SYSTEM APPROACH TO DETERMINATION OF RESULTING GREEN HOUSE GAS EMISSIONS OF ENGINEERING PRODUCT

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Recently, it has been possible to observe toughening of requirements to reduce environmental burden and environmental profile of products. While the first requirements were rather general, in the course of time they have toughened and focused on spheres that most considerably affect the environment, namely, on energy-related products. According to high energy consumption in the industrial sector, an increase of legislative requirements for engineering products is also expected. Currently, majority of environmental legislation also apply to engineering products. This development should draw an attention of machinery manufacturers to the changes planned for the near future that they can also be concerned with. The present article is devoted to the development of methodology for evaluation of environmental burdens caused by greenhouse gas emissions (in this case it is carbon dioxide) arising from production of engineering materials (e.g. cast iron); from mining and processing of raw materials to casting and transporting of finished product to the site of its subsequent processing.

KEYWORDS

carbon dioxide emissions, cast iron, energy consumption, Life Cycle Assessment

1 INTRODUCTION

The Kyoto Protocol ranks among the first and the most important international documents related to climatic changes. It obliges the signatory countries to a long-term reduction of greenhouse gas emissions. This reduction applies to the six greenhouse gases - carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) expressed in the form of the so-called carbon dioxide equivalent (CO_2e). Under the Kyoto Protocol, the signatories should achieve a 20% reduction of greenhouse gas emissions by 2020 relative to 1990. This goal is accompanied by the commitment of the European Union to achieve 20% final energy consumption from renewable sources and 20% energy efficiency improvement by 2020 [Lau et al. 2012].

One of the most recent documents in this area is "A policy framework for climate and energy in the period from 2020 to 2030". The goal of this document is to propose a 40% reduction of greenhouse gas emissions in the EU in 2030 relative to emissions in 1990. One of other important goals is an increase of renewable energy share by at least 27% and energy savings by 25% [EC 2014].

One of the most effective ways to control carbon dioxide emissions is to reduce the use of fossil fuels for power generation. The solution of this task is a substitution of fossil fuels by renewable energy sources, e.g. hydro, wind, solar or geothermal energy. Another commitment related to energy savings can be met by reducing the energy intensity of production processes and increasing the energy efficiency of energy-related products. Meeting of these two commitments can fulfill the goal to reduce the greenhouse gas emissions. Due to high energy consumption, the largest potential for reduction of greenhouse gas emissions is in the industrial sector.

Energy consumption accompanies any product throughout its life cycle. Of course, it also applies to engineering products. Therefore, when reducing the environmental impact of the product, it is necessary to reckon with its environmental profile. It consists of environmental impacts during the raw materials extraction and production of necessary materials through the production and use to the disposal of the product. For evaluation of product environmental impacts throughout its entire life cycle, the LCA (Life Cycle Assessment) method is used.

2 EVALUATION METHODOLOGY

LCA is a method of evaluating the potential environmental impacts associated with the product life cycle. The LCA method has a fixed structure and is conducted according to international standards ISO 14040. A definition of LCA, established by a series of these standards, is as follows: "LCA is a collection and evaluation of input, output and potential environmental impacts of the product life cycle on the environment". Therefore, LCA uses the approach "from cradle to grave", taking into account all phases of the product life cycle, i.e. from raw material extraction to final waste landfilling. Moreover it is the only tool that assesses the environmental impacts of the product throughout the entire life cycle. This method can therefore be used to identify the potential for improvement of the considered product at all phases from raw material extraction to disposal or recycling [Blecha 2013]. In the engineering production LCA is used in combination with visualization of energy flows in machine-tool and simulation of machining cycle of the characteristic workpiece. It enables evaluation of energy consumption in the usage phase of product life and to control it [Tuma et al. 2014], [Auguste et al. 2013].

The LCA method is described in the standard ISO 14040. According to this standard, the scope of assessment of the product life cycle is divided into four phases, which are shown in Fig. 1 and described in detail below.

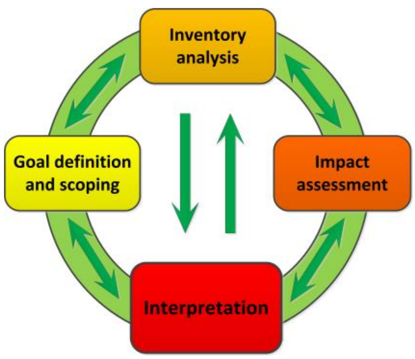

Figure 1. Scope of assessment of life cycle according to ISO 14040 [Blecha 2013]

