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Effects of Life Cycle Analysis on Environment and Economy[1]

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SUMMARY

This paper summarises the main elements, the methodological developments of LCA, and the steps of the assessment (defining the goal and scope of study, life cycle inventory, life cycle impact assessment and interpretation of the study). It describes the weighting process as the base of assessment, and the different applications of LCA. It also presents a case study for polystyrene and biopolymer packaging, in which investigates the environmental and economic results of comparative LCA - between LCA of PS and Bio-polymer. LCA is a decision support tool. It can help to ensure the environmentally sound practices, from a financial aspect it means a new approach to process optimisation. The assessment has been supported by software aids to determine the benefits, the weaknesses, and the IO –LCA shows the economic benefit of the process.

EVOLUTION OF LIFE CYCLE ANALYSIS (LCA)

The aim of the life cycle analysis is to describe, to know and to understand the environmental relations and the possible environmental impacts and to create possibilities for decreasing their effects consciously in the course of the whole life cycle or describing only one stag of the product life, technology or service from the raw material production through processing and use till the final disposal of the product (from its cradle to grave).

The LCA analysis serving for environmental protection, studies the whole material and energy balance of the system and the balance of mutual relationship between system and environment. It differs from the product life analysis used in the business area significantly, evaluating the financial aspects of a product from the birth of the idea till the death of the product [13].

The first LCA studies had been published in the end of the sixties, but the method began to extend in the nineties. The development of environmental sciences and the energy price boom in the seventies played an important role in the evolution of LCA studies. These facts inspirited seeking for technological solutions requiring lower energy and studying the rentability of alternative energy resources (sun cells, alcohol etc.). An ECO-balance preparation based on the similar principle was developed in Europe at the beginning of the seventies. It primarily served for measuring the energy used for packaging [3]. Debates about the packaging material disposal in the middle of the eighties largely helped developing and spreading the method. The Society of Environmental Toxicology and Chemistry (SETAC) undertake a pioneer role in the methodological development and standardisation of the life cycle analysis (LCA) and life cycle assessment (LCA) [6]. The first LCA study (European guidelines for life cycle analysis) was published in 1993 [1]. K. TÖPFER (Minister of Environmental Protection in Germany) played an important role in making this method popular. He charged the Fraunhoffer Institute with a commission about the life cycle of packaging materials in order to establish control for the packaging material basing on the results of the analysis. The established regulation created big debates in the German society [12].

At first, big companies applied the LCA for marketing purposes in order to demonstrate advantageous environmental characteristics. After a while it became a tool for obtaining the environmental friendly etiquette [15]. It played also an important role in revealing environmental problems, introducing more conscious measurements of environmental protection and establishing environmental management systems. In our days, it is an essential tool of environmental

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conscious production, service technology planning and helps measuring environmental performance [4, 7].
The evolution of the method was accompanied by continuous professional debates which contributed greatly to the increase in the method's sensitivity and reliability. These debates inspired software development and the standardisation process largely as well. The standardisation of the method began at the beginning of the nineties. The first standard (ISO14040) was accepted in 1997. 5 standards have already been published, two ones has not been approved yet. The first softwares appeared in 1992-93, for today, the number of them exceeds 30; however, the SimaPro software developed by the Dutch is the most widely used in the world.
The elaboration of LCA may be carried out on three levels, namely conceptional LCA, simplified LCA and detailed LCA, depending on the fields of application [5]. The detailed LCA is the most comprehensive; it is an analysis tool for all stages of life cycle, but it is cost and time consuming, therefore rarely applied. The application of life cycle analysis may be very different:

- Environmental development of production systems and products,
- Identification of weak points,
- Comparing and studying environmental impacts,
- Development of environmentally conscious management system,
- Development of indicators for environmental performance,
- Determination of BAT technologies,
- Development of criteria concerning Eco-labels,
- Development of long-term strategies, studying alternative policies,
- Development of product standards,
- Marketing and communication relationships, information etc.

