A Survey of Researches in the Field of Ecodesign Related to Intralogistics at the University of Belgrade - Faculty of Mechanical Engineering (2010-2017)

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Since its inception in the educational process at the Faculty of Mechanical Engineering (University of Belgrade) in 2008/2009 (Master and PhD studies), as the result of the Tempus project JEP 40069 “Design in Mechanical Engineering” (2006-2008), the field of ecodesign and sustainable logistics has a permanent growth both in tuition and research. That finally resulted in establishing Laboratory of ecodesign and logistics in 2014 and several researches conducted through the work in this Lab. Some of them have been done in the cooperation with some foreign academic institutions. The main stream of the mentioned researches was related to the assessment of environmental effects of intralogistics equipment, such as material handling (cargo handling equipment in ports such as are cranes and terminal tractors) and conveying (belt conveyors) equipment. Accordingly, the conducted researches and findings have been presented to a broader scientific community and published in international journals, books and presented at the international conferences. This paper gives a survey and compilation of those publications in the period 2010-2017.

Keywords: Ecodesign, sustainable logistics, life cycle assessment, cargo handling equipment, conveyors

1. INTRODUCTION: ECODESIGN AND LCA AS ITS CORE

From the environmental point of view, sustainability represents the system’s capacity (in this case the Earth) to support anthropogenic activities’ impact on the environment without putting the future of human race under risk. From the designer point of view, sustainable development is about designing objects that use limited resources; it is also about social responsibility and ethics [1], [2].

Growing interest in environmental condition and concept of sustainable development resulted in appearance of design disciplines with goal to develop solutions for decreasing the impact of human activities and industrial products on environment. Such discipline is well known as Ecodesign or Design for Environment. Based on fundamentals of ecodesign, all products and services must be designed to scope all of their life cycles stages. Processes needed for manufacturing, distributing and disposing of the product at the end, are considered to be one. Beside the design of product itself, this approach designs product system, in a way that it defines all possible events in product life cycle [3].

In 2006 the European Environment Agency defines Ecodesign as “the integration of environmental aspects into the product development process, by balancing ecological and economic requirements. Ecodesign considers environmental aspects at all stages of the product development process, striving for products which make the lowest possible environmental impact throughout the product life cycle.” Ecodesign integrates the idea of sustainability as well as environmental considerations into the product development. It considers the contribution of the product to environmental impact through all of its life cycle stages. Speaking of Ecodesign and environmental friendly product development it is important to bring together environmental requirements from stakeholders, as well as legal frameworks. For the purpose of product improvement, Ecodesign process integrates stakeholder and environmental point of view, see Figure 1 [4].

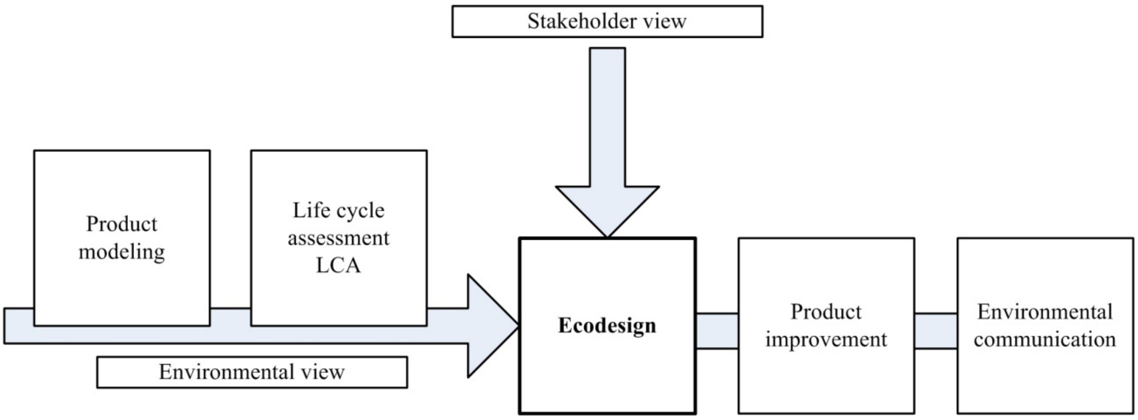

Figure 1: Inputs to the Ecodesign process [4]

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Having this in mind, ecodesign as relatively new engineering discipline makes a radical discontinuity with traditional design process [5]. The purpose of this is to design product life cycles, in order to indentify and efficiently combat environmental impacts. In other words, it is possible to create product and minimize the input of raw materials and energy, and the impact of all emissions and waste.

Before design of any new product life cycle, and before any improvement of existing product life cycles, it is of vital importance to estimate the present effects on environment. The only way to both quantitatively and qualitatively calculate the harm of all effects of products and human activities on environment is to conduct Life Cycle Assessment or LCA [6]. As the core of ecodesign LCA is quantitative tool for assessment of environmental impacts of products and services such as climate change, global warming, ozone depletion, (smog) creation, eutrophication, acidification, toxicological impact on humans and ecosystems, the depletion of resources, and others. It is systematic approach for analyzing the entire life cycle stages of products from material extraction through manufacturing, use and eventually disposal or recycling preferably. Therefore it is often called a “cradle-to-grave” analysis [3].

LCA is an iterative technique. In accordance with EN ISO 14040: 2006, life cycle of a product consists of five consecutive and interlinked stages. Therefore life cycle includes:

1. Raw material stage,
2. Manufacturing stage (design and production),
3. Distribution stage (packaging and transportation),
4. Use stage, and
5. End of life stage (EoL).

In accordance with the same standard EN ISO 14040: 2006, the formal structure of an LCA contains four phases:

- Goal and scope definition,
- Life cycle inventory analysis (LCI),
- Life cycle impact analysis (LCIA),
- Life cycle interpretation.

These phases are consecutive and interlinked, as life cycle stages, see Figure 2 [7].

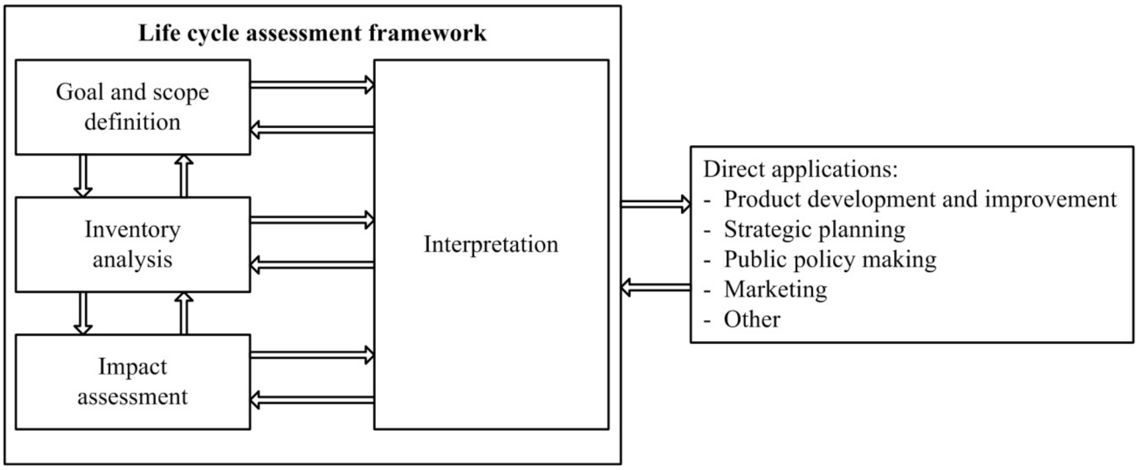


Figure 2: Phases of an LCA [7]

2. 2. CURRENT TRENDS IN GREEN (INTRA)LOGISTICS

The forum intralogistics at the association “Verband Deutscher Maschinen- und Anlagenbau” (VDMA) defines intralogistics as the organization, control, realization and optimization of in-plant goods and their material flow and logistics, of the streams of information as well as the movement of goods in industry, trade or public facilities [8].

Corresponding to the 20 mega-trends specified in [9] specific subject areas have been established as important future research focuses (Figure 3).

As it can be concluded from Fig. 3 of the 20 global megatrends one of the most significant trends for intralogistics as a part of logistics sector (energy consumption in intralogistics is estimated to about 25% of the whole logistics sector [10]) is climate change and environmental impact, while one of the main

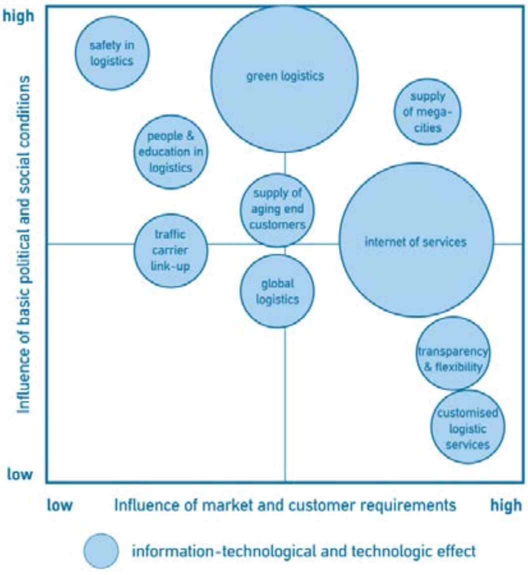


Figure 3: Tasks in intralogistics in the future [11]

research thrusts is “Green Logistics”. Although the logistics greenhouse gas (GHG) footprint may appear relatively modest (estimated for around 5.5% of global emissions), transport sector has been increasing its output of these gases, while other sectors are reducing their footprint [12]. For this reason it is quite sure that in the next few decades a major challenge for the companies in logistics sector will be to implement practical and cost-effective carbon mitigation strategies to cut their GHG emissions in an effort to achieve very ambitious carbon reduction targets at national, EU and global levels by 2050 [13].