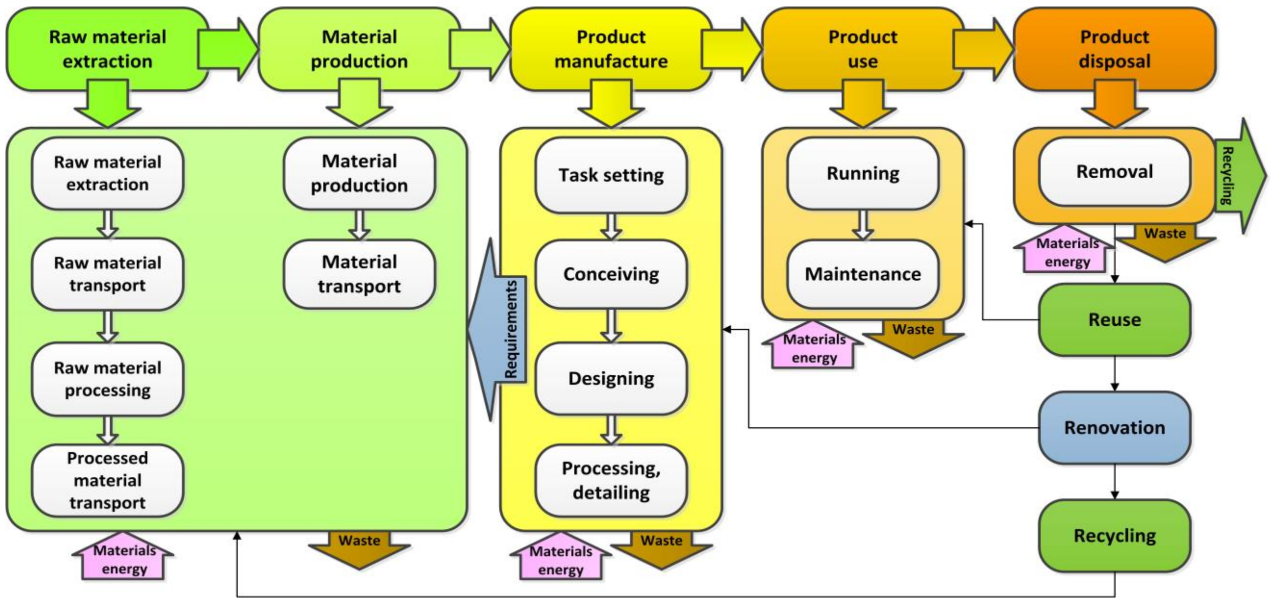

Figure 2. Methodology of evaluation of environmental impact throughout the product life cycle

Fig. 2 shows a diagram of the product life cycle according to ISO 14040 and its consistency with the process of creating a technical object. Linking of these two processes allows, as early as in the design phase of the product, to evaluate and mitigate its impact on the environment.

LCA is primarily used to identify the environmental profile of the product at all phases of its life cycle with the possibility of its improvement. It is also used for the analytical phase of eco-design. The results of study allow such a product design that would be the least harmful to the environment, yet retaining the properties of the product, its quality and reliability [Koci 2010]. Currently, due to high energy consumption in industrial sector the area of eco-design is one of the most promising potential applications of LCA. Despite this fact, the use of LCA in engineering production has not been so far sufficiently widespread. All this makes the question of LCA application to engineering products a much more up-to-date issue. A scheme of evaluation of carbon dioxide emissions produced during the manufacture of engineering materials is shown in Fig. 3 (based on [Yu et al. 2014, Norgate et al. 2007]).

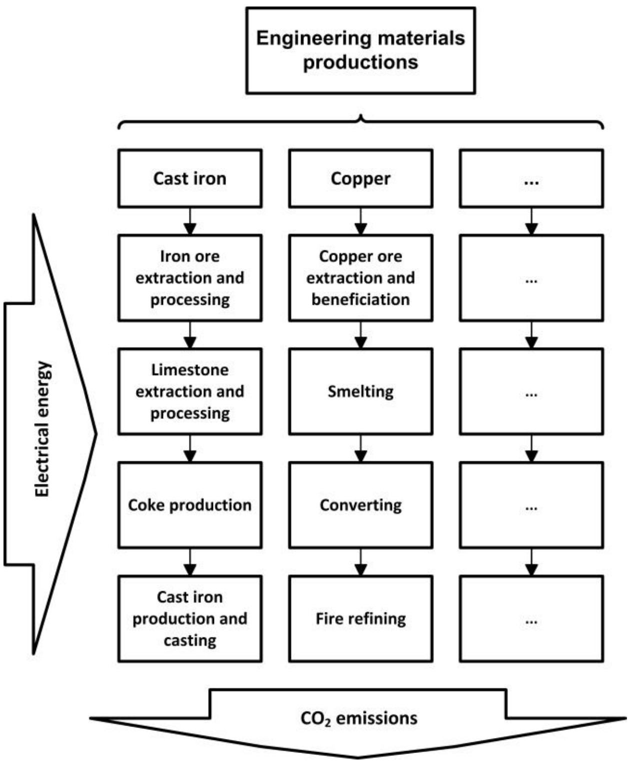

Figure 3. A diagram evaluating the emissions of CO_2 generated during production of engineering materials

The above-mentioned methodology was used to calculate the environmental burden of carbon dioxide emitted during the production of one of the most basic engineering materials – cast iron. The results of computations are presented in the following chapter.