METHODOLOGICAL ASPECTS OF LIFE-CYCLE ANALYSIS

The LCA impact study contains four independent stages according to the ISO 14040 standard group:

- Determination of target and field,
- Survey of initial and boundary conditions of life cycle,
- Life cycle impact study
- Interpretation of life cycle

First of all the clear and accurate determination of the aim of the study and establishing the boundary of the system on basis of reconstructed process tree are all important. The unit of measurement has to be chosen and determined that will be used for basis of comparison. We have to determine the demand for necessary data, requirements, approach of the method and the allocation procedures. All of these have to be given in such a way that the LCA can be applied for all products involved in the comparison especially in case of comparing LCA. The exact determination of the unit of measurement establishes the fundament of life cycle analysis preparation. Characteristics, use and quality of the product influence the determination of the unit of measurement (e.g. 1 piece, 1000 pieces, 1 kg, 1 m^3 etc.), but the chosen unit of has to comply with the aim of the study. The unit of measurement must be clearly defined or measurable. The wrongly chosen unit of measurement may induce wrong decisions and unfavourable processes or products may be preferred from environmental point of view of [9].

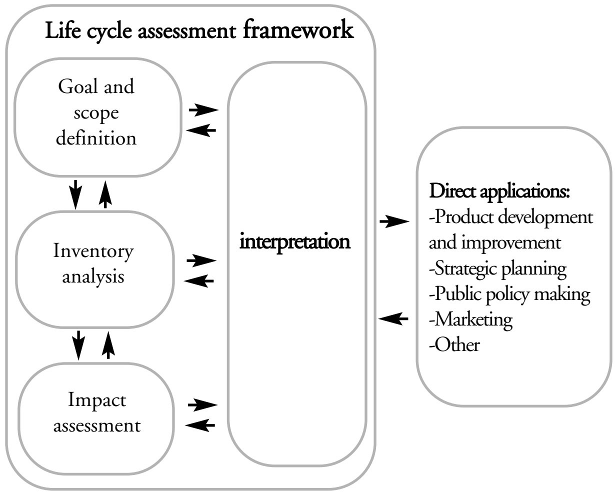

Figure 1. Stages of the life cycle analysis (as laid down in ISO 14040:1997)

Fixing the boundaries of the investigated system can cause several problems in the course of the analysis. The following questions arise where we should draw the boundary of the process and what should be included in the analysis - generally in crossing processes- and what should be left outside the boundary.
The life cycle inventory analysis means the collection of the data related to the process tree and counting procedures giving a quantitative analysis about the input-output side of the whole system from an environmental aspect. We have to emphasise atmospheric emission, water polluting materials, solid wastes, and land use. The aim of the life cycle impact analysis is to identify and evaluate the potential environmental impacts on basis of the life cycle inventory analysis. The first step of the impact analysis is the summarisation of similar effects standing on the output side of the inventory using characteristic factors (e.g. all gases with glass house effect, all kind of acid components, heavy metals, CFC substances etc.), and then reducing the number of parameters through grouping them into effect categories. Data of the inventory may be grouped only in few effect categories. The effect categories will scatter within the whole effect according to their relative importance on basis of reference values. The relative importance of different effects can be given in the normalisation procedure. The results can be summarised by different effect categories as well. The effect estimation of life cycle analysis is a technical, quantitative or qualitative process for characterising and estimating the effect of the environmental load determined in the inventory. In the course of evaluation we have to consider effects on ecology and human health as well: the change of living place, or noise phenomena [6].

The evaluation of results rests mainly on scientific basis though it includes several subjective and social elements as well. Nowadays, there is no generally accepted method for ordering life cycle inventory data to higher aggregation. The weighing of the effect categories can be carried out according to region, geography, and time and risk as well. The ECO-indicator ‘95 or its further developed version ECO-indicator ’99 can be well applied in practice but the final value of the two methods are not comparable because their weightings are based on another principles. The ECO-indicator ‘95 studies the environmental damage caused by emissions, meanwhile the ECO-indicator ‘99 considers treatment of wastes and exhausting of power sources as well. The environmental impacts can be given as the summarised amount of points in both methods. In case of comparison the environmental benefits can be measured in comparison to the reference product basing on the value-difference. Life stages and environmental impact resulting the largest pollution decrease can be determined as well [8].

