Green Factory Bavaria Colloquium 2014

Green Factory BAVARIA

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Green Factory Bavaria Colloquium 2014

Selected, peer reviewed papers from the
1st Green Factory Colloquium,
September 30 - October 1, 2014, Nuremberg, Germany

Edited by

Jörg Franke and Sven Kreitlein

Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland
http://www.ttp.net

Volume 655 of
Applied Mechanics and Materials
ISSN print 1660-9336
ISSN cd 1660-9336
ISSN web 1662-7482

Full text available online at *http://www.scientific.net*

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printed in Germany

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Colloquium 2014

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Preface

Processing trade and industry consume more than half of the electric energy in Germany. Producing enterprises expend up to and sometimes even more than 10% of their total cost on energy. The steadily increasing energy demand with limited fossil resources and the tendencial cost and investment intensive renewable energy will inevitably lead to further increases in expenditures on energy in manufacturing companies. Together with the strong perception of an environmentally friendly behavior among customers, employees and society energy is developing into the most important strategic competitive factor. Therefore, companies increasingly consider the economical use of energy. The potential savings are enormous: up to 30% or about 10 billion euro in Germany annually.

The model factories for energy efficiency production of the Fraunhofer Institute in Munich/Augsburg and Bayreuth and of the Universities in Erlangen-Nuremberg, Amberg/Weiden, Ansbach, Coburg, Hof and Schweinfurt/Wuerzburg are targeting the long-term objective to produce energy self-sufficient methods, technologies to optimize energy consumption in production and to minimize the heat loss in the laboratory halls, as well as strategies for adapting the energy consumption to the offer and procedures for decentralized renewable energy are developed and implemented in the Green Factories. The Green Factories in Bavaria combine up the research skills of all relevant fields for energy efficient production, e.g. mechanical engineering/manufacturing technology, electrical engineering, information technology, process engineering, materials science and economic science. They also consider all major types of energy, e.g. for motion, illumination, information processing, manufacturing processes and thermal control. Furthermore, Green Factories address the use of energy in production, logistics and administration. With clear focus on energy efficiency in the production and state-wide, interdisciplinary collaboration, these Green Factories are aiming to expand into an international research network. In the model factories for energy-efficient production, innovative industrial partners should have the opportunity to present and to develop advanced techniques and technologies for energy-efficient production together with scientists from the participating research institutions in the available laboratories and production areas. They also allow for intensive networking and to pass on knowledge effectively to users and students.

This unique concept of collaborative research between industry and universities guarantees an efficient research and a fast and more efficient transfer of the results into the economy.

The project partners would like to express their sincere thanks to the Freistaat Bayern for funding the project "Green Factory Bavaria" in the framework of the "future initiative Aufbruch Bayern".

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CHAPTER 1:

Sustainable Manufacturing Strategies

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doi:10.4028/www.scientific.net/AMM.655.3

Life Cycle Assessment Tool in the Early Stage of Development

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Keywords: Life Cycle Assessment, Life Cycle Design, Product Development Process, Early Stage of Development

Abstract. Life cycle assessment is becoming increasingly important for industry. Like the economic impact the ecological impact is mainly determined in the early stage of development. The challenge in this context is that the impact is difficult to predict, if the product has not been completely designed yet and if the production processes are not known. For the economic impact many empirical formulas exist, whereas for the ecological impact such formulas are still missing. Therefore, an easy to use life cycle impact assessment tool has been developed which supports the developer during all stages of development.

Introduction

Product development is characterized by data incompleteness and a high economic and ecologic improvement potential [1]. Technology planning already realized that the environmental impacts are a benchmarking criterion for the choice of production technologies [2]. To support the developer in designing an environmentally friendly product it is necessary to perform a life cycle assessment (LCA) in four phases: the goal and scope definition phase, the inventory analysis phase, the impact assessment phase, and the interpretation phase [3]. Within the development of a product the scope is already defined. To calculate the impact factor it is necessary to build up a life cycle inventory analysis and link it to company-relevant environmental indicators. The results can be interpreted and used for further improvements. As surveys show [4], one of the barriers for implementing environmental strategies in manufacturing companies are inadequate tools. Hence, in this paper a new software tool is presented, which simplifies the life cycle impact assessment in early stage of development and guides the novice LCA conductor. In contrast to existing LCA tools such as GaBi, Umberto or SimaPro this tool is simpler and thus easier to use. On the downside it does not allow for complex LCA methods such as different allocation methods or disposal schemes.

Structure

The structure of the software distinguishes between basic items and design items. All items are linked to environmental impact factors comprising four phases in terms of extraction (e.g. metals) or production (e.g. polymers) of the raw materials, production, usage and end of life. Basic items do not have to be changed by the developer and should already be provided by the LCA department of the company. Construction items are the representation of the product and are classified into groups and parts (see Fig. 1). This classification is based on DIN 6789 [5], with which the user is already familiar from his daily work. This fact will shorten the training period with the tool and enhance user satisfaction.

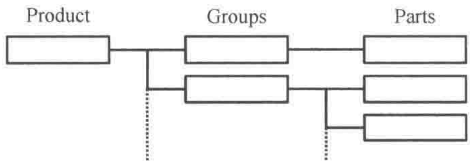

Fig. 1: Product structure - structural overview in accordance with DIN 6789 [4]

Parts are the smallest item of a product. Fig. 2 shows the assignment logic for the calculation of the LCA of each item (part, group…) and their subitems. Each target value in the columns is calculated by the sum of each row. For an easier usage processes already contain the materials, process actions, transportations and norm parts used. Because norm parts always need a process in order to be applied to another item, they can only be added this way. An example for a process is "Screwing of M6". The material is Loctide, process action is the screwing of one screw, norm part is the screw and also a transport will be needed to get the item to and away of the screwing station.

life cycle: acquisition	a	life cycle assesment of:																															
production	p	basic items																				construction items											
usage	u	material				transport.				process action				norm part				process				part				group				product			
end of life	e	a	p	u	e	a	p	u	e	a	p	u	e	a	p	u	e	a	p	u	e	a	p	u	e	a	p	u	e	a	p	u	e
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part	a																									X				X			
part	p																										X				X		
part	u																											X				X	
part	e																												X				X
group	a																													X			
group	p																														X		
group	u																															X	
group	e																																X
		single elements												combined elements																			

Fig. 2: The matrix shows the rules for calculation of the single phases of life cycle assessment. The available combinations are marked white, non-available are marked grey. The 'X' indicates which phase is related to another.

The Life Cycle Impact Indicators

A current version of the developed software provides eleven LCA impact indicators. Four of those indicators belong to the ReCiPe endpoint indicator group [6], i.e. ReCiPe ecosystem quality, human health, resource depletion and their aggregated value "ReCiPe total". The advantage of such endpoint indicators is the aggregation of many different (midpoint) environmental impacts into three or even one final dimensionless number. Among all indicators providing endpoint indicators, ReCiPe is a popular choice [7]. In addition to endpoint indicators, midpoint indicators can be selected, which relate to current environmental indicators used by the company. Examples would be water usage, cumulated energy demand, global warming potential or eutrophication.

Data

Another important aspect is the data basis in order to determine the numerical value of life cycle impact indicators in the early stage of development. During development and construction product specific data, like parts lists, materials and production processes needed are generated. This data platform is the product specific basis for the tool and needs to be linked to a life cycle data basis to calculate the impact in the early development.

The usage of different data for each life cycle phase is shown in Fig. 3. There exist different data sources for the acquisition, production and usage phase, which will be shortly characterised below in respect of their accuracy. During the usage phase it is possible, that the material consumption is influenced by the weight of the product (e.g. transportation systems). In this case the tool is linked with the weight of the product to calculate the impact factor (see fig. 3). For the product end of life the impact factor can be calculated as it is described in the next section.

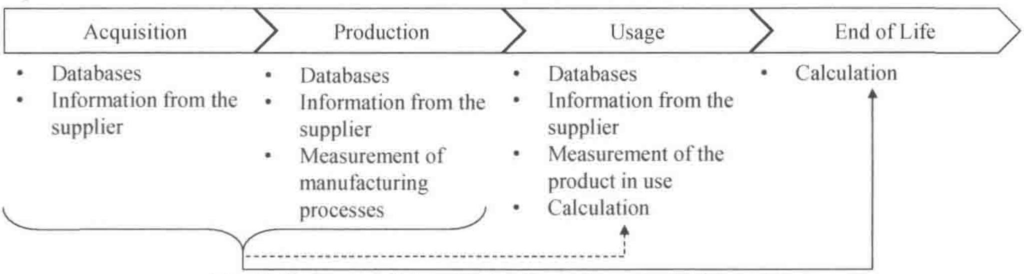

Fig 3: Sources of data in the four phases of life cycle

There are three different sources with varying precision level for filling the life cycle data platform with information. The most exactly way to generate life cycle data is to measure the consumption of resources directly at the production facilities and to derive reference values for manufacturing processes. The second way to gather data for manufacturing processes is to demand the supplier for the impact of their offered production facilities. This opportunity to have access to realistic values from suppliers is also used for raw, auxiliary and operating materials. Each company has its own procedure for collecting the necessary data, because ISO 14001 [8] gives only a draft and not a specific structure. If there is no supplier chosen or available to give the demanded data, the use of databases for ecological factors is the third way to collect data and a very good possibility to calculate with a roughly estimated impact factor. In this case a lot of different procedures exist to obtain the required data, which are described in each case in the database to make the generated impact factor for the user more transparent. The databases can be divided into general (e.g. econinvent, ProBas) and specific databases (e.g. PlasticsEuropes).

Recycling

Introduction. Another important question is how recycling is being assessed by LCA software. In literature numerous allocation procedures for recycling exist [9, 10], for example the cut-off method (also called recycled content), the substitution method (also called avoided burden), system expansion, economic allocation, the loss of quality method and the multiple recycling method. Frischknecht [11] et al and Hofstetter et al [12] explain that there is no *right* choice of recycling allocation, but that the choice may depend upon the moral point of view of the LCA practitioner. The great importance of recycling allocation is also reflected by the fact that in the new life cycle database ecoinvent version 3.0 (www.ecoinvent.org) two types of allocation methods are provided, the cut-off and substitution method. This section will explain which allocation method was chosen for the LCA software and for which reasons.

When Recycling is beneficial. At first materials which can be recycled an infinite amount of times shall be considered only. Fig. 4 shows the life cycle of a material from resource extraction over processing, recycling and waste disposal.

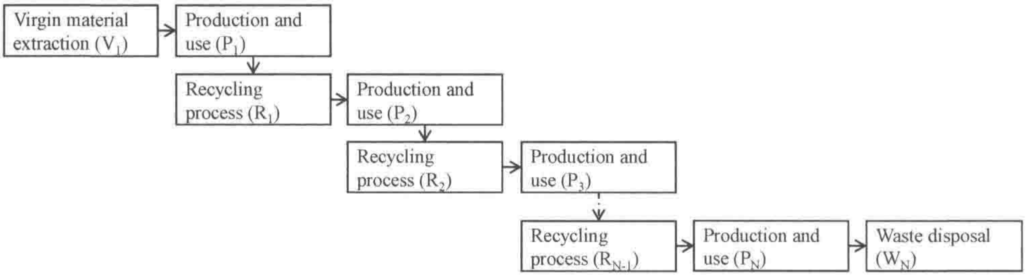

Fig. 4: Simplified illustration of a cascading product life cycle with N uses. The recycling process assumes 100 % recycling and comprises collection, dismantling and reprocessing.

The production and use phase can be excluded for the recycling allocation issue, since it is clear to which user it must be allocated [7]. The residual environmental impact over the materials life cycle is V + (N-1) R + W assuming identical recycling processes $R=R_1=R_2=\ldots=R_{N-1}$. If all N users would use virgin material and dispose the material to waste instead of to recycling, the impact would be N (V+W). Through comparison it can be concluded that recycling creates lower environmental impacts, only if

$$V + (N-1)\,R + W < N\,(V+W) \qquad \Rightarrow \qquad R < V + W \tag{1}$$

In the following it is assumed that R=4, V=3 and W=2 so that the inequation holds and recycling is beneficial.