3 COMPUTATION OF CARBON DIOXIDE EMISSIONS IN THE PRODUCTION OF CAST IRON

Evaluation of carbon dioxide emissions generated during the production of cast iron is given by the sum of the individual emissions generated during the production and processing of iron ore, limestone and coke. The computation must also include the actual production of cast iron and the following production of castings. The computation was made on the basis of recorded data on energy consumption by the individual production operations. These data on the emissions of carbon dioxide in the selected countries during the production of 1 kWh of electricity were converted into the emissions generated during the production of one ton of cast iron. Finally, the computations were made of carbon dioxide emissions generated by cargo transport using several types of transportation means.

Tab. 1-4 describe the input values of energy intensity of individual operations in the production of cast iron; these were subsequently used to compute the energy intensity of the individual processes and CO_2 emitted during these processes in the selected countries. Tab. 5 shows Total CO_2 emissions generated during the production of cast iron in the selected countries

To compute the energy consumption, the following amounts of individual components needed to produce 1 t of cast iron were selected: 2 t of iron ore, 0.7 t of limestone, and 1 t of coke. Upon converting the amount of energy consumed into carbon dioxide emissions, it was envisaged that in China the generation of 1 kWh of electricity produces 0.00058 tons of CO_2, in Canada it is 0.00014 tons, in the Czech Republic 0.00049 tons, in Germany 0.00052 tons, and in Russia it is 0.00047 tons [Iskandirova et al. 2014].

Table 2. CO_2 emissions produced during the extraction and processing of iron ore in the selected countries [De La Torre de Palacios 2011]

Operations	Energy consumption, kWh/t	Amount of iron ore, t	Energy consumption, kWh	Emissions CO_2, t				
				China	Canada	Czech Republic	Germany	Russia
Perforation	0.50	2	1	0.00058	0.00014	0.00049	0.00052	0.00047
Blasting	0.85		1.7	0.00099	0.00024	0.00083	0.00089	0.00080
Loading	1.85		3.7	0.00216	0.00051	0.00180	0.00193	0.00174
Transport to treatment (10 km)	14.90*		149	0.08708	0.02073	0.07259	0.07784	0.06989
Primary crushing	0.23		0.46	0.00027	0.00006	0.00022	0.00024	0.00022
Coarse screening	0.01		0.02	0.00001	0.00000	0.00001	0.00001	0.00001
Secondary crushing	0.61		1.22	0.00071	0.00017	0.00059	0.00064	0.00057
Grinding	19.35		38.7	0.02262	0.00538	0.01885	0.02022	0.01815
Magnetic separation	1.00		2	0.00117	0.00028	0.00097	0.00104	0.00094
Fines screening	0.20		0.4	0.00023	0.00006	0.00019	0.00021	0.00019
Agglomeration	0.42		0.84	0.00049	0.00012	0,00041	0.00044	0.00039
Transport by truck (10 km)	0.22*		4.4	0.00257	0.00061	0.00214	0.00230	0.00206
Total			203.44	0.11890	0.02830	0.09912	0.10628	0.09542

* - kWh/t·km

Table 2. CO_2 emissions produced during the extraction and processing of limestone in the selected countries [University of Tennessee 2009]

Operations	Energy consumption, kWh/t	Amount of limestone, t	Energy consumption, kWh	Emissions CO_2, t				
				China	Canada	Czech Republic	Germany	Russia
Perforation Blasting	69.40	0.7	48.580	0.02839	0.00676	0.02367	0.02538	0.02279
Loading	1.85		1.295	0.00076	0.00018	0.00063	0.00068	0.00061
Transport to treatment (5 km)	14.90*		52.150	0.03048	0.00725	0.02541	0.02724	0.02446
Crushing Separation Coarse grinding	520.80		364.560	0.21305	0.05071	0.17761	0.19045	0.17100
Transport by truck (10 km)	0.22*		1.540	0.00090	0.00021	0.00075	0.00080	0.00072
Total			468.125	0.27357	0.06512	0.22807	0.24455	0.21957

* - kWh/t·km

Table 3. CO_2 emissions produced during the production of coke in the selected countries [IEA 2007

Operations	Energy consumption, kWh/t	Amount of coke, t	Energy consumption, kWh	Emissions CO_2, t				
				China	Canada	Czech Republic	Germany	Russia
Black coal mining	-*	1	-	-	-	-	-	-
Loading	1.85		1.85	0.00108	0.00026	0.00090	0.00097	0.00087
Transport (5 km)	14.90		74.50	0.04353	0.01036	0.03630	0.03892	0.03494
Carbonization	1111.00		1111.00	0.64927	0.15454	0.54128	0.58039	0.52111
Coke extrusion	1.85		1.85	0.00108	0.00026	0.00090	0.00097	0.00087
Coke separation	1.85		1.85	0.00108	0.0026	0.00090	0.00097	0.00087
Transport by truck (10 km)	0.22		2.20	0.00129	0.00031	0.00107	0.00115	0.00103
Total			1189.55	0.69733	0.16598	0.58135	0.62335	0.55969

* - data are not available

Table 4. CO_2 emissions produced during the production and casting of cast iron in the selected countries [Yoon et al. 2014]

Operations	Energy consumption, kWh/t	Amount of cast iron, t	Energy consumption, kWh	Emissions CO_2, t				
				China	Canada	Czech Republic	Germany	Russia
Production of non-permanent sand mould	7780.00	1	7780.00	4.54663	1.08220	3.79042	4.06427	3.64921
Filling the high blast furnace with necessary material								
Melting of material								
Transport of melt to the casting site								
Filling the mould with melt								
Gravity casting								
Auxiliary operations								
Total			7780.00	4.54663	1.08220	3.79042	4.06427	3.64921

Table 5. Total CO_2 emissions generated during the production of cast iron in the selected countries

Operations	Total CO_2 emissions, t				
	China	Canada	Czech Republic	Germany	Russia
Extraction and processing of iron ore	0.11889	0.02829	0.09912	0.10628	0.09542
Extraction of limestone	0.27357	0.06511	0,22807	0.24455	0.21957
Production of coke	0.69733	0.16598	0.58135	0.62335	0.55969
Production and casting	4.54663	1.08220	3.79042	4.06427	3.64921
Total	5.63643	1.34160	4.69895	5.03845	4.52389

From Tab. 5 it is evident that most of CO_2 is generated during the production of cast iron in China, which may be caused by a large share of coal in the country's energy mix. It is followed by Germany and the Czech Republic. In the energy mix of Germany, the largest share is represented by fossil fuels and biomass, resulting in more carbon dioxide emissions than in the

Czech Republic. The Russian Federation is one of the most appropriate sites for industrial production. It has a large share of natural gas in its energy mix; therefore it produces less carbon dioxide than other countries. However the fewest emissions are produced in Canada; this can be explained by a large share of hydro power plants generating electricity.

A significant role in the environmental burden is played by transport. Even the less environmentally intensive production, having chosen an unsuitable location and type of transport, can produce a significantly higher amount of emissions than the more energy intensive production. Table 6 refers to carbon dioxide emissions (in tones and in grams) produced by several types of transportation means during transport of 1 t of cargo at a distance of 100 km and 1 kg of cargo at a distance of 1 km.

Table 6. CO_2 emissions produced by several types of cargo transportation means [Hill et al. 2009]

Type of transport	Ship	Truck	Railway
Emissions of carbon dioxide, t/t·100 km	0.00130	0.00824	0.00285
Emissions of carbon dioxide, g/kg·km	0.01300	0.08240	0.02850

From the above Table 6, it is possible to draw a conclusion that the most environmentally friendly means of transport is shipping, followed by rail transport while the worst is truck transport. When selecting the type of transport, you should begin with the location of manufacture site of the product, since far not every location enables the use of the greenest form of transport. Furthermore, you should also consider the distance between the site of manufacture of the product and the site of its further processing. For shorter distances, the amount of emissions would not be significant, but for longer distances the influence of the type of transport on the amount of emissions could be crucial.

4 CONCLUSIONS

The present article deals with a proposal of methodology for evaluating the environmental impact of product life cycle. In this methodology, life cycle phases were divided into the individual operations which included the inputs in the form of materials and energy, and the outputs in the form of waste. This methodology also comprises the process of creation of a technical object; this allows us to show its links with the product life cycle. Furthermore, on the basis of the data on energy intensity of the individual production operations, we computed the emissions of carbon dioxide generated during the production of one of the most basic engineering materials – cast iron. From the results it is evident that the environmentally least intensive production is in Canada, which can be explained by the structure of the country's energy mix. In conclusion, an assessment of environmental burden was made on the basis of emissions of carbon dioxide produced by cargo transport using fundamental types of cargo transport.

Currently, when assessing the environmental impact of engineering products, only self-regulatory measures can be applied. However, due to the increased activity of legislative bodies in the field of ecology, it is possible to expect that in the near future these measures may be replaced by compulsory ones. One of the most fundamental problems in this field is a current lack of preparedness of companies for this change. A current status of legislative requirements should be viewed by every manufacturer of engineering products as a warning that in the near future the ecological profile of the product could form the basis of its competitiveness.

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