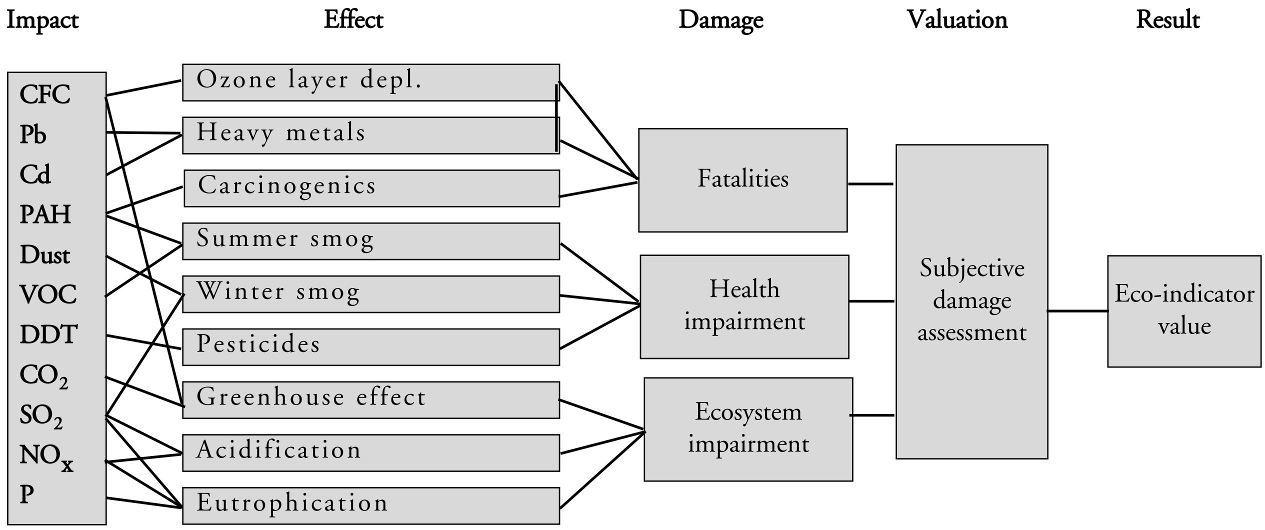

Figure 2. Scheme for the Environmental impact value in case of ECO-indicator ‘95

Table 1. Weighing factors of environmental impacts in the ECO-indicator ’95 system

Effects	Unit	Weighing factor	Criterion
Glasshouse effect	kg CO_2	2,5	A temperature increase by 0,1°C in 10 years results 5 % damage in the ecosystem
Thinning of the ozone layer	kg CFC11	100	1 fatal case/year/ 1000000 people
Acidification	kg SO_2	10	5 % degradation of the ecosystem
Eutrophisation	kg PO_4	5	5 % damage of the Ecosystem of rivers and lakes
Summer smog	kg C_2H_4	2,5	Occurring smog periods, health damage, asthmatic illnesses, in case of old people
Winter smog	kg SPM	5	Occurring smog periods, health damage, asthmatic illnesses, in case of old people
Pesticides	kg akt.total	25	5 % Ecosystem damage
Heavy metals (in air)	kg Pb	5	Pb concentration in blood of children, deviant development, slower learning and ability for understanding
Heavy metals (in water)	kg Pb	5	Cd concentration in water
Carcinogen substances	kg Ba	10	1 fatal case/year/ 1000000 people

Source: [8]

The SimaPro version 3.0 applies the method above, meanwhile the SimaPro version 5.0 carries out the evaluation basing on Eco-indicator '99 where the effect categories are ordered to 3 categories of risk (Figure 3):

- ➢ Human Health (HH), unit: DALY, Disability adjusted life years – weighed values of disability resulting different illnesses,
- ➢ Environment quality (EQ), unit: PDF (Potentially Disappeared Fraction of plant species) $*m^2$ year, and
- ➢ Resource (R), unit: MJ surplus energy, how many additive energy is needed for compensating the reduced lot of minerals of the future.

