Management
2013
Vol.17, No. 2

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Computer Applications in Eco-efficiency Assessment in Logistics

1. Introduction

Eco-efficiency is one of the key factors of sustainable development. The eco-efficiency analysis integrates economical factors and environmental impact, two pillars of sustainable development. Eco-efficiency concept is known for many years, but the novelty of the paper is to assess the eco-efficiency at every stage of life cycle. For this purpose the software tools are needed, especially when we are dealing with complex systems

2. Eco-efficiency assessment

The eco-efficiency concept was first defined in 1989 by The World Business Council for Sustainable Development (WBCSD) as being achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the earth's carrying capacity. According to ISO 14045:2012 eco-efficiency is an aspect of

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sustainability relating the environmental performance (measurable results related to environmental aspects) of a product system (collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product) to its product system value. Within eco-efficiency assessment, environmental impacts are evaluated using Life Cycle Assessment (LCA) according to ISO 14040:2006 (Hellweg et al. 2005). More information about LCA quantification of chosen production system was done in paper (Burchart-Korol 2013) and eco-efficiency in supply chain in the paper (Burchart-Korol et al. 2012). New solutions in enterprise manager are needed (Saniuk et al. 2011, Saniuk et al. 2013). Eco-efficiency assessment covers principles such as life cycle perspective, comprehensiveness, functional unit approach, iterative nature, transparency and priority of a scientific approach. The following principles are fundamental and serve as guidance for decisions relating to both the planning and the conducting of an eco-efficiency assessment. An eco-efficiency is a relative concept and a product system is only more-or-less eco-efficient in relation to another product system. The result of Life Cycle Inventory (LCI) study may be used directly as input to an eco-efficiency assessment. The product system value assessment shall consider the full life cycle of the product system. Material Flow Analysis (MF A) is a method to establish an inventory for an LCA.

3. Review of eco-efficiency assessment in logistics

According to Wang et al. (2013) the question of trading off the environmental and economic effects embodied in eco-efficiency in the hybrid manufacturing and remanufacturing logistics network design in the context of low-carbon economy was analyzed and presented. Remanufacturing supply chain consists of the traditional forward logistics network for manufacturing and distribution and the reverse logistics supply chain logistics network for remanufacturing. Till now among eco-efficient logistics network design research Bloemhof-Ruwaard et al. (2004) and Krikke et al. (2003) developed the logistics network design and model for eco-supply chain optimalization. Quariguasi Frota Neto et al. (2009) presented methodology for eco-efficiency assessing in logistic networks. Table 1 describe the family of methods, their applicability, main advantages and limitations.

There are known the research on eco-efficiency assessment methods which cover: methods based on single efficiency index, methods based on weighting, multi-objective methods, multicriteria methods.

Table 1. Main streams of research on eco-efficiency in logistics network

No	Family	Trade-off	Flexibility	Visual Trade-off	Sources
1	Single ratio	no	no	no	CML 2001 Kobayashi et al. 2005 Kuosmanen 2005 Schulz et al. 2005
2	Weighting	no	yes	no	Bloemhof-Ruwaard et al 2004
3	Multi-objective	yes/no	yes	no	Krikke et al. 2003
4	Eco-topology	yes	yes	yes/no	Quariguasi Frota Neto et al. 2009

Sources: own analysis based on Quariguasi Frota Neto et al. (2009)

4. Methods

In this paper the logistics system was developed with the Umberto for Eco-efficiency software which is modeling tool for Material Flow Networks. Umberto for Eco-efficiency software is a suitable tool for the eco-efficiency analysis and environmental impact of processes, products or technology evaluation with life cycle approach. On the basis of material and energy flow models provided by the software, it integrates the perspective on the environmental performance into the company's management and can lead to the rational use of resources (Spengler 2009).

The applicability of Umberto for Eco-efficiency software:

- sankey diagrams,
- graphic modeling of assessing the impact of logistics, systems, process,
- visualization material flows in whole life cycle,
- modeling material flow networks and energy flow networks,
- modeling and visualization of complex system,
- calculation of environmental indicators, inter alia: carbon footprints.

The steps of procedure for eco-efficiency assessing, using Umberto for Eco-efficiency software was shown in figure 1.

