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Environmental Profile Assessment of Passenger Car Components

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ABSTRACT
A comprehensive, high-quality product offered in the network of automotive suppliers must meet increasingly stringent environmental criteria and standards. The assessment of the environmental quality of a product must cover all stages of its life cycle, from 'cradle to cradle', and must result in an improvement in the producer's environmental performance. The paper identified, analysed and evaluated the environmental aspects, impacts and risks of individual phases of the production components life cycle of a passenger car, bumper, fender, and door. In the evaluation phase, progressive environmental management tools, LCA and the eco-indicator method were used in the case studies. Their combination for individual components created a methodological procedure that can be used to evaluate the environmental profile of other components of cars and other products in general.

Keywords: environmental life cycle profile, car components, environmental aspect, eco-indicator, impact assessment, LCA method.

INTRODUCTION

In order to ensure green economic growth, systematically coordinated action is needed at national, European and global levels, guaranteeing sustainable development not only in general but also in car production. By using the right tools to support green growth, it is possible to face the environmental threats facing humanity today while maintaining economic growth. However, to make progress, it is essential to innovate and environmentalize industrial processes, products and business practices. Sustainable progress is a condition for the implementation and widespread use of environmental innovations, environmentally sound materials, technologies and products as such.

The automotive industry is a separate sector that, as a supplier of commercial goods and common technologies used in various industries, acts as an integrative link, causing a domino effect in many European industries. It is a key innovative industry, which is why the European environmental policy must consider it a strategic sector. The design, development and innovation of cars at all stages of the life cycle, as a whole and in components, must be carried out in such a way that the product as a whole meets the requirements of the best available techniques and technologies (BAT) and best environmental management practices (BEMP).

MATERIALS AND METHODS

Progressive methodological tools for environmental profile assessment include ecodesign – environmental designing and usage of products. The application of its tools enables the achievement and promotion of strategic development goals.

The exact definition of the term "ecodesign tools" has not yet been established and various authors explain it in different ways with larger or smaller deviations – see. e.g. Stevels, Yawood and Eagan, Caluwe, Muransky. It seems that the most suitable but indirect explanation is given by Caluwe. Either he considers eco-design tools as the software or non-software tools, the importance of which lies in the analysis and improvement of the environmental performance of a product, process or overall design strategy. The methodological basis of software tools does not differ much, as they pursued the same goal – to improve the environmental level of products at crucial stages or in their whole life cycle. Based on these facts, the usual sub-goals of the developers of these tools may be different, which results in their differentiation. This is as follows (Badida et al., 2011):

- Analysis of the existing products and processes and the use of the information obtained as feedback to improve the environmental performance of the product – LCA / LCI tools.
- Analysis of the existing products and processes and the use of the information obtained to improve certain aspects of the product – DFX tools.
- Comparison of certain materials and processes in order to determine the different levels of their impact on the environment – PP and WP tools, meaning to prevent the generation of pollutants (PP) and waste (WP).

The application of non-software tools is possible and rational often without the means of computer technology. These tools and their combinations are usually the basis of the ecodesign-oriented software tools (Caluwe, 1997). This fact was enforced by the practice and legislative measures of states in connection with the protection of the environment and the promotion of the sustainable development principles at the local, regional and global levels (Enviromagazín, 2008; Majerník et al., 2002).

Improvement analysis is a systematic assessment of the needs and opportunities to reduce the environmental burden associated with the effects of environmental impact throughout the life cycle of a product, process or activity, see Figure 1.

The aim of the life cycle interpretation is to analyse the results and drawn conclusions, explain the limitations, provide recommendations based on the findings of previous phases of the LCA or LCI, and to report in a clear way the results of the life cycle interpretation (Geodkop et al., 2001; Fedra, 1990). The intention of the life cycle interpretation is also to provide a clearly understandable, complete and uniform presentation of the LCA and LCI study results, in accordance with the defined aim and subject of the study (Stevels, 1998).

EI 99 method, Figure 2, in terms of knowledge, is a «damage-oriented» method of environmental impact assessment with many conceptual breakthroughs.

It is also the basis for calculating EI points for materials and processes. These can be applied as an acceptable user tool for environmentally oriented design, for designers and product managers to improve products. The methodology is highly compatible with the requirements of ISO 14042 (STN EN ISO, 2003). Standard EI 99 points can be applied to carry out the product's own environmental assessment. More than 200 predefined EI 99 points for commonly used materials and processes are available, so the application can be carried out without restrictions. An acceptable Eco – it user program with

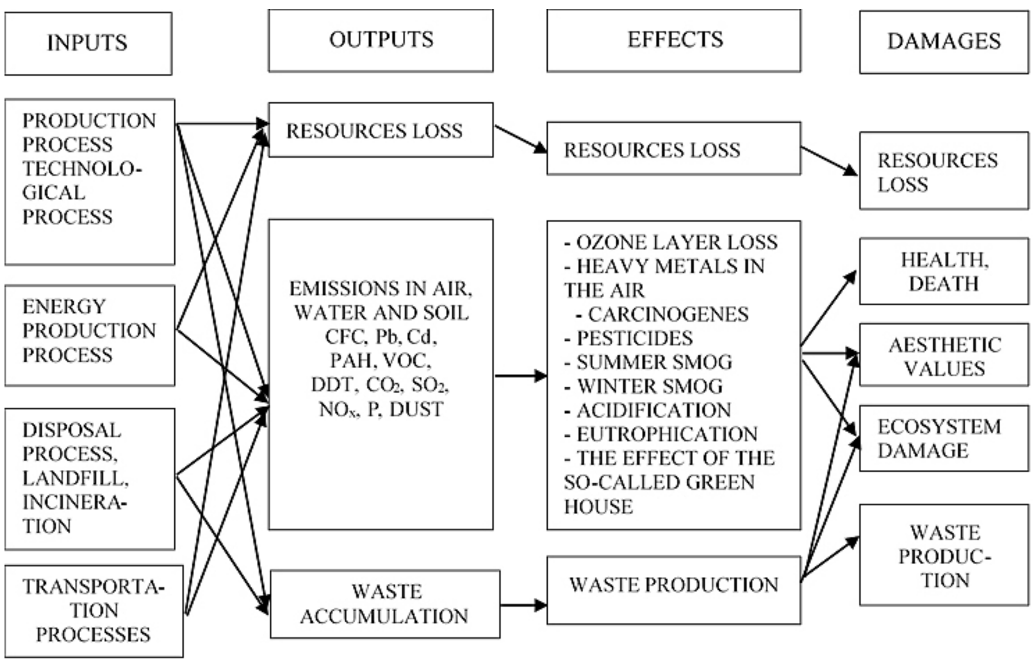

Figure 1. Structure of object life cycle analysis

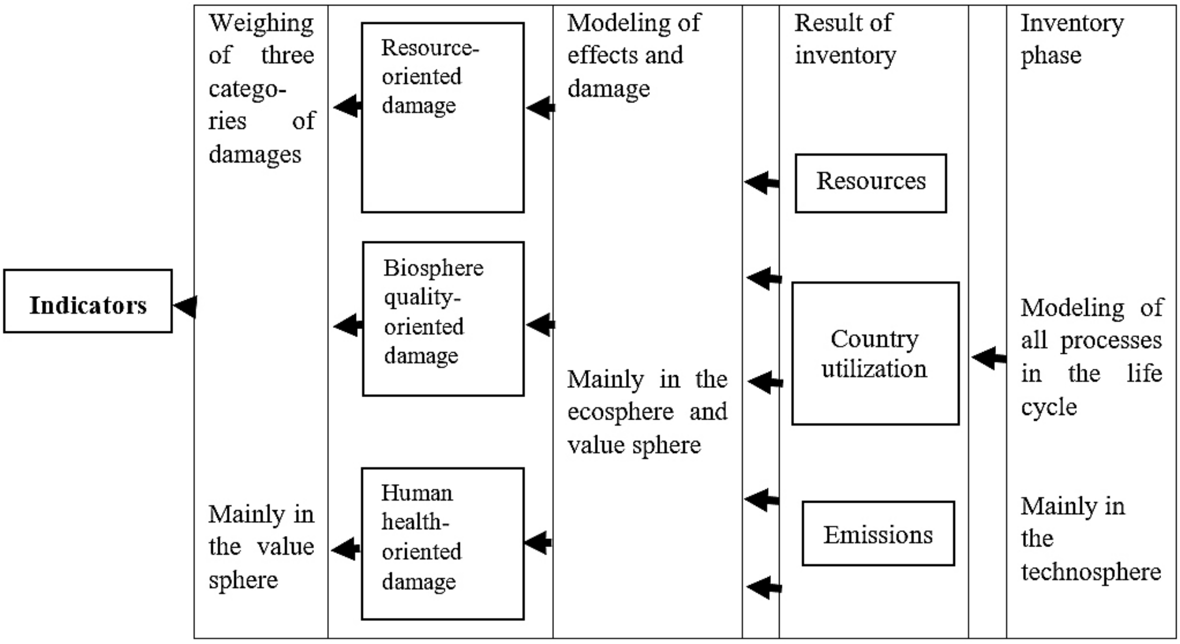

Figure 2. Simplified diagram of the EI 99 methodology (adapted according to [9])

an EI database is available (Yarwood et al., 1999). In addition, specific EI 99 points can be calculated using the LCA software, such as e.g., SimaPro.

However, it turns out in this context that none of the analysed methods has a complex nature of assessment for the object of assessment thus specified. The complexity of the solution could be contributed by the proposed LCA and EI 99 for the car, with the application of LCA or EI 99 for one of its components. The results of the conducted experiments (carried out in the past also in the laboratory of Recycling Dismantling of Car Wrecks) formed the basis for the gradual refinement of the solution and approach to standardised solutions.