Companies can reduce carbon emissions from their logistics operations in many ways. According to [12] several ideas for decarburization of logistics activities, focus is on five key freight transport parameters: reducing freight transport intensity, shifting freight to less carbon-intensive transport modes, increasing vehicle utilization, raising the energy efficiency of freight transport operations and finally reducing the carbon intensity of the energy source (i.e. the amount of CO_2 emitted per unit of energy consumed either directly by the vehicle or indirectly at the primary energy source for electrically-powered freight transport operations, what will be particularly considered later in this paper) used in logistics. Obviously, decarburization must be followed by developing innovative technologies [14] in order to improve intermodal transport chains, logistics services and consequently environmental performances of logistics equipment.

3. 3. ENVIRONMENTAL EFFECTS OF CARGO HANDLING EQUIPMENT (CHE) IN CONTAINER PORTS

With almost 90 percent of non-bulk cargo moved worldwide by containers, the container shipping and handling industries have immense economic footprint both locally and globally. Ports play a huge role in the regional economies and the growth and the development is directly related to ports abilities to adapt to new challenges [15]. As according to Guerrero and Rodrigue [16], the five waves (phases or cycles) of containerization that essentially influenced development of port and terminals are presented in Fig. 4, 2014, [17]).

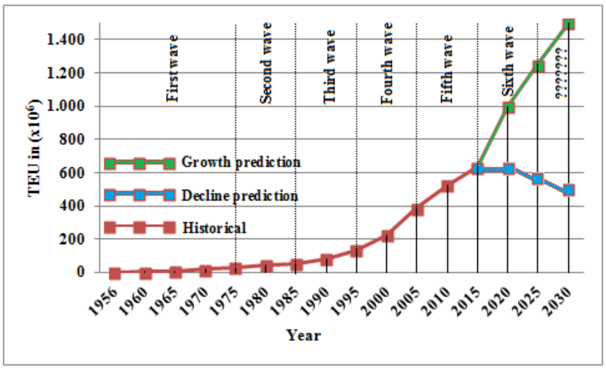


Figure 4: TEU number (1956-2015 with 2030 prediction) and waves of containerization according to Guerrero and Rodrigue [16],[17]

After summarizing the containerization development and having in mind the mentioned megatrends, the imposing conclusion is to seek challenges and changes in containerization not only within technological arena, but equally significant social and economical ground. Containerization has given revolutionary change for the transportation and shipping industry, leading to globalization. The technology could provide evolution for the containerization to maintain its important role, but it is strong belief that only the social and economical changes at global scale can make revolutionary change, Fig. 5 [17].

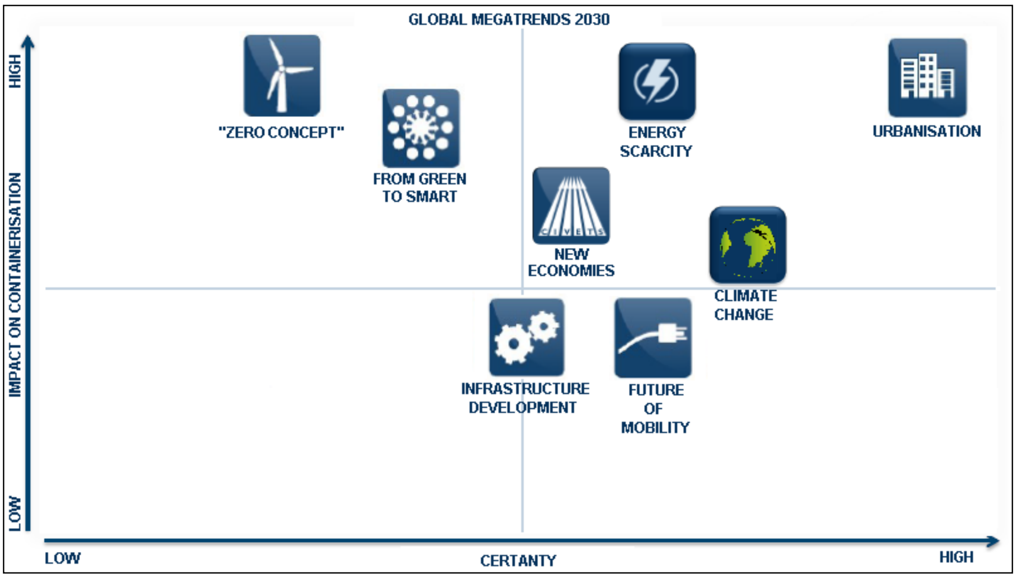


Figure 5: Impact of global megatrends on containerization [17]

It is also important to underline that the environmental footprint of the ports is rising to the top of the port authorities’ agenda in the moment when economic downturn has already exerted container operations struggling to hold on cost effective side. The new demands are pushing port related industries to offer “green” solutions for ports who seek to mitigate their environmental footprints. Emissions in ports come from operations of three different sectors. The first sector is related to the arrival and berthing of vessels, the second involves activities within the port boundaries such as unloading of cargo from the ships and their transfer by Cargo-Handling-Equipment (CHE) and the third includes the transport (vehicles, trains and inland shipping) within or near the port and departure [15].

In port container terminals, cargo (in this paper only containers) are ferried around using special designed machines called CHE. These machines usually include various types of cranes and specially designed forklifts, tractors or trucks. The containers are lifted from a marine vessel by a crane at latter moved or picked by other crane, handler or forklift. In between each use of a crane or pick, the container is transported around the terminal using a yard truck.

Greatest in CHE fleet population are the yard trucks and forklifts, followed by handlers and gantry cranes. These machines are conventionally power with Internal-Combustion-Engine (ICE) which most often is a diesel. Due to the fact that handling container with as much as 40 tonnes of cargo is an energy-intensive function and the fact that CHE is powered with diesel burning engines it is often considered as one of the most significant sources of air pollution caused by terminal operations [15].

Fortunately, an answer to port “green” strategies, the CHE industry offered a wide range of solutions, from retrofits to brand new high efficiency models, such as hybrid and all-electric drives. Depending on solution and equipment type some technologies are advertised to reduce the CO_2 emissions up to 70 percent and NO_X and SO_2 up to 90 percent (according to manufacturers). Most common pieces of CHE found in container terminals are [15]:

- Rubber Tired Gantry (RTG) cranes (RTGs)
- Utility tractor rigs (UTRs), which is also known as Yard Trucks or Terminal Tractors
- Straddle Carriers
- Container Forklifts
- Reach Stackers

Determining environmental footprint of container terminal or CHE is important and complex task. The environmental footprint of CHE activities at container terminals can be defined either by directly measuring emissions or estimating them using various models or methods [15]. Generally, CHE emissions at ports are estimated using either the off-road emission models or methods similar to those in the models [18]. In order to understand the environmental impact of container terminals, various models and tools that quantify the emissions of relating sources are used or developed. Each model can vary greatly in terms of complexity and accuracy on one side, and time and resources on the other. The non-modeling approach to create an emission inventory of CHE is to directly measure emissions or energy consumption. Although it could be considered as the most accurate way, it is also the most expensive and time demanding and can only be done as aftermath. Direct emissions measurement, thus disables early stage planning process and is more suitable for establishing the baseline inventory. The modeling is therefore more appropriate as preventive approach, as support for decision making. The complexity of modeling methodologies can also vary depending on intended use and users and can also be time and resource consuming if detailed and validated model is wanted, according to [19]. Regardless of which modeling approach is chosen it enables prediction of emission of any source at port without actually ever visiting facility. That can be also used for comparison of different types of CHE. The drawback of modeling is that any uncertainty in baseline parameters can eventually lead to significant uncertainty in the final results of estimated CHE emissions. This is of great importance, particularly when comparison of any type of CHE is made, since even the slightest aberration in early modeling can result in favoring one piece of equipment over other [13].

On the significance of CHE emissions, also reveals the fact that many ports today are considered to be the largest sources of air pollution in coastal cities. For instance, according to the data collected in report [20] in 2007, the Port of Long Beach found that 81% of the CHE port wide was employed by its container terminals and that 8% of total NO_X emissions were due to CHE; the Port of Houston found that 15% of its 2007 total NO_X emissions came from CHE; New York/New Jersey found that 25% of their 2006 NO_X emissions were due to CHE. To get better fuel economy and accordingly to reduce GHG emissions, ports around world are considering using either “low carbon” (hybrid) or “zero emissions” (electric) technologies that are currently deployed for port equipment such as cranes – Rubber Tired Gantry Cranes [21] and UTRs [22] and other vehicles.

In the presented research the concept was on the RTG cranes and UTRs, since they are the most common pieces of CHE found in container terminals accounting combined over 55% of all CHE [23]. RTGs are dependable on the support of UTRs for quick container transport across the terminal and combined evaluation of their environmental impact and operating costs is common approach in terminal planning, also recommended by Böse [24].

3.1. Examples of RTGs [25], [26]

In port container terminals, RTG cranes are used for movement of shipping containers, once they are placed on to the distribution channels from a vessel. The cranes are powered by a diesel generator set (genset), which consists of a diesel engine coupled with an alternator. An RTG crane is capable of moving containers weighing up to 50 tonnes at a rate of 20 moves per hour. Since it is one of the largest machines on tires in the world powered by large non-road diesel engine, turning it into the eco-friendly machine is a challenging task.

A conventional diesel genset provides electrical power for the hoist, trolley, and gantry electric motors, as well as for the routine demands of the crane. Utilizing this type of power system on a RTG allows the crane to move independently throughout the container terminal as is required by daily port operation. The freedom of movement and the high peak power demand for hoist motor consume a large amount of fuel and emit significant emissions of GHG.

Today, variety of technologies and systems are available to reduce fuel consumption and emissions and improve overall RTG efficiency. They include technologies such as, variable-speed generators, flywheel energy storage, hybrid RTGs with regenerative breaking and super or ultra capacitor technology and electrified "zero emission" cranes (E-RTGs). Most of them are available as retrofits for conventional cranes, but also as manufactured brand new RTG option.

An electrified RTG (E-RTG) crane in the past was often avoided due to complicated electric-power feeding via cable, narrowed movability and limited flexibility. Today E-RTG's disadvantages are overcome with the cable reel and latest with drive-in conductor bar solution with collector trolley that automatically engages and disengages. Although the main disadvantage remains – the need to adapt the terminal for electrification, the fact is that with the latest solutions, environmental advantages of E-RTG are in prime again. The 90% of operating time electrified RTG cranes uses solely electricity and 10% of time uses diesel engine, during block changes and maintenance. The manufacturers promise E-RTG staggering potential for CO_2 reduction.

