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Challenges and Practical Approach of End of Life Calculation Methods in Life Cycle Assessment

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Nowadays, recycling and reuse of products have become common. The meaning of recycling and reuse is not only seen in the reduction of resource consumption and waste in End of Life (EoL), but also as the improvement of the entire Life Cycle of a product. One method to calculate these improvement is Life Cycle Assessment (LCA). Depending on the process efforts and outputs, the EoL of a product causes burdens and benefits regarding environmental impacts.

Today, several EoL calculation methods are applied to account benefits and burdens. Depending on the applied method LCA results are different.

This paper reports on the challenges of the application of the common different EoL calculation methods by using a practical industrial project as an example. Additionally, the comparison of the different results of LCA using above mentioned methods are presented. Since the synthesis of practicability and scientific sophisticated model could not be achieved with the common methods, an adapted approach was developed by IKP, which is also presented in this paper.

Key words: Recycling, End of Life Calculation, Life Cycle Assessment (LCA), ECO2-Indicator

1. INTRODUCTION

Today, there has been an increase in the number of studies on Life Cycle Assessment (LCA). LCA has established as the leading method for environmental assessment for materials, products and processes. As well known LCA is meanwhile not only applied in research institutes but also in industries, to analyze their products life cycle.

However, since the field of LCA is a quite young science with high developing and improving potential, several methodological difficulties are still not solved. E.g. the "allocation" is one of the most discussed method in LCA. Depending on the allocation criteria based on weight, cost or energy etc. the environmental impact of the considered product life cycle varies. While the assessment of a primary life cycle already has methodological difficulties, the consideration of recycling, recovery and reuse of products and product parts leads to additional challenge, which also influence the LCA results. A lot of approaches have been developed but so far there is not any generally accepted method apparent.

On the one hand recycling processes provide usable secondary materials or products, which is a benefit for the product life cycle, but they cause additional environmental impact for the regarded life cycle. Therefore a recycling, a recovering or a reuse system has not necessarily to be ecologically and/or economically beneficial.

There are several methods to calculate the impacts and benefits of recycling, recovery or reuse, considering the gained secondary materials and products. A debatable point is that the result of the assessment differs depending on the applied method.

Furthermore, these methods have several disadvantageous regarding e.g. their definition of criteria used for the calculation.

In addition, a method has still not been established which enables to consider both ecological and economic aspects. The purpose of this study is to present the method developed by IKP and its applicability, which challenge is to abolish these advantageous and furthermore to integrate ecological and economic perspective of an End of Life.

Several methods and the new approach developed by IKP are presented on this paper by applying a practical industrial project.

2. DESCRIPTION OF FTP-PROJECT

The industrial project FTP (Kreislaufführung Füssigkeitstragender Polymerbauteile), which serves as example model on this paper, is funded by the Federal Ministry of Education and Research of Germany (BMBF). This project aims the development of a recycling concept for used automobile gasoline tanks, which are contaminated with gasoline. In spite of its sized weight of 6-8 kg and its homogenous HDPE (High Density Polyethylene) material, the ecologically beneficial and cost efficient material recycling of this contaminated polymer is still an unsolved topic. The FTP project examines a new technological concept for the recycling of such contaminated components by using supercritical CO_2 as a solvent for the extraction of migrated fuel from the polymer material. A consortium of industrial partners, universities and research institutes deal with this project. IKP, together with the PE Europe GmbH the world's largest LCA and Life Cycle Engineering (LCE) working group, supports the project by evaluating the concept in view of environmental impact using the Software GaBi 4 [1].

At the actual stage of the project, the considered secondary material, which is recovered after treatment by above mentioned CO_2 extraction with particular technical conditions, is likely to have the same physical quality to primary HDPE material, thus this is appropriate to be used as material for manufacturing of gasoline tanks (closed-loop-recycling).

This paper shows the results of the analysis and evaluation of the mentioned recycling concept considering the ecological and economic aspects, using an End of Life Calculation method. Since the project is not completed, the result shown on this paper does not present the final result.

3. COMMON END OF LIFE CALCULATION METHODS

Today, several End of Life Calculation methods are applied in LCA. Common and often used methods are "system expansion" and "allocation". However, the application of these methods is accompanied by difficulties in agreeing on the criteria and rules, as is often pointed out. Furthermore, an economic assessment has to be carried out additionally to fulfill the Life Cycle Engineering idea and to complete the evaluation of a system.

The following evaluation of the FTP recycling is done by using various End of Life Calculation methods. For the presentation of the results, the following environmental impact categories are chosen: "Global Warming Potential (GWP)", "Photochemical Ozone Creation Potential (POCP)" and "Acidification Potential (AP)". Furthermore, the normalization "Germany" and an evaluation factor by "expert judgment" are used [1][2]. The value of GWP, AP and POCP are aggregated to a single point value presented as total in the presented results.

3.1 System Expansion

In case of practical applying system expansion, generally "benefits" caused by usable secondary products or materials are calculated representing the saved environmental impact in an other life cycle of the product. Quantification of this benefit depends primarily on the quality of the secondary product and the definition of its application [3].

It is presumed in the presented example, that the gained secondary plastic substitutes primary material. Therefore, the burdens of the processing of primary materials can be subtracted from the first life cycle, which leads to a decrease of the environmental impact.

In case of FTP, the gained secondary HDPE material substitutes primary HDPE material without decreasing tank quality. In this case, the saved amount of primary HDPE material is the "benefit" of this life cycle. The life cycle of the tank is decreased in environmental impacts by the effort for the production of the particular amount of the primary HDPE material.

Fig.1 shows the results of the evaluation for FTP recycling system compared to thermal waste treatment (incineration) system, which is an alternative EoL option for used tanks. However, on this paper, the results are shown for the EoL phase, i.e. the effort caused by recycling and the benefit caused by the gained material, but not the entire life cycle to keep the transparency of the statement.

The bulks on the Fig.1 show the environmental burdens. The bulk for each categories are the net of the burdens and benefits. The burdens are shown above the zero line, the benefits below zero line. Negative net value can occur, which shows the environmental benefit for the recycling system. In this case a little ecological benefit occurs for FTP in AP and POCP considering the EoL. The value of GWP, AP and POCP are aggregated to a single point value presented as total in Fig.1.

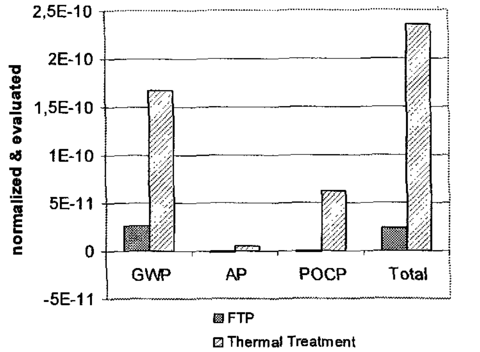

Fig.1: ecological assessment using system expansion

The criteria used for the this method is not unitary. The criteria have to be defined by the examiner. A debatable point of this method is how to count and measure the quality of the secondary product compared to the primary product

3.2 Allocation

Various allocation methods are generally applied in LCA. The criteria for allocation in EoL are widespread and point of discussion. Basically, the allocation method does not calculate benefits for recycling or gained recycled materials or products for the life cycle under consideration. The idea of the allocation is to distribute burdens that arise in primary life cycle to other life cycles, which benefits from the first one. Thus, the environmental impacts are decreased from processes that turn out in one life cycle but provide functions to other life cycles.

An example for the allocation method is the 50/50 method. This method allocates the burdens of the recycling process to the considered and the following life cycle. It has to be noticed, that a 50/50 allocation also has several methods with different rules concerning e.g. the allocation of recycling effort or allocation of recycling and primary material provision, etc. [3]. In case of FTP, the application of one of the 50/50 method shows the result for the environmental assessment as seen on Fig.2. In this case, the primary life cycle is considered. The result is shown for the End of Life. GWP, AP and POCP are presented. Analogous to system expansion, the same normalization and evaluation factors are applied. The aggregated single point value "total" shows that the quantitative relation between FTP and thermal treatment changed compared to system expansion. Fig.3 shows the result of the environmental assessment using a further 50/50 method with different rules [3]. Using these rules, the total environmental burdens in EoL caused by FTP counts higher than by thermal treatment.

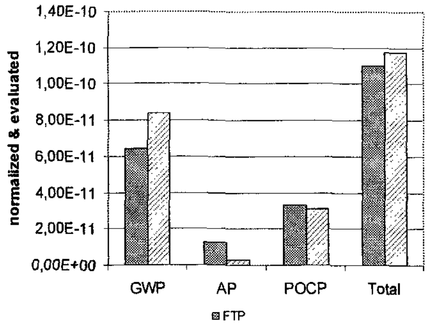

Fig.2: 50/50 allocation method (allocation of recycling)

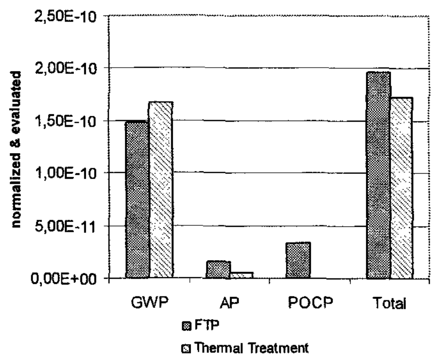

Fig.3: 50/50 allocation method (allocation of recycling and primary material provision)

The influence due to the choice of the method is significant. The numerous further allocation methods, rules and results are not presented on this paper. The result of environmental assessment differs also by the considered life cycle (primary, second...). The principal problem of allocation is, therefore, the decision for the allocation rules and the considered life cycle.

The results show that not only the quantitative value but also the qualitative result changes depending on the choice of End of Life Calculation method.

4. NEW METHOD FOR END OF LIFE CALCULATION

In order to disseminate an unitary applicable and transparent End of Life Calculation method, IKP developed a new method [4]. The advantage of this method is the assessment of a EoL system regarding economic and ecological aspects under same boundary conditions. Within this method a relation between the ecological and the economic assessment is established.

The basis of this method is the creation of a reference system which serves to define the assessment scale: economic and ecological reference indicators. The idea is to have a scale from a theoretical maximum to a theoretical minimum.

Economic reference indicator states the economic effort of a recycling system. The maximal achievable value is the ideal case which the materials or semi-finished products are gained in without any kind of cost (zero cost), and have the identical quality to primary materials. Therefore, this is a theoretical value. A minimum value is basically not definable because cost can rise unlimited, but a supporting point is calculated, e.g. an economic unbeneficial recycling. The value zero occurs by an effort which is equal to the yield.

In case of ecological reference indicator, the minimum value stands for a system without ecological effort and is equal to zero. The material or semi-finished product has the same quality as the primary material or semi-finished product. A maximum value is not definable analogues to economic zero, but serves as supporting point, which means e.g. an ecological unbeneficial recycling system. To refer the ecological evaluation system to the gains of the secondary products, their economic value serves as a quotient (X/benefit Fig.4). Thus, different gained product quality will be integrated in the environmental evaluation.

The following graph (Fig.4) shows economic and ecological reference indicators. This presentation allows the evaluation of a recycling system integrating both aspects.

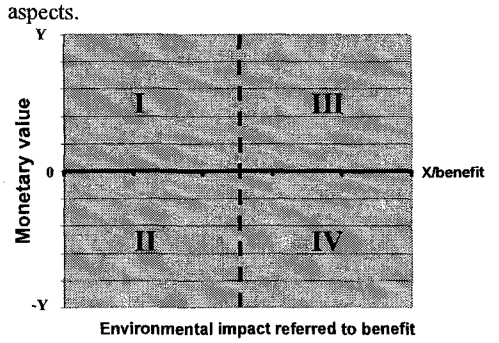

Fig.4: ECO2-Graph

Considering the overall recycling process, category I (upper left) states the best solution, which means the economic benefit (+Y) and low environmental impact per gain (X/benefit). In contrast, category II shows an ecologically advantageous solution, which is however not economically beneficial. Category III shows an economically beneficial solution, which ecological impact must or shall be reduced. Category IV states a solution, which is neither economically nor ecologically advantageous. The borderline between the categories seen as a dotted line shall be drawn by the examiner due to the technical and market economic possibilities as well as to the goal definition.

This method is implemented in the FTP project. The definitive recycling cost (=effort) differs depending on the machine capacity, total amount of processable HDPE material etc. Assuming an effective concept and plan, the recycling cost can reach the level of approximately 2,-Euro/kg HDPE. This cost factor includes all recycling steps including disassembly, plastic treatment and extraction. However, since similar products such as used heating oil tanks will improve the total amount of treating material, a definitive cost cannot be estimated at this stage of the project. The basis for the incineration effort is also an estimation at this stage of the project.

Fig.5 shows the economic reference indicator for FTP recycling and thermal treatment (incineration) of used gasoline tanks. The bulks "total" presents the sum of the benefit and effort due to the end of life systems. A positive bulk for total would occur by an economically beneficial system. In both cases, the economic effort of recycling and recovery is higher than the benefit due to the gained material.

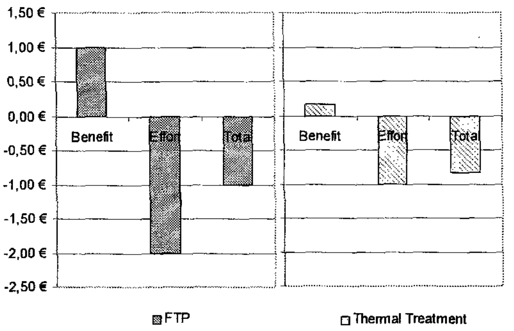

Fig.5: economic reference indicator for FTP and Incineration

For the environmental impact as already described, GWP, AP and POCP are regarded and normalization and evaluation are applied (Fig.6 left). The ecological reference indicator is shown on Fig.6 (right figure), which is obtained by referring the normalized and evaluated environmental impact to each benefits counted in Euro. The reference of the environmental impact to the benefit of the product, presented in Euro, allows the consideration of the gained material quality. Therefore, the relation of both FTP recycling and thermal treatment changes as seen by comparing both figures.

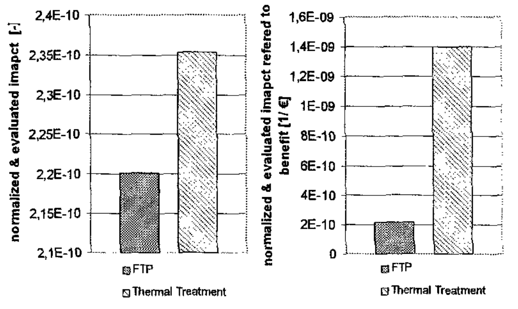

Fig.6: ecological reference indicator for FTP and incineration

At least both indicators will be put on the Eco2-graph.

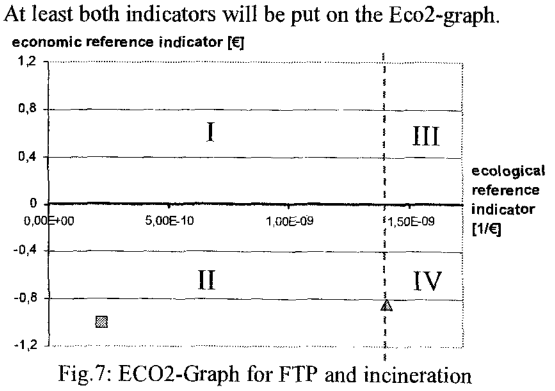

Fig.7: ECO2-Graph for FTP and incineration

The economic reference indicator and ecological reference indicator are also presented in one graph. A borderline is drawn by the examiner at the value of the thermal treatment, since this serves as a reference system. The recycling of HDPE tank by FTP causes a little more cost than incineration, however from the point of economic the system reduces the environmental impact significantly.

5 CONCLUSION

The End of Life Calculation in LCA is unavoidable regarding life cycles with recycling, recovery or reuse system. Various methods can be applied, however most of them cause problems and include often debatable aspects. E.g. the criteria for the system expansion is not unitary. A debatable point of this method is e.g. the choice of the right process for the system expansion as well as the cut-off criteria.

The End of Life Calculation by using an allocation method several options come into question. Depending on the chosen allocation method and its rules. the quantitative and qualitative results of the assessment differs. Beside the definition of allocation rules, such as how to allocate the material to the next life cycle, the determination of the number of life cycles which have to be taken into consideration is one of the basic problems.

The results cannot explicitly show the environmental strengths of an EoL system because of the arbitrary results which depend on the choice of e.g. allocation factor or description at system expansion.

Generally, the environmental assessments for an EoL requires additional economic assessment to complete a sensible evaluation of a recycling concept. The consistency of the criteria of environmental and economic assessment is a point unsolved.

The ECO2-method enables to integrate the economic and ecological assessment of a EoL system applying the same criteria for both aspects. Thus, due to this method, a consistent evaluation of a recycling can be ensured. In addition, this method allows the consideration of the gained product or material quality into both economic and ecological perspectives.

Furthermore, as demanded in the ISO 14040 [5] and following, the application of allocation method will be avoided, as well as the system expansion.

It is not necessary to implement a study comparing various systems. The reference indicators serve as scaling measure for the evaluation.

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