GCSM
11th Global Conference on Sustainable Manufacturing
2013
23rd - 25th September
Berlin - Germany

6.5 Ecological holistic assessment for production technologies

R. Steinhilper [1], M. Süchting [1], A. Kruse [1]

[1] Chair of Manufacturing and Remanufacturing Technology, Bayreuth University, Germany

Abstract

Treating the natural environment in a responsible manner is becoming a key challenge for manufacturing companies. This challenge also regards the planning, implementation and modernization of production technologies. In this case, a new technology should not only have economic advantages, such as higher productivity or flexibility, but should address ecological aspects as well. Many existing approaches only focus on air pollution, measured in CO_2, and therefore consider only one ecological dimension. So these approaches disregard other effects on the natural environment, such as water and soil pollution. Only through a holistic approach, the influences of a production technology on the environment can be considered completely and comprehensively. The following article describes a holistic ecological assessment approach and illustrates this with an example. This approach enables manufacturing companies to ecologically assess production technologies in a holistic way.

Keywords:
Ecological evaluation, Manufacturing, Production Technology

1 INTRODUCTION

Manufacturing companies are always producing in the conflict between high quality, reasonable time consumption and minimal costs. At least since the 1990s the goal of an environmental friendly production has been added to this conflict of cost, time and quality. Especially because of political and social requirements the customers' demand for green products and processes has increased steadily in the last years.

Manufacturing companies themselves also see the need for action in terms of an environmental friendly production. This fact is demonstrated by a continuing high interest from companies in an integration of climate and environmental objectives into their business strategy through an environmental certification according to ISO 14001 [1]. The still growing number of companies that publish data or join environmental initiatives such as the Carbon Disclosure Project underlines this fact, too [2].

In the first instance many attention has been paid for limiting the global warming and the reduction of greenhouse gases. In science, therefore especially methods for the evaluation and reduction of climate-damaging emissions have been developed. Nowadays other environmental aspects such as the protection of water and soil have to be focused, too. However, many of the developed methods consider only one ecological dimension, neglecting other effects on the natural environment such as water and soil pollution.

2 STATE OF THE SCIENTIFIC KNOWLEDGE AND NEED FOR ACTION

2.1 Relevance of environmental system water

Even though the earth's surface is about 71% of water, only 0.62% of the world's available water is groundwater, and therefore drinking water [3]. While in the less industrialized parts of the world, agriculture accounts for almost 90% of water consumption, in highly industrialized areas the industrial sector is responsible for nearly 50% of water consumption. However, according to the UN World Water Development Report little information is available about how much water is consumed and removed by industry for manufacturing processes [4]. Many of today's manufacturing processes are responsible for contamination affecting the chemical quality of the water, the using and the production of drinking water [5]. Even though statistics show that industry, in the macro view, is not necessarily the worst polluter in terms of concentrations and loads, the effects can be very significant. Industrial contamination tends to be even more concentrated, more toxic and harder to treat than other pollutants [4]. The importance of environmental system water should not be underestimated [6]. The reason why water was not regarded intensively enough in the past could be that ecological assessments were mainly developed in countries without water scarcities [7].

2.2 Relevance of environmental system soil

Soil is a finite, non-renewable resource that is essential for the survival of ecosystems. But the quality of the soil is endangered by human activities such as industrial emissions or pollution erosion [8] [9] [10]. So it is not surprising that there is a stated goal of the EU soil protection strategy to prevent further soil degradation, to preserve soil functions and to achieve an increasing public awareness of the need to protect soil [11]. In Germany 2009 daily 94 hectares natural area were sealed. The goal is to limit the sealing of natural areas to 30 hectares per day by 2020 [12].

2.3 Relevance of environmental system air

Currently most attention is paid to the air pollutant emissions. According to the Federal Emission Control Act air pollution is defined as "changes in the natural composition of the air from smoke, soot, dust, gases, aerosols, vapors and odors" [13]. Another term related to the environmental system air is the

G. Seliger (Ed.), Proceedings of the 11th Global Conference on Sustainable Manufacturing - Innovative Solutions
ISBN 978-3-7983-2609-5

greenhouse effect. The greenhouse effect describes the disturbance of the balance between heating and cooling of the earth, and is caused by greenhouse gases such as carbon dioxide, methane, nitrous oxide and other substances that affect the climate [14]. With the legal validity of the Kyoto Protocol in February 2005, the international community has committed to implement binding action objectives and instruments to implement the global climate protection [15]. The target of the German government is a reduction of greenhouse gases by 40% until 2020 [16].