Certain solutions for RTG cranes have advantages over others and certain terminal configurations and port authorities favor some of them, but from environmental point of view it is important to find out which solution is more eco friendly. Again, certain methodologies for assessment of environmental impact of products have advantages over others, but according to the author's opinion the most appropriate way is to carry out Life Cycle Assessment (LCA) of three most widespread implemented technologies of nowadays RTG cranes which include conventional solution and two emerging technologies (hybrid and electrified zero emission RTGs).

Thus, the objective of this research is twofold. The first objective is to evaluate environmental benefits of emerging technologies for RTG cranes over conventional and the second is to promote the use of (LCA) methodology for this purpose. In this way, comparison of RTG cranes will offer results which could be used in further research of CHE emerging technologies.

Once the environmental impact of manufacturing stage of a conventional type of RTG is obtained, these results could be used for evaluation of environmental performances of future CHE technologies. Essentially, RTG support structure and its corresponding manufacture process are basically unchanged since these machines have been introduced in operation. Majority novel solutions offered for brand new cranes are also available as upgrades for older models [25].

Since conventional model of RTG crane is set as basic model, other two models: the hybrid RTG and electrified E-RTG are in essence upgraded versions of the basic model which use same gantry structure. The difference between basic (conventional) model over hybrid and E-RTG is in add-ons over standard diesel generator set. This principle of modeling allows the authors to use the most of inventory base of the first RTG crane which is in accordance with real life, dockside experience where conventional cranes already in use are modernized by new state-of-the-art add-on features.

The system boundaries are defined according to ISO 14000 recommendations and responding to work principle of used LCA software. The assessment is divided in two parts. First is "cradle to gate", sometimes noted as "upstream", where iron ore extraction and depletion and materials processing is addressed, then parts production and gantry assembly and finally distribution is evaluated. The second stage of this assessment "gate to grave" basically consist of "use" and "downstream" phase in one. It refers to operational life of crane at port and scrapping and disposal/recycling.

The manufacturing step has been modeled as common parameter for all the three RTG cranes and is chosen to be the same. This includes the raw materials, the manufacturing processes, the energy consumption and the transport by rail and truck of the manufactured car to the end-user determent only for conventional RTG. The components which are specific to the Hybrid and E-RTG technology are modeled separately and added over results of conventional crane. For example carbon super-caps energy storage for Hybrid crane and collector trolley for E-RTG.

The "cut-off" criteria in manufacturing phase is applied, leaving out components with weight of less than 5% of the total mass of crane, thus excluding parts which contribution to overall results of this phase is insignificant.

The Functional Unit (FU) defined in this assessment, although simplified, corresponds to the use of a RTG cranes in port operations during average 5,000 working hours per annum and 15 years of lifetime. The FU is 1 working hour of container manipulation which consists of 32 percent of hoisting operations, 16 percent of spreader movement and 52 percent of crane movement across the port yard.

The work environment of RTG cranes is in accordance with GaBi software inventory base. The power grid mix is chosen to be current EU-25 (ports at EU seas). Fuel used for diesel generator set is off-road petroleum diesel with high sulfur content. The end-of-life has been modeled with respect to the state-of-the art in EU recycling plants and according to GaBi software available data. The recycling process of large steel sheet gantry construction and consumption of resources during the recycling process have been included having in consideration the dominance of steel material over others.

The LCA of three RTG cranes is carried out using state-of-the-art software GaBi developed by PE International as the most represented LCA tool on the market. A full LCA was conducted, and the necessary input/output data were determent using immense GaBi data base. Since modeling the life cycle of such a complex machine as RTG crane, certain assumptions are done to simplify the assessment. These approaches are common in order to lower the costs of LCA and eliminate data uncertainties [27], especially due to fact that study is entirely independent. The goal of study is intended solely for scientific research and therefore critical review is not necessary.

The adopted conventional structure of RTG crane with lifting capacity of 40 tonnes is shown in Figure 6. Its self weight is ca. 115 tonnes, which consist of 80 tonnes steel box gantry structure, spreader and trolley with total weight of 25 tonnes and remain weight of diesel generator set, cables and other features. This support structure is adopted for evaluation of all three analyzed solutions of RTG cranes. Adopted drive system is on board diesel generator set. It has got 600 kVA AC/DC generator with 6 cylinders, 12 liter (732 cubic inches) diesel engine with power of over 300 kW [25].

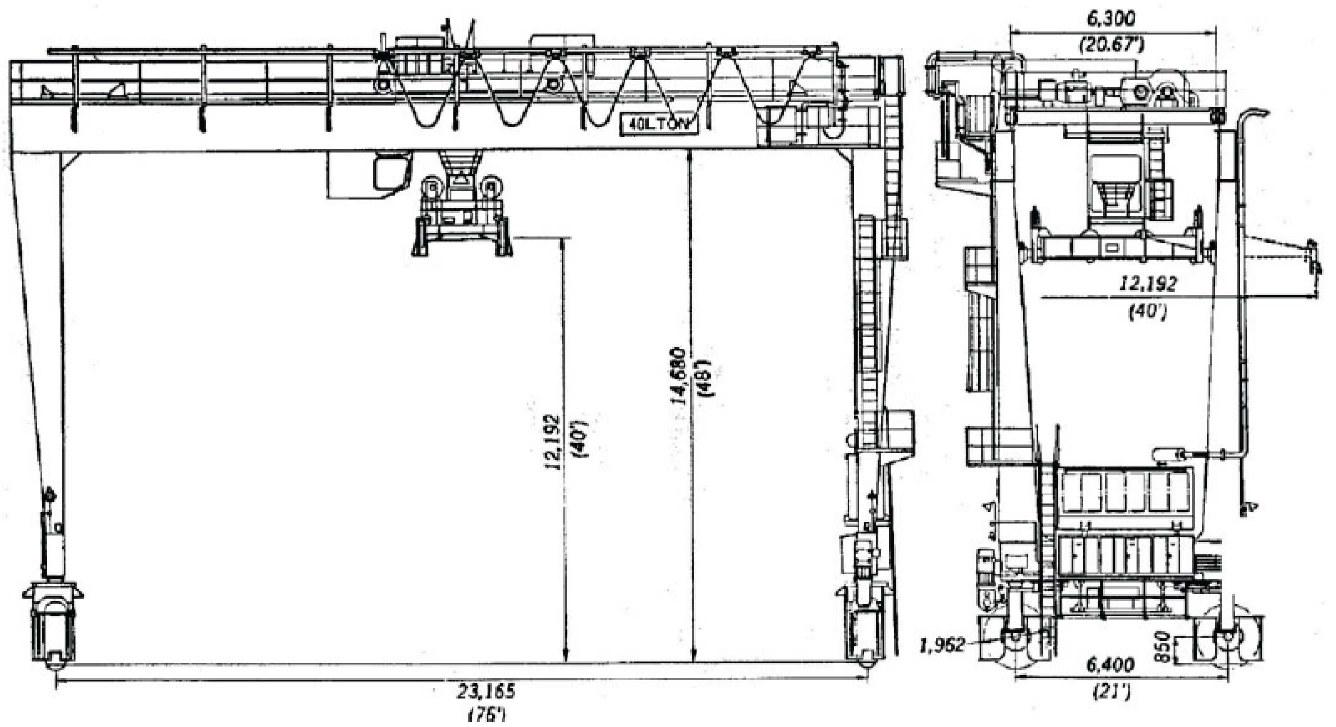


Figure 6: 40 tonnes RTG crane

The obtained results of the LCA of RTG cranes are presented in accordance to ISO 14040 principles with the highlight on two most representative impact assessment methods Dutch CML and US TRACI. The results are also divided according to system boundaries (Fig. 7): “Cradle-to-gate”, “Gate-to-grave” and finally as entire life-cycle-impact-assessment “Cradle-to-grave”. In this way, overview of footprints of “upstream” and “off-road” or operational part of life are clearly divided.

As for the most vehicles and long-life machineries (life cycle over 5 years) the use phase tends to be the most dominant one part of entire life cycle. The same applies RTG cranes. The operational life of RTG cranes spans from 15 to 30 years with engine overhauling which puts the use phase in focus since it contributes to overall results in great proportion. Environmental profile of RTG crane is given in Figure 7. Nevertheless it is important to conduct entire LCA in order to rule out significant issues that could appear in the production phase.