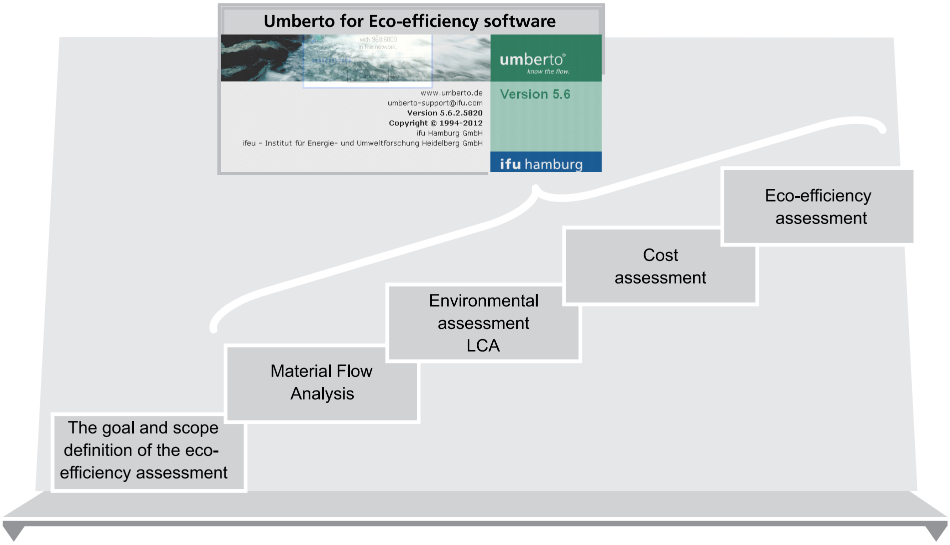


Figure 1. Eco-efficiency assessment procedure with computer application

Source: own study

Material Flow Analysis is an important constituent of Environmental Management Information Systems (EMIS). As modeling approach in material flow analyses so called Material Flow Networks are applied making use of special application software. Material Flow Networks are a method from Environmental Informatics and support computation of material and energy f1ows (Page et al. 2008, Wohlgemuth V et al. 2006).

Notation used in Material Flow Networks Model are presented in figure 2:

1. The central components of Material Flow Networks are the **Transitions,** which are marked as blue boxes in the network. They specify energy and material transformation processes. There are predefined rules for transformation of input into output materials which can be based on parameters, mathematical functions, standard transitions from libraries, or user defined transformation programs.
2. Circles are so-called **Places,** i.e. inventory and connections without material transformation. They describe system boundaries (Input-/Output), take care of branching and fusing in the network or denote inventories. Green circ1es marked with a vertical line on the left are Input Places for materials

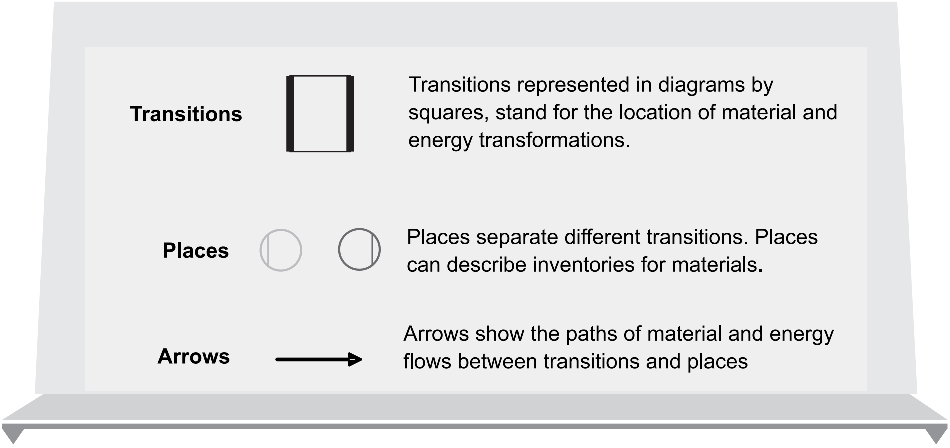


Figure 2: Graphical notation used in Material Flow Networks Model

Source: own analyses based on Page et al. 2008, Page et al. 2005, Pimpisut et al. 2007

and energy; red circ1es are Output Places for products and emissions. Yellow circ1es are connection places for material flow branching and storage.