2.4 Need for action

Water, soil and air are the heart of our natural ecosystems and have a major impact on biodiversity and life on earth. To protect and maintain their functionality is not only of interest in politics, but also for many companies. A recent study that was conducted in 2012 among 2.000 small and medium-sized enterprises (SME) by the Fraunhofer project group process innovation at Bayreuth University underlines the importance of environmental aspects. In this study 83% of the interviewed SMEs responded that either green products, manufacturing processes or factories are in demand in the future. 30% suspect that this will happen even in the short term, so in the next 1-3 years [17]. 31% of surveyed SMEs think that the green impact on process chains and production procedures will increase.

The current practice in SMEs, however, displays a different picture. In SMEs investments in new technologies are mainly chosen on the basis of an economic and technical point of view - and hardly consider any ecological aspects. The reason is that especially for SMEs, practical assessment methods to gain the necessary transparency of process chains' impacts on the environmental systems such as water, soil and air are missing.

The following described holistic ecological assessment represents a practical approach that combines all three environmental systems water, soil and air. Through this approach manufacturing companies, especially SMEs, should be helped to evaluate the environmental effects of their processes completely, comprehensively and to adjust their production environment-friendly.

Due to the increasing environmental awareness and the demand for ecologically transparent products and processes, many different ecological assessment methods are available. Lots of the resulting methods are geared to the framework for life cycle assessment (LCA) according to DIN EN ISO 14040 including definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase as well as the life cycle interpretation phase [18]. Although lots of ecological assessment methods are based on this norm, many LCA are created in the context of a specific actor or individual interests and therefore are always very subjective [19].

The cumulative energy demand (in German: KEA) for example is defined according to VDI 4600 as the amount of the energy expenses and includes all process-specific consumptions that are not consumed in the process, but is retained in the final product. KEA wants to assist in making energy technological data available and comparable within a uniform framework. So KEA confirms only one dimension [20]. Also the methods "Carbon Footprint" (environmental system: air) or "Virtual Water" (environmental system: water) use only one dimension.

Besides, some methods like the "Critical volumes" method (environmental systems: water, air) or the "Method of the Federal Environment Agency" (different environmental systems) assess more than one environmental system. The latter one tries to develop a comparative classification or rank formation of different environmental impacts in terms of prioritization. Furthermore the life cycle inventory analysis results (LCI results) for each impact category are aggregated and then classified in a final step and placed in a rank order. So several different environmental effects must be placed in a rank order against each other and it has to be decided, which environmental category weighs heavier.

All the various LCA methods have different frameworks and are designed with different priorities and objectives. Only a few existing approaches can be adapted for a holistic ecological assessment that focus on the three environmental systems water, soil and air. Following a new integrative approach, which combines the strengths of different ecological assessment methods, is presented.

3 CONCEPT OF THE METHODOLOGY

The presented approach is intended to help companies, especially SMEs, to evaluate, analyze and improve the choice of their production processes in a holistic way. So there are connections to the environmental management systems according to ISO 14001:2004 and also to life cycle assessments according to DIN EN ISO 14040 and 14044.

3.1 Method selection

Holistic in this context means that all three environmental systems water, soil and air are considered. The presented approach is an integrative approach which connects the strength of the most suitable assessment methods in their area for all three environmental systems. Therefore, three out of twelve possible methods were selected and were evaluated by experts according to different criteria. The most important criteria are:

1. Implementation in manufacturing technologies
   Many methods have been developed for other areas, such as agriculture. These are not really suitable for transfer to manufacturing technologies.
2. Effort to data collection
   The target of this new approach is to ensure suitability for daily use. Therefore, the data collection for the application of each method should not be too elaborate.
3. Data quality
   In addition, the quality of the input data used in the method is important. Depending on the method this can vary greatly.
4. Expenditure of time
   The presented approach should not be too exceeding and too time-consuming in data collection.

The selected methods for the three environmental systems are:

- environmental system water: "Ecological Scarcity method"
- environmental system soil: "LANCA method"
- environmental system air: "Global Warming Potential"

The methods are described in more detail below.

