Design for Environment

Design for Environment in the Automotive Sector with the Materials Selection Tool euroMat

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1 Introduction

Materials selection is a crucial step in the process of developing new components and products for the automotive and other sectors. The material selected for a specific application does not only set performance, manufacturing technologies, costs, and life-span of the component, but also affects the environmental impacts of the complete life-cycle as well as the recycling options. The latter issues are more and more relevant for all industries, but specifically for the automotive industry due to European regulations on recycling and integrated product policy as well as changing customer demands across the globe. These issues can also be seen in a much broader sense, in the context of sustainable development, which encompasses economic, environmental, and social considerations as integral elements of industrial activities. These three goals can also be referred to as the 'triple-bottom-line'. The methodology and tool euroMat (Concurrent Engineering Design Tool for the Selection of Environmentally Sound and Recyclable Materials) presented in the following offers the opportunity to deal with two-thirds of this triple-bottom-line by integration of environmental and costing assessments into the design process of components and products.

Currently a software version of euroMat is being developed. This development is carried out with two companies from the automotive sector, Ford Motor Company and Sachsenring Entwicklungsgesellschaft mbH. Also involved are the aerospace industry (MAN Technologie AG) and a company from the sector of storage systems for hazardous and other materials (Denios AG).

After a brief introduction to sustainable development (sustainability) and why it is worth dealing with this paradigm shift, the methodology of euroMat is presented. This is followed by a case study, where euroMat was applied to the materials selection for a front subframe system of a passenger car. Finally, conclusions are drawn and an outlook on the software development is given.

2 The Challenge of Designing (more) Sustainable Products

Since the concept of sustainable development has been introduced in 1987 in the report of the World Commission on Environment and Development (also known as the 'Brundtland Report') [1] it has gained more and more acceptance in academia, industry, government, and non-governmental organizations [2].

Therefore, more and more industrial companies are trying to incorporate sustainability aspects into their policies and business practices. Some organizations, such as the World Business Council for Sustainable Development (WBCSD), assume that sustainability will be as much a factor in the future of business and industry as product quality is today. These assumptions are based on the fact that alternative products are increasingly becoming more and more similar concerning functionality, availability, quality, price, and individual specifications (mass customization). Therefore, providing (more) sustainable products is an opportunity for differentiation in the market. Market surveys show that consumers are preferring products with less environmental impacts if the other aspects do not differ. In some market segments consumers are even willing to pay a premium for more environmentally friendly products.

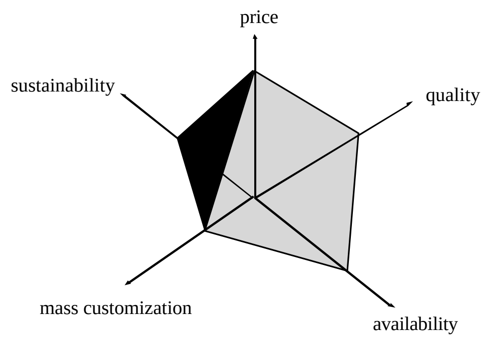

Fig. 1: Value star product-service portfolio [3]

Following on this line, sustainability opens up a new dimension for the success of products (see the black area in **Fig. 1**), specifically in the highly industrialized countries, since here cost leadership is difficult – if not impossible – to achieve and the other conventional criteria can also be met more and more by industries from emerging economies, e.g. in Asia. On the other hand, dealing with environmental issues regarding production, use, and end-of-life of products also bears high potentials for cost savings due to savings resulting from using less raw materials and energy as well as reduced waste management and emission control costs.

As a result of the growing relevance of sustainability the engineering designer is faced with additional tasks and requirements, he or she has to e.g., lower the impacts in the use phase of an automotive component, increase the recyclability, etc. Also more and more materials are available to choose from. Consequently the designer has a huge amount of different complex criteria and requirements besides the conventional ones (functionality, quality, costs, etc.) to consider. The situation the designer is faced with is illustrated in **Fig. 2**.

