THE IMPORTANCE OF LCA IN THE MANAGEMENT OF NATURAL RESOURCES IN STEEL INDUSTRY

BURCHART-KOROL Dorota

Central Mining Institute, Department of Energy Saving and Air Protection, Plac Gwarkow 1, 40-166, Katowice, Poland,UE

dburchart@gig.eu

Abstract

Life Cycle Assessment (LCA) is important management tool for evaluation of the environmental impacts in whole life cycle of product or technology from the extraction of the raw materials to the end-of-life. In the paper, special attention is given to the role of LCA as a tool for natural resources management, environmental implications of critical raw materials evaluation and resources depletion assessment in the steel industry. It was presented environmental life cycle impact assessment methods and impact categories relevant to the assessment of natural resources in steel sector. Based on the own analysis, it was found that LCA can help optimize environmental performance connected with natural resource and critical raw materials management in steel industry.

Keywords: natural resources management, steel industry, critical raw materials, life cycle assessment

1. INTRODUCTION

Management of natural resources is one of the priorities of environmental policy in steel industry and represents a significant part of the strategy for sustainable development. Therefore, the steel sector begins to use new methods to assess depletion of natural resources. Life Cycle Assessment (LCA) is one of the tools to allow assessment of depletion of metals, minerals and fossil fuels, water etc. LCA is important management tool for evaluation of the environmental impacts in whole cycle of product or technology from the extraction of the raw material through the manufacturing, packaging, the use stage, re-use and maintenance, this end-of-life. LCA can have more potential in improvement and development opportunities of natural resources, including critical raw materials (CRMs) used in steel industry.

In the European Union, a more efficient use of resources is at the core of policy aimed at promoting sustainable growth. According to European Commission [1] resource security is objective in flagship initiative under the Europe 2020 Strategy A resource-efficient Europe, which addressing all the types of natural resources (metals and minerals, water, air, land and soil, marine resources), and advocating more efficient use of resources for ensuring the security of supply, decoupling economic growth from resource use; and reducing the environmental pressure related to resource extraction and use. The metals which have the highest share of net import over apparent consumption (more than 50 %) in EU-27 are: antimony, cobalt, molybdenum, niobium, platinum, rare earths elements, tantalum, titanium minerals, vanadium, manganese ore, iron ore, bauxite, tin, zinc and chromium [2]. Raw materials are fundamental to Europe’s economy, growth and jobs and they are essential for maintaining and improving our quality of life. According to [3] twenty raw materials were identified as critical raw materials: antimony, beryllium, borates, chromium, cobalt, coking coal, fluorspar, gallium, germanium, indium, magnesite, magnesium, natural graphite, niobium, PGMs (platinum group metals), phosphate rock, HREEs (heavy rare earth elements), LREEs (light rare earth elements), silicon metal and tungsten. The PGMs consist of six metals: palladium, platinum, rhodium, ruthenium, iridium and osmium. The REEs are a group of seventeen metals, which are often discussed together due to their similar properties. These critical raw materials have a high economic importance to the EU combined with a high risk associated with their supply [2]. LCA is suitable tool for management of Critical Raw Materials [3]. Up to now carbon footprint and changes in raw materials and ecoinnovations for steel supply chains were presented in papers [4-8]. The main goal of this study is to present life cycle impact assessment methods relevant to the assessment of natural resources in steel sector.

2. REVIEW OF RESOURCES DEPLETION ASSESSMENT METHODS

For natural resource depletion are used different approaches, which can be applied for environmental impact assessment. This approach differ perceptions of the problem, coverage of resources typologies and results in terms of environmental impacts [9]. Existing models for the resource availability assessment in LCA relate to mass and energy of a resource used, exergy impacts, future consequences of resource extraction (e.g., surplus cost, surplus energy), or diminishing geologic stocks [9-13]. Natural resources are generally categorized in the context of LCA and beyond as abiotic and biotic resources or stock, fund and flow resources. Abiotic resources are inorganic or non-living materials at the moment of extraction. Biotic resources are living at least until the moment of extraction from the natural environment [14]. Metrics for fossil depletion according to selected life cycle impact assessment (LCIA) was shown in **Table 1**. LCA methods and impact categories for metal and minerals depletion assessment was shown in **Table 2**.