3.2 System boundaries

According to DIN EN ISO 14044 the system boundary determines which unit processes shall be included within the LCA. The selection of the system boundary shall be consistent with the goal but can vary widely [21]. The system boundaries will be illustrated with reference to the environmental impact of CO_2 on the environmental system air. Figure 1 shows the result of a cradle-to-gate analysis of a value chain of automotive components measured in kg CO_2eq.

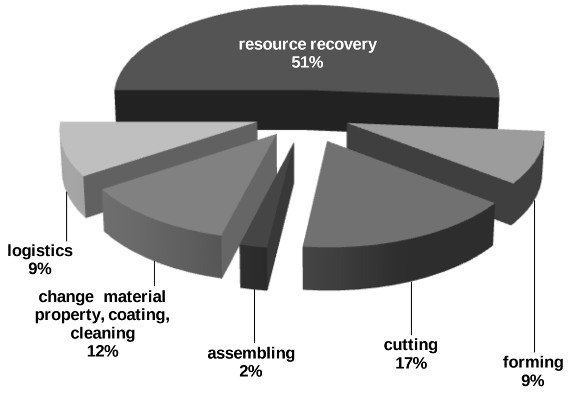

Figure 1: Analysis of value chain of automotive components ("cradle-to-gate") measured in kg CO2eq [22].

It can be shown that energy-intensive processes of resource recovery with 51.33% presents the largest percentage of CO_2eq in the new production. These processes are often parts of preliminary processes of the supply chain. Especially SMEs, due to their low purchase quantity and low market power, are not really able to influence their raw material suppliers. For SMEs, however the CO_2 effect of their manufacturing processes, like cutting or forming, are much more important. These are the CO_2 emissions SMEs can influence. According to this influences of the system boundaries the following model is composed.

3.3 Model description

The model for the presented approach considers a sequence of particular processes, in which a raw material is manufactured into a product (see Figure 2). In this case, the material which is transformed into the product is not considered, because SMEs are not able to influence the ecological impact of the raw material, as already described. Cleaning operations provide the functionality of the tool safety and are therefore seen as part of the process chain. The system boundary line is drawn at all particular processes that compose the complete process chain. Therefore, in accordance with ISO 14044, the gate-to-gate approach is applied. So this approach has a more specific framework than a general LCA.

3.4 Water assessment using "ecological scarcity"

This method is a material flow-based evaluation method and is used for the life cycle impact assessment. The input variables are the life cycle inventory analysis results. The result is expressed in "eco-points" (EP) [24]. The method uses the “distance-to-target” principle and defines the current flow in relation to defined limits, specifications or guidelines. By differentiation between a country and a reference area regional variations can be considered. In this case only the German territory and also no reference substance are considered.

