Tools for assessing environmental impacts of technological applications

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Abstract. The foremost goal of industrial activities is represented by the desire to improve the living standard of humanity. However often happened that beside positive direct and desired effects of technological applications, undesired negative effects on the environment and society have been registered. With regard to sustainability goals the chances and challenges of technological developments have to be carefully analysed and assessed. The pretty new discipline called "Technology Assessment", started in the United States in the '70s, becoming pretty well known during the '80s in Western Europe, is offering analytical methods and instruments for carrying out studies in the field of environmental impact assessments. Presently the most discussed one on international level is the life cycle assessment (LCA), but also environmental management systems or ecoaudits. In the present paper general notions regarding these tools will be presented as well as application possibilities will be debated.
Key Words: environmental impacts, life cycle assessment, life cycle stations, matrix of emissions, aggregated emission indicator.

Introduction. Especially after the World War II humanity started to concentrate on the technological developments, because it was the hope that this will generally bring human prosperity and well-being. At the latest, after publication of the first report to the Club of Rome „The Limits to Growth" in 1972 and in the same year after taking place the Conference for Environment in Stockholm, it was understood that technological progress can bring not only desired effects, but also unwanted negative effects can occur. Presently the most discussed elements of the so-called "global problems" are represented by the world population growth, growth of energy and natural resources consumption and environmental pollution (Meadows et al 1972), as presented in Figure 1.

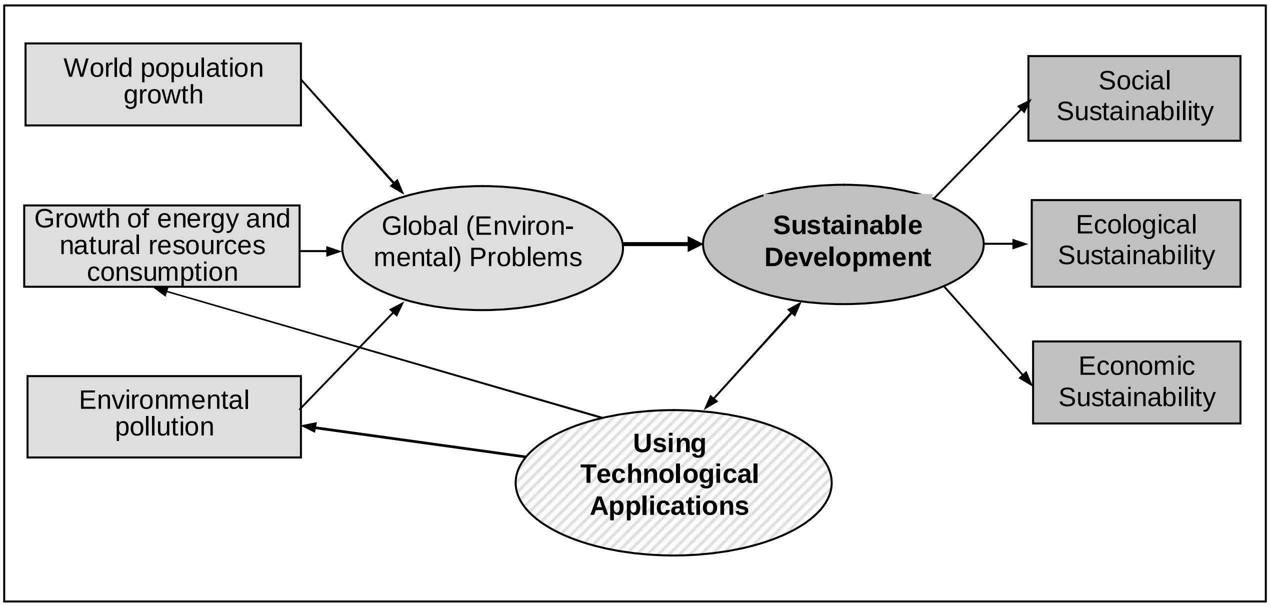

Figure 1. Technological applications for assuring sustainable development as response to the global problems.

A lot of debates took place on different levels and in different circles, scientific, political, social, cultural ones, in order to try finding the best solutions on a global level to overcome the created conflictual situation because of the rapid technological developments. After several tryings to deliver a concrete solution for the arisen problems, the concept of sustainable development was defined in 1987 in the Brundtland Report of the World Council on Environment and Development (Hauff 1987). Pretty fast this concept was accepted as the viable solution for the created global complex ecological, economical and social problems (Jischa 2005). The idea of sustainable development was very much discussed during the Conference for Environment and Development in Rio de Janeiro 1992, that ended by adopting the closing document „Agenda 21“ (Agenda21 1992). Further debates followed during the World Summit on Sustainable Development in Johannesburg in 2002 and later in 2012 during the United Nations Conference on Sustainable Development, globally known as ”Rio+20”-Conference (Rio+20 2012).

The operationalisation of the concept of sustainable development means the transformation or translation of its goals into political measures and controlling instruments. A general methodology in order to concretely apply sustainable development on regional and local level is presented in Figure 2 (Tulbure 2003). Going into details there is a need to consider different phases, starting with the definition of the concrete regional problem concerning assuring sustainability, followed by the necessity to state the specific space and time scales. In order to find the best sustainability solution, there is a need to approach the region in a systemic way by modelling the most important interactions. Thereafter it is relevant to establish concrete aims for the analyzed situation, depending on the followed goals in the considered region, where sustainnability has to be achieved, especially by assessing environmental impacts, as shown in Figure 2.