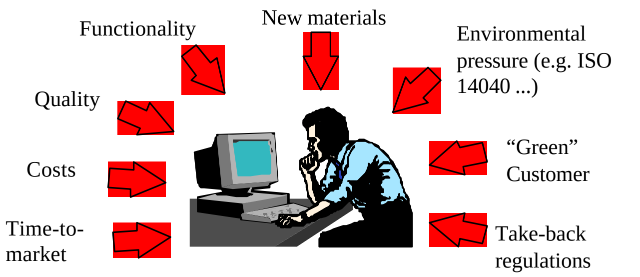

Fig. 2: Tasks and requirements an engineering designer has to deal with nowadays

In the engineering design phase the total environmental impacts caused by the production, use, and end-of-life treatment of a product are fixed to a high degree [4,5]. This is also true for the total costs (life cycle costs) associated with the life cycle [6,7]. For these reasons, product design tools that are capable of regarding potential environmental impacts as well as life cycle costs in the early design stages have to be employed. euroMat is a methodology and tool featuring those capabilities.

3 The Design for Environment Methodology euroMat

The Design for Environment (DfE) methodology euroMat empowers the engineering designer to incorporate sustainability issues into his or her day to day business. euroMat gives hands-on information and decision support on the environmental and recycling implications of choosing a certain material as well as on identifying the best suitable materials for a specific application. Also estimations for life cycle costs are given. euroMat is based on sophisticated selection and assessment methods that expand the conventional materials selection process by taking all materials and (theoretical) materials combinations into account (top-down approach) as well as including selection and assessment criteria concerning manufacturing issues, environmental and recycling performance, life cycle costs, work environment, and risk aspects (integrative nature) [8,9].

The selection of materials based on their technological feasibility (functionality) and the identification of suitable manufacturing and recycling processes is illustrated in **Fig. 3**. Starting with a profile of requirements defining the technological performance of a product (as e.g., in section 4, Table 1) all materials and material combinations possibly meeting those requirements are identified. Theoretical material combinations are modeled based on estimation formulas for the properties of composites as well as on estimations concerning the influence of additives on polymers, alloy elements on metals, etc. For the resulting materials the manufacturing options are identified by matching the materials with the manufacturing processes desirable for the specific component or product. Analogously, the availability and feasibility of recycling options are determined. Only after this selection process is finished, the remaining materials are assessed for life cycle impacts using specific simplified life cycle assessment (LCA), life cycle costing (LCC), risk- and work environ-ment assessment procedures.

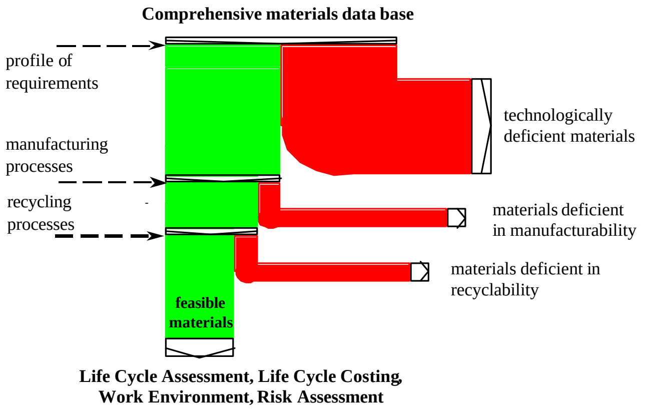

Fig: 3: Procedure of euroMat [10]

As mentioned above, this life cycle approach is extremely relevant for making the concept of sustainability operational. Environmental impacts for example have to be regarded from 'cradle-to-grave' incorporating impacts from raw material extraction, processing of materials, manufacturing, consumption, and end-of-life (reuse, recycling, and disposal) as well as energy consumption and transports in all life cycle stages. However, this is not only relevant for environmental aspects, also the cost management view should be extended to include the complete life cycle as shown in **Fig. 4**. The life cycle costs together with the environmental assessment deliver an assessment of two-thirds of the 'triple-bottom-line' (see section 1), making a move towards more sustainable products possible.