The weighing can be graphically illustrated with the help of a triangle diagram [8] carried out by software automatically.

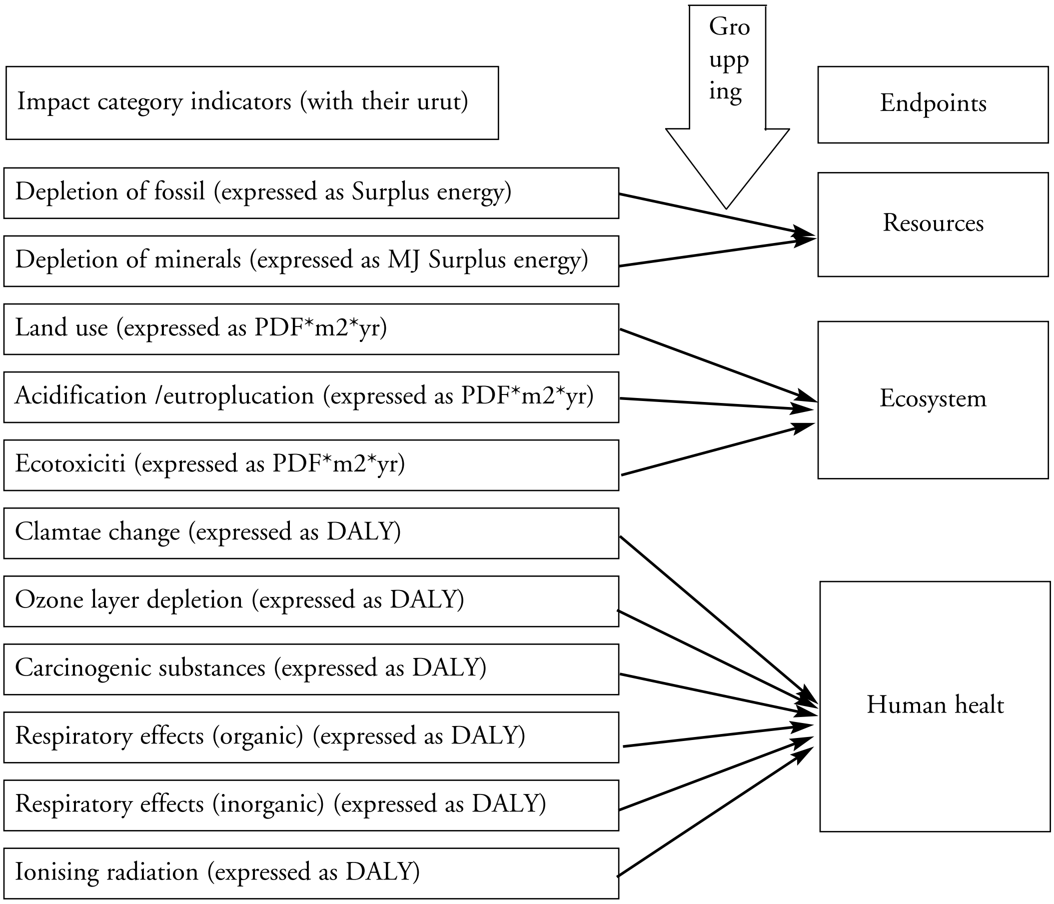

Figure 3. Classification of effect categories in the Eco-indicator '99 method

The description of life cycle shows and evaluates the results according to the application aim and establishes decisions. The critical areas can be determined from the development's point of view. Environmental savings can be well reflected concerning new products.

Within the life cycle effect study the *input-output life cycle effect analysis (*IO-LCA (Input-Output Life Cycle Assessment) is the result of methodological development of recent years. The aim of the input-output analysis is to make the process analysis easier and to help carrying out life cycle analysis and impact analysis according to the ISO 14040 standard. So the IO-LCA analyses the environmental effects by using a specific methodological approach containing certain economic elements. It defines the system as more complex, the input-output approach appears integrated in the frame of the LCA. The roots of the environmental input-output analysis grew up from the frames of the economic input-output analysis related to the Leontief's works, which showed the pollution in 1970 within the life cycle effect study as by-products of economic activity. They are illustrated in a matrix projected on one unit of industrial product. Later on energy consumption was included in the analysis and there were attempts to calculate the external costs as well. The United Nation Environment and Development Committee (UNEP) developed this model further and elaborated the system of the integrated environmental and economic accounting. The System of Integrated Environmental and Economic Accounting (SEEA) moved from static systems towards dynamic models. However, the environmental analysis basing on IO tables caused problems in case of analysing the consumer's behaviour or governmental measurements and in studying export-import wastes. In our days, this latter one is the less elaborated field [11].

The IO-LCA has strengths and weaknesses and compared to the process LCA. Taking an inventory on data related to "cradle" and to primary resources is extremely important. The exact determination of the system boundary of processes will cause problems as well, especially in case of complex process trees, containing almost all figures of a factory from labour to machines. The IO-LCA is based on national accounting and informs us about the use of the goods offered by the industrial and service sector as well. At the same time it shows sectorial and national differences related to demand and distribution. The IO-LCA can be used e.g. for calculating sustainable pollution coefficients (emissions, gases with glasshouse effect or toxic substances) by using the results of the pollution matrix related to energy. The strength of the process LCA (P-LCA) is in its peculiarity, namely the comparability of detailed alternatives (e.g. among the plan versions from different environment aspects), meanwhile the IO-LCA simplifies the determination of costs and results economic benefit.

The essence of LCA is to look for those product technologies that offer the most advantageous, optimal total environment impact, with other words the least environmental impact per time unit (generally per year) under definite conditions, in such a way that it can be economically acceptable as well. We have carried out such analysis in the NKFP project for biologically degradable newly developed packaging materials.

COMPARABLE LIFE CYCLE ANALYSIS OF PACKAGING MATERIALS

With the life cycle analysis of the packaging materials we wanted to answer the question how large environmental impact could be expected in case of biologically degradable packaging compared to traditional packaging materials and whether their production and use was rentable. We used the SimaPro software for the analysis. We completed this analysis with input-output LCA study as well.

We carried out the investigations for polystyrene (PS) tray and for grain based bio-polymer tray with rigid wall. In order to make a comparison we have worked within the same system boundaries.

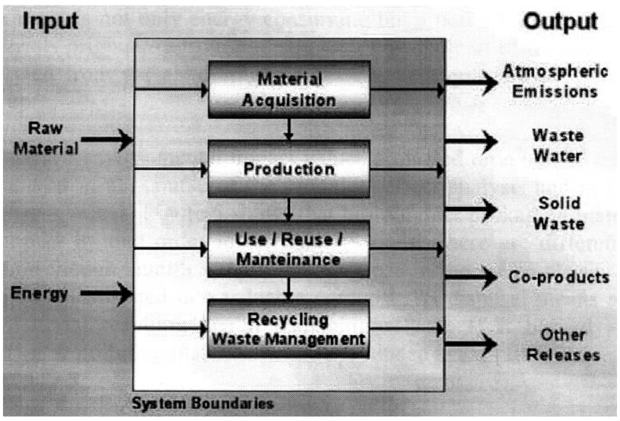

Figure 4.
Process flow sheet for life cycle analysis
Sources: http://www.etse.urv.es/DEQ/web_cat/recerca /aga/English/EntryEnglish.html

Both the life cycle of the polystyrene (PS) and the bio-polymer showed a composite system. The process illustrated above has been simplified in order to make the data-collection and the analysis based on process steps easier, namely *Raw material production- product processing-use –waste treatment,* in separate modules and then projected on the unit of measurement summarised. If the life cycle analysis starts from mineral oil mining, then the cradle of bio-polymers will be agricultural production. For carrying out the analysis we have to know the system very well and a rather whole inventory is needed, because raw material production and raw material processing can result big differences in environmental impacts due to different technologies. Even on the same technology lines –in the stages of production and use - big variances due to material characteristics may arise. In order to follow the differences in the course of the comparing and determining environmental impacts, we have to our calculations on the measured data and figures and on statistical average of technology lines instead of literature data and figures because of reliability. Concerning packaging materials the stage of use means application for food packaging and human consumption where data of industrial usage are major factors. Factory figures are needed even in such cases when both packaging materials are used on the same packaging line because differences due to different material characteristics (different waste, lower capacity) may arise. In case of high similarity –see our investigation - this stage of life cycle can be ignored, if not the measure of environmental impact on the whole life cycle but the difference between environmental impacts of the two products is only the question.

Beyond resource use waste management plays major role. Disposal and treatment of huge amount of communal wastes coming from packaging material are one of the major environmental problems in the analysis. As nowadays the possible ways of waste treatment are different as well (burning, disposal, composting, separation, recycling) lot data and figures based on measurements are needed for a reliable analysis: concerning air and water pollution, transfer (ton km), energy consumption and final waste treatment. Unfortunately, there is a big uncertainty in these fields. The accounting of deliveries related to the life cycle of the product is always an important part of all life cycle analysis. The delivery is not only energy consuming but a polluting resource as well. In case of raw materials originating from biomass CO_2 was the part of the analysis as well, which was extracted from the air during the growth, as a quantity not contributing to global warming up.

The summarised environmental impact values projected on a unit of measurement can be well compared in the course of the modules' effect analysis and in determining environmental impact values. Figure 5 shows that bio-polymer packaging material has an environmental impact by one order lower than PS ones. There are differences in raw material production though significant differences arose in the waste phase. Meanwhile bio-polymer can be transformed into valuable compost; PS disposal means a long term site occupying material resulting health damaging effects. If it burned – though it generates energy – new polluting materials will be produced again [10].

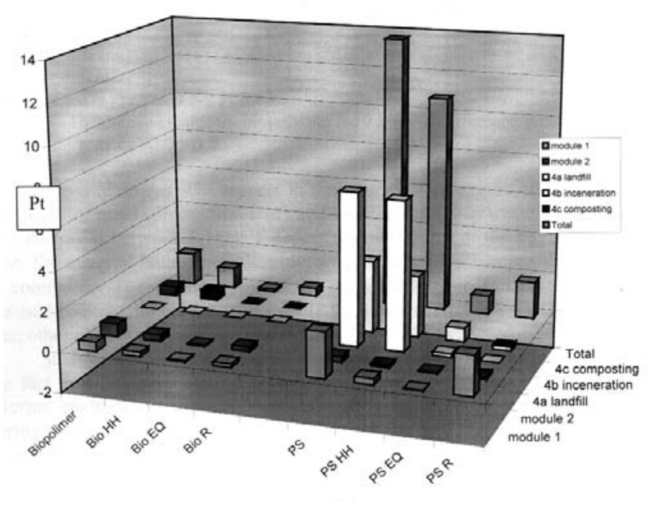

Figure 5
Comparison of environmental impacts of PS and Biopolymer packaging materials

We can see from the analysis that raw material production has a lower environmental impact compared to the production of trays in case of the Bio-polymer. The opposite is true for PS. The LCA of the polystirol tray (ECO-indicator '99) showed that the environmental impact is related to waste treatment (75%) and not to raw material production. In the course of waste treatment the disposal means a 3 times higher environmental impact than the raw material production considering a burning ratio of 10%, a disposal ratio of 90% and lacking selective collection of wastes. Raw material production gives 15% of environmental impacts; processing in the production of packaging and processing in food industry represent 10% of the environmental impact depending on the energy demand of operations. Health effects represent the most important environmental load. The LCA results published earlier demonstrated that the biologically degradable packaging materials had less harmful substance emissions and their exhausting resource demands was less as well. Investigations carried out until today showed that composite effect of the production of 1kg raw material was only one tenth of the traditional plastic production.

Table 4 Symbolic presentation of the Environmental benefits

Life stages	Sum of points (Pt)	Health damages (Pt)	Environment damages (Pt)	Resource demand (Pt)
Module 1	❍ ❍			❍ ❍
Module 2				
Module 3	Taking not into account			
Module 4	❍ ❍ ❍ ❍ ❍	❍ ❍ ❍ ❍ ❍	❍ ❍	❍ ❍

Waste treatment
Difference is greater: 0,5-2 Pt for PS
❍❍❍❍❍Difference greater for biopolymer 2-10 Pt, ❍❍ difference greater for biopolymer 0,5-2 Pt, ❍: difference>0,05-0,5

We emphasised two aspects in the course of economic efficiency considerations: the prices of trays (production cost) and the differences in waste treatment. The net cost of a PS tray is between 4-14HUF depending on the size of the trays. The price calculated from the material balance of bio-polymer is competitive compared to PS trays available in commerce. The smallest size of PS trays made from foil costs 14 HUF/piece. The planned commercial price of trays made from biomaterial is 3,33HUF/piece which is less than other current products in the market.

Savings due to waste treatment are based on the same facts as in PS study and on the fact that bio-trays can be converted into compost within a short time. We used a relevant environment management study and considered the waste management concept during the evaluation as well [2, 10]:

- ➢ The outer profit due to a change from disposal to composting is low: 1-4 EUR/tons in general. When the change happens from anaerobic treatment of selective collected waste to composting we can count on a higher outer profit.
- ➢ The profit due to a change from burning to composting is much higher 12-25 EUR/tons.
- ➢ The cost-benefit analysis of composting is the most advantageous among the possible waste treating scenarios.

Composting can result savings of 2.1-6.1 EUR/tons, so the risk related to the disposal can be avoided, moreover, compost can be sold as well.

CONCLUSION

As our case showed the best alternative of development from environmental and rent ability aspect can be chosen by using LCA. It is an ideal method for planning the variants having highest environmental benefits and economic savings. The investigation carried out until today demonstrated that the use of biodegradable packaging materials and tools was sensible especially when their proper functional characteristics were even better than those of traditional products of petrol chemistry.

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Zusammenfassung

Diese Artikel zusammenfasst die Hauptelemente und Methodologieentwicklung von LCA und die Schritte der Schätzung (Determination des Zieles und die Kreis der Studie, LCA Bestandaufnahme, Schätzung des Effektes in LCA und Interpretation der Studie). Sie schreibt der Gewichtung des Prozesses, wie die Fundament der Schätzung, und die verschiedene Anwendung von LCA. Sie zeigt auch eine Fallstudie über die Verpackung von Polystyrol und Biopolymer mit der Untersuchung von umweltlichen und ökonomischen Resultaten der komparative LCA. Der LCA ist ein Unterstützungsmittel in dem Entscheidungsprozess. Es kann bei der Besorgung des umweltfreundlichen Praktikums helfen. In der finanziellen Seite es bedeutet eine neue Annäherung für die Prozessoptimierung. Die Schätzung wurde mit Software durchgeführt um die Vorteilen und schwache Stelle zu determinieren. Das IO –LCA zeigt die ökonomische Vorteilen des Prozesses.

Összefoglaló

A cikk az életciklus elemzés fő elemeit, módszertani fejlődését és a hatásvizsgálat lépéseit foglalja össze (cél és vizsgálat keretei, életciklus leltár, életciklus hatásvizsgálat és tanulmány bemutatása). Leírja az elemzés alapját képező súlyozási folyamatot és az LCA különböző alkalmazási lehetőségeit. Bemutat egy esettanulmányt, amely a polisztirol és biopolimer csomagolások közötti összehasonlító életcikluselemzésre vonatkozik. Az LCA, mint döntést támogató eszköz, segíti a környezetbarát gyakorlat megvalósítását, pénzügyi oldalról pedig a folyamatoptimalizálás új megközelítése. A szoftveres elemzés a nyereségek és gyengeségek meghatározását célozza meg, az IO-LCA a folyamat gazdasági nyereségét mutatja meg.