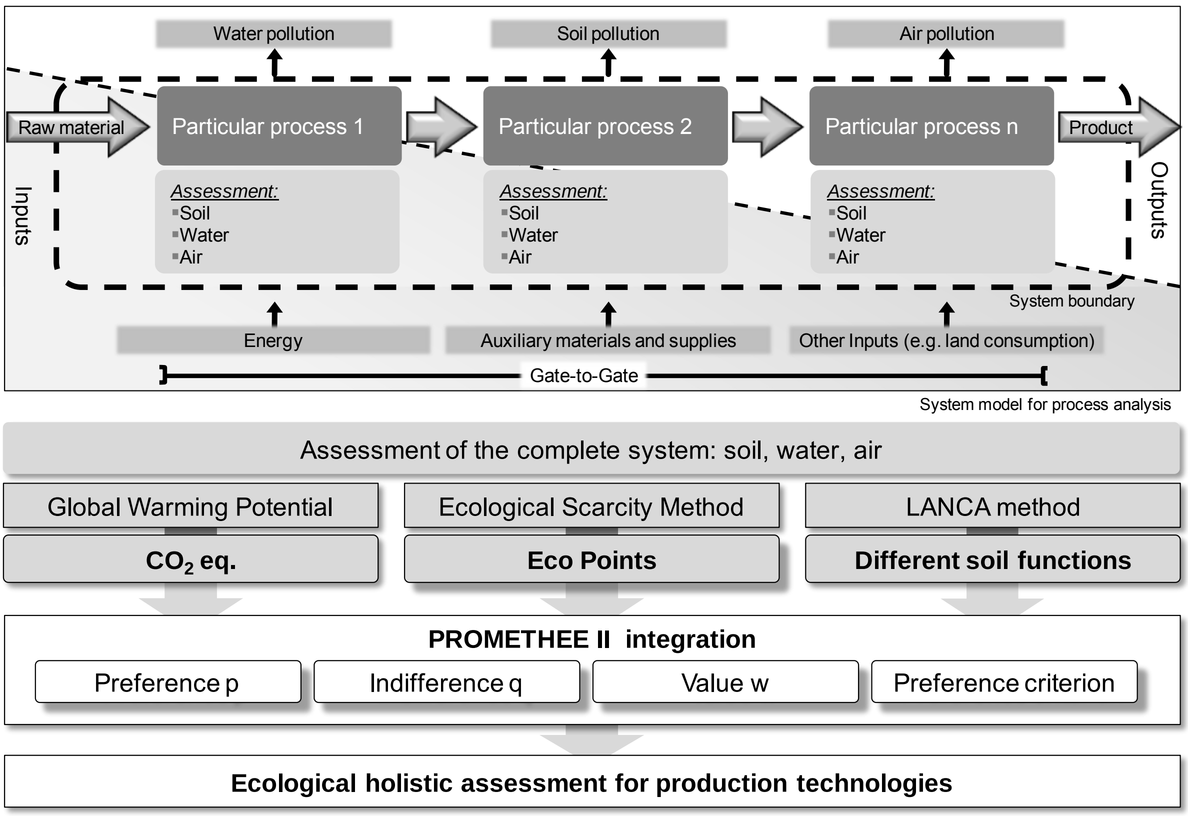

Figure 2: System model for process analysis (according to [23]) and ecological holistic assessment for production technologies.

3.5 Soil assessment using "Land Use Indicator Value Calculation in Life Cycle Assessment - LANCA"

The LANCA method quantifies the effects of different land uses on land functions for an application within LCA. According to [10] only two principal approaches survived: Land use quantification using biodiversity and land use quantification using soil functionality.

LANCA pursues the objective of a low effort for the data collection and needs fewer assumptions. In the LANCA method different soil qualities are compared at different points in time (see Figure 3). LANCA distinguishes between Occupation und Transformation, whereas Occupation [m²*a] is defined as the occupation of an area during the time of its use and Transformation [m²] is the irreversibly affected area of a land use [10].

The LANCA method rated these two parameters Occupation and Transformation in four different soil functions:

- ER - Erosion Resistance
- MFC - Mechanical Filtration Capacity
- PFC - Physiochemical filtration Capacity
- GR - Groundwater Replenishment

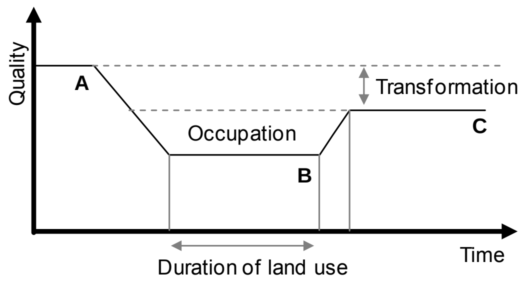

Figure 3: Land Occupation and Transformation [10].

3.6 Air assessment using "Global Warming Potential"

The assessment of emitted Greenhouse Gases (GHG) is based on the so-called Global Warming Potential (GWP) method. The GWP was developed in 1990 by the Intergovernmental Panel on Climate Change (IPCC) and later used in the Kyoto protocol [25]. The GWP is divided into a direct and indirect GWP. Especially indirect GWP have a strong dependence of time and place. As is common practice, all CO_2eq. mentioned in this paper refer to a time frame of 100 years [3].

3.7 Integration method

The result of the method of ecological scarcity, the LANCA method and the GWP method are many output values, which are independent from each other. These values are comparable for each of the individual processes, but have no relation to each other. To achieve comparability of process chains, a further characteristic value has to be developed through an integration method (see Figure 2).

This integration method is the approach of Multi-Attribute Decision Making (MADM), which assumes that the decider is not aware of the preferences between his decisions. In the MADM approach two methods, function-based and relation-based, are distinguished. Especially the relation-based method can show preferences between decision options. This opens the possibility to perform ratings, also with incomplete information. To assess the manufacturing process's influence on the different environmental systems water, soil and air the possibility of comparison and the consideration of weak preferences is necessary. The acceptance of weak preferences is an advantage over a utility analysis.