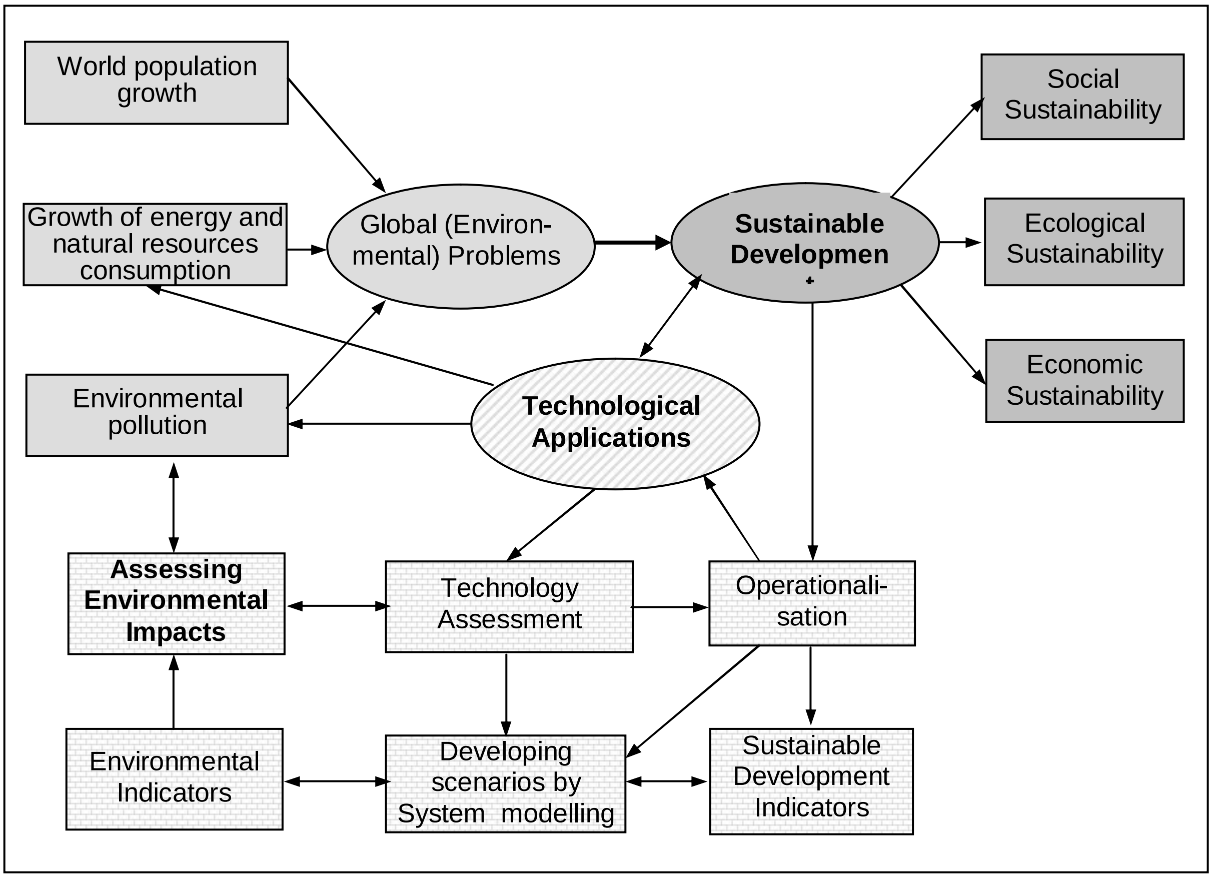

Figure 2. Operationalisation of sustainable development by assessing environmental impacts of technological applications.

By knowing the intended aims it is possible to derive some specific measures by establishing priorities in order to achieve the put aims. Depending on the level of the technological development in the considered region, very often technological applications are considered as possible solutions to achieve sustainability, as shown in Figure 1. In order to succeed getting sustainable development, the possible results to be got after concretely applying the proposed measures have to be analyzed (Jischa 2005). This can be made by developing different scenarios using system modelling and by comparing these scenarios regarding possible developments in technical and socio-economic field, but not only (Tulbure 2003). The comparing process can be led by using existing indicators or by developing new ones in the form of sustainable development indicators, see Figure 2. When all these steps are clarified, then the developed concept can be applied into the practice on regional or local level for getting the sustainable development of the considered region or city.

Material and Method. The operationalisation is only possible, when for an individual problem-case concrete aims are established and from these aims concepts to achieve them are developed. From an engineering point of view such aims are represented especially by developing and using technologies. Achieving sustainability actually means to develop and use technological applications so that the environmental impacts during their development and usage are minimum. Sustainability is to be defined for each different case. This means that for assuring sustainability on regional level, assessing environmental impacts of technological applications plays a relevant role (Jischa 2005).

Evaluation and controlling instruments are sustainable development indicators (SDI) (Tulbure 2016). These indicators permit to quantitatively formulate the proposed sustainable development objectives and goals. After introducing the proposed measures, the implementation degree can be controlled by calculating these indicators and by comparing them to the reference values. The possibility to make corrections is assured in this way (Grunwald 2002). On the other hand indicators serve as an instrument which helps to understand possible effects by introducing certain measures and to inform the public in the process of sustainability operationalization, as presented in Figure 2. In the last time there is a consent among political economists and engineers that the gross national product does not represent a measure for the life quality of a nation. It gives information about national economies, but it does not consider many parameters which influence the quality of life, as for instance: environmental pollution or different social aspects. That is why new indicators have to be developed on each level (Jischa 2005).

Technology Assessment (TA). Part of what engineers do is to evaluate developments in technology. Their evaluation has been up to now almost without exception focused on technical aspects and on economic aspects following legal and financial boundary conditions (Grunwald 2002). With respