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Application of stochastic approach based on Monte Carlo (MC) simulation for life cycle inventory (LCI) to the steel process chain: Case study

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HIGHLIGHTS

• The benefits of Monte Carlo simulation are examined.
• The normal probability distribution is studied.
• LCI data on Mittal Steel Poland (MSP) complex in Kraków, Poland dates back to 2005.
• This is the first assessment of the LCI uncertainties in the Polish steel industry.

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ABSTRACT

The purpose of the paper is to present the results of application of stochastic approach based on Monte Carlo (MC) simulation for life cycle inventory (LCI) data of Mittal Steel Poland (MSP) complex in Kraków, Poland. In order to assess the uncertainty, the software CrystalBall® (CB), which is associated with Microsoft® Excel spreadsheet model, is used. The framework of the study was originally carried out for 2005. The total production of steel, coke, pig iron, sinter, slabs from continuous steel casting (CSC), sheets from hot rolling mill (HRM) and blast furnace gas, collected in 2005 from MSP was analyzed and used for MC simulation of the LCI model. In order to describe random nature of all main products used in this study, normal distribution has been applied. The results of the simulation (10,000 trials) performed with the use of CB consist of frequency charts and statistical reports. The results of this study can be used as the first step in performing a full LCA analysis in the steel industry. Further, it is concluded that the stochastic approach is a powerful method for quantifying parameter uncertainty in LCA/LCI studies and it can be applied to any steel industry. The results obtained from this study can help practitioners and decision-makers in the steel production management.

1. Introduction

Life cycle assessment (LCA) is an environmental management technique, which has a very wide application (Kulczycka and Henclik, 2009). It is a relatively new (Kowalski et al., 2007) and developing (Finnveden et al., 2009) environmental management technique described in international ISO standards, which has been developing since the mid-1980s.

The purpose of this paper is to describe the results of research on the implementation of Monte Carlo (MC) simulation proposed for stochastic study of life cycle inventory (LCI) concerning the steel process based on the data from Mittal Steel Poland (MSP) complex in Kraków, Poland (case study). In order to assess the uncertainty, the software CrystalBall® (CB), which is associated with Microsoft® Excel spreadsheet model, is used. The total production of steel, coke, pig iron, sinter, slabs from CSC, sheets from HRM and blast furnace gas was analyzed and used for MC simulation of the LCI model. The framework of the study was originally carried out for 2005 data because important statistics are available for this year and also because it represents the data, which is the foundation for the MSP Environmental Impact Report, collected (as of 2005) and evaluated annually (Mittal Steel Poland, 2007).

MSP was the largest steel producer in Poland. Today, ArcelorMittal Poland (AMP) (previously MSP) boasts a full production system — from pig iron to final, highly processed steel products. At present steel production capacities reach 7.6 million tons of crude steel and about 6.5 million tons of rolled products per year. AMP plants are located in: Kraków, Dąbrowa Górnicza, Sosnowiec, Świętochłowice and Chorzów (ArcelorMittal Poland, 2012). In Poland, crude steel is produced at a rate of 8.8 million tons per year, an increase of 9.8% from that of 2010 (Burchart-Korol, 2013).

An LCI analysis usually requires a large amount of data. The uncertainty of these parameters directly affects the outcome of any environmental impact method (Sonnemann et al. 2004). The overall uncertainty of an LCI is usually dominated by a few major uncertainties (Bieda and Tadeusiewicz, 2008). The use of stochastic model helps to characterize the uncertainties better than a purely

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Table 1
MSP main products.

MSP main products	Year 2005
Total steel	1,677,987 Mg
Coke	1,027,905 Mg
Pig iron	1,504,088 Mg
Sinter	1,668,111 Mg
Slabs from continuous casting	1,581,684 Mg
Sheets from hot rolling mill	1,494,860 Mg
Blast furnace gas	3,818,658,000 m^3

analytical mathematical approach. Stochastic nature of the MC method is based on random numbers. MC simulation generates a mean value and upper and lower boundary value for each LCI exchange (Doka and Hischier, 2005). Moreover, according to LaGrega et al. (1994), MC simulation can be considered the most effective quantification method for uncertainties and variability among the environmental system analysis tools (Sonnemann et al. 2004). In the MC method the uncertainty distribution of every single parameter must be specified (Bieda, 2012a, 2012b, 2012c). A number of various LCA-based software tools are available, which are facilitators of the uncertainty assessment of parameters with the use of MC simulation. Among them, the following software packages can be highlighted: SimaPro, Gabi, Umberto. All previously mentioned software packages provide the ability to perform the MC simulation. In order to apply the MC method, it is necessary to translate the information on uncertainty into a standard distribution type (e.g. SimaPro supports 4 types of distributions: uniform, triangular, normal and log-normal (Goedkoop et al. 2007)). Generally, there is no major difference in the MC simulation of uncertainty assessment provided by previously mentioned LCA software packages.

The LCI study was conducted in accordance with all requirements of the International Standards ISO 14040, 14041 and 14043 relating to LCI, as well as delineated in the International Organization for Standardizations ISO 14040 (1997) and in the Polish standards RPrPN-EN ISO 14041 (1998) without the life cycle impact assessment (LCIA) phase.

2. Methodology

2.1. Goal and scope

The definition of goal and scope is perhaps the most important component of a life cycle assessment (LCA) because the study is carried out in accordance with assumptions made in this phase, which define the purpose of the study, the expected product, system boundaries, functional unit (FU) and other assumptions (Roy et al. 2009). Although there are many analytic models for inventory management, the complexity of many practical situations often requires simulation (Evans and Olson, 1998). The MC simulation, one of the most widespread stochastic model uncertainty analyses, along with the CB analytic tool, spreadsheet add-in software, constitutes a practical methodology for determining the uncertainty of LCI parameters.

The goals of this study were as follows:

- To develop a stochastic approach for LCA technique limited to LCI uncertainty assessment, in an annual cycle, for MSP steel process route from CP and SP to HRM with a view to facilitating the range of emerging impact assessment methods in future studies.
- To promote the development of LCI and/or LCA research and its application in Poland.

In the present study I decided to resign from the analysis of the main environmental load (input, output): consumed energy and raw materials, produced wastes and emissions into the air, water and soil from the MSP's steel-making process in favor of main products (steel, coke, pig iron, sinter, slabs from CSC, sheets from HRM and blast furnace gas) manufactured by MSP (Table 1).

The complete inventory assessment integrated with the steel-making process in MSP from an annual perspective (2005) was conducted and presented in the study carried out by Kulczycka and Henclik (2009) as well as in a recently published author's work (Bieda, 2012c). Moreover, detailed LCI concerning MSP's IBF and BOF have been presented in Bieda (2012a, 2012b).

Fig. 1 shows a simplified steel manufacturing process flow diagram in MSP and boundary (main products — highlighted with a darker color marker) of the system studied with the corresponding main input and output. The system boundary included the following steel process products: total production of the steel, coke, pig iron, sinter, slabs from CSC, sheets from HRM and blast furnace gas. It does not include the steel manufacturing processes. Moreover, MSP's power plant, mining and transportation of raw coal, crude oil and natural gas were not included. Key characteristics for MSP are shown in Table 1 (Mittal Steel Poland, 2007).

2.2. Uncertainty assessment in LCI

In the Commission Decision of 18 July 2007 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council, uncertainty means: "a parameter associated with the result of the

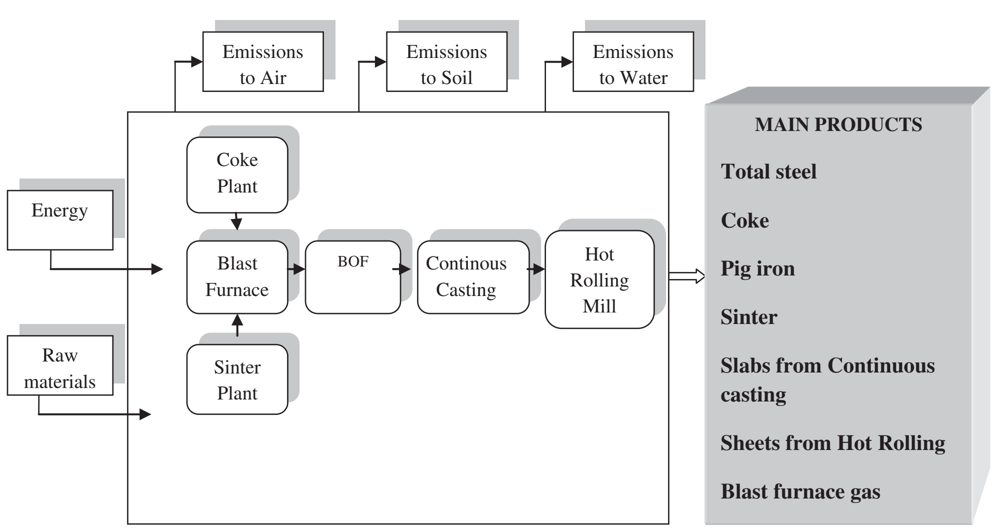

Fig. 1. System boundary (main products — highlighted with a darker color marker) and process flow diagram of the MSP steel plant activity.