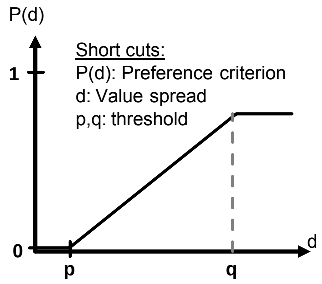

Figure 4: Criterion with linear preference with indifference area [26].

The applied Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE II) in the following is a relation-based method and has gained more and more importance in the past.

The PROMETHEE II method works with different preferences and a pairwise comparison of all dimensions (in this case the three environmental systems). The preference criterion can be chosen from six different options [27]. The appropriate step function in this case is a linear preference with indifference area (see Figure 4). Then the thresholds, the indifference q and the preference value p, need to be defined. The values and weights are subjectively determined by the decider, depending on which dimension is more important. As result the decider gets a complete ranking of options [28] [29].

4 APPLICATION ON THE BASIS OF AN EXAMPLE

The approach described above is illustrated by an example. As a simple example, a single-stage milling process is considered. A complex aluminum part with six small holes, one large hole and two slots has to be manufactured in wet processing with cutting fluid use. The system boundary line is drawn at the machine and the necessary operating, storage and transport areas, but without social, sanitary and administrative areas. In the following, an existing production technology T1 is to be compared with two alternative production technologies T2 and T3. T2 is an advanced technology that requires slightly larger area, but due to the shorter processing time less electric energy, but more cutting fluid is required. T3 is a technology similar to T1 that requires also slightly larger area than T1, but due to the longer processing time required more electric energy, but less cutting fluid. All of the following analyzes were created with data from the scientific database Ecoinvent.

First, the influence of a milling process on the environmental system water is considered, especially the pollutants Phosphorus, Chemical oxygen demand (COD), Short Chain Chlorinated Paraffin (SCCP), Phenols and others. The comparison of the three production technologies are shown in Figure 5.

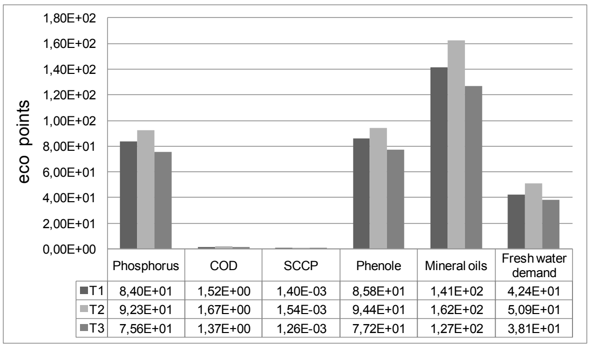

Figure 5: Results of water assessment.

To calculate the impact on the environmental system soil, different inputs are needed which can be extracted from maps, such as the EU Soil Atlas and soil analyzes. As described above, the four soil functions have to be analyzed in terms of Occupation and Transformation. Concerning the comparison of different production technologies, these data do not change, only the area occupied by the technology. Furthermore only the Occupation is considered, because this is the status to be evaluated at the end of use of the soil. It was assumed that the soil after use as a production area is still partially sealed. The results of the soil assessment are shown in Figure 6.

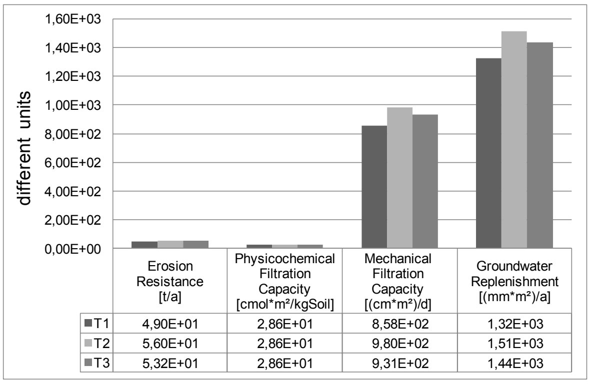

Figure 6: Results of soil assessment (Occupation).

For the impact calculation on the environmental system air especially the electrical energy is considered, furthermore the air emissions from cooling lubricant and fleece (see Figure 7).

