Def, U Carton board box production, with offset printing {GLO}| market for | Alloc Def, U Transport, freight, lorry >32 metric ton, EURO3 {GLO}| market for | Alloc Def, U Electricity, medium voltage {RS}| market for | Alloc Def, U
Sub Roller bearing (RB)	4	42.5	Same as above×42.5	Same as above

2.3.1.1. Roller

Analyzed BC consists of three different types of rollers: carrying, impact and return rollers. All three types of rollers used in this BC are modeled with the basic smooth roller. All rollers consist of parts made of steel (SR1 and SR2), two ball bearings 6310 (BB) – 2 pieces per roller - while impact and return rollers are additionally equipped with rubber discs (RD) and rubber rings (RR) (Table 1). The production processes for both SR1 and SR2-type rollers are modeled identically, with the only difference being that SR2 is 2.3 times larger than SR1 (see Table 2).

Table 2. SR1 and SR2 Inventory

	SR1	**SR2**
SimaPro processes used	**Unit**	**Unit**
Steel, low-alloyed {GLO}| market for | Alloc Def, U	15.9 kg+40 % scrap	36.7 kg+40 % scrap
Steel removed by turning, primarily roughing, conventional {GLO}| market for | Alloc Def, U	6.36	14.68
Transport, truck >20t, EURO3, 20%LF, empty return/GLO Mass	15.9 kg×20 km	36.7 kg×20 km
Electricity, medium voltage {RS}| market for | Alloc Def, U	49.2 MJ	113.6 MJ

Both carrying and impact idlers are troughed and comprise three rollers measuring Ø159×600 mm, except for the two idlers adjacent to the terminal pulleys, known as transition-type idlers, which consist of a single center roller. The return idler, on the other hand, consists of a single horizontal roller measuring Ø159×1800 mm and is fitted with rubber discs and rings.

More detailed description of each roller model is given below:

1. **Carrying rollers** – modeled solely as SR1. The analyzed BC contains 16 of these rollers, which are represented as SR1-type smooth steel rollers, equipped with two ball bearings. Therefore, the input for the production phase can be expressed as 16×(SR1+2×BB) (Table 1).
2. **Impact rollers** – modeled as SR1 with the addition of rubber discs. The analyzed BC contains 19 impact rollers, represented as SR1-type rollers, each equipped with two ball bearings and nine rubber discs. Therefore, the input for the production phase can be expressed as 19×(SR1+ 9×RD+2×BB) (Table 1).

3. **Return rollers** – modeled as SR2 with the addition of rubber discs and rings. The analyzed BC contains 4 return rollers, represented as SR2-type rollers, each equipped with two ball bearings, sixteen rubber discs, and four rubber rings. Therefore, the input for the production phase can be expressed as 4×(SR2+16×RD+4×RR+2×BB) (Table 1).

Transport of rollers is carried out by 20-ton truck over a distance of 20 km, from the "Kolubara Metal" production facility to the open-pit mine. Rubber discs and rings are produced from the same rubber compound as the belting (as described later in the text) by injection molding at the "Kolubara Univerzal" production facility. Polyamide and polypropylene components - used to seal and secure the ball bearings - are omitted from the model due to the negligible environmental impact.

2.3.1.2. Pulleys

The analyzed BC consists of two pulleys: the drive (head pulley) and the return pulley (tail pulley, which also serves as the take-up pulley for this BC). Both pulleys are modeled with the drive pulley being 1.5 times heavier than the actual drive pulley [8]. Pulley components are modeled as Steel parts, High Alloy parts, Rubber parts, Steel Zn parts and two Roller Bearings (RB). For each component corresponding unit processes in SimaPro are used (Table 1). For modeling of rubber parts, a new process is created (detailed explanation in "Belting", see Table 3). Steel Zn parts are excluded due to their negligible mass contribution (Table 1).

2.3.1.3. Ball bearing (BB) and Roller bearing (RB)

The analysis of the 6310 C3 ball bearing is conducted on a per-unit basis, with specific process names corresponding to those used in the software (see Table 1). Additionally, the process Vegetable oil, refined {GLO} is available in the EcoInvent 3.1 database and is considered a lower-impact alternative to standard lubricating oil [11, 32–34]. The quantities of materials, transport, and energy consumption entered into the software were determined through calculations in accordance with previous research [15]. For modeling of roller bearings (RB) the same subprocess for manufacturing the ball bearings are used, only its components are scaled to values corresponding to the roller bearings actual size (RB are 42.5 times bigger than BB) (Table 1).

2.3.1.4. Electric motor

The electric motor type RZKT 280 M-4 is analyzed, considering the following elements: windings and bars - made of copper; housing - made of cast iron; steel parts - stator and rotor; transport - carried out using a 20-ton truck, with a transport distance of 250 km from the factory located in Subotica; For EM production, medium voltage electricity {RS}, process is used [8, 14] (see Table 1).

2.3.1.5. Belting

The belting is parameterized according to the unit of length, 1 m. Total length of the belting considered in this study is 16 m. It consists of a rubber compound and textile reinforcing plies made of nylon (i.e., polyamide). Nylon is produced in Germany by "DOMO Chemicals" from Leona by injection molding, with an SEC of 19 MJ/kg [29] and is transported by a 20-ton truck. Considering that injection molding technology has advanced compared to [29], it is reasonable to expect that the actual environmental impact of newer technologies is lower. The production of the belting requires medium voltage electricity produced in both Serbia and Germany. The production of steam for the calendering of the rubber compound and vulcanizing the belting requires the combustion of a certain amount of coal (data is obtained from “Kolubara Univerzal”) (Table 1). The rubber compound is made from natural rubber (NR), synthetic rubber (SR), carbon black and chemicals (lime, zinc concentrate, oils and other chemicals) in a certain ratio. These processes are created in accordance with the data obtained from the “Kolubara Univerzal” factory. According to these data, the ratio of ingredients of the rubber compound is approximately: NR – 19%, SR – 31%, carbon black – 34%, chemicals – 16%. In accordance with [8], electricity consumption for belting manufacturing is 0.719 kWh.

2.3.1.6. NR and SR production

NR is produced in Thailand {TH}. For its production water and latex are used (Table 3). Latex production requires formic acid and the use of electricity for the drying process. It takes approximately 4-6 liters of fresh latex to produce 1 kg of dry natural rubber, depending on the dry rubber content (DRC) of the latex. Latex typically contains 30-40% rubber by weigh [35].

Table 3. Inventory for production of Natural and Synthetic rubber

Natural Rubber (NR) production		Synthetic Rubber (SR) production	
Used Processes from SimaPro	**Unit (per 1 kg)**	**Used Processes from SimaPro**	**Unit (per 1 kg)**
Latex	5.4 kg	Butadiene E	0.765 kg
Water, river, TH	0.2 m^3	Styrene E	0.235 kg
Electricity, medium voltage {TH}| market for | Alloc Def, U	0.03 kWh	Water, cooling, unspecified natural origin, RoW	0.045 m^3
Formic acid {RER}| market for | Alloc Def, U[3]	0.003 kg	Chemical, organic {GLO}| market for | Alloc Def, U	0.058 kg
Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Def, U	Distance, L=16,000 km via ocean from Thailand to Rotterdam (NL)	Soap {RoW}| production | Alloc Def, U	0.02 kg
Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}| market for | Alloc Def, U	1,800 km Rotterdam (NL) -Veliki Crljeni (RS)	Electricity, medium voltage {RU}| market for | Alloc Def, U	0.719 kWh
		Water/m^3 Water, RoW	0.017 m^3 0.027 m^3
		Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Alloc Def, U	Distance, L=2,500 km from Voronezh (RU) to Veliki Crljeni (RS)

The density of fresh natural latex typically ranges between 0.92 and 0.98 kg/l, depending on the specific composition and water content. This means that 1 liter of fresh latex generally weights approximately 0.92 to 0.98 kg. Considering the density of 0.9 kg/l and amount of 6 l of fresh latex needed to produce 1 kg of dry natural rubber (input), the input of 6 l of fresh latex weights 5.4 kg. The transport of natural rubber from Thailand to Serbia is carried out via transoceanic shipping to the port of Rotterdam (approx. 16,000 km), followed by road transport by truck from Rotterdam to Veliki Crljeni (approx. 1,800 km). The SR is made from butadiene, styrene, soapy water, and chemicals, as shown in Table 3. This SR compound, designated as SBR-1705, was obtained from the city of Voronezh, located in Siberia, Russia. The quantities of ingredients were obtained from the manufacturer and from [35-37].

[3] density of formic acid is approximately 1.22 g/mL at room temperature - coagulated with 0.3 l of 1.0% Formic Acid/Kg of rubber

2.3.1.7. Gearbox (Other parts)

The following elements are taken into account for the analysis of the gearbox: steel, chromium steel 18/8 {GLO}; cast iron {GLO}, steel, low-alloyed {GLO}; lubricating oil; transport, via a 20-ton truck, and medium voltage electricity {RS} (see Table 1 and [8]). The gearbox contains 50 liters of Reduktol oil. As the gearbox is manufactured at the "Goša FOM" factory in Smederevo, transport distance is approx. 75 km and is carried out by a 20-ton truck. Electricity is used for casting, forging, and machining of the gearbox parts (Table 1).

2.3.1.8. Coupling, Drum brake and chute (other parts)

The coupling and the chute are produced by Kolubara Metal, with the production facility located about 20 km from the open-pit mine where the BC is utilized. The drum brake is manufactured in Germany and transported by a 20-ton truck over a distance of approximately 1500 km. The production processes are calculated and expressed as thermal energy (see Table 1 and [8]). The relevant elements considered for this part of the analysis include low-alloyed steel, transport by a 20-ton truck, and medium voltage electricity {RS} (Table 1).

2.3.1.9. Total energy consumed

The energy required for the production of the BC consists of both thermal and electrical energy. The electrical energy share comes from belting production, amounting to $E_E = E_{E,Belting} = 800$ kWh [13]. The thermal energy share is calculated as follows:

$$E_T = E_{Rollers} + E_{Pulleys} + E_{IM,Belting} + E_{EM} + E_G + E_{Other}$$
$$= 6{,}702 + 13{,}794 + 2{,}140 + 947 + 2{,}230 + 1{,}650 = 27{,}463 \text{ MJ} \qquad (1)$$

2.3.2. Use phase - Spare parts, electricity and lubrication

During operation, the BC requires spare parts, lubricating oil, grease, and electricity to function. Impacts from the use phase of the BC are considered for 1 year of operation (Table 4).

Table 4. BC USE Inventory

Item	Amount	Unit	Replacement
Roller (carrying)	16	p	Every year
Roller (impact)	19	p	Every year
Roller (return)	4	p	Every year
Pulleys	1.5×05=0.75	p	Every 2 years
Belting (16 m)	16×0.5=1.5	m	Every 2-3 years
Lubricant oil (for Gearbox use)	50	l	Every year
Electricity {RS} for electro motor use (1,980 kWh per day, 296 days per year)	1,980×296=586,080	kWh	Annual use

Rollers are replaced once a year, resulting in use of 16 carrying rollers, 19 impact rollers and 4 return rollers per year. Pulleys are replaced every two years; therefore, and spare parts and maintenance are represented by 0.75 pulleys per year (1.5 pulleys per replacement cycle×0.5 cycles per year. The whole amount of Reduktol oil from the gearbox (in total of 50 liters) is changed annually. The electric motor (EM) consumes approx. 586,080 kWh of electricity annually, based on an average daily consumption of 1,980 kWh over 296 working days.

3. Results

The life cycle impact assessment (LCIA) results for the raw materials, production phase and transport of the belt conveyor (BC) components are shown in Figure 2 and Table 5.

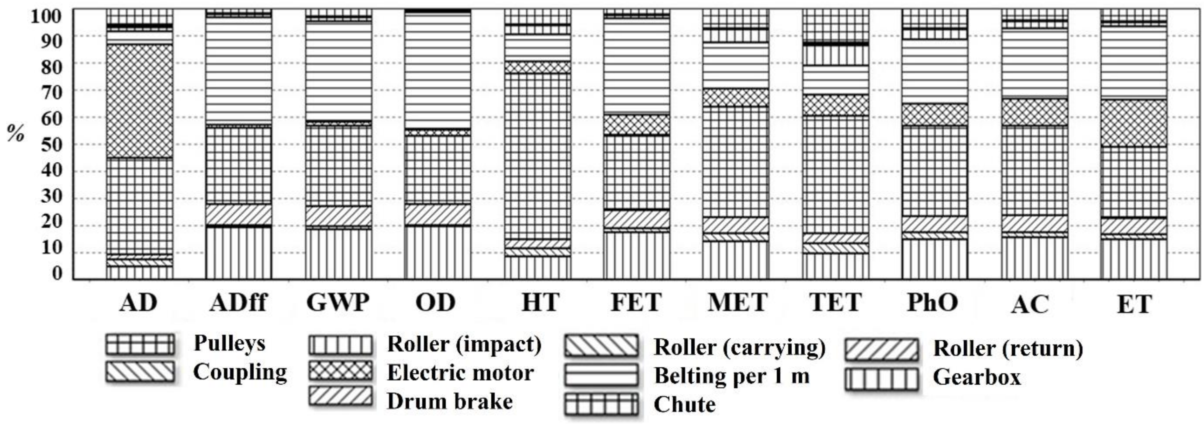

Figure 2.Results of the characterization for BC production

The results reveal that the **pulley** is the most environmentally impactful component, which corresponds with its dominant mass share of approximately 40% in the total BC structure. Pulleys exhibit the highest impact in several categories, including *human toxicity* (61%), *terrestrial ecotoxicity* (43%), *marine aquatic ecotoxicity* (41%), *photochemical oxidation* (33%), and *acidification* (33%) (Table 5). The **belting** ranks as the second most environmentally burdensome component, primarily due to the intensive nature of rubber production. It contributes most significantly to *abiotic depletion* (40%), *global warming* (37%), *ozone layer depletion* (43%), and *freshwater aquatic ecotoxicity* (36%) (Table 5).

Table 5. Results of the characterization for the BC Manufacturing phase

Impact category	*Unit*	*Total (units)*	*Roller I (%)*	*Roller C (%)*	*Roller R (%)*	*Pulleys (%)*	*EM (%)*	*Belting (%)*	*Gearb. (%)*	*Coupl. (%)*	*Brake (%)*	*Chute (%)*
AD	kg Sb eq	0.77	5	2	2	36	42	5	2	0	0	6
ADff	MJ	1,993,805.02	19	1	8	28	1	40	1	0	0	2
GWP100a	kg CO2 eq	136,798.16	19	1	7	29	1	37	1	0	0	3
OD	kg CFC-11 eq	0.02	20	0	8	25	2	43	1	0	0	1
HT	kg 1,4-DB eq	210,520.88	8	3	3	61	4	10	3	0	0	6
FET	kg 1,4-DB eq	1,948.44	18	1	7	28	7	36	1	0	0	2
MET	kg 1,4-DB eq	26,085,242.64	14	3	6	41	7	17	5	0	0	7
TET	kg 1,4-DB eq	575.67	9	4	4	43	8	11	7	0	1	13
POC	kg C_2H_4 eq	29.04	15	2	6	33	8	24	3	0	0	7
AC	kg SO_2 eq	553.19	16	2	6	33	10	26	3	0	0	4
ET	kg PO_4 eq	86.53	15	2	6	26	18	27	1	0	0	5

The **impact rollers** also demonstrate considerable environmental impact, largely due to their quantity—19 units per BC. They contribute notably to abiotic *depletion* (19%), *global warming* (19%), *ozone layer depletion* (20%), and *freshwater aquatic ecotoxicity* (18%), while in categories such as *photochemical oxidation*, *acidification*, and *eutrophication*, their contribution remains consistently around 15% (Table 5). The **electric motor (EM)** shows highest impact in the category of abiotic depletion (42%), due to copper and steel use for its production. All other components exhibit minimal environmental impact, whereas coupling and chute have negligible impact in all categories (<1%).

In *human* and *terrestrial toxicity* impact categories, the highest contribution comes from the production of high-carbon ferrochromium (68% Cr), which is used in stainless steel manufacturing (the primary raw material for pulley manufacturing). In *abiotic depletion*, significant impacts are associated with the production of chromite ore concentrate and copper, used mostly for production of pulleys and EM. In *abiotic depletion (fossil fuels*) and *ozone layer depletion*, the highest impact comes from petroleum production, primarily due to its role as a feedstock for synthetic rubber (belting), as well as its extensive use as an energy source in upstream extraction, refining, and manufacturing processes.

The process "Transport, freight, lorry 16–32 t, EURO5" shows the highest contribution in *global warming, photochemical oxidation, acidification,* and *eutrophication* impact categories. This is due to the transport of numerous heavy BC components over long distances — including drum brakes (1,500 km), belting (1,320 km), electric motors, and ball bearings. Even locally produced parts like the chute (1,950 kg) and coupling add considerable environmental burden when transported by road. The combined weight and distance result in significant emissions of CO_2 , NO_x, and SO_2 , which are directly linked to these impact categories.