RESULTS AND DISCUSSION

The applied and practically usable methods for comprehensive and integrated assessment of technological, economic, environmental and social factors are appropriately combined,

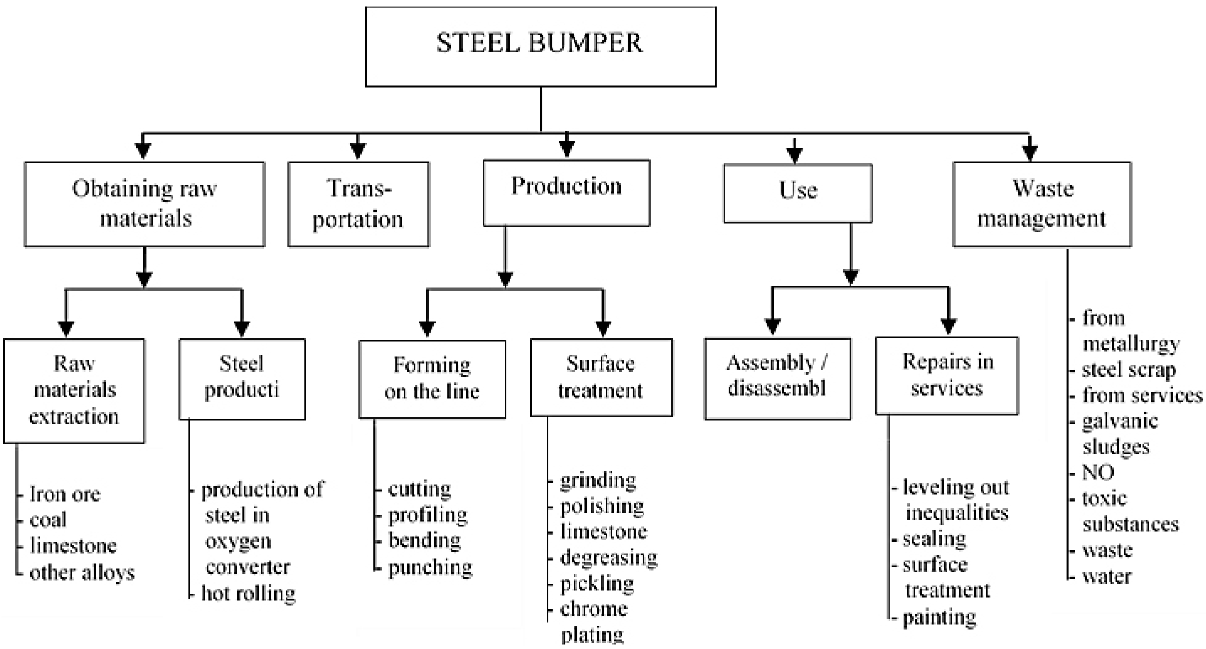

Fig. 3. Product system – steel bumper

while on the basis of a synthetic indicator of the technological process the technologies are compared with the emphasis on the selection of environmentally appropriate technology or best available techniques (BAT).

The choice of approach then depends mainly on the purpose of the evaluation. One of the most important criteria for evaluating the changes in the system is the criterion of the quality of nature as part of the quality of the human environment, i.e., the social criterion. This aspect is also highly topical today in connection with the recycling of old vehicles – an economic-environmental problem.

Application of the LCA method – car bumper

A bumper was investigated as a product system, which can be divided into partial processes (see Fig. 3 and Table 1, first column).

Application of the LCA method – car fender

The aim of this study was to compare the materials used in the manufacture of a car component. The subject is the fender of a car, which can be made of:

- steel,
- aluminium alloy,
- plastic.

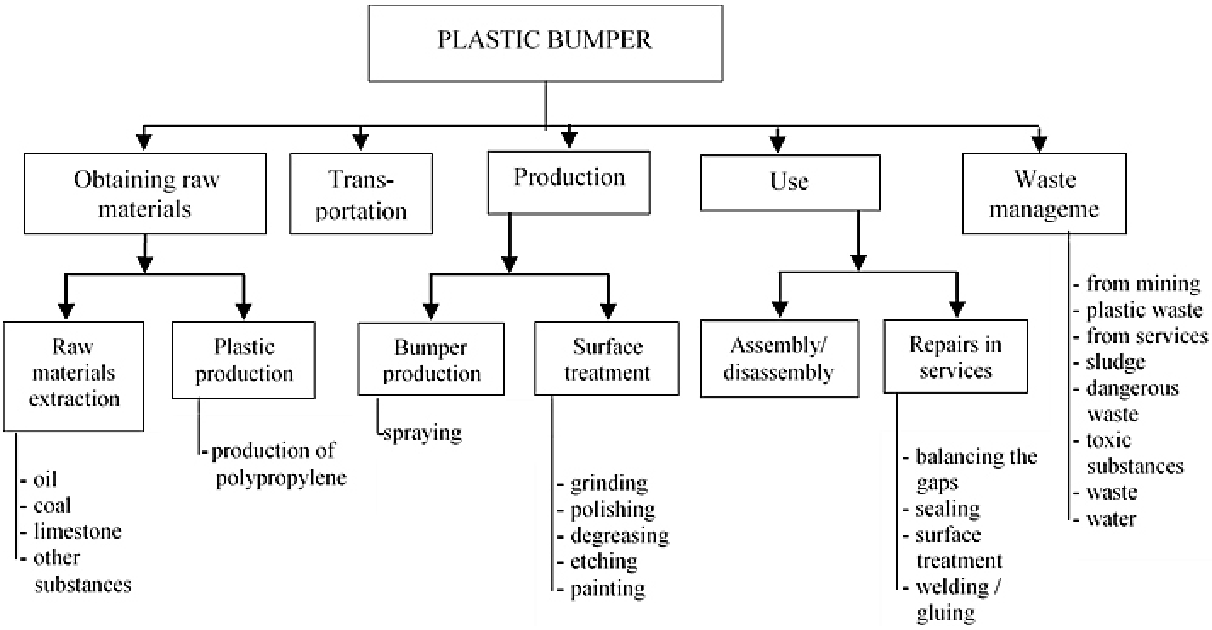

Fig. 4. Product system – plastic bumper

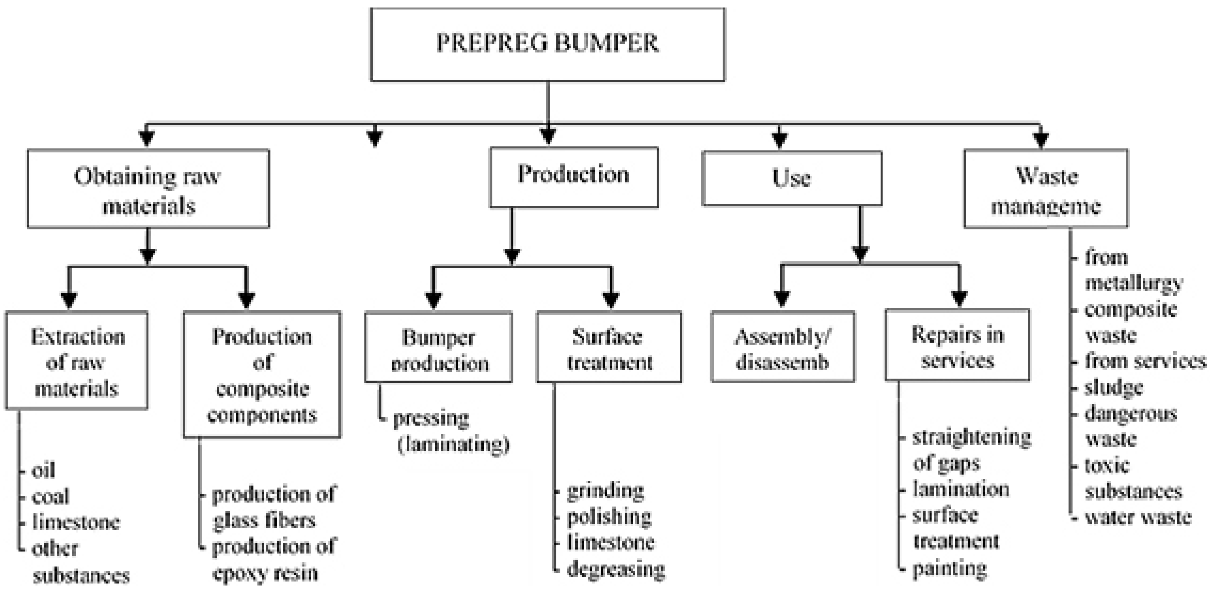

Fig. 5. Product system – prepreg bumper

Table 1. Environmental assessment of a steel bumper

Working process - EA	Negative effects on the environment Environmental impact - EI	Corrective measures
Extraction of raw materials	• noise and vibration • air pollution by dust • to water and soil by possible leakage of oil and other chemicals • emissions from mining equipment • devastation of the environment	• strict compliance with safety regulations • installation of filters for exhaust exhausts • appropriate solution for operations • reclamation of land after mining
Steel production	• formation of blast furnace sludge • significant water consumption • formation of brown fumes of ferric oxide • CO and CO2 production • soil contamination • water and air pollution by fly ash and other chem. substances • NOx, SO2 emissions to air	• installation of filters and dust traps • address waste management issues • waste cleaning. water and their recycling • cleaning of unburned gas from dust • regular monitoring and evaluation of emissions and immissions
Hot rolling	• emissions from heat treatment • during heating and forming, the formation of scale containing various oxides • noise and vibration • water pollution	• separation of gaseous and dusty pollutants • wastewater treatment plants and their recycling • compliance with security measures • change of machine constructions (soundproofing)
Forming: • pressing • rolling • cutting	• noise and vibration • the possibility of environmental pollution during oil cooling	• change of machine constructions • mounting machines on solid foundations • use of covers, noise protection of the space • oil leak detection
Grinding Polishing	• air dust, especially around the workplace • for water and soil with dust washed away by the coolant • grinders are a major source of noise • possibility of chemical contamination	• dust collectors • precautions • protective equipment • noise control measures • capture of metal particles, abrasives and chemicals before releasing into the environment
Degreasing Pickling Chromium plating	• possibility of chemical leakage • for water during pickling • on the air with scale and gases from thermal heating of metals • during galvanization, the concentration of problematic substances in wastewater • harmful expeditions in the work environment	• address waste management issues • wastewater treatment and recycling • protective equipment • capture of chemical leaks • appropriate location of the operation • process automation • precautions
Painting	• air pollution by high concentration of problematic substances • harmful fumes in the working environment • water and soil from chemicals	• appropriate location of the operation • adherence to working procedures • local extraction in the paint shop
Transportation	• concentration of CO, NOx and CxHy in the air near roads • lead substances in soil and air • devastation of the environment due to the construction of roads • leakage of oils and fuels into water and soil	• application of filters and catalysts for cars • use of unleaded fuels • inspection and maintenance of vehicles

Table 2. Environmental assessment of a polypropylene bumper

Working process - EA	Negative effects on the environment Environmental Impact - EI	Corrective measures
Oil extraction	• contaminated soil • in offshore extraction, the possibility of oil spills into the water • possibility of explosion • noise • devastation of the environment	• prevention of oil spills • strict adherence to safety rules • work discipline • specialized staff
Extraction of raw materials (coal, limestone)	• noise and vibration • air pollution by dust • to water and soil by possible leakage of oil and other chemicals • emissions from mining equipment • devastation of the environment	• strict compliance with safety regulations • installation of filters for exhaust exhausts • reclamation of land after mining
Production of polypropylene	• water pollution chem. substances and oil • possibility of leakage of substances into the soil • spread of odor • dispersion of emissions into air and water • generation of hazardous and toxic waste • harmful fumes at work. environment	• safety precautions • protective equipment • gaseous pollutants separators • prevention of oil spills • WWTPs and their recycling • process automation • neutralization or stabilization of hazardous and toxic wastes
Pressspraying	• emissions from heat treatment • vapors and gases escaping from the process site • noise	• separation of gaseous pollutants • strict compliance with safety regulations • process automation • gaseous pollutants separators
Mechanical adjustment	• air dust, especially around the workplace • for water and soil with dust washed away by the coolant • grinders are a major source of noise	• dust collectors • protective equipment • noise control measures • capture of abrasives and chemicals before release into the environment
Etching	• possibility of chemical leakage • concentration of problematic substances in wastewater • harmful fumes and gases in the working environment	• address waste management issues • wastewater treatment and recycling • protective equipment • capture of chemical leaks • appropriate location of the operation • process automation • precautions
Painting	• air pollution by high concentration of problematic substances • harmful fumes in the working environment • water and soil from chemicals • the possibility of leakage into the environment when using the plasticizer	• appropriate location of the operation • compliance with working procedures • local extraction in the paint shop • prevention of leakage of chemicals into the environment
Transportation	• concentration of CO, NO_x a C_xH_y in the air near roads • lead substances in soil and air • devastation of the environment due to the construction of roads • leakage of oils and fuels into water and soil • possibility of oil leakage during transport	• application of filters and catalysts for cars • use of unleaded fuels • inspection and maintenance of vehicles • use of special oil transporters

Table 3. Environmental assessment of a prepreg bumper

Working process - EA	Negative effects on the environment Environmental impact - EI	Corrective measures
Oil extraction	• contaminated soil • in offshore extraction, the possibility of oil spills into the water • possibility of explosion • noise • devastation of the environment	• prevention of oil spills • strict adherence to safety rules • work discipline • specialized staff
Extraction of raw materials	• noise and vibration • air pollution by dust • water and soil by possible leakage of oil and other chemicals • emissions from mining equipment • devastation of the environment	• strict compliance with safety regulations • installation of filters for exhaust exhausts • reclamation
Production of prepreg	• water pollution by chemicals and oil • the possibility of leakage of substances into the soil • spread of odor • dispersion of emissions into air and water • generation of hazardous and toxic waste • harmful fumes in the working environment	• safety precautions • protective equipment • gaseous pollutants separators • prevention of oil spills • WWTPs and their recycling • process automation • neutralization or stabilization of hazardous and toxic wastes
Pressing	• emissions from heat treatment • vapors and gases escaping from the process site • noise	• separation of gaseous pollutants • strict compliance with safety regulations • process automation • gaseous pollutants separators
Grinding	• air dust, especially around the workplace • water and soil with dust washed away by the coolant • grinders are a major source of noise	• dust collectors • protective equipment • noise control measures • capture of abrasives and chemicals before release into the environment
Disposal of the prepreg	• major disposal problems (separation of matrix from glass fibers is not possible) • recycling problems	• find a progressive method of disposal (Research)
Transportation	• concentration of CO, NO_x a C_xH_y in the air near roads • lead substances in soil and air • devastation of the environment due to the construction of roads • leakage of oils and fuels into water and soil • possibility of oil leakage during transport	• application of filters and catalysts for cars • use of unleaded fuels • inspection and maintenance of vehicles • use special oil transporters

Already at the material decision stage, it is necessary to consider the environmental impacts that may result from production, use and disposal.

Application of the method EI 99 – car door

This study compared the structural structures of car doors. Possible variants are:

a) welded construction from sheet metal stampings – different construction method
b) multi-component composite construction – composite, construction method
c) cast aluminium construction with integrated expanded aluminium – integrated construction method.

Step 1. Initiation (justification) of the importance of the EI calculation.

Table 4. Environmental assessment of a steel fender

Working process - EA	Negative effects on the environment Environmental impact - EI	Corrective measures
Extraction of raw materials	• noise and vibration • air pollution by dust • leakage of oil and other chemicals into water and soil • emissions from mining equipment	• strict compliance with safety regulations • waste management solutions
Steel production	• high water consumption • formation of blast furnace sludge • emissions to air • water and air pollution by ash and other chemicals	• filters and dust collectors • waste water treatment plants and their recycling • addressing the issue of waste management • monitoring and evaluation of emissions
Transportation	• lead substances in water, soil and air • leakage of oils and fuels into water and soil concentration of CO, NO_x a C_xH_y in the air • construction of roads	• filters and catalysts for cars • inspection and maintenance of vehicles • use of unleaded fuels
Shaping Pressure machining: • volume forming (pressing) • rolling	• noise and vibration during rolling	• compliance with security measures • change of machine constructions (soundproofing) • process automation • replacement technologies
Change in physical-mechanical and chemical properties of materials Diffuse plating: • aluminium plating	• for water when removing impurities from the metal surface, rinsing • harmful fumes in the working environment • for electrolytic and emulsion degreasing with various solvents based on petrol, kerosene, trichlorethylene and tetrachlorethylene • during the plating itself, the concentration of problematic substances in the wastewater • harmful fumes in the working environment	• wastewater treatment, neutralization and recycling • compliance with safety regulations • appropriate location of the operation • waste management solutions • process automation
Dividion of materials Cutting: • mechanical	• noise and vibration, by cutting with hydraulic shears	• change of machine constructions • mounting machines on solid foundations • oil leak detection
Joining of semi-finished products Welding: • spot	• on a small scale on the air, especially welding in a protective atmosphere • irradiation of the surroundings • noise from welding units	• strict compliance with safety regulations • safety tarpaulins against strong radiation • process automation • covers, anti-noise treatment of the space • use of protective equipment (goggles, gloves)
Finishing processing Polishing Grinding	• air dust, especially around the workplace • for water and soil washed away with coolant • grinders are a major source of noise	• dust collectors • precautions • protective equipment • noise control measures • capture of metal and abrasive particles before they escape into the environment

Table 5. Environmental assessment of an aluminium fender

Working process - EA	Negative effects on the environment Environmental impact - EI	Corrective measures
Extraction of raw materials	• see steel fender	
Steel production	• significant water consumption • contaminated soil • emissions to air	• address waste management issues • regular monitoring and evaluation of emissions and immissions
Transportation	• see steel fender	
Shaping Casting: • vacuum pressure Pressure machining: • volume forming (pressing)	• emissions from furnaces and workplaces for the preparation of molding compounds and the cleaning of castings • pollutants from burnt, fusible and chemically soluble models	• separation of gaseous and dusty pollutants • waste water treatment plants and their recycling • compliance with security measures • replacement technologies • process automation
Change in physical-mechanical and chemical properties of materials Refining Aluminium oxide plating	• for water when removing impurities from the metal surface, rinsing • harmful fumes in the working environment • for electrolytic and emulsion degreasing with various solvents based on petrol, kerosene, trichlorethylene and tetrachlorethylene • during the plating itself, the concentration of problematic substances in the wastewater • harmful fumes in the working environment	• wastewater treatment, neutralization and recycling • compliance with safety regulations • appropriate location of the operation • waste management solutions • process automation

Table 6. Environmental assessment of a plastic fender

Working process - EA	Negative effects on the environment Environmental impact - EI	Corrective measures
Extraction of raw materials	• see steel fender	
Paper production	• pollution of wastewater from paper mills by short pulp fibers	• waste water treatment plants and their recycling
Bakelite production	• water pollution by chemicals and oil • the possibility of leakage of substances into the soil • odor spread, vapors • dispersion of emissions into the air • hazardous waste	• compliance with security measures • protective equipment • process automation • oil and oil spill response • waste water treatment plants and their recycling
Transportation	• see steel fender	

- Product description. It is the only component, produced in the number of 450 thousand pcs / year, for which 3 design solutions were proposed, including different production technologies.
- It is a comparison and analysis of three product variant
- High accuracy of analysis is required, as it is a large-scale production.

Step 2. Defining the life cycle. Block diagrams of the life cycle of individual variants are shown in Figure 6.

a) welded construction,
b) composite construction,
c) integrated aluminium construction.

Step 3. Quantification of materials and processes, based on life cycle block diagrams. Formulations of details and specialization of conditions are found in Table 7.

The data in Table 7 can be reproduced as follows: The values of the indicators, expressed in units (mP/kg), (mP/kWh), or (mP/MJ), are

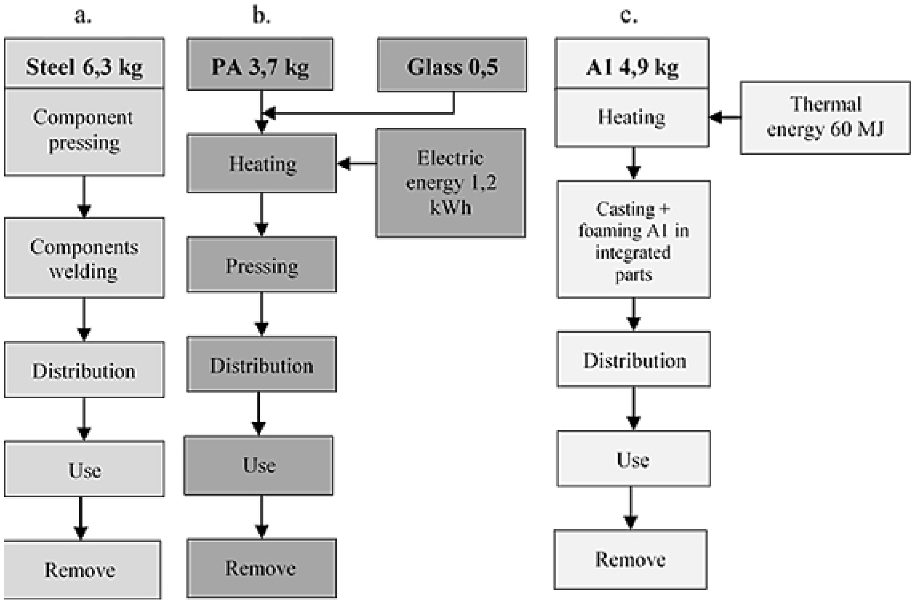

Figure 6. Block diagram of the life cycle of individual door variants

according to the tables of generally recommended eco-indicators. Multiplying the quantities of material with the appropriate indicator gives partial results. This applies to the design phase. In the production phase, the indicators that are characteristic of the respective processes apply, which are again multiplied by the respective quantities. It should be noted that in the case of welding for variant a) these are spot welds, while the indicator for 1 spot weld with a diameter of 7 mm has a value of 5 mP/point. For 102 spot welds (according to the manufacturer) a value of 510 was thus obtained.

Other values apply to the production of aluminium as a solid primary material (0% recycled) – 780 mP/kg and others to a solid secondary material (100% recycled) – 60 mP/kg. In the case of casting, it is already a process, so the indicator value of 60 mP/kg has been chosen here.

Negative values of indicators in the removal phase express the suitability of recycling these materials, which saves the environment (non-renewable resources, energy savings, etc.), which is especially significant in the recycling of aluminium. In the case of variant b), since it is a non-separable material (PA is reinforced with

Table 7. Data form for all phases of the life cycle of the three possible car door variants

Name of the object of evaluation: Passenger car doors - variants												
Var.	a)				b)				c)			
Life cycle phase	Type of material or process	Quantity (kg) or energy kWh, MJ	Indicator mP/kg, mP/kWh mP/MJ	Result	Type of material or process	Quantity (kg) or energy kWh, MJ	Indicator mP/kg, mP/kWh mP/MJ	Result	Type of material or process	Quantity (kg) or energy kWh, MJ	Indicator mP/kg, mP/kWh mP/MJ	Result
Proposal	Steel	6.3	86	541.8	PA Glass	3.7 0.5	630 49	2331 24.5	Aluminium	4.9	780	3822
Production	Steel Stamping	6.3	23	144.9	Glass	0.5			Aluminium Heating	4.9 60	22	1320
	Welding	6.3	510	3213	Heating	1.2	22	26.4	Casting	4.9	60	294
					Pressing	4.2	6.4	26.9				
				3900				2408				5436
Distribution	Not considered - same for all variants											
Use	Not considered - same for all variants											
Removal	Type of material or process	Quantity (kg)	Indicator (mP/kg)	Result	Type of material or process	Quantity (kg)	Indicator (mP/kg)	Result	Type of material or process	Quantity (kg)	Indicator (mP/kg)	Result
	Steel industrial waste	63	- 70	-441	PA + glass dump	4.2	3.5	14.7	Aluminum industrial waste	4.9	-720	-3528
Total sum				3459				2393				1908

glass fibers), recycling is practically impossible here. A landfill was therefore chosen for the management of this waste.

Step 4. By applying the EI form, represented in tab. 6, the data on materials, processes, quantities, energy consumption for carrying out some processes have been filled in. Relevant values of indicators were found in the normalized tables, relative and partial results were calculated, including summary results – these represent grand totals.

Step 5. Interpretation of results. On the basis of the comparison of the total sum of the results, in all phases of the life cycle of the car door, it can be stated that from the environmental point of view of variant c) i.e. the production of aluminium doors with integrated expanded aluminium reinforcements, will be the most environmentally friendly. The question is whether a similar result would be achieved based on an economic analysis. Unfortunately, the necessary starting data was not provided by Ford Motor Co. production (Bareš, 1988).

However, it provided the data on another door production technology, which is still in the experimental stage. It is a production of doors from PP, which is reinforced with hemp fibers. The data for this variant, which is marked as variant (d), can be found in the Table 8.

According to the total, it is evident that from an environmental point of view, variant (d) is the most attractive and it can be assumed that if this production technology is managed to such a form that it is suitable for large-scale production, it will also be the most economical.

The issue of removing these products (passenger car doors) after survival remains problematic here. It is common knowledge that nature cannot deal with composite materials (landfilling), their incineration is problematic, recycling PP is advantageous (unlike some types of PA), the separation of fibre reinforcement is questionable. This issue becomes a problem when disposing of huge quantities of these products (manufacturing of 450,000 cars/year, 4 doors per car, an average car life of 8 years – a dizzying number of 14,400,000 pcs of the doors for disposal is considered).

In conclusion to this example, it should be stressed that the designer, at the beginning of the design process by varying the types of materials, processes, types of energy needed, can significantly affect the environmental performance of the future product, in this case, the component – passenger car doors.

CONCLUSIONS

The life-cycle assessment method is making a significant contribution to sustainable development, as it combines economic and environmental aspects in a holistic view of the entire production, user and waste system. Life cycle assessment is directly linked to the production system, which can be understood as a transformation process of transforming inputs into outputs. When selecting input materials, an organization applying the LCA principles must consider whether the material itself will not cause a negative environmental impact at some stage of the product life cycle and whether its production is not a source of negative environmental impacts in itself. This approach has also led to activities of development, recognition

Table 8. Data form of the production of passenger car doors made of PP reinforced with hemp fibers (variant d)

Object name: Passenger car door - variant d					
Life cycle phase	Type of material, process or waste	Quantity (kg)	Energy needed (MJ), (kWh)	Indicator (mP/kg), (mP/MJ), (mP/kWh)	Result
Proposal	PP	3.3		330	1089
	Hemp fibers (KV)	0.5		39	19.50
Production	PP + KV heating	3.8	0.8	22	17.60
	PP + KV pressing	3.8		6.4	24.32
	Subtotal				1150
Distribution	These phases are not considered - they are the same for all variants				
Use					
Removal	PP + KV industrial waste	3.8		3.5	13.3
Total					1164

and gradual application of the principles of eco-labelling not only in the production system itself but also in supplier relations. Many customers already directly supply their suppliers with eco-labelled materials, which guarantee that their production does not harm the environment. The relationship to transport, packaging materials of the automotive industry, etc. is developing in a similar direction.

Life cycle assessment is one of the methods of environmental management that assesses the environmental aspects and possible impacts of a product or activity on the environment throughout its life cycle. In the El 99 project, the weighing step is performed in groups as part of a carefully prepared procedure. The whole effort is oriented so that this step is made as understandable as possible.

The unit of the eco-indicator is a dimensionless quantity, the value of which represents the eco-indicator point marked as (Pt). In practice, thousandth values (mPt – milipoint) are applied, so 700 mPt = 0.7 Pt. The absolute value of the points is not relevant, as their main significance lies in the comparison of the relative differences between the products and their components. The scale should be chosen in such a way that the value of lPt is representative of one-thousandth of the annual environmental burden of the average European population. This value was calculated according to the share of the total environmental burden in Europe per capita and multiplied by 1000 (scale factor) (Muránsky, et al., 2001). For the overall evaluation of the life cycle, it is possible to use the complete methodological procedure of successive phases of LCA, their mutual combination or it is possible to use only the results of inventory analysis and on their basis decide on a product with better environmental parameters or propose measures, which in the future would lead to an improvement in the properties of the existing state, e.g. by combining LCA and EI 99 methods and supporting them with Sima Pro Classroom software in the university laboratory.

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