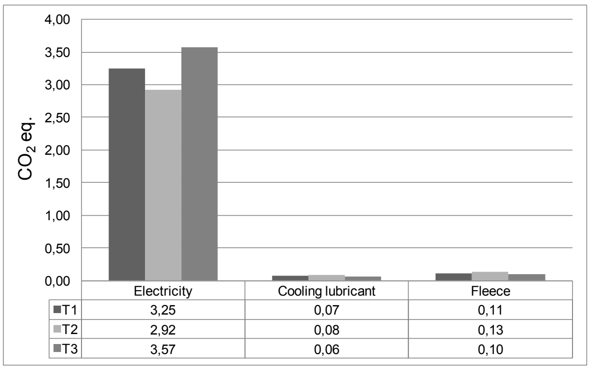

Figure 7: Results of air assessment.

Finally, the results of all the three methods LANCA, Ecological Scarcity and GWP were merged by the PROMETHEE II method. As already mentioned, it is important to define the thresholds, the indifference q and the preference value p. In this example, the threshold values result from the average values. The indifference value q is defined as 10% and the preference value p as 90% the average values of each of them. These values can be changed on each individual decider. Each criterion is also assigned by a weighting. In this case, all criteria are equally weighted. From this follows that each criteria value for water (EP) and air (CO_2eq.) is 1/3. For the four different soil functions a value each of 1/12 is used.

Table 1 shows the different rankings of the production technologies depending on the different valuation methods. In this case, the GWP method assesses technology T1 with the third rank in comparison to the other two technologies. In comparison, the Ecological Scarcity method assesses the same technology T1 with the first rank. Under the given conditions, according to the PROMETHEE II method, technology T3 should be preferred to the current technology T1. In contrast T2 is worse than the current technology T1.

Table 1: Results of the ecological holistic assessment.

Ranking	T1	T2	T3
Eco. Scarcity [EP] (water)	2	3	1
LANCA [ER] (soil)	1	3	2
LANCA [PFC] (soil)	1	1	1
LANCA [MFC] (soil)	1	3	2
LANCA [GR] (soil)	1	3	2
GWP [CO2] (air)	2	1	3
Ranking by PROMETHEE II	**2**	**3**	**1**

5 CONCLUSION UND OUTLOOK

In this paper, an ecological holistic assessment approach was presented, which not only assesses the impacts on the environmental system air but also on water and soil. Therefore, an assessment method for each environmental system was selected, which was specifically developed and optimized for the evaluation of the specific environmental system. Afterwards the results of each method were merged by the use of an integration method. The PROMETHEE II method can create a ranking, even if the decider does not know his preferences between the possible options or information are missing,

As a part of further research work additional support for the application and implementation of the PROMETHEE II method should be developed. For example, ranges for practical thresholds could be developed. Furthermore, the interdependencies between the various environmental systems should be examined in more detail. On the one hand the same influences cannot be calculated twice and on the other hand reinforcing or weakening effects between the environmental systems must be taken into account.

6 REFERENCES

[1] N.N., The ISO Survey of certifications 2011, 2012, online available: http://www.iso.org/iso/iso-survey, last review: 16.03.2013.

[2] Marcus Pratsch; Matthias Dürr, 2012, Investieren im Kontext von Klimaschutz, CDP Deutschland, Österreich, Schweiz 350 Klimawandel-Bericht 2012, DZ Bank AG, Berlin, online available: https://www.cdproject.net/CDPResults/CDP-DACH-350-Report-2012.pdf, last review: 14.04.2013.

[3] Kappas, Martin, 2009, Klimatologie, Spektrum Akademischer Verlag, Heidelberg.

[4] UNESCO, 2012, The United Nations world water development report 4, Luxembourg.

[5] Arle, J., Blondzik, K. et al., 2010, Wasserwirtschaft in Deutschland, Federal Environment Agency Germany, online available: .http://www.umweltbundesamt.de/ uba-info-medien/3470.html, last review: 14.04.2013.

[6] Koehler, A., 2008, Water use in LCA: managing the planet's freshwater resources, Int. J. Life Cycle Assessment 13.

[7] Klöpffer, W., 2009: LCA Wirkungsabschätzungsmethoden und Querverbindungen – Unterschiede zum Risk Assessment, in Ökobilanzierung 2009, Feifel, S. et al. (Hrsg.), KIT Scientific Publishing

[8] Baitz, Martin, 2002, Die Bedeutung der funktionsbasierten Charakterisierung von Flächen-Inanspruchnahmen, Shaker Verlag, Aachen.

[9] Blume, H.P; Scheffer, F.; Schachtschabel, P., 2010, Lehrbuch der Bodenkunde, Spektrum Akademischer Verlag GmbH, Heidelberg.

[10] Beck, T.; Bos, U.; Wittstock, B.; Baitz, M.; Fischer, M.; Sedlbauer, K., 2010, LANCA - Land Use Indicator Value Calculation in Life Cycle Assessment - Method Report, online available: http://www.lbp-gabi.de/files/lanca_website.pdf, last review: 16.03.2013.

[11] Kommission der Europäischen Gemeinschaften, 2006, online available: http://www.bmu.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/ kom_bodenschutz_vorschlag.pdf, last review: 14.04.2013.

[12] Federal Bureau of Statistics Germany, 2012, Nachhaltige Entwicklung in Deutschland Indikatorenbericht 2012, online available: https://www.destatis.de/DE/Publikationen/Thematisch/Umweltoekonomische Gesamtrechnungen/ Umweltindikatoren/IndikatorenPDF_0230001.pdf?__blob=publicationFile, last review: 14.04.2013.

[13] Bundes-Immissionsschutzgesetz, part 1, §3, online available: http://dejure.org/gesetze/BImSchG/3.html, last review: 14.04.2013.

[14] Federal Bureau of Statistics Germany, 2012, Umwelt - Erhebung bestimmter klimawirksamer Stoffe, online available: https://www.destatis.de/DE/ Publikationen/Thematisch/UmweltstatistischeErhebungen/Luftreinhaltung/

ErhebungKlimawirksamerStoffe5324201117004.pdf?__blob=publicationFile, last review: 14.04.2013.

[15] Federal Environment Agency Germany, 2012, Berichterstattung unter der Klimarahmenkonvention der Vereinten Nationen und dem Kyoto-Protokoll 2012, Dessau

[16] Federal Environment Agency Germany, 2012, press release, Röttgen: Minderung der Treibhausgasemissionen ein großer Erfolg; Dessau-Roßlau

[17] Freiberger, S., Süchting, M., Kafara, M., Müller, R., Technologie-Roadmap Oberfranken – Ergebnisse der Datenerhebung „Technologie-Roadmap Oberfranken“. Fraunhofer - Projektgruppe Prozessinnovation am Lehrstuhl Umweltgerechte Produktionstechnik, Bayreuth, 2013.

[18] ISO 14040:2006: Environmental management -- Life cycle assessment -- Principles and framework, International Organization of Standardization

[19] Schmitz, s., Paulini, I., 1999, Bewertung in Ökobilanzen, online available: http://www.umweltdaten.de/publikationen/fpdf-l/3619.pdf, last review: 22.04.2013.

[20] VDI Richtlinie 4600: Kumulierter Energieaufwand (KEA)-Begriffe, Berechnungsmethoden, 2012, Verein Deutscher Ingenieure, Düsseldorf.

[21] DIN Deutsches Institut für Normung e.V., 2006, Umweltmanagement-Ökobilanz-Anforderungen und Anleitungen (ISO 14044:2006), Beuth Verlag, Berlin.

[22] Köhler, D.C.F., 2011, Regenerative Supply Chains, Shaker Verlag, Aachen.

[23] Steinhilper, R., Süchting, M. Kruse, A., Westermann, H.-H., 2012, How Complexity in the Field of Production Planning and Control influences CO2 Emissions, in Proceedings: 10th Global Conference on Sustainable Manufacturing, Instanbul.

[24] Frischknecht, R. et al., 2008, Ökobilanzen: Methode der ökologischen Knappheit - Ökofaktoren 2006, Öbu, Zürich.

[25] UNFCCC, 1997, Kyoto protocol to the United Nations framework convention on climate change, online available: http://unfccc.int/resource/ docs/convkp/kpger.pdf, last review: 21.04.2013.

[26] Kahraman, C., 2008, Fuzzy Multi-Criteria Decision Making, Springer-Verlag, Berlin.

[27] Brans, J.P.; Vincke, P., Mareschal, B., 1986, How to select and how to rank projects: The PROMETHEE method, European Journal of Operational Research

[28] Zimmermann, H.-J.; Gutsche, L., 1991, Multi-Criteria Analyse: Einführung in die Theorie der Entscheidungen bei Mehrfachzielsetzung Springer-Verlag, Berlin, Heidelberg.

[29] Steinhilper, R., Süchting, M. Kafara, M., 2013, Total Cost and Environmental Impact of Ownership – TCEIO, ZWF, 1-2: 63-67, Carl Hanser Verlag, München.