In the toxicity-related impact categories—including *freshwater aquatic ecotoxicity, marine aquatic ecotoxicity*, and *human toxicity*— brake wear emissions from freight transport emerge as significant contributors. These emissions result from the long-distance road transport of heavy BC components. Brake wear particles contain heavy metals such as copper, zinc, and antimony, which are highly toxic, persistent, and can enter aquatic environments through runoff, ultimately affecting both freshwater and marine ecosystems. Additionally, these fine particles contribute to human toxicity via airborne exposure (e.g., PM2.5) and contamination of water and food sources. Although such emissions are not directly associated with the production of the BC itself, they are embedded within its transport-related life cycle stages, underscoring the broader environmental and health implications of logistics and material flow within the product system.

In the category of *marine aquatic ecotoxicity,* the processes "Electricity, medium voltage {RS} | market for | Alloc Def, U" and "Electricity, high voltage {RS} | electricity production, lignite | Alloc Def, U" show the highest contributions. These impacts are primarily associated with heavy metal emissions to water and air—such as mercury (Hg), arsenic (As), and cadmium (Cd)—that occur during the combustion of lignite, which is the predominant source of electricity in Serbia. These pollutants can enter marine ecosystems through atmospheric deposition and wastewater discharge from power plants. A notable contribution to *eutrophication* in the LCA results stems from the process "Sulfidic tailings, off-site {GLO} | treatment for", which reflects the environmental burden of managing mining waste rich in sulfide minerals. This impact is primarily linked to the extraction and refining of metals such as copper and chromium, which are used in components like the electric motor, pulleys, rollers, and bearings. Tailings from metal ore processing can release nitrates, sulfates, and heavy metals into water systems, promoting nutrient enrichment and ecological imbalance in aquatic environments. The LCA results for the use phase of the belt conveyor (BC) per year, reveal that electricity consumption—primarily due to the operation of the electric motor (586,080 kWh, Table 4)—has the greatest environmental impact across nearly all impact categories (Figure 3). This includes global warming, ozone depletion, abiotic depletion, and all major toxicity-related impacts. Additional contributions come from lubricant oil use and belting wear, which affect human toxicity and aquatic ecotoxicity. Impacts from the use of other BC components are associated with the same processes as in the production phase, but their relative contributions differ due to the frequency and intensity of their use within the one-year period. The production processes and raw materials, when compared to the use phase of the BC, have a greater impact primarily in the abiotic depletion and human toxicity categories (73% and 52%, respectively), with a notable share also in terrestrial ecotoxicity (42%) and freshwater aquatic ecotoxicity (30%). In all other impact categories - including marine aquatic

ecotoxicity, global warming, ozone depletion, photochemical oxidation, acidification, and eutrophication - the use phase dominates, as shown in

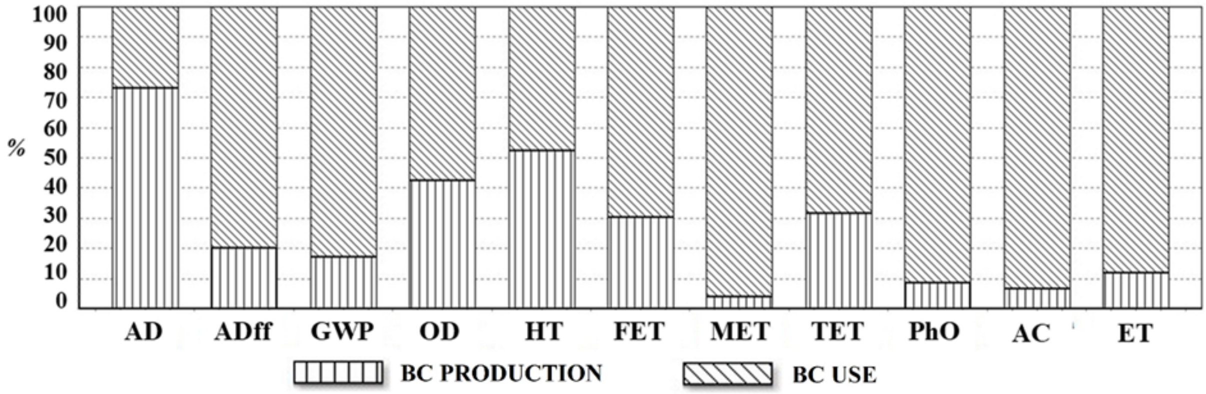

Figure 4.