The impact categories for fossil fuel depletion, metals and minerals are expressed in different units. ReCiPe Midpoint characterisation factors for metal depletion are converted with iron as a reference substance (kilograms of iron-equivalent). According to ReCiPe Midpoint method fossil depletion is expressed as oil equivalent. 1 kg oil equivalent has a lower heating value of 42 MJ. The unit of endpoint characterisation factor according to ReCiPe Endpoint for abiotic resource depletion is increased cost ($). According to IMPACT 2002 the unit MJ primary means MJ total primary non-renewable energy. In EcoIndicator 99 method resource depletion is expressed as the surplus energy needed for future extractions of minerals and fossil fuels. According to CML model abiotic resource depletion impact category indicator is related to extraction of scarce minerals and fossil fuels. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels based on the remaining reserves and rate of extraction. Antimony (Sb) is used as the reference case for minerals depletion and the reference unit is therefore kg Sb equivalent [10-19].

Table 1 Life cycle impact assessment methods for fossil depletion analysis

LCIA method	Impact category	Unit	Source
Cumulative Energy Demand (CED)	Non renewable, fossil	MJ	[15]
Cumulative Exergy Demand (CExD)	Non renewable, fossil	MJ_{ex}	[10,11]
CML	Abiotic depletion (fossil fuels)	MJ	[16,17]
IMPACT 2002	Non-renewable energy	MJ primary	[18]
ReCiPe Midpoint	Fossil depletion	kg oil eq	[13]
ReCiPe Endpoint	Fossil depletion	$	[13]
EcoIndicator 99	Fossil fuels	MJ surplus	[12]

Table 2 Life cycle impact assessment methods for metal and minerals depletion analysis

LCIA method	Impact category	Unit	Source
CExD	Non renewable, metals	MJ_e	[10,11]
CExD	Non renewable, minerals	MJ_{ex}	[10,11]
CML	Abiotic depletion	kg Sb eq	[16,17]
IMPACT 2002	Mineral extraction	MJ surplus	[18]
ReCiPe Midpoint	Metal depletion	kg Fe eq	[13]
ReCiPe Endpoint	Metal depletion	$	[13]
EcoIndicator 99	Minerals	MJ surplus	[12]

CML-IA is a LCA methodology developed by the Center of Environmental Science (CML) of Leiden University in The Netherlands. Depletion of abiotic resources is measured in two impact categories: abiotic depletion (elements, ultimate reserves) and abiotic depletion (fossil fuels). Resource depletion is assessed by means of the abiotic depletion potential (ADP), differentiation between fossil depletion and element (metals/minerals) depletion [16,17]. In the ADP model, the decrease of the resource itself is taken as the key problem [17].

Exergy is another way to express energy contents than energy content itself. Exergy has been described as 'the upper limit of the portion of a resource that can be converted into work'. Exergy is a measure for the useful "work" a certain energy carrier can offer [10,11,19].

The surplus energy approach, as adopted in the Eco-Indicator 99 (EI99) [12] and IMPACT 2002+ [18], is based on the assumption that as more of a resource is extracted over time, quality of deposits still available tends to decrease. Each extraction of a certain amount of a resource from a deposit in the present will require an earlier move to more energy-intensive extraction from lower-quality, less accessible deposits in the future.

Monetizing the energy requirements of resource extraction, as in the ReCiPe methodology, provides a more universally applicable indicator; in principle, marginal extraction costs can also be utilized as a metric for renewable resource extraction. The ReCiPe 2008 method follows an idea similar to the surplus energy concept, but in addition uses monetization of surplus energy demand for characterising future efforts for resource extraction. Marginal increase of extraction cost per kilogram of extracted resource forms the basis of the model, differentiated by deposit and assuming a discount rate over an indefinite time span [13].

3. RESULTS AND DISCUSSION

In the paper results of fossil fuels, mineral and metals depletion assessment for steel based on different life cycle impact assessment methods were presented (**Table 3** and **Table 4**). The analysis was done for the integrated steel plant. According to the paper [20] fossil fuels are the most important abiotic resources in steel production. Fossil fuels cover natural gas, petroleum, lignite, hard coal and peat [9]. Functional unit (FU) of this life cycle impact assessment was one ton of BOF steel produced. The results were obtain for BOF steel according to the mass allocation for cast steel and co-products: blast furnace (BF) slag and basic oxygen furnace (BOF) slag. The system boundary of integrated steel plant covered included all unit processes in the steel plant: the iron ore sinter plant, blast furnace, lime production plant, basic oxygen furnace, continuous casting plant and hot rolling plant. Particulate results of the life cycle inventory (LCI), the environmental impact assessment of steel production based on the Recipe Midpoint and process flow diagram of the steel manufacturing were shown in papers [20,21].