3. **Connections** shown as directed lines represent material and energy flows from Places to Transitions and from Transitions to Places. Several materials can flow in one arrow.
4. Embedded blue boxes within another box denote **Submodels** which include another partial network in order to reduce model complexity (Page et al. 2008, Page et al. 2005, Pimpisut et al. 2007)

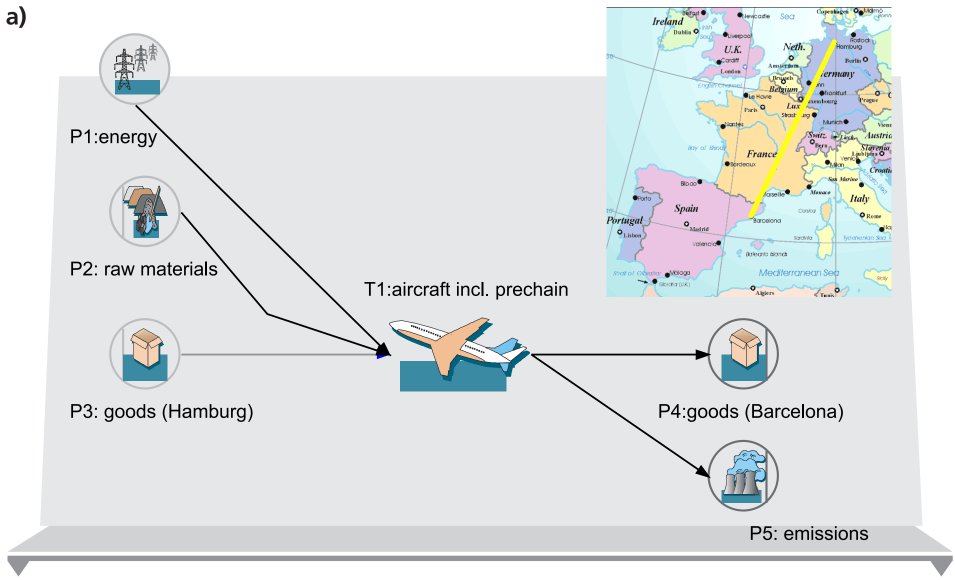
5. Results and Discussions

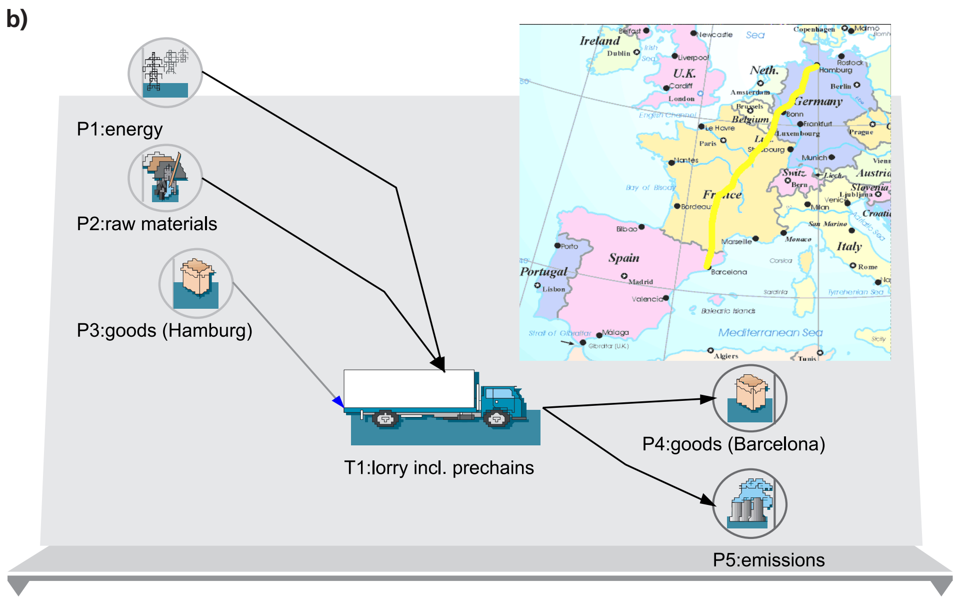
The computer applications in eco-efficiency assessment in logistics was presented on the case of five scenarios of logistics systems of goods transport from Hamburg to Barcelona. Material Flow Analysis (MF A) and Life Cycle Assessment (LCA) are the most suitable for environmental analysis and eco-efficiency. In this paper Umberto for Eco-efficiency 5.6 has been applied for valuation of the different logistic possibilities. Transition Parameters of each logistics system are shown in table 2. Material Flow Networks for different logistic possibilities were shown in figure 3.