Shortcomings of Cut-off and Substitution Method. According to the cut-off method the users L_1, L_n and L_N are allocated the impacts $L_1=V=3$, $L_n=R=4$ and $L_N=R+W=6$, where n may be n=2, 3, ..., N-1. This allocation does not seem fair. L_n is attributed higher impacts than user L1, even though Ln does recycle material at its end of life and additionally uses recycled material. According to the substitution method the users are allocated the impacts $L_1=R=4$, $L_n=R=4$ and $L_N=V+W=5$. Here, users L_1 and L_n are assessed equally, so that there is still no incentive for user L_n to use recycled material.

Proposed Solution. To provide an incentive for using recycled material, allocation must obey the following rules. The impacts V + (N-1) R + W can be rewritten as

$$NR + (V+W-R) = N(V+W) - (N-1)(V+W-R) \tag{2}$$

The left side of Eq. 2 can be interpreted such that *not* recycling yields an additional impact of (V+W-R). This additional impact should be spread onto both the first and last user, since they disrupt the theoretically infinite recycling chain. The right side of Eq. 2 can be interpreted such that each recycling step lowers the environmental burden by (V+W-R). This negative impact should be spread onto both the user using recycled material and the user disposing the material into recycling. If any of these two recommendations are followed, there will be both an incentive for recycling and for using recycled material. If the environmental burden (V+W-R) is spread with a factor of 50% / 50% onto the partners, the known 50/50 recycling allocation method evolves. In the case defined before the users are attributed $L_1=0{,}5(V+W+R)$, $L_n=R$, $L_N=0{,}5(V+W+R)$. However, as mentioned above, the factor 50% / 50% is just one possibility and other factors may seem more appropriate depending upon the specific situation.

Implementation in Software. To give an incentive for both recycling and using recycled material the 50/50 allocation method was chosen for the software. To assess the choice of input material and disposal method independently from each other, the 50/50 allocation method can be disaggregated as shown in Tab. 1.

Downcycling. For materials which can be recycled only a finite number of times the loss of quality method is recommended:

$$L_n = R + (Q_n - Q_{n+1}) / Q_n * (V+W-R) \quad , n=1\ldots N, Q_{N+1}=0 \tag{3}$$

where Q_n represents the quality of the material at user L_n measured e.g. by its sale price. Please note the similarity to the left hand side of Eq. 2. The term (V+W-R) can again be regarded as the additional burden of *not* recycling, distributed over all users in this case.

Tab. 1: *(left)* The combination of input material and disposal method creates the according environmental impacts. *(right)* These values can be disaggregated, so that input material and disposal method are independent from each other.

Disposal / Input	Waste	Recycling
Virgin material	V+W	0,5*(V+W+R)
Recycled material	0,5*(V+W+R)	R

Input: Virgin	V
Input: Recycled	0,5*(V-W+R)
Disp: Waste	W
Disp: Recycling	0,5*(-V+W+R)

Tool

The software implements the above mentioned structure, indicators and data in one unique and easy to use tool as seen in Fig. 5. The software is written in C# using the .net 4.0 Framework and the MVVM pattern (Model View ViewModel).

Fig. 5: Software tool showing the tab "basic data" and the sub tab "material".

When a product and its different variations have been imported into the program, the LCA is presented in a graphical way for further control and optimisation (Fig. 6). The required data don't have to be added at once, but can be detailed as required in each phase of the development cycle, so the LCA is becoming more and more accurate.