Table 3 Fossil fuels depletion for BOF steel according to different LCIA methods.

LCIA method	Impact category	Unit	BOF steel	Cast steel	BOF slag	BF slag
CED	Non renewable, fossil	MJ/FU	35110	24310	7371	3430
CExD	Non renewable, fossil	MJ_{ex}/FU	35827	24806	7521	3500
CML	Fossil fuels depletion	MJ/FU	35110	24310	7371	3430
IMPACT	Non-renewable energy	MJ primary/FU	36175	25047	7594	3534
ReCiPe Midpoint	Fossil depletion	kg oil eq/FU	793	549	167	77
ReCiPe Endpoint	Fossil depletion	$/FU	131	91	28	13
EI 99	Fossil fuels depletion	MJ surplus/FU	1345	931	282	131

Source: own analysis

Table 4 Minerals/metals depletion for BOF steel according to different LCIA methods.

LCIA method	Impact category	Unit	BOF steel	Cast steel	BOF slag	BF slag
CExD	Non renewable, metals	MJ_{ex}/FU	3127	2165	656	305
CExD	Non renewable, minerals	MJ_{ex}/FU	165	114	35	16
CML	Abiotic depletion	kg Sb eq/FU	0,0022	0,0015	0,0005	0,0002
IMPACT	Mineral extraction	MJ surplus/FU	82	57	17	8
ReCiPe Midpoint	Metal depletion	kg Fe eq/FU	1240	859	260	121
ReCiPe Endpoint	Metal depletion	$/FU	89	61	19	9
EI 99 H/A	Minerals	MJ surplus/FU	76	52	16	7

Source: own analysis

Calculations performed based on presented LCIA methods allowed to determine the largest abiotic resource depletion in steel production. It was found that the largest fossil fuels depletion in integrated steelmaking route has hard coal coke, the largest minerals depletion has refractory and the largest metal depletion has iron ore. Application of LCA can assist decision-makers manage of natural resources and allows determination of the key processes and raw materials, on which should be focused ecoinnovations, in order to reduce the consumption of resources, including fossil fuels, mineral and metals depletion.

4. CONCLUSION

Life cycle approach and life cycle assessment are fundamental elements for sustainability assessment. LCA is a suitable method for depletion of abiotic and biotic resources assessment. Different LCIA models exist for the assessment of fossil fuels, metals and minerals.

Characteristic of resource depletion assessment methods and their applications in steel production were presented in the article. It was found that the choice of method depends on purpose of LCA. The study showed that LCA is appropriate method for evaluating depletion of natural resources and resource management in the steel sector. LCA is one of the most important assessment tool of Environmental Manegement System (EMS). LCA method can help to steel industry to provide information about depletion of natural resource in whole life cycle, support benchmarking of technology assessment and carry out environmetal impact assessment to reduce the impacts. Life cycle impact assessment methods help to increase efficiency of steel production and improve environmental performance. Thanks to the environmental assessment carried out using the LCA is possible to optimize the depletion of natural resources, which is imperative for the development of sustainability steel.

This work highlights the role of LCA as an important and helpful tool for sustainable management of natural resources and critical raw materials in steel industry.

ACKNOWLEDGEMENTS

The research was carried out within the framework of the statutory work of the Central Mining Institute in Katowice (Poland) entitled: The environmental impact assessment of steel production technology based on the natural resource depletion analysis, No. 11340455-324

REFERENCES

[1] A resource-efficient Europe—flagship initiative under the Europe 2020 Strategy. European Commission COM(2011) 2

[2] MANCINI L., SERENELLA S., RECCHIONI M., BENINI L., GORALCZYK M., Pennington D., Potential of Life Cycle Assessment for Supporting the Management of Critical Raw Materials, The International Journal of Life Cycle Assessment No.20, 2015 pp. 100–116

[3] REPORT ON CRITICAL RAW MATERIALS FOR THE EU, European Comission 2014

[4] PUSTĚJOVSKÁ P., JURSOVÁ S. Measure to reduce CO_2 emissions i metallurgy. In METAL 2011: 20th International Conference on Metallurgy and Materials. Ostrava: TANGER, 2011