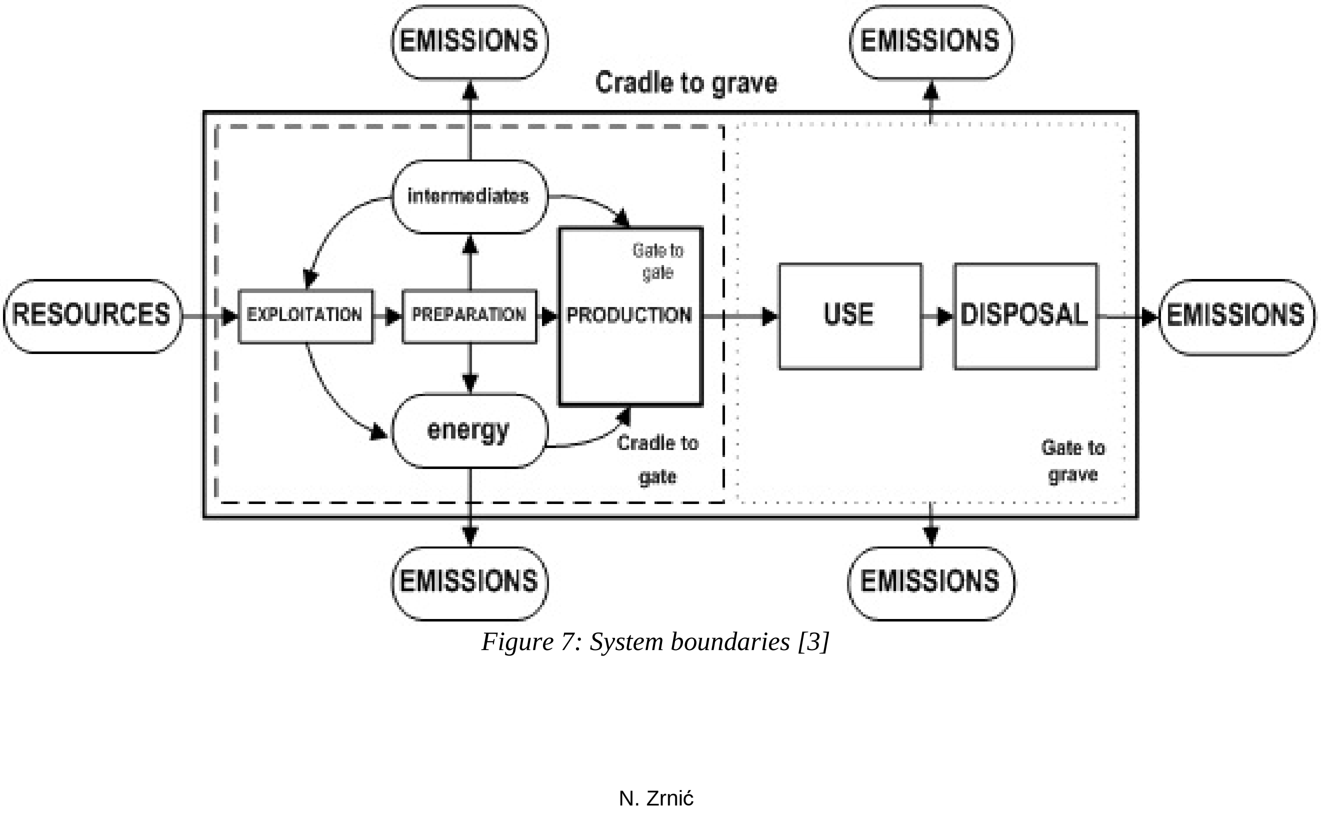


Figure 7: System boundaries [3]

Some obtained results are presented in Figures 8, 9, 10, 11 [25].

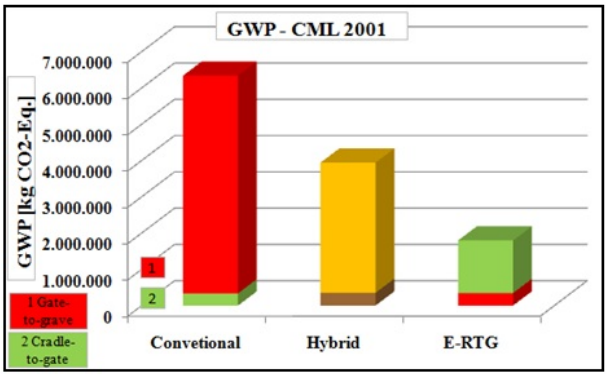


Figure 8: Global-warming-potential of RTG cranes

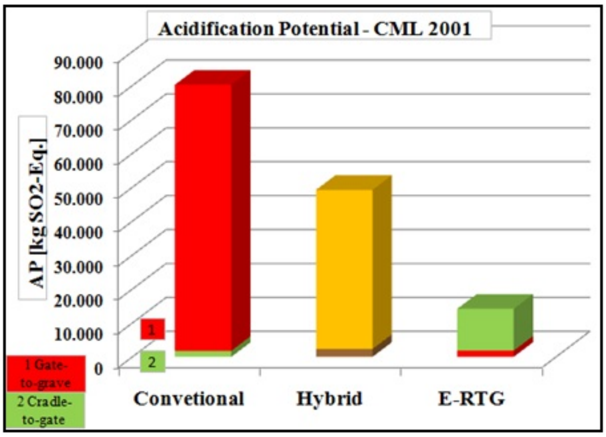


Figure 9: Acidification-potential of RTG cranes

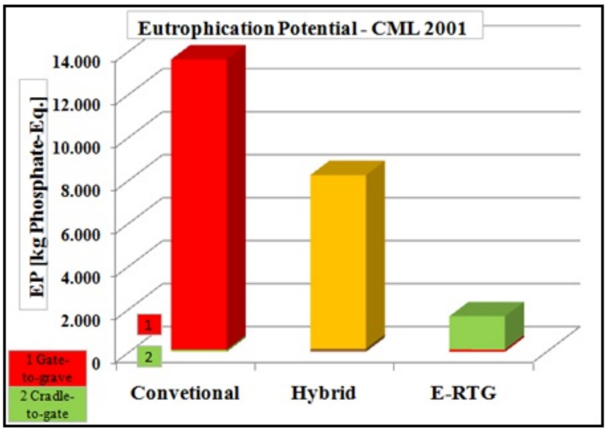


Figure 10: Eutrophication-potential of RTG cranes

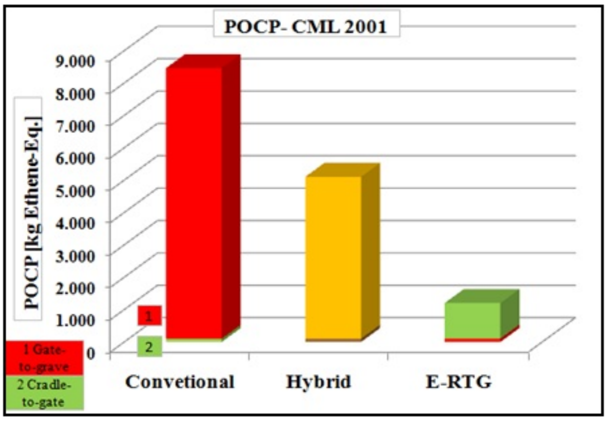


Figure 11: Photochemical-ozone-creation-potential of RTG cranes

After analyzing the results and comparison of conventional RTG with Hybrid and E-RTG, clear conclusion can be made. Today, when environmental concerns are part of almost every day discourse conventional RTG cranes are obsolete. The hybrid super-cap. systems and electrified solutions offered by CHE industry are desirable from both environmental and entrepreneurs perspective. The Hybrid and E-RTG have significant emission reduction and fuel saving potentials and their introduction in to the port operations has almost no environmental downside.

In this way emerging CHE technology for RTG cranes could settle environmental concerns of port authorities without jeopardizing everyday container handlings and at the same time lower operational and maintenance costs in long term.

3.2. Examples of UTRs [13]

The UTRs are heavy-duty off-road single cab vehicles designed for towing trailers with containers in terminals. They are by far the most common type of CHE used at container terminals, especially in North America and often cover over 50% of the total CHE population. In typical operations at container terminal UTRs support almost every CHE for swift ferrying of the containers across the terminal [13].

The duty cycle of UTR consist of long idling periods and stop and go movements with high or low load accelerations. This results in inefficient operation of diesel engine and significant air emission and noise pollution. Based on some annual port emission reports and available air emissions inventories, it is stated that UTRs contribute with half of entire terminal carbon and particulate matter (PM) emissions associated by CHE. This is due to the fact that currently, conventional UTRs are fitted internal combustion engine (ICE) with fuel consumption reaching average of up to 10 liters per hour [28].

Despite major advances in technologies improving vehicles environmental performance (especially in automotive industry), the application of diesel alternatives for off-road vehicles is still in "baby steps". Several solutions are being on and off recognized as top contenders for making mainstream application. From the alternative fuels to powertrain variations the corresponding industries forced by policy makers and environmentally concerned public are actively pursuing a pathway to mitigate emissions. Based on market success of hybrid passenger vehicles and re-emerging electric vehicles, the heavy duty off-road manufacturers are exploiting the potential of well understood technology that can be integrated with UTRs. The transition from ICE to broad use of zero (electric) and near zero emission (hybrid) is the most governed solution at present and seams as the most feasible.

The hybrid solutions for yard tracks exploit the random duty cycle in order to improve the overall efficiency of diesel engine. In a UTR equipped with a diesel hybrid drive system, the engine is shut down during idling periods and regenerative braking allows kinetic energy normally wasted during braking to be captured by the hybrid energy storage system, subsequently improving fuel efficiency and lowering emissions. There are two hybrid systems available for UTRs, which defer only in concept of kinetic energy storage. The first is electric hybrid system which endorse battery storage solution, while second is based on hydraulic high pressure accumulator energy storage.

The diesel electric hybrid UTR uses basically the same hybrid technology proven in on-road hybrid vehicles. The battery pack (most common is lithium-ion) or ultra capacitor is used to store kinetic energy when decelerating or braking. Stored energy is later used for to assist ICE during acceleration, or for short distance zero emissions movement in battery mode. The latest evolution of electric hybrid UTRs is plug-in hybrid with additional option of battery recharging at grid. With this feature diesel generator set could be used as range-extender enabling downsizing of ICE.

The hydraulic hybrid UTR is alternative for electric hybrid truck often criticized for battery fallibility and hazards potential. The hydraulic hybrid system uses high accumulator and low pressure reservoir filled with hydraulic fluid and nitrogen (N_2) to capture kinetic energy. During vehicle braking, the rotating energy of the wheels is used to pump fluid from the low pressure reservoir into the high pressure accumulator where nitrogen is compressed. Up to 70% of the kinetic energy stored can be reused for vehicle acceleration. The system can also be equipped with start-stop feature enabling engine shut down to eliminate idling.

One of the latest trends in CHE industry is fully electric UTR, advertised as zero-emission equipment since it has no “tail-pipe” emissions. This system uses electric motor and battery storage system (lead, nickel or lithium-ion battery packs). The electric UTR range is from 80 km to 150 km, depending on battery pack size which is up to 300 kWh. Overall autonomy is sufficient for two shift operations. The overall success of electric UTR concept in making mainstream is linked to outlook of battery development for electric vehicles.