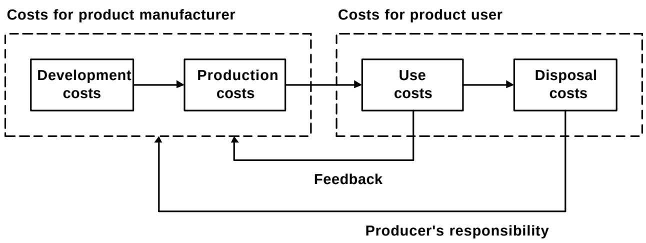

Fig. 4: Life cycle costs and interdependencies [11]

In order to make the method and the huge amount of data needed manageable the method is based on an iterative procedure, which starts with groups of materials and very

rough estimations, which are being detailed step by step. Also the materials are specified in more detail within the process. In the procedure less and less materials are therefore assessed in more and more detail, allowing for sorting out the materials that are not optimal for the application.
Presentations of the general method of euroMat [9], the methods for identifying materials and corresponding manufacturing and recycling processes [12], the simplified LCA [13], the simplified LCC [11], and the work environment assessment [14] can be found in the literature.

4 DfE Case Study for a Front Subframe System

As mentioned in section 1, euroMat has been developed in cooperation with Ford Motor Company. A case study on a front subframe system of a passenger car was carried out. The front subframe system is shown in **Fig. 5**.

Fig. 5: Front subframe system

As a first step the specified product performance had to be transformed to representing requirements regarding materials specifications. **Table 1** presents some of the requirements for the front subframe system.

Table 1: Profile of requirements of the front subframe system (excerpt)

Product performance	Representing material specifications	Requirements
Mechanical strength (> 700 N) and stiffness (> 45 N)	Modulus in flexure	> 1.1 GPa
Resistance against hood slam impact	Impact strength	> 16.0 kJ/m^2
Weight of subframe system < 4.9 kg	Density	< 10.2 kg/dm³

The requirements have to be seen in relationship with constructional constraints. In this case the wall thickness of the subframe system was variable from 0.5 to 5.0 mm. Some of the resulting materials and the corresponding constructional data are listed in **Table 2**.

Table 2: Identified materials for the front subframe system (excerpt)

Material for subframe system	Wall thickness	Weight
Steel	0.9 mm	6.8 kg
Magnesium	1.6 mm	2.6 kg
PA, glass fibre-reinforced	3.0 mm	4.3 kg
PP, hemp fibre-reinforced	3.0mm	3.5 kg

In Table 2, steel is listed though it does not allow the design of the component within the required maximum weight of 4.9 kg. It is nevertheless included here to show the performance of a standard material for this application. However, one can see that in this case only the fibre-reinforced thermoplastics and magnesium offer the performance needed. Therefore steel was excluded from the further assessment. From the remaining three materials glass fibre-reinforced PA and magnesium are feasible materials, i.e., product performance, manufacturing, and recycling requirements can be met. Hemp fibre-reinforced PP is potentially feasible, though there is research and development (R&D) necessary to solve the existing manufacturing problems (manufacturing by injection moulding, the desired technology in this case, is currently not (yet) possible). However, to explore the potential of this material it is included in the further assessment, which could help in answering the question if business resources should be allocated to developing/adapting manufacturing processes for this material. In the following the results for the environmental and the LCC assessment of the remaining three materials are presented.
Fig. 6 shows the global warming potential (GWP) for the complete life cycle of the subframe system from the materials glass fibre-reinforced PA, hemp fibre-reinforced PP, and magnesium as well as the distribution of impacts in the life cycle. The direct life cycle costs, i.e., the direct material-, manufacturing-, transport-, use-, and recycling costs are presented in **Fig. 7** (direct cost indicator – DCI).