[5] GRACZYK M., BURCHART-KOROL D., WITKOWSKI K. Reverse Logistics Processes in Steel Supply Chains. In METAL 2012: 21st International Conference Metallurgy and Materials. Ostrava: TANGER, 2012

[6] SANIUK S., SANIUK A., Prototyping of Production Networks in Regional Metallurgical Cluster. In METAL 2012: 21st International Conference Metallurgy and Materials. Ostrava: TANGER, 2012

[7] LENORT R. , WICHER P., Concept of a system for Resilience Measurement in Industrial Supply Chain, In METAL 2013: 22nd International Conference Metallurgy and Materials. Ostrava: TANGER, 2012

[8] BURCHART-KOROL D., KOROL J., FRANCIK P., Application of the New Mixing And Granulation Technology of Raw Materials for Iron Ore Sintering Process. Metalurgija, No. 5, 2012, p. 187-190.

[9] KLINGLMAIR M, SALA S, BRANDAO M., Assessing Resource Depletion in LCA: A Review of Methods and Methodological Issues. The International Journal of Life Cycle Assessment Vol. 3, No. 19, 2014, pp.580–592

[10] BÖSCH ME, HELLWEG S, HUIJBREGTS M, FRISCHKNECHT R., Applying Cumulative Exergy Demand (Cexd) Indicators to the Ecoinvent Database. The International Journal of Life Cycle Assessment Vol. 3, No 12, 2007, pp. 181–190

[11] FINNVEDEN G, ÖSTLUND P., Exergies of Natural Resources in Life Cycle Assessment and Other Applications. Energy, Vol. 9, No. 22, 1997, pp.923–931

[12] GOEDKOOP M., SPRIENSMA R.,.MÜLLER-WENK R, HOFSTETTER P., KÖLLNER T., METTIER T., BRAUNSCHWEIG A., FRISCHKNECHT R., VAN DE MEENT D., RIKKEN M., BREURE T., HEIJUNGS R., LINDEIJER E., SAS H., EFFTING S.: The Eco-indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment. Methodology Report. Third Edition, Amersfoort: Pré Consultants, 2001.

[13] GOEDKOOP M, HEIJUNGS R, HUIJBREGTS M, SCHRYVER AD, STRUIJS J, ZELM RV., ReCiPe 2008: A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level. Pré Consultants, CML, RUN, RIVM, Amersfoort 2013.

[14] Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials. UNEP International Panel for Resource Management, Paris UNEP 2010

[15] FRISCHKNECHT R., JUNGBLUTH N., (Editors), ALTHAUS J., BAUER C., DOKA G., DONES R., HISCHIER R., HELLWEG S., HUMBERT S., KÖLLNER T., LOERINCIK Y., MARGNI M., NEMECEK T., Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent Swiss Centre for LCI. Dubendorf, No 3, 2007,

[16] GUINÉE JB, BRUIJN H, VAN DUIN R, GORREE M, HEIJUNGS R, HUIJBREGTS M, HUPPES G, KLEIHN R, DE KONING A, VAN OERS L, SLEESWIJK A, SUH S, UDO DE HAES HA (eds) Handbook on Life Cycle Assessment- an Operational Quide to the ISO Standards. Kluwer Academic Publishers, Dordrecht 2002.

[17] VAN OERS L, DE KONING A, GUINÉE JB, HUPPES G., Abiotic Resource Depletion in LCA. Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam 2002

[18] JOLLIET O, MARGNI M, CHARLES R, HUMBERT S, PAYET J, REBITZER G, ROSENBAUM R (2003) IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. The International Journal of Life Cycle Assessment Vol. 6, No. 8, 2003, pp.324–330

[19] CZAPLICKA-KOLARZ K., BURCHART-KOROL D., KOROL J.: Application of Life Cycle Assessment and Exergy to Environmental Evaluation of Selected Polymers, Polimery, Vol. 7-8, No. 58, 2013, pp. 605-609

[20] BURCHART-KOROL D., Life Cycle Assessment of Steel Production in Poland. A Case Study, Journal of Cleaner Production, No. 54, 2013, pp. 235-243

[21] BURCHART-KOROL D., KRUCZEK M., Water Scarcity Assessment of Steel Production in National Integrated Steelmaking Route, Metalurgija, Vol. 1, No. 54, 2015, pp. 276-278