In order to straightforward the LCA comparison having in concern its goal and scope and intended purpose, certain simplifications and assumptions are made. These are done relating to duty cycles of UTRs and dock side operation experience avoiding data uncertainties. Therefore conventional diesel model UTR is determent as base models, while other three: hydraulic hybrid, electric hybrid and full electric cover use over 98% of the same construction and components (chassis, wheels, diesel engine, cabin, interior features). Adopting this modeling principle most of inventory base of conventional diesel UTR can be used for creation of inventory base of hybrid and electric models.

The size of selected conventional UTR, set for a base model for LCA study is the same as for hybrids and electric, and the dimensions are presented in Fig. 12. The net weight is 7 tonnes and gross combined weight is 40 tonnes. The powertrain variations are shown in Table 1.

The Functional Unit (FU) is also defined according to the LCA practice. The FU for the UTR is defined as one operating hour at container terminal (yard work), where 40% of a time is spent in idling, 35% of time is related to lower load and 25% with high load. The annual operation time for UTRs in this LCA comparison is 2,500 working hours. The life cycle is 10 years. The fuel consumption of selected models is calculated based on LCA software inventory and checked with reports from [28].

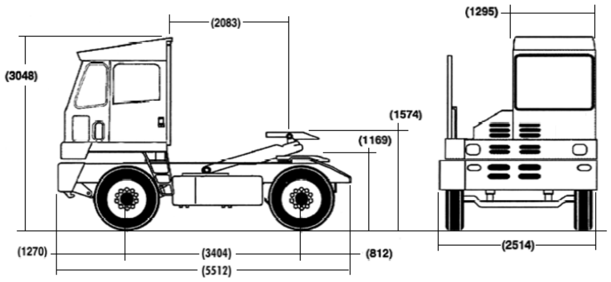


Figure 12: Base model of a UTR with dimensions in millimeters [13]

Table 1: Powertrain variations of compared UTR models [13]

Powertrain	Feature	Conventional diesel	Hydraulic hybrid	Electric hybrid	Full electric
Diesel engine	Size	6.7 l	6.7 l	6.7 l	-
	Power	150 kW	150 kW	150 kW	-
Battery	Capacity	-	-	5 kWh	150 kWh
Electric motor	Power	-	-	80 kW	140 kW
	Voltage	-	-	150 V	230 V
Hydraulic system	Pressure	-	400 bar	-	-
	Power	-	160 kW	-	-
Reservoir	Capacity	-	0.5 kWh	-	-

The results conducted assessment are classified and characterized in accordance with ISO 14040. For the comparative LCA the most significant impacts are evaluated and presented via life cycle impact assessment (LCIA) problem-orientated method developed by Institute of Environmental Sciences from Leiden (CML 2001) and damage orientated Swiss method Ecoinvent.

The “upstream” stage illustrates significant differences between UTRs equipped with diesel engine and electric motor. The environmental impact of lithium-ion battery pack production is much greater than of conventional diesel engine. The global warming potential (GWP) of 150 kWh battery pack selected for electric UTR model is approx. 40,000 kg of CO_2 equivalent, which is twenty times larger than GWP of 6.7 liter diesel engine. This ratio is an “issue” that determents the “upstream” stage.

The results of “use” stage reveal lesser environmental impact of electric UTR over other three models. This is due to selected EU-25 power grid mix with average of 0.539 kg of CO_2 eq. per kWh. Other power grid mix scenarios could influence results of electric UTR in both directions. The two hybrids show certain reduction of environmental impact in range of 20% over conventional, but in small favor of hydraulic due to burden of electric hybrid’s batteries impact.

The “end of life” stage is again influenced with lithium-ion batteries of electric UTR, while conventional and hybrid versions share near the same results. The additional abbreviations used in Table 2 are: acidification potential (AP), eutrophication potential (EP), phosphate (Ph.) and radioactive waste (RW).

Table 2: LCIA of UTRs in kg (CML 2001- problem method)

UTR	**Impact**	**Upstream**	**Use**	**End of life**	**Total**
Conventional diesel	**GWP [CO_2 eq]**	35,850	499,152	247	**535,249**
	AP [SO_2 eq]	192	6,508	1	**6,701**
	EP [Ph. eq]	9	1.201	0,06	**1,210**
	RW	117	0	0.8	**118**
Hydraulic hybrid	**GWP [CO_2 eq]**	38,880	432,126	265	**471,271**
	AP [SO_2 eq]	210	5,647	1.00	**5,859**
	EP [Ph. eq]	9	973	0.06	**982**
	RW	135	0	0.9	**136**
Electric hybrid	**GWP [CO_2 eq]**	43,135	438,101	1,239	**482,475**
	AP [SO_2 eq]	278	5,725	1	**6,009**
	EP [Ph. eq]	14	986	1	**1,001**
	RW	140	0	0.33	**140**
Full electric	**GWP [CO_2 eq]**	68,025	269,500	4,950	**342,475**
	AP [SO_2 eq]	361	1,430	3	**1,817**
	EP [Ph. eq]	25	65	4	**94**
	RW	221	875	1	**1,097**

Table 3: LCIA of UTRs (Ecoinvent - damage method)

Life cycle impact [units]	**Conventional diesel**	**Hydraulic hybrid**	**Electric hybrid**	**Full electric**
Acidification [PDF*m^2*a]	828,521.00	688,122.00	715,401.00	542,485.00
Ecotoxicity [PDF*m^2*a]	1,173	963.38	990.59	698.44
Climate Change [DALY]	16.00	13.63	13.86	9.26
Respiratory (inorganic) [DALY]	0.95	0.97	1.27	2.00
Respiratory (organic) [DALY]	0.07	0.05	0.06	0.04

The comparative LCA of different UTR concepts reveals limitations of application of electric-diesel hybrid technology for off-road vehicles in terms of environmental benefits. On the other side, the results promote full electric UTR as cleaner solution if the right power grid mix is selected. However, the hydraulic-diesel hybrid could turn out as more simple near future alternative, if the battery technology goes to a standstill. The presented example illustrates importance of life cycle thinking for decision making and identifying the drawbacks of technologies promoted as solutions to mitigate environmental impacts.

4. SIMPLIFIED LCA OF BELT CONVEYORS

Belt conveyors belong to the class of high performance machines (HPMs) and present also the backbone of surface mining and conveying systems [29]. Up to now several researches related to environmental effects, such as LCA studies [30] and energy efficiency issues have been conducted [31].

Previous researches in the Laboratory of ecodesign and logistics at the FME Belgrade were focused on investigation of environmental properties of belt conveyors on BWEs and similar types. It is based on simplified LCA of SRs 1201 BWE's belt conveyor and its components, which is a part of an ECS system. Each one of simplified LCAs, presented in scientific papers [32], [33], [34] and [35] was conducted with Ecodesign Assistant (EA) and Ecodesign PILOT (EP) software tools [36], [4]. In addition to the conducted simplified analysis of the complete belt conveyor and its main components, three more simplified analyses were conducted in order to verify previously obtained results. These analyses included simplified LCA of ball bearing 6310 C3, belt conveyor gearbox BKF 320 and conveyor belting. Analysis of belting is conducted for the second time with more accurate data, obtained from the manufacturer. However, this analysis has shown the same result as the one previously obtained and published in [34].

Unlike formal LCA with energy values where absolute numbers are derived, the Ecodesign Assistant (EA) and Ecodesign PILOT (EP) only calculate relative environmental impacts by comparing the occurring impacts of the different life cycle stages of the product [4]. In that way EA and EP define basic type of a product which is determined with the most significant stage of its life cycle. Relative to life cycle stages, there are 5 basic types of the product:

- Basic type A - raw material intensive product,
- Basic type B - manufacture intensive product,
- Basic type C - transportation intensive product,
- Basic type D - use intensive product and
- Basic type E - disposal intensive product.

Analysis of the BWE's belt conveyor, which is 8.3 m long, with 1.6 m wide belting and throughput of 3,465 m^3/h of brown coal was presented in [37].

In accordance with its throughput the functional unit of the belt conveyor is determined as: "Transportation of 3,465 m^3/h of brown coal". Functional unit is used for normalization of total energy, materials and emissions. In such way different conveyors with the same throughput of brown coal can be compared. Moreover, results of such comparison can lead to improvement of design of short conveyors from the environmental point of view or choosing adequate type of conveyor for required purpose (perhaps change in concept or some other changes).

Minimum service life of a belt conveyor is expected to be 5 years. It is calculated in accordance with l10 bearing service life. Actual life span of a belt conveyor is considerably longer and it equals 25 to 30 years. Therefore, ball bearings are to be replaced at least 5 to 6 times during the conveyor lifetime. Gearbox oil is changed on a yearly basis. Most of the data are taken from previous partial analyses and implemented into the analysis presented in [38].

For the purpose of the presented analysis, the belt conveyor is divided into five main groups of parts as presented in [38], see Figure 13 [37]:

