EVALUATION OF ENVIRONMENTAL LIFE CYCLE COST OF STEEL PRODUCTION - CASE STUDY

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Abstract

The life cycle thinking is a concept promoted by the World Steel Association as a basic requirement for making all manufacturing decisions. One of the tools of this approach is life cycle costing. It is a process of an economic analysis to assess life cycle costs (LCC) of a product over its life cycle from its conception and fabrication through operation to the end of its life. In most cases the process takes into account only the pure financial costs incurred in the product life cycle called conventional LCC. There is another type of LCC in the literature - the environmental LCC. It comprises all costs of life cycle product directly covered by actors involved in the product life cycle and externalities felt by society and environment, which are anticipated to be internalized in the future. The paper presents the results of research work aimed at expressing the LCA results in monetary terms and calculation the environmental life cycle costs based on these results. This allowed to connect and present LCA and LCC results in one value which can be used in the decision-making process where there is a choice of options. Proposed conception has been used for estimating the environmental LCC for selected steel products.

Keywords: Life cycle costs (LCC), life cycle assessment (LCA), disability adjusted life year (DALY), potentially disappeared fraction of species (PDF)

1. INTRODUCTION

Steel production is one of processes which has significant negative impact on the environment quality. On the other hand, the steel is a 100% recyclable product, which can be recycled repeatedly without loss of steel utility functions. For that reason it is important that the analyse of environmental impact of steel products does not focus only on the stage of their production, but takes into account impacts at each phases of life cycle (beginning from resource extraction, through manufacture, use and end-of-life management). This approach, called the life cycle thinking, is promoted by World Steel Association as a basic requirement for making all manufacturing decisions [1].

Life cycle thinking can be achieved through the application of tools such as the life cycle assessment (LCA) or the life cycle costs (LCC). Life cycle assessment (LCA) is a comprehensive method for estimating the impact of products/services or processes on the environment throughout their life cycle. LCA methodology allows to express environmental impact in terms of volume as categories of impact (midpoints) or categories of damage (endpoints). Life cycle costs (also known as conventional LCC) are the sum of all costs directly paid by actors involved in the product life cycle. These costs are not take into consideration the value of environmental effects, but only direct monetary costs involved with a product or service. For that reason conventional LCC should not be associated with LCA. However, it should be noted that the term ‘environmental life cycle costs’ exists in literature on the subject. This kind of LCC includes conventional LCC and the value of externalities felt by society and environment, which are anticipated to be internalised in the future.

Calculating the value of environmental LCC is not easy, because it requests to express in monetary terms environmental effects which don’t have a market value in most cases. Nevertheless, there are non-market methods valuing this kind of effects. These methods include stated preference methods (e.g. contingent valuation method and choice experience) and revealed preference methods (e.g. hedonic price method, travel cost methods, opportunity costs or restitution costs method). The choice of valuation methods mostly depends on a kind of environmental effects and availability of the data.

The main goal of this article is presentation of conception expressing the LCA results in monetary terms and calculation the environmental life cycle costs based on these results. Proposed conception has been used for estimating the environmental LCC for selected steel products.

2. ENVIRONMENTAL LIFE CYCLE COSTS

As mentioned in the introduction, life cycle costs belong to the set of life cycle approach. According to the IEC 60300-30-3 standard, life cycle cost (LCC) is the total cost incurred in product life cycle. This cost consist of acquisition costs (investment costs), ownership costs (which are the sum of operation and maintenance costs) and end-of-life disposal costs [2]. In literature on the subject there is one more term related to LCC - life cycle costing. Life cycle costing (LCC) is a process of economic analysis which aims to assess all costs generated in product life cycle. The evaluation may include a whole product life cycle, a single phase of the product cycle or a combination of the different phases of the product life cycle. The life cycle costing was primarily used as a tool to support investment decisions and complex projects in the field of defence, transportation and the construction sector. It was found that purchasing decisions should not be based solely on the initial acquisition cost, but also on the costs for operation and maintenance and for disposal [3]. This approach is used today in e.g. public procurement.

Over the years, the conception of LCC has been developed and used extendedly in many sectors [4]. Currently, there are three types of life-cycle costs: conventional LCC, environmental LCC and social LCC. Conventional LCC includes all costs which are directly covered by the main producer or user in the product life cycle. Their assessment is focused on real, internal costs and for their valuation the ABC method (activity- based costing method) or total cost of ownership (TCO) is used. So denominated costs do not include the results of the life cycle assessment [3]. Environmental LCC contains conventional LCC and the value of externalities (positive or negative) resulting in different phases of the product life cycle. Costs are directly related to one or more actors in the supply chain and thanks to the expression in monetary values they can be internalized in the account of polluters. The third kind of LCC is societal LCC. It includes environmental LLC and the value of externalities covered by anyone in the society, which could potentially occur in the future as a result of various phases of the product life cycle and which are not internalized in the account of polluters. This concept is still in the development phase [more in: 5, 6].