Table 2. Transition Parameters of each analysed logistics system

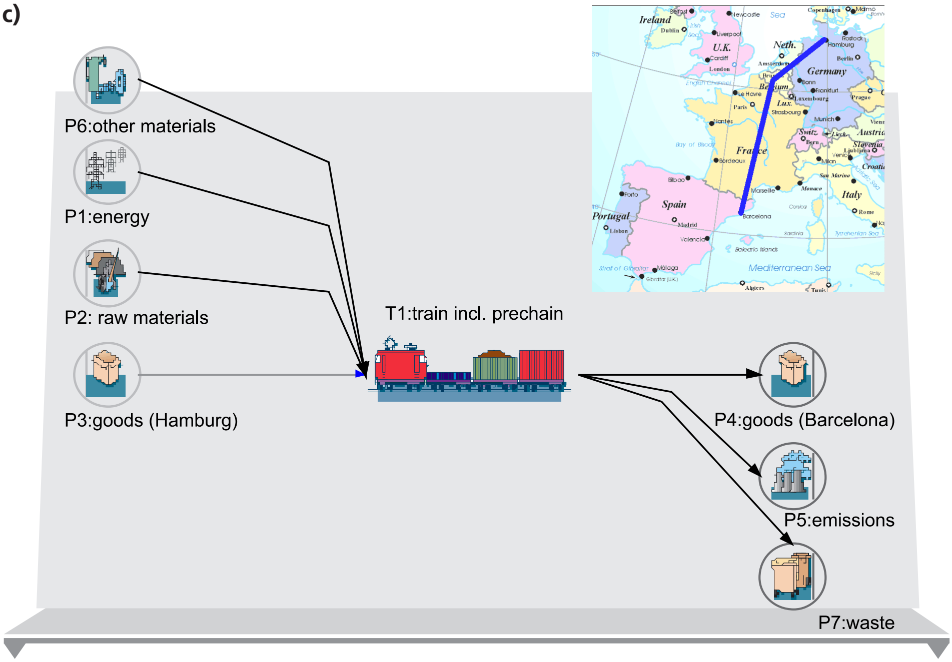
Logistics system	Transition Parameters	Unit	Logistics
Aircraft	flown distance	km	1530
	degree of efficiency	%	90
Lorry	distance	km	1760
	degree of efficiency	%	80
	type of lorry (1 to 5; 6=average)		4
	motorway (percentage of complete distance)	%	80
	country road	%	15
	other	%	5
Train	distance	km	1650
	0=electric engine, 1=diesel engine		0
	one goods waggon=0, short train=1, whole train=2		1
Combination vessel/train	distance	km	1800
	type of vessel (1=small to 5=oil tanker)		1
	distance	km	450
	0=electric engine, 1=diesel engine		0
	one goods waggon=0, short train=1, whole train=2		1
Vessel	distance	km	3915
	type of vessel (1=small to 5=oil tanker)		1