1. Idlers/rollers,
2. Pulleys,
3. Belting,
4. Electric motor (EM),
5. Other.

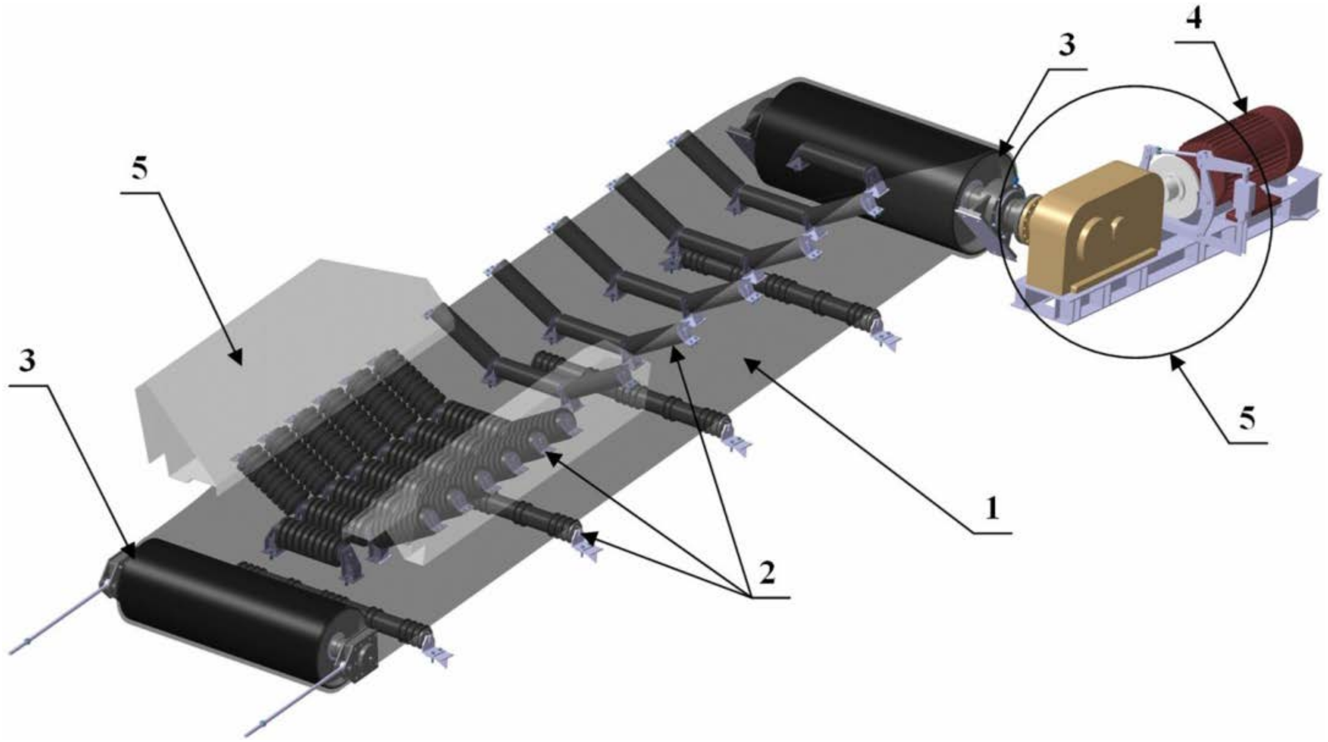


Figure 13: Main components of a conveyor: 1. belting, 2. idlers/rollers, 3. pulleys, 4. electric motor, 5. other

Group of parts named "other" consists of belt conveyor drive components (without EM), take up device and accessories. Drive components considered here are gearbox unit, coupling and drum brake, see Figure 14 [37]. Take-up device is not considered within the analysis because of the lack of data. Normally, take-up device could be considered as component that:

1. Consumes electric or other kind of energy,
2. Does not consume energy.

In case that take-up device consumes energy, the type and amount of consumed energy per use should be calculated and added to the total energy consumed by the belt conveyor in its use stage. In the second case, take-up device is considered a part predominantly made of steel which is produced by machining. Generated waste during the production stage of take-up device is assumed to be 10% of its mass. The second case will be used as a pattern for modelling parts and components predominantly made of single material and do not consume energy.

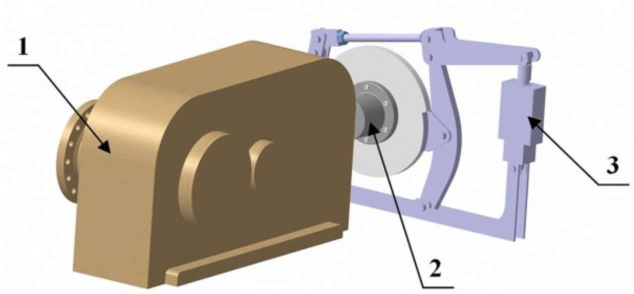


Figure 14: Belt conveyor drive components: 1. gearbox, 2. coupling, 3. drum brake

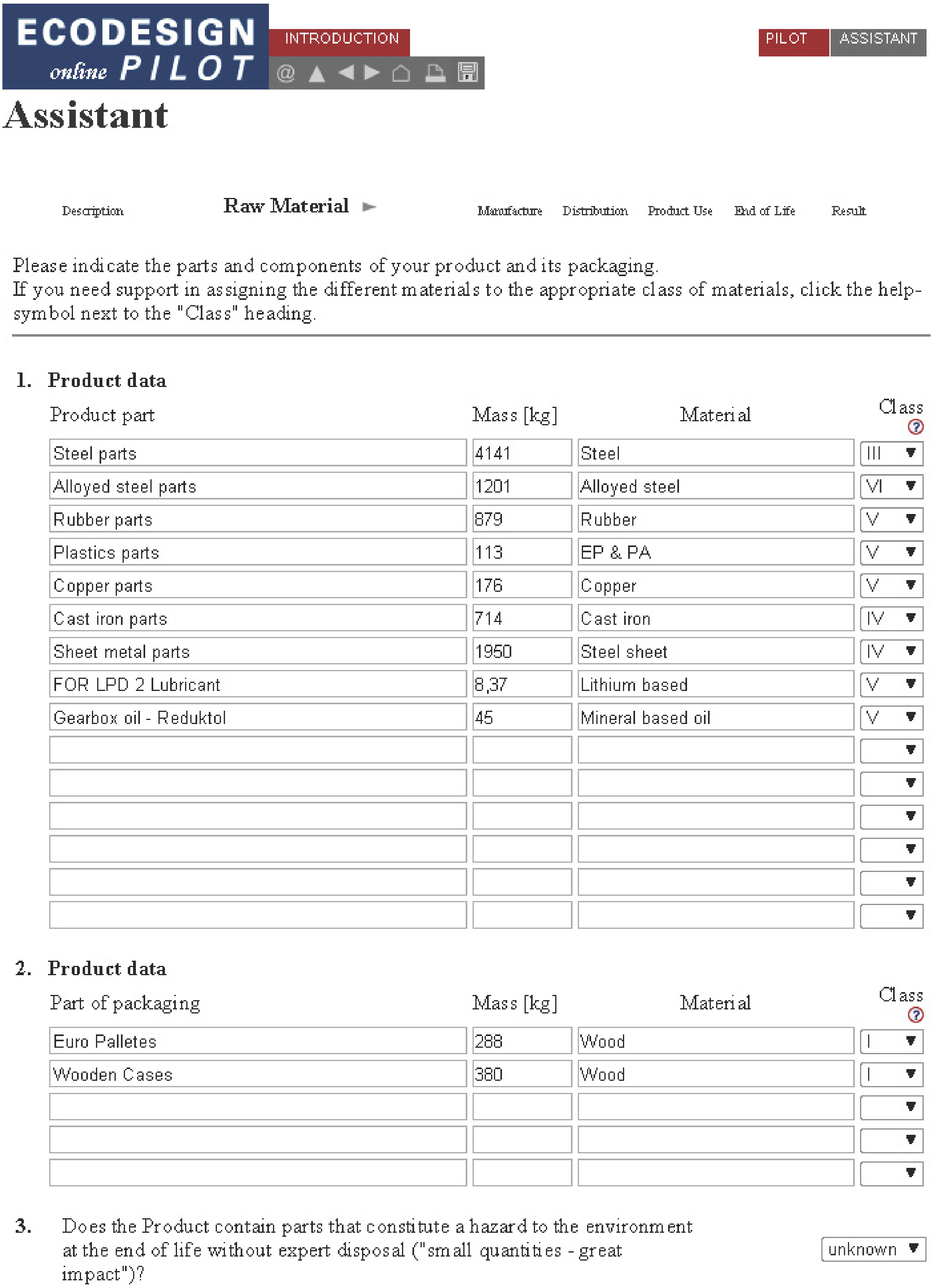
Parts and components which belong to the accessories are analyzed the same way as the take-up device. The only component from this group of parts considered here is chute. During the analysis, the belt conveyor is divided into 5 groups of parts. These 5 groups are further classified in accordance with their constituent materials. This classification is presented in Table 4 and summarized in Figure 15 [38].

Table 3: LCIA of UTRs (Ecoinvent - damage method)

Group of parts	**Pieces**	**Weight/piece [kg]**	**Weight [kg]**	**Material**	**Class**	**Scrap [kg]**
1. Rollers						
Steel parts	47 rollers	27.8	1,307.0	Steel	III	10% = 130.7
Rubber parts	31 rollers	6.2	192.0	Rubber	IV	10% = 19.2
Lubricating grease:						
considered in raw material stage			7.52	Li-based oil	V	
considered in use stage			0.023 kg/use		V	
2. Pulleys						
Steel parts	1.5	1,252.0	1,878.0	Steel	III	10% = 187.8
Alloyed steel parts	1.5	751.3	1,127.0	Alloyed steel	VI	10% = 112.7
Rubber parts	1.5	157.37	236.0	Rubber	IV	10% = 23.6
Lubricating grease:						
considered in raw material stage			4.095	Li-based oil	V	
considered in use stage			0.013 kg/use		V	
3. Belting						
Carcass	1	112.64	112.64	EP & PA	V	10% = 11.3
Covers	1	450.56	450.56	Rubber	IV	10% = 45.1
4. Electric motor						
Windings and bars	1	176.0	176.0	Copper	V	10% = 17.6
Housing	1	264.0	264.0	Cast iron	IV	10% = 26.4
Steel parts	1	440.0	440.0	Steel	III	10% = 44.0
5. Other						
5.1 Gearbox	1		900.0			
Casing	1	450.0	450.0	Cast iron	IV	10% = 45.0
Flange	1	74.0	74.0	Alloyed steel	VI	10% = 7.4
Steel parts	1	376.0	376.0	Steel	III	10% = 37.6
Lubricating oil:						
considered in raw material stage			50 l ≈ 45 kg	Mineral oil	V	
considered in use stage			0.144 kg/use		V	
5.2 Coupling	1	20.0	20.0	Steel	III	≈50% = 10.0
5.3 Drum brake	1	120.0	120.0	Steel	III	10% = 12.0
5.4 Chute	1	1,950.0	1,950.0	Steel sheet	IV	10% = 195.0

In accordance with the "cut-off" rule, parts with mass inclusion lower than 5% of total mass of the product have been neglected. In this case, since there were partial analyses conducted, "the product" stands for components of the belt conveyor presented in papers [32], [33], [34], [35] and summarized in paper [38]. "Cut-off" rule based on energy inclusion gives similar results.