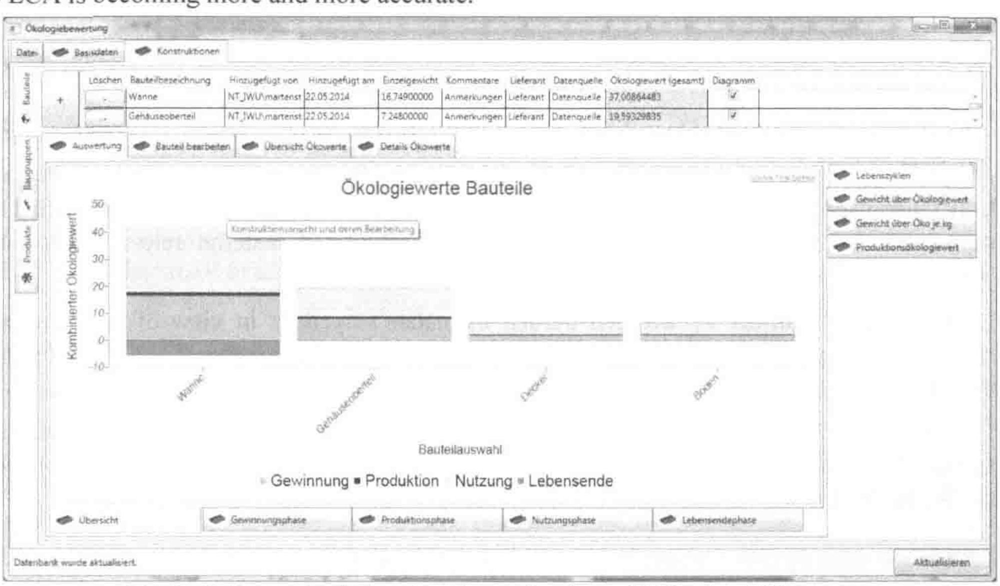

Fig. 6: Software tool showing the evaluation of LCA for different parts.

Summary

As LCA is becoming increasingly important for industry and is mainly caused in the early stage of product development, the developer needs to take care of the ecological impact in that phase of the development. To achieve this, a software tool including its choice of environmental indicators, data collection procedure and recycling allocation was presented. The tool is intended to guide the developer through all phases of the development, starting with rough data which can be detailed in each phase.

Acknowledgement

The project Green Factory Bavaria is funded by the Bavarian Ministry of Economic Affairs and Media, Energy and Technology within the program "Zukunftsinitiative Aufbruch Bayern".

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Applied Mechanics and Materials Vol. 655 (2014) pp 9-14
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.655.9

Contribution for the life cycle oriented evaluation of costs and resource efficiency of production machines in procurement

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Keywords: Life cycle costing, resource efficiency, life cycle assessment, machine procurement

Abstract. Even though the share of the production machine's environmental impact might be negligible compared to the product's own use phase, the environmental impact at the factory site of is potentially significant. Thus, this article presents a contribution for the life cycle oriented evaluation of costs and resource efficiency applied in procurement of a production machine.

Introduction

Increased awareness in sustainability let customers prefer products that reduce environmental impacts. Yet, this must not be at the detriment of economic efficiency [1]. Regarding energy savings, this manufacturing industry can reduce electrical energy consumption corresponding to 24.9 million private households within the next ten years in Germany alone. Contribution to energy efficiency can be reached threefold, i.e. by developing efficient technology, buying it and optimization of usage at the operator [2]. This is also acknowledged in regulations, such as the EcoDesign Directive of energy related products (2009/125/EG) which applies to machine tools [3]. Currently, the EU Commission is deciding on restrictions in the usage of energy and auxiliary materials to support the reduction of environmental impact in machine usage [4]. Furthermore, the energy management norm ISO 50001 demands operators of machines to develop purchasing specifications for their energy intensive machinery. Those need to include criteria for the type and amount of energy needed and the energy efficiency over the planned life cycle of the equipment [5]. The purchasing decision by a machine operator is thus, a lever in using resource efficient technology. Overall, there is a need to evaluate ex ante the resource consumption and environmental burden related to the operation of the purchased machine. Yet, such an evaluation will only be used in practice if it is related to the calculation of the machine's cost [6].

Hence, the focus of this work is to give a contribution for a method for the purchasing process to evaluate cost and resource efficiency of production machines. In the following section current methods to evaluate life cycle costs of machines are presented. This is followed by a brief discussion about the meaning of resource efficiency and the common way of ecological evaluation, i.e. life cycle assessment (LCA), with regard to production machines. The concept for integration of both views is discussed in section three and the last section concludes.