Figure 3. Results of the characterization for BC use

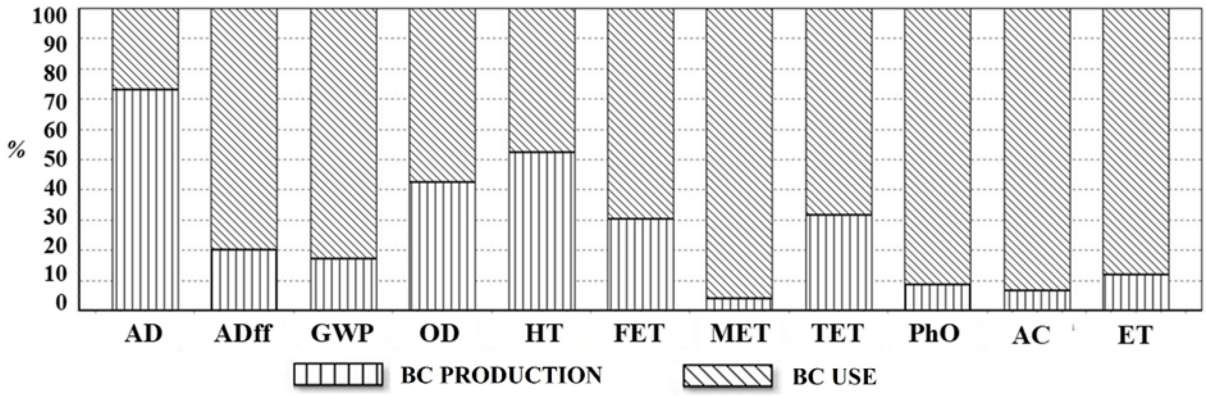

Figure 4. Results of the characterization for BC production and use

4. Conclusions

In this paper, a "cradle-to-grave" LCA study was conducted on the short-flight belt conveyor (BC). The results of the LCIA indicate that the use phase, particularly the electricity consumption of the electric motor (586,080 kWh per year), has the highest environmental burden in most impact categories, including global warming (~80%), ozone depletion (~85%), acidification (~90%), and aquatic and human toxicity (60–90%). Electricity generation from lignite contributes significantly to these impacts, especially through emissions of CO_2 , SO_2 , NO_x, and heavy metals such as mercury and cadmium. These findings emphasize the crucial role of operational energy use and highlight electricity sourcing as a key area for sustainability improvement.

In the manufacturing phase, pulleys exhibit the highest environmental burden, contributing 61% to human toxicity, 43% to terrestrial ecotoxicity, and 41% to marine aquatic ecotoxicity. This is primarily due to the use of high-carbon ferrochromium (68% Cr) in stainless steel production and pulleys' high mass share (40%) in the total BC structure. Belting contributes 40% to abiotic depletion, 37% to global warming, and 43% to ozone depletion, driven by petroleum-derived rubber production. Impact rollers also show significant impact due to their quantity (19 units per BC), contributing 19% to abiotic depletion, 20% to ozone depletion, and 18% to freshwater aquatic ecotoxicity. Transport processes, particularly road freight (16–32 t lorries, EURO5 standard), also have notable environmental effects, dominating in photochemical oxidation (~95%), acidification (~90%), and eutrophication (~80%). Brake and tire wear emissions linked to transport are major contributors to toxicity categories and aquatic pollution. Consequently, transport logistics emerge as a critical hotspot in the environmental profile of BC production.

Other relevant contributors include sulfidic tailings treatment (eutrophication) and upstream petroleum and copper production (abiotic depletion, ozone layer depletion). This finding highlights the importance of considering upstream mining practices in the overall environmental profile of industrial equipment like belt conveyors.

To reduce environmental burdens, several strategies are recommended:

- Adoption of high-efficiency electric motors
- Use of self-cleaning idlers, self-adjusting components, and energy-saving bearings
- Extension of component life via condition monitoring (e.g., thermography, vibrodiagnostics)
- Increased reuse and recycling of pulleys, rollers, and rubber parts
- Material substitution with low-toxicity alternatives
- Sourcing electricity from renewable sources or installing on-site generation

Although these improvements may require higher upfront investment, the most significant long-term energy savings can be achieved by using the most energy-efficient motor available on the market. Extending the operational life of the BC system also contributes to long-term sustainability.

Some of these solutions are already implemented in practice. For instance, roller shells are repaired and reused, pulleys are regularly serviced, and damaged rubber elements are recycled or reused for other applications.

In conclusion, by implementing the strategies discussed in this study, substantial environmental improvements and savings can be realized—contributing to the development of a more sustainable, or “green,” belt conveyor system.

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