Lubricants can be considered either within raw material stage or within use stage. Regardless of which of these two options are chosen, the result remains the same. Besides the belt conveyor parts, packaging and packaging material are taken into account as presented in [38]. Total energy input and generated waste during the manufacturing of the belt conveyor are obtained from [38] and shown in Figure 16. Data from the manufacturing stage form for initial iteration are shown in Figure 16. The initial iteration presents the worst case scenario and basis for further optimization of environmental properties of the belt conveyor. The belt conveyor, as a part of BWE, is utilized at the open pit mine near Lazarevac. Most of the belt conveyor components are supplied from the manufacturer in the proximity to the open pit mine. Calculated hauling distance for transportation of external parts by truck was 1,865 km. In accordance with [37], this distance can be classified as "rather short". The drum brake is transported from the greatest distance (approximately 1,500 km) and it is considerably affecting total transportation distance [38].



Assistant

Please indicate the parts and components of your product and its packaging.
If you need support in assigning the different materials to the appropriate class of materials, click the help-symbol next to the "Class" heading.

1. Product data

Product part	Mass [kg]	Material	Class
Steel parts	4141	Steel	III
Alloyed steel parts	1201	Alloyed steel	VI
Rubber parts	879	Rubber	V
Plastics parts	113	EP & PA	V
Copper parts	176	Copper	V
Cast iron parts	714	Cast iron	IV
Sheet metal parts	1950	Steel sheet	IV
FOR LPD 2 Lubricant	8,37	Lithium based	V
Gearbox oil - Reduktol	45	Mineral based oil	V

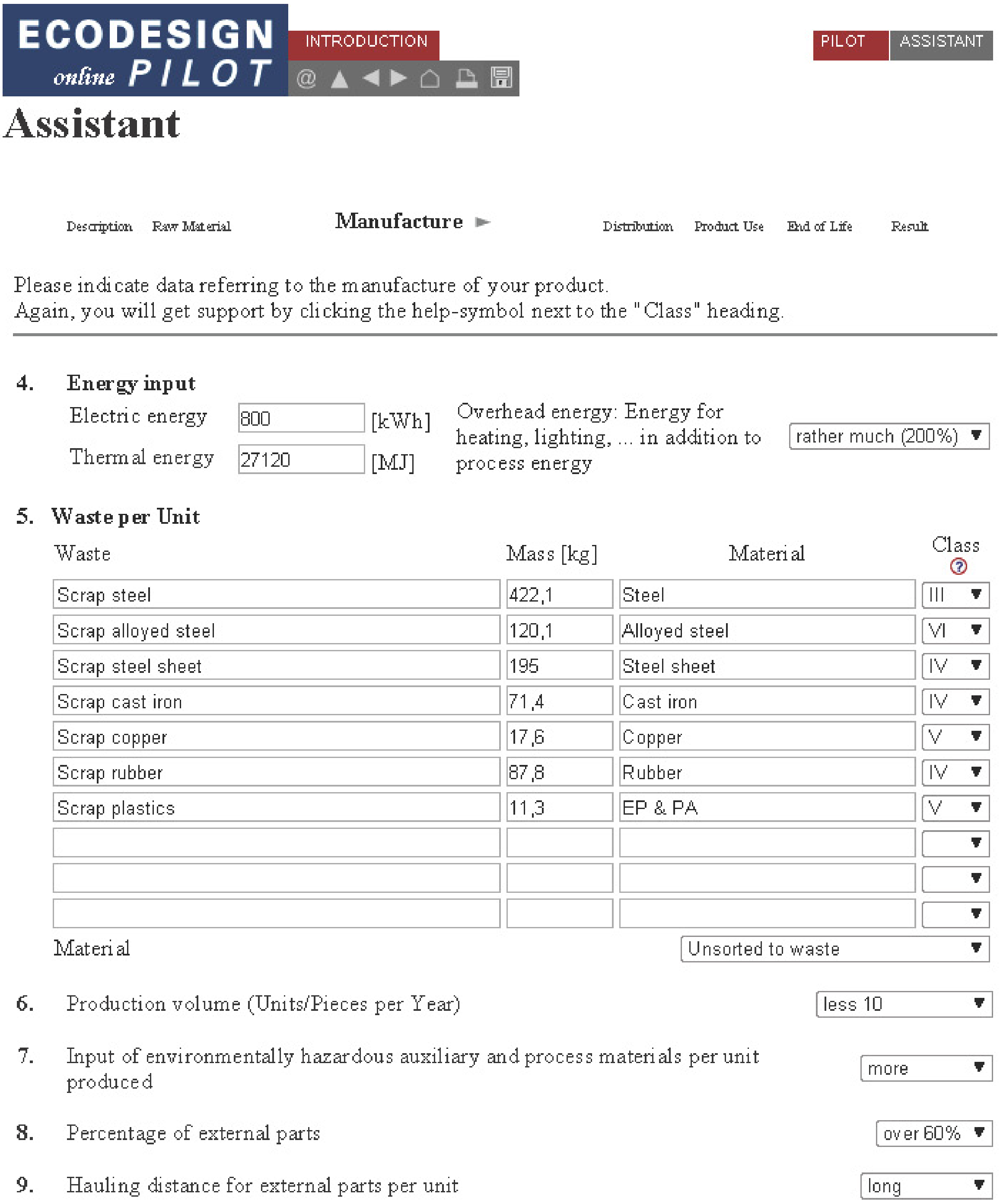
2. Product data

Part of packaging	Mass [kg]	Material	Class
Euro Palletes	288	Wood	I
Wooden Cases	380	Wood	I

3. Does the Product contain parts that constitute a hazard to the environment at the end of life without expert disposal ("small quantities - great impact")? unknown

Figure 15: Raw material stage form with lubricants considered within it [38]

The use stage is determined with the number of operating hours per day and consumption of electricity and auxiliary material. The belt conveyor operates 20 hours per day 325 days a year. It is assumed that one use equals one working day. The belt conveyor consumes 2.64 MWh/use, but due to software limitations this value is set to 1.0 MWh/use. However, this fact does not affect the result. Besides the electricity consumption, the belt conveyor needs lubrication for its proper operation. Lubrication could be considered either in this stage or in raw material stage. In case of lubricating the belt conveyor in use stage there is a need for 0.036 kg/use of FOR LPD 2 lubricating oil for ball bearings and 0.144 kg/use of Reduktol oil for gearbox unit. As previously stated, both options give the same result [38].



Assistant

Please indicate data referring to the manufacture of your product.
Again, you will get support by clicking the help-symbol next to the "Class" heading.

4. Energy input
Electric energy 800 [kWh]
Thermal energy 27120 [MJ]
Overhead energy: Energy for heating, lighting, ... in addition to process energy: rather much (200%)

5. Waste per Unit

Waste	Mass [kg]	Material	Class
Scrap steel	422,1	Steel	III
Scrap alloyed steel	120,1	Alloyed steel	VI
Scrap steel sheet	195	Steel sheet	IV
Scrap cast iron	71,4	Cast iron	IV
Scrap copper	17,6	Copper	V
Scrap rubber	87,8	Rubber	IV
Scrap plastics	11,3	EP & PA	V

Material: Unsorted to waste

6. Production volume (Units/Pieces per Year): less 10

7. Input of environmentally hazardous auxiliary and process materials per unit produced: more

8. Percentage of external parts: over 60%

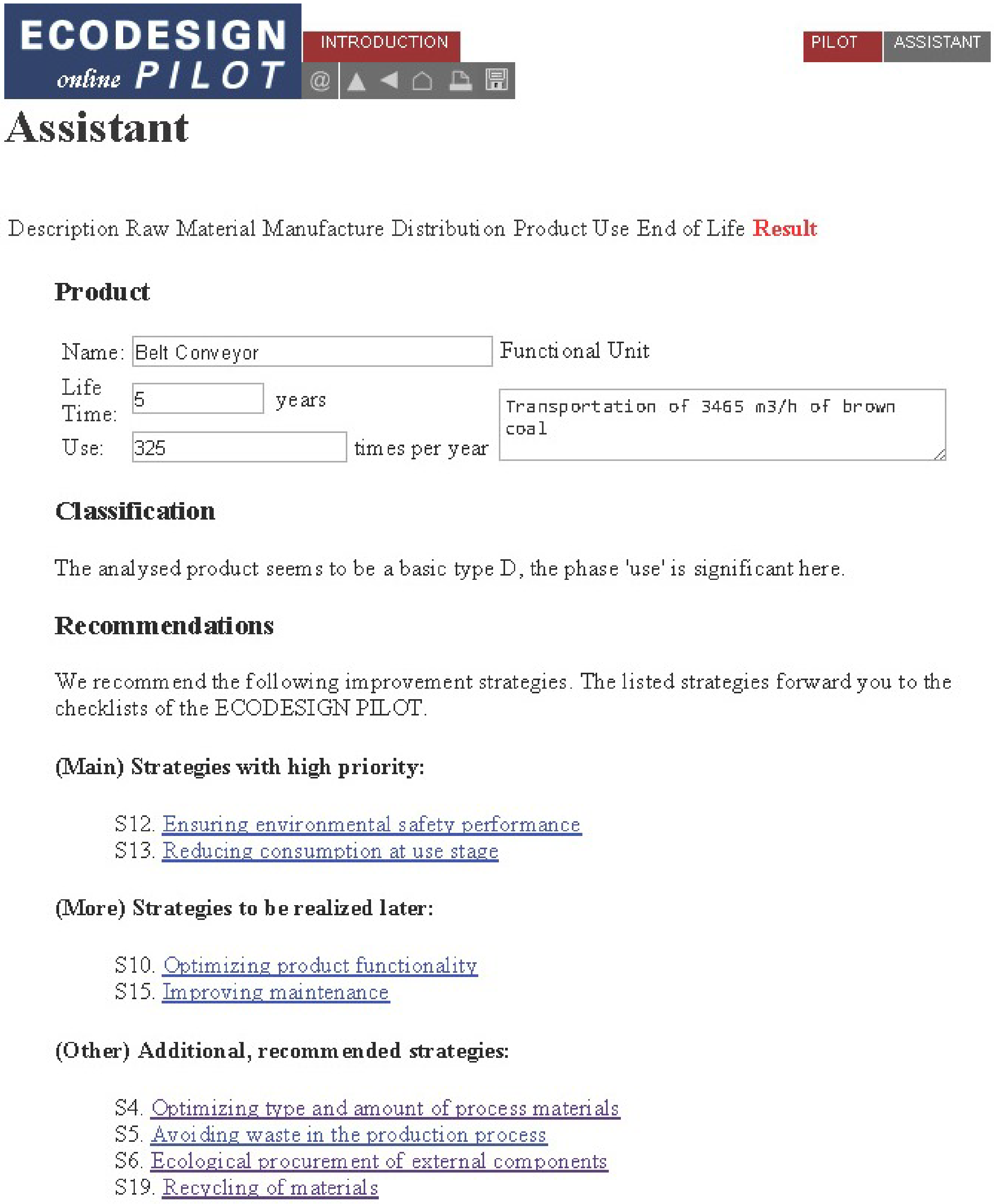
9. Hauling distance for external parts per unit: long

Figure 16: Manufacturing stage form for initial iteration [38]

Spare parts and their consumption were not considered during the analysis presented in [38]. This fact will certainly affect the increasing consumption of auxiliary material in the use stage. However, this will not change the result since use stage already has the greatest impact to the environment in accordance with [38]. Spare parts and their consumption affect more the maintenance strategy and service intervals.