Environmental LCC approach has been developed by a scientific working group within SETAC in 2002- 2007. The evolution of this kind of LCC arose from the fact, that conventional LCC was often not suitable for an assessment of the economic implications of a product life cycle in a sustainability framework. Besides, there was a need to develop the methodology which allows to connect the LCA and LCC results.

It should be noted, that incorporating external effects in LCC is not an easy issue to deal with. A valuation of external effects, which do not have a value set by the market is indispensable. . As mentioned in the introduction, there are two basic non-market valuation approaches suggested for valuing environmental effects - stated and revealed preference approach. The Stated Preference Methods (SP) which include Contingent Valuation method (CVM) or Choice Experience (CE) - ask individuals how much they would be willing to pay (or willing to accept) to compensate for an improvement (deterioration) of environmental quality. In these methods a hypothetical market for environmental quality changes is constructed and then respondents are surveyed for their willingness to pay (WTP) for environmental quality improvements affecting the quality of people's life. The Revealed Preference methods provide an indirect estimate of the value of a cost or benefit using surrogate market goods and commodities. They include methods based on individual behaviour or actions in the markets where prices reflect differences in quality of environment (e.g. in hedonic price method the value of environmental effects such as noise or air pollution could be valued through decreasing value of property sited near highway in comparison with value of property sited away from highway) or cost based methods, which collect (through direct observation) information about e.g. actual price of substitute goods or value of activities which have to be done to repair damages in environment.

The calculation of environmental LCC can involve assessing monetary value to each effect, which impacts on the environment and society, or either can be based on the LCA results expressed in monetary terms. The first approach is very labor intensive and requires gathering large amounts of data to the valuation of externalities. In the case of the second approach, it is necessary to perform life cycle assessment and to express in monetary impact category (midpoints) or categories of damages (endpoints). In this approach, the environmental LCC should be complemented by LCA with an equivalent system boundary and functional unit. It is very important that the elements considered in the LCA impacts have not been included in the LCC - it is necessary to avoid counting between LCC and LCA.

3. THE CONVERSION OF LCA RESULTS TO MONETARY VALUE - CASE FOR POLAND

Life cycle impact assessment (LCIA) is one of the important phases of LCA. In this phase each life cycle inventory result (LCI) is connected, as far as possible, with the corresponding environmental impact at midpoints (impact category) or endpoints (damage category) level. There are various LCIA methods in practice. Some of them (e.g. EDIP 2003 and CML 2001) are midpoint-oriented methods, other (e.g. Eco-indicator 99 and LIME) are damage-oriented methods. One of the LCIA methods is IMPACT2002+. This is a midpoint/damage-oriented method, which links all types of LCI results via 14 impact categories (midpoints) to four damage categories (endpoints) [7].

Due to the fact that later in the article the IMPACT 2002+ methodology has been applied, the valuation will be carried out in relation to the results of the LCA expressed at endpoints, such as:

- Human health - damages affecting the health of current and future generations induced by diseases, disabilities or premature death as a result of changes in the environment. This kind of damages is expressed in DALY - disability adjusted life year. DALY is a measure which accounts for the number of years someone loses because of a certain environmental mechanism [8].
- Ecosystem quality - damages stated as a change/loss or a change in location of different species of plants and animals. This kind of damages is expressed as 1 PDF (potentially disappeared fraction of species), i.e. the percentage of species which have disappeared due to the environmental load.
- Climate change - damage caused as a result of substances entering the atmosphere causing global warming. This kind of damages is expressed in kg $CO_{2\text{-eq}}$ emitted into air.
- Resources - the reduced availability of resources for current and future generations. This damage category is expressed in MJ surplus energy. This is based on the assumption that a certain extraction leads to an additional energy requirement for further mining of this resource in the future, caused by lower resource concentrations or other unfavorable characteristics of the remaining reserves [9].

3.1. Monetary valuation of DALY

Taking the WHO guidelines into consideration, according to which 1 DALY represents the loss of one year of equivalent full health [8], it was decided to value 1 DALY on the basis of value of an additional year of life (VOLY) with regard to health status of the respondents (EQ-index). Based on research conducted in Poland on a sample of 900 randomly selected respondents the mean value which people are willing to pay for the additional year of life as a result of taking action to protect the environment has been estimated (detailed description of the VOLY calculation is included in: [10]). Then, on the basis of questions evaluating the state of health, the EQ-index describing the state of each respondent's health has been estimated. These two values (WTP and EQ-index) were the basis for determining the value of additional year life in full health, which amounts to PLN 51,750 (in 2013 prices). This value is equivalent to 1 DALY.

3.2. Monetary valuation of PDF

Valuation of PDF was based on data obtained in NEEDS project. The restoration cost method was applied. The minimal marginal cost of improving biodiversity per potentially disappeared fraction of species was recognised as a PDF value. The lowest restoration cost (€0.49/PDF/m^2 in price of 2005) was identified for organic arable and this value is adopted as PFD value [11]. The obtained PDF value has been converted to a Polish value (taking into account purchasing power parity) and then has been updated. The value of environmental damages for Poland has been set at 1.25 PLN/PDF/m^2/year (in prices of 2013).