Source: Umberto for Eco-Efficiency 5.6

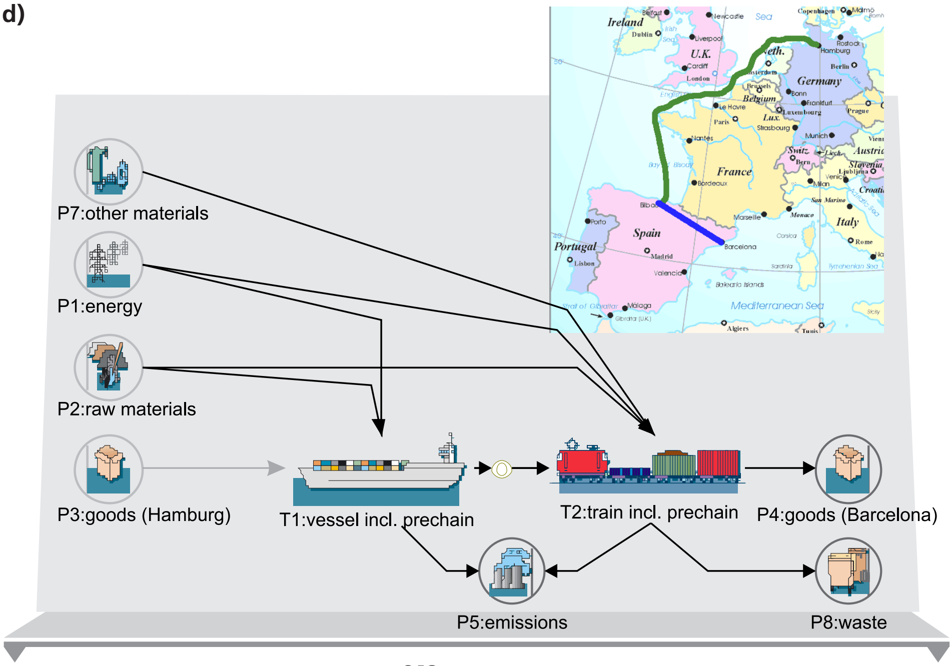

a)
P1:energy
P2: raw materials
P3: goods (Hamburg)
T1:aircraft incl. prechain
P4:goods (Barcelona)
P5: emissions


b)
P1:energy
P2:raw materials
P3:goods (Hamburg)
T1:lorry incl. prechains
P4:goods (Barcelona)
P5:emissions

c)


P6:other materials
P1:energy
P2: raw materials
P3:goods (Hamburg)
T1:train incl. prechain
P4:goods (Barcelona)
P5:emissions
P7:waste
Ireland
U.K.
Neth.
Germany
France
Spain
Portugal
Italy
Mediterranean Sea

d)


P7:other materials
P1:energy
P2:raw materials
P3:goods (Hamburg)
T1:vessel incl. prechain
T2:train incl. prechain
P4:goods (Barcelona)
P5:emissions
P8:waste
Ireland
U.K.
Germany
Belgium
France
Spain
Portugal
Italy
Mediterranean Sea

e)

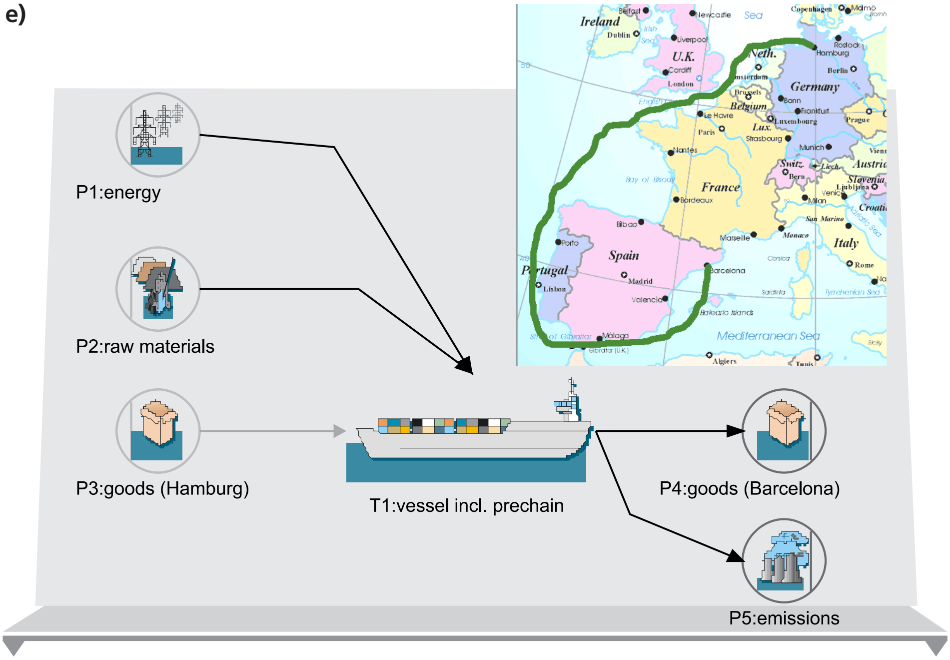


Figure 3. Material Flow Network for different logistic possibilities. (a) aircraft, (b) lorry, (c) train (d) combination vessel/train (e) vessel

Source: Umberto for Eco-Efficiency 5.6

6. Valuation System

In this paper valuation of the different logistic possibilities was shown. The Valuation System is one part of the sophisticated CML Valuation System that is delivered with Umberto for Eco-efficiency. CML is the Centre for Environmental Studies in Leiden, Netherlands. The Valuation System aggregates several material flow, which have an environmental impacts and creates indicators like the Global Warming Potential (GWP) (CML 2000, CML 2001). Valuation system results based on Environmental Impact Logistics was presented in table 3.