The first iteration assumed the worst case scenario for EoL options also. All of the belt conveyor components are disposed of in a landfill. When lubricants are considered as a parts in raw material stage, at the EoL stage there has to be chosen the way of their disposal.

Finally, it was concluded that the belt conveyor is a D-type product [37]. Initial iteration is conducted in a way that results in maximum environmental load. Result of initial iteration is initial result, and it serves as a basis for further environmental improvements of the belt conveyor, refer to Figure 17. Further optimizations of environmental properties of the belt conveyor are described in [38]. Regardless of variations in input parameter values through iterations the belt conveyor remained use intensive product. Strategy S13 remained the strategy with the highest priority (main), while strategies S10, S12 and S15 had been assigned to the strategies that are to be realized latter (more) and all other strategies disappeared from recommendations due to proper optimization of input parameters that already involved their implementation.



Assistant

Product

Name: Belt Conveyor

Life Time: 5 years

Use: 325 times per year

Functional Unit: Transportation of 3465 m3/h of brown coal

Classification

The analysed product seems to be a basic type D, the phase 'use' is significant here.

Recommendations

We recommend the following improvement strategies. The listed strategies forward you to the checklists of the ECODESIGN PILOT.

(Main) Strategies with high priority:

S12. Ensuring environmental safety performance
S13. Reducing consumption at use stage

(More) Strategies to be realized later:

S10. Optimizing product functionality
S15. Improving maintenance

(Other) Additional, recommended strategies:

S4. Optimizing type and amount of process materials
S5. Avoiding waste in the production process
S6. Ecological procurement of external components
S19. Recycling of materials

Figure 17: The result of the first iteration - initial result [38]

In compliance with previously conducted researches and related published papers it can be said that:

- Since EM is a belt conveyor component that contributes most to electricity consumption, just increase in its energy efficiency delivers the greatest reduction of environmental impact,
- Adequate maintenance strategy and similar service intervals for different components of the belt conveyor ensure reduction of overhauling time,
- Reliability of the belt conveyor is largely dependent on selected maintenance strategy,

- Improving functional quality increases reliability, improves maintenance and reduces consumption,
- Replacement of process and auxiliary materials, especially lubricants, with renewables contributes to reduction of environmental impact of the product,
- Lubricants are marked as hazardous waste and they have to be treated in a proper manner at the EoL; possible improvements related to lubricant characteristics will be considered later,
- In-house recycling eliminates transportation needed in case of external recycling or disposal,
- Regionally available parts and materials reduce need for transportation,
- Production volume does not affect the result,
- Number of external components has greater impact than their hauling distance,
- Steel parts are recycled (this applies particularly to the rollers),
- Any EoL option for packaging does not affect the result, but it is likely that the euro pallets are reused and the wooden cases are disposed of in a landfill.

The listed issues with corresponding recommendations have been thoroughly further elaborated in [37].

CONCLUSIONS

Among all other aspects intralogistics is related to material handling and conveying technologies and equipment. Consequently, investigations and research of potential improvements of environmental properties of intralogistics equipment, especially energy efficiency, has great impact on future trends in intralogistics. Development of innovative technologies is strategically focused on improving environmental performances and reducing emissions. Therefore, it would be recommendable to prove the real environmental benefits of newly established innovative technologies. The presented researches conducted in the recent years at the Faculty of Mechanical Engineering in Belgrade are related to cargo handling equipment and belt conveyors. The presented examples illustrate importance of life cycle thinking for decision making and identifying the drawbacks of technologies promoted as solutions to mitigate environmental impacts.

The efforts of CHE industry in providing ports and container terminals with environmentally more efficient technologies are becoming more visible than ever. Almost every piece of CHE today is offered with some solution for reduction of emissions and energy consumption, from alternative fuels and hybrid technology, to promising "zero emission" concept. The "zero emission" concept applied on RTG crane and UTR as core of CHE is investigated in the presented researches using LCA methodology. The LCA proved itself as a valuable tool for comparison of even such complex products as the CHE. It offers systematic approach for sustainability evaluations of life cycles of conventional and novel technologies. However, in order to avoid any major data inventory uncertainties often pointed out by LCA critics, the random comparison of onsite measurements results with functional unit assumptions is recommended.

The entire life cycles of conventional diesel RTG crane and UTR were compared with electric ones in order to reveal any sustainability sensitivities that are common with energy source transitions. In this respect, the results of LCA present electrification of CHE as a feasible and sustainable solution aimed to mitigate environmental impact of ports. The transition from diesel to electric handling equipment is a step forward, although "zero emission" operations from LCA perspective are impossible to be achieved.

The fact that selection of power grid mix can, due to nature of LCA, provide completely different results, a short "what if" analysis was conducted in [26]. In order not to overextend the comparison of data, only GWP is taken into account. The calculation for replacement of lithium ion battery pack of electric UTR after 5 years is also shown in Figure 18 [26]. The assumptions made, for instance, for comparison of environmental impacts of UTRs are:

- Electric 1 refers to result from LCA, without battery change and EU-25 power grid mix with GWP of 0.539 kg of CO_2 eq. per kWh;
- Electric 2, same as above with battery replacement (disposal of old batteries and entire life cycle of new batteries);
- Electric 3 – For this UTR, the power grid mix is adopted to be the world average with GWP of 0.749 kg of CO_2 eq. per kWh; the battery replacement is also taken into account.
- Electric 4 – The power grid mix is an average GWP for coal power plant approximated to 1 kg of CO_2 eq. per KWh;
- Diesel – results from LCA study.

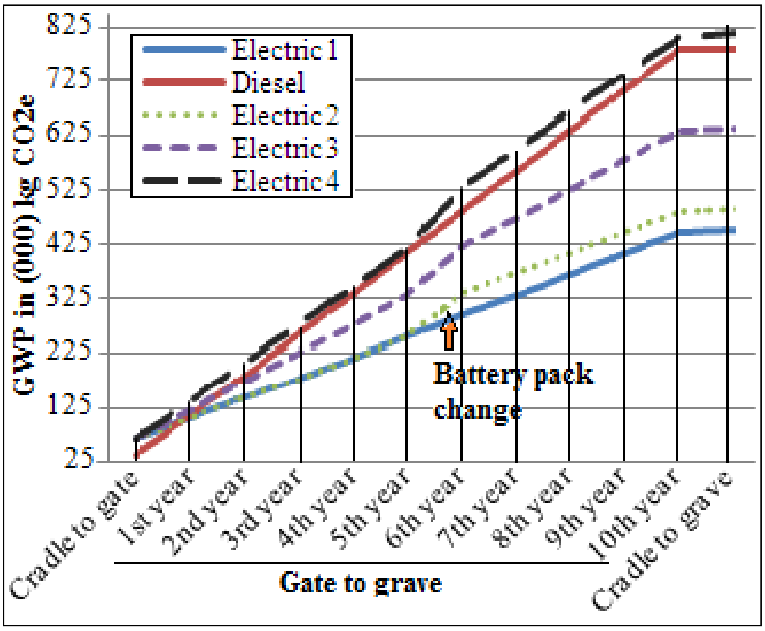


Figure 18: LCA of UTRs depending on power grid mix [26]

Analysis shows that electric over diesel UTR has lower GWP only up to the level of 0.9 kg of CO_2 eq. per kWh of electric energy. In the case of coal burning power plants, the emissions of conventional diesel UTR are only replaced with similar level of GWP of electric UTR. If the additional environmental impact of battery replacement is taken into account, as with case of presented electric UTR no. 4, the overall results are actually worse than conventional diesel burning UTR [26].

If we speak about the conducted simplified LCA analysis of a complete belt conveyor presented in [37], it shown that the most significant stage of a BWE belt conveyor life cycle is its use stage. Besides EM, consumption of the belt conveyor is determined with different kind of resistances to motion. Improving EM efficiency together with reduction of these resistances contributes to minimization of electricity consumption, reduction of wear of moving parts such as belting surface, prolonging of belt conveyor's life and consequently to sustainable development in general.

Further and deeper research should consider generalization which should include:

- most common types of idlers/rollers, normalized by their length and diameter;
- pulleys with different kinds of coatings, normalized by their length and diameter;
- steel cord beltings and beltings with textile reinforcing plies, normalized by their unit of length, belt width and reinforcing plies (in case of beltings with textile reinforcing plies, normalization should be done in accordance with number of reinforcing plies and in case of steel cord beltings, normalization should be done in accordance with steel cord diameter), establishment of relation between power and weight of EM and normalization of EM in accordance with its power.

The idea of this simplified LCA was to implement further the gained generalizations into formal LCA, which will be conducted with corresponding LCA software.

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