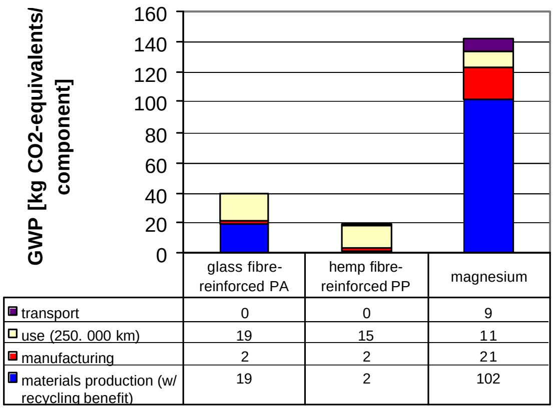

Fig. 6: Global Warming Potential (GWP) for three material options

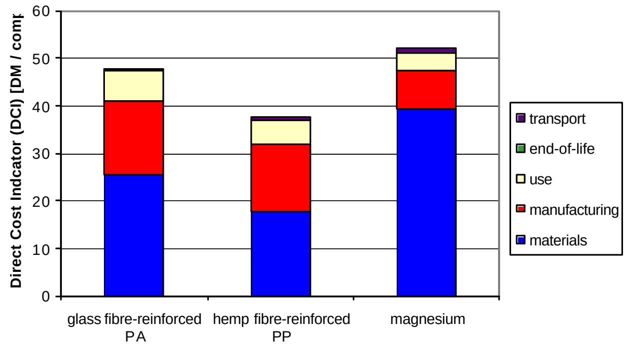

Fig. 7: Direct life cycle costs for three material options (manufacturing costs based on estimates)

However, the DCI is just one side of the medal of direct costs. Qualitative estimations for R&D costs as well as market oriented aspects (market acceptance, price stability for the raw materials, etc.) have also to be taken into account. The final result of the LCC assessment is the life cycle cost indicators (LCCI), which aggregates the DCI and the qualitative cost assessment. The LCCIs for the three materials considered are shown in **Fig. 8**. These cost assessments do not include overhead costs or revenues, just those costs that can be directly allocated to the component are considered.

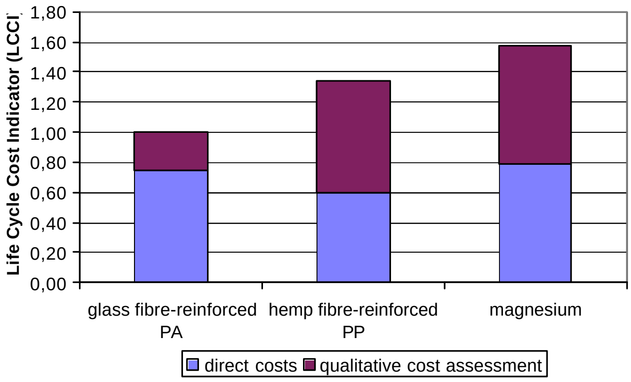

Fig. 8: Life cycle cost indicator (LCCI) for the three materials options as an aggregation of the direct cost indicator (DCI) from Fig. 7 and the qualitative cost assessment (including R&D, market aspects)

One can see that both from an environmental as well as an economic view, a replacement of the currently used glass fibre-reinforced PA by magnesium is not preferable, since both environmental impacts as well as life cycle costs of magnesium are higher for the application. Hemp fibre-reinforced PP promises significant improvement potentials for both assessment criteria, but at present is not yet technologically feasible (the supply of natural fibres with defined specifications is another problem). Therefore the recommendation is to keep the current material in the short term and to invest in R&D for the manufacturing of the component from natural fibre-reinforced thermo-plastics. Magnesium as an option for the component should not be considered further.

5 Conclusions and Outlook

The capabilities of the DfE methodology and tool euroMat have been validated by the presented and several other case studies (see e.g. [10,15]), three of them from the automotive sector. Improvements of the environmental and economic performance of products by choosing 'the right' material can be identified. Additionally, the top-down approach offers the possibility to explore new frontiers, to widen the horizon by incorporating a broader spectrum of materials than commonly practiced. Thus the innovation potential of new design options is enhanced.

However, one can easily imagine that such a selection and assessment process is timely and costly unless a software system is available that models the methodological procedures and contains the necessary ground data on materials specifications, costs, material- and energy flows, etc. Therefore the technical University Berlin together with the software engineering firm CTB CAMTEC Berlin GmbH currently develops a software version of euroMat. This software will enable the engineering designer to incorporate the paradigm of sustainable development into strategic as well as operative decision making, resulting in more competitive and efficient products.

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