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Table 3. Valuation System Results of the different logistic possibilities

Methods	Complete Energy Consumption	Global Warming Potential 100y
Unit	**kWh**	**kg CO_2 eq**
Aircraft	85154.66	23540.57
Lorry	9397.54	2608.05
Train	3492.93	1 248.70
Combination vessel/train	4249.77	991.89
Vessel	7 171.31	1 416.67

Source: Umberto for Eco-Efficiency

It is concluded that the highest impact of the different logistic possibilities on greenhouse gas emissions has aircraft and the lowest has vessel and train.

7. Conclusions

This research highlights the importance of Material Flow Analysis in complex systems and for logistics system. Eco-efficiency is important method which is used for assessing the technology, products and logistic systems, but for detailed analysis software tools are needed. In this paper Umberto for Eco-efficiency was proposed for Material Flow Network and Life Cycle Assessment. It is sophisticated tool for eco-efficiency analysis in whole life cycle and for each unit process.

The results of this study can be used as the first step in performing a full cradle-to-grave eco-efficiency that includes all phases of the logistics system.

Abstract

Computer Applications in Eco-efficiency Assessment in Logistics

The goal of this study is to present computer applications in eco-efficiency assessment in Logistics based on Umberto for Eco-efficiency software. The study defines the major components of eco-efficiency analysis like: Life Cycle Assessment (LCA) and

Material Flow Analysis (MFA). According to ISO 14045:2012 eco-efficiency assessment is a quantitative management tool which enables the study of life-cycle environmental impacts of a product system along with its product system value for a stakeholder. Within eco-efficiency assessment, environmental impacts are evaluated using Life Cycle Assessment (LCA). The eco-efficiency methodology is proposed with using Umberto for Eco-efficiency software. Therefore, this article presents the results of Life Cycle Assessment according to methods used in Umberto software on the case study of valuation of the different logistic possibilities. The results of this study can be used as the first step in performing a full cradle-to-grave eco-efficiency that includes all phases of the logistics system.

***Keywords*:** *Umberto for Eco-efficiency, logistics, Material Flow Analysis, Life Cycle Assessment, eco-efficiency.*

Streszczenie

Aplikacje komputerowe w ocenie ekoefektywności systemów logistycznych

Celem tej pracy jest przedstawienie aplikacji komputerowych w ocenie ekoefektywności systemów logistycznych z wykorzystaniem oprogramowania Umberto for Eco-efficiency. Niniejszy artykuł zawiera wybrane elementy analizy ekoefektywności jak: ocena cyklu życia (LCA- Life Cycle Assessment) i analizy przepływu materiałów (MFA - Materiał Flow Analysis). Przedstawiono przegląd literatury dotyczący zastosowania analiz ekoefektywności w logistyce. Zgodnie z normą ISO 14045:2012 ekoefektywność jest narzędziem zarządzania, które umożliwia kwantyfikację oddziaływania na środowisko systemu produktów wraz z systemem wartości produktu. W ekoefektywności oceny oddziaływania na środowisko są oceniane za pomocą oceny cyklu życia (LCA). W artykule zaproponowano przeprowadzenie MFA i LCA z zastosowaniem oprogramowania Umberto for Eco-efficiency. Przedstawiono wyniki oceny środowiskowej dokonanej dla wybranych systemów logistycznych jako studium przypadku. Wykonane do tej pory analizy stanowią pierwszy krok w celu dokonania pełnej oceny ekoefektywności w całym cyklu życia.

Słowa kluczowe: *Oprogramowanie - Umberto for Eco-efficiency, systemy logistyczne, analizy przepływu materiałów (MFA), oceny cyklu życia (LCA), ekoefektywność.*