Current methods of cost evaluation

Life cycle costing. The efficiency gains of production machines, which are characterized by their long duration of usage, become important while utilization. Thus, the machine often has higher initial while lower follow-up costs. A favorable method to judge alternatives in the purchasing process is life cycle costing (LCC) [7]. In this work the focus is on costs occurring for the operator of a machine. Life cycle phases which are relevant from the viewpoint of the operator of the machine are the procurement phase, use phase and end-of-life phase and correspondingly, the initial investment costs, the operating costs and the end-of-life costs [9].

VDI 2884 [8] implies seven steps for a procurement process if LCC is used (see **Figure 1**). The three first steps comprise of: (1a) the identification of alternatives that can fulfill the demanded requirements, (2a) accordingly, an adequate maintenance strategy is defined as well as (3a) the application conditions and the life span of the machine is estimated. In the next step (4a) the desired criteria for evaluation are chosen. Here, different cost types are taken into account and decision making criteria that are not quantifiable in monetary terms may be included. Within the life cycle phases costs can be characterized as occurring only once in the life time of the machine, like investment and waste disposal costs, and those which are recurring and follow-up costs, e.g. costs for consumables and auxiliaries. The goal is to reduce the recurring and follow-up costs even at the expense of the initial costs, since the majority of costs occur in the use phase [10]. Thereafter, information in the chosen cost categories are (5a) collected.

For (6a) the quantitative evaluation step static and dynamic methods of investment analysis are used. The latter has a time dependency of occurring costs in the life time of the machine and discounts them to a common reference point. Thereby, alternatives are made comparable over their whole life cycle [7, 9]. The procurement process is concluded with a decision (7a).

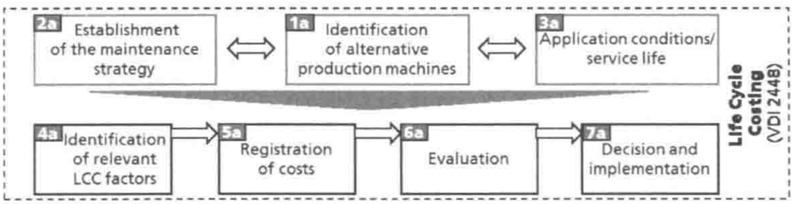

Figure 1: Steps in life cycle costing (based on [10])

Existing approaches of LCC of energy efficient machines often combine both the perspective of the machine builder and operator or target the development phase of the machine [7]. They neither necessarily support the procurement process nor estimate environmental impacts other than those related to energy usage (i.e. global warming potential). Yet, they can serve as a basis for modeling.

Current methods of ecological evaluation

Definition of resource efficiency. In this context, resources and resource efficiency needs to be defined in a way targeted at reducing environmental impacts. Following [11, 12], resources are natural resources, i.e. renewable and non renewable primary raw materials, physical space, environmental media, flow resource, and biodiversity. For machine developers and manufacturing industry this translate into energetic and material resources used for production of goods. Material is raw material, consumables and auxiliaries as well as unfinished goods. Therefore, the focus of resources here is narrow, in contrast to classical definitions of production resources which also include people, capital or information [13]. Resource efficiency is the ratio of a defined output to the necessary input of resources [11]. Therefore, the goal is to minimize natural resource use and environmental impact while keeping the desired level of output [14]. To sum up, resource efficiency of production machines needs to be integrated into an indicator of the ecological and economical effort.

Life cycle assessment. For the estimation of ecological impact over the life cycle of a product the methodology of life cycle assessment (LCA) as defined in ISO 14040 [15] is used. It is based on four steps: (1b) the goal and scope definition, (2b) the life cycle inventory analysis (LCI), (3b) the life cycle impact assessment (LCIA) and (4b) the life cycle interpretation phase.

The life cycle of the product can be summed up into four phases: raw material extraction / refinement, manufacturing, use, and end-of-life treatment. No simple rule applies which resources are to be considered. Instead it is highly related to the defined scope of the LCA, the data availability and the chosen cut-off criteria [15]. With respect to the first step in LCA (**Figure 2**) this