3.3. Monetary valuation of kg $CO_{2\text{-eq}}$

In order to value 1 CO_2 emitted to the atmosphere a market method has been applied which is based on a sales price of 1 emission rights sold in the market under the European Emissions Trading Scheme. One permission allows the emission of 1000 kg of CO_2 into the atmosphere. Analysis of the data contained on the EEX platform made it possible to determine the average value of one entitlement. This value amounted to PLN 18.46 (in prices of 2013), which in terms of kg of CO_2 resulted in a rounded PLN 0.02.

3.4. Monetary valuation of MJ

The valuation of 1 MJ of extra energy, which has to be used for the extraction of the market method is used. Na analysis of sales prices of electricity and heat in Poland allowed the determination of the average selling price of 1 GJ of energy at the level of PLN 53.57 (in prices of 2013), which in terms of 1MJ resulted in a rounded PLN 0.05 .

The monetary value of each LCA result indicators (damages unit) estimated on the basis of data for Poland has been presented in **Table 1**.

Table 1 Monetary value of LCA result indicators estimated on the basis of data for Poland

Damage category (Endpoints)	Damage unit	Valuation method used	Estimated value [PLN/damage unit]
Human health	1 DALY - Disability adjusted life years	Contingent Valuation method (CVM)	51,750.00
Ecosystem quality	1 PDF *m^2*yr - Potentially disappeared fraction of species	Restoration cost method/transfer benefits	1.25
Climate change	1 kg $CO_{2\text{-eq}}$ into air	Market value	0.02
Resources	1 MJ surplus energy	Market value	0.05

4. THE VALUATION OF ENVIRONMENTAL LIFE CYCLE COSTS FOR SELECTED STEEL PRODUCTS

The valuation of environmental life cycle cost has been made for selected steel products - wire rod and hot rolled coils. The system boundary was set as “from cradle to gate”. The analysis included following processes: upstream processes (comprising of: acquisitions of raw materials, energy and auxiliary materials), transportation, production processes (comprising of such subprocesses as: coke production, sintering, blast furnaces, basic oxygen furnaces, continuous casting and hot rolling). 1 ton of wire rod and 1 ton of hot rolled coils have been set as a functional unit. Data on life cycle assessment of selected products were based on the results of research described in [12]. In these research the environmental impact was determined on the basis of the methodology IMPACT2002+.

In order to determine the environmental LCC, the value of conventional LCC has been determined and the results of LCA were converted into monetary values. Due to the difficulty in obtaining economic data, the conventional LCC has been calculated on the basis of data on steel production costs in Central Europe [13] and they are shown in **Table 2**. Depreciation have also been included in the **Table 2** as a settlement of capital expenditure per 1 ton of product. Data presented in **Table 2** should be treated as estimated values. **Table 3** shown the values of externalities (LCA results converted into monetary values).

Table 2 Conventional LCC for 1 ton of hot rolled wire rod and hot rolled coils

Cost category	Wire rod [PLN]	Hot rolled coils [PLN]
Raw materials	1,190.0	1,025.0
Labour	60.0	205.0
Electricity	235.0	80.0
Natural Gas	40.0	165.0
Other energy	10.0	20.0
Other costs	205.0	330.0
Depreciation	215.0	225.0
SUMMARY COST:	1,955.00	2,050.00

Table 3 Value of LCA result indicators for 1 ton of hot rolled wire rod and hot rolled coils

Damage category	Wire rod		Hot rolled coils	
	Damage amount	Calculated damage value [PLN]	Damage amount	Calculated damage value [PLN]
Human health	3,66E-03 DALY	190.00	4,30E-03 DALY	225.00
Ecosystem quality	2,68E+02 PDF	335.00	3,01E+02 PDF	375.00
Climate change	1,57E+03 kg CO_{2-eq}	31.00	1,51 kg CO_{2-eq}	30.00
Resources	8,98E+03 MJ	449.00	8,60E+03 MJ	430.00
	SUMMARY COST:	1,005.00		1,060.00

On the basis of calculations, environmental LCC was calculated for 1 ton of selected steel products. It accounts: 2,960.00 PLN/ton for wire rod and 3,110.00 PLN/ton for hot rolled coils.

5. CONCLUSION

LCA is increasingly used tool for determining the level of influence on the environment of selected steel products. The LCA results are mostly expressed in impact category unit and for that reason they could not be comprehensible for everyone. For this reason, the concept of converting the results of LCA into the monetary value proposed in this paper is very useful. It allows to express the LCA results in one monetary value. This is easily comparable and widely understood by users. It should be noted that this concept is a supplement and update the results of research work carried out so far in this regard.

Expressing LCA results in monetary values allows their inclusion in the cost-benefit analysis, which should take into account both economic and ecological effects generated by the proposed solution. This is particularly important in the evaluation of eco-innovative solutions, as high economic cost at low levels economic benefits are often pointed out as barriers for its implementation [14].

Calculation of life cycle environmental costs allows to identify a solution more economically and environmentally favorable. In addition, these values can also be used, inter alia, in the analysis of costs and benefits and that evaluate the eco-efficiency of the proposed solutions (more on this topic in: [15]).

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