References

1. Bloemhof-Ruwaard JM, Krikke H, van Wassenhove LN. (2004), *OR Models for Eco-Eco Closed Loop Supply Chain Optimization*. In Dekker R, Fleischmann M, Inderfurth K, van Wassenhove LN, editors. Reverse Logistics: Quantitative Models for Closed-Loop Supply Chains. Springer/ Verlag: 357-379.
2. Burchart-Korol D., Czaplicka-Kolarz K., Kruczek M. (2012), *Eco-efficiency and eco-effectiveness concepts in supply chain management*, Carpathian Logistics Congress, Jesenik 2012.
3. Burchart-Korol D. (2013): *Life Cycle Assessment of Steel Production in Poland. A Case Study*. Journal of Cleaner Production, 54 (1), 235-243.
4. CML Guinee J.B. et al. (2000), *An operational guide to LCA*. Preliminary version, Leiden: CML, 2000; http://www.leidenuniv.nl/interfac/cml/lca2/index.html.
5. CML (2001), *Characterisation factors of CML.* Version 1.00, Leiden: CM L, Januar 2001; http://www.leidenuniv.nl/interfac/cml/lca2/index.html.
6. Hellweg S., Doka G., Goran, F., Hungerbuhler H. (2005), *Assessing the eco-efficiency of end-of-pipe technologies with the environmental cost efficiency indicator: A case study of solid waste management*. Journal of Industrial Ecology 9 (4), 189-203.
7. Kobayashi Y., Kobayashi H., Hongu A., Sanehira K. (2005), *A practical method for quantifying ecoefficiency using eco-design support tools*. Journal of Industrial Ecology, 9 (4), 131-144.
8. Krikke, H., Bloemhof-Ruwaard, J.M., van Wassenhove, L.N. (2003), *Current product and closed-loop supply chain design with an application to refrigerators*. International Journal of Production Research, 41 (16), 3689-3719.
9. Kuosmanen, T., Kortelainen, M. (2005),. *Measuring eco-efficiency of production with data envelopment analysis*. Journal of Industrial Ecology, 9 (4), 59-72.
10. Page B., Wohlgemuth V. (2005), *Linking economic optimisation and simulation models to environmental material flow networks for eco-efficiency*. In: Hilty, L.M., Seifert, E.K., Treibert, R. (Eds.), Information Systems for Sustainable Development. Idea Group Publishing, Hershey, 94-108.
11. Page B., Wohlgemuth V., Raspe M. (2008), *Material Flow Analysis for Eco-Efficiency with Material Flow Network Reference Models – Concepts and Case Study*, iEMSs 2008: International Congress on Environmental Modeling and Software Integrating Sciences and Information Technology for Environmental Assessment and Decision Making.

12. Pimpisut D., Page B., Spehs T., Wohlgemuth V. (2007), *An Environmental Management Information System for Eco-Efficiency of Agro-Industries in Thailand based on Material Flow Networks*. In: O. Hryniewicz, et.al. (Eds.): Proc. 21 st Intern. Conf. Informatics for Environmental Protection. Warsaw, Poland, 12-14th Sept. 2007, Shaker Publ., Aachen, pp. 219-227.
13. Quariguasi Frota Neto J., Walther G., Bloemhof 1., van Nunen J.A.E.E., Spengler T. (2009), *A methodology for assessing eco-efficiency in logistics networks*, European Journal of Operational Research, 193, 670-682.
14. Saniuk A., Jakabova M., Babcanova D. (2011), *New solutions in enterprise management*, in: Innovations in information management systems, Monograph, (ed. by Anna Saniuk, Sebastian Saniuk), Wyd. Instytutu Informatyki i Zarządzania Produkcją Uniwersytetu Zielonogórskiego, Zielona Góra , s. 44-61, ISBN: 978-83-933843-0-3.
15. Saniuk A., Witkowski K., Saniuk S. (2013), *Management of production orders in metalworking production*, 22nd International Conference on Metallurgy and Materials - METAL 2013, TANGER, Czech Republic, Brno, CD-ROM, ISBN: 978-80-87294-39-0.
16. Scholz, R.W., Wiek, A. (2009), *Operational eco-efficiency: Comparing firms' environmental investments in different domains of operation.* Journal of Industrial Ecology 2005, 9 (4),155-170.
17. Spengler T. *A methodology for assessing eco-efficiency in logistics networks*, European Journal of Operational Research, 193, 670-682 http://www.ifu.com.
18. Wang Y., Zhu X., Lu T., Jeeva A.S. (2013), *Eco-efficient based logistics network design in hybrid manufacturing/ remanufacturing system in low-carbon economy*, Journal of Industrial Engineering and Management JIEM, 6, 200-214.
19. Wohlgemuth V., Page 8., Kreutzer W. (2006), *Combining discrete event simulation and material flow analysis in a component-based approach to industrial environmental protection*, Environmental Modeling & Software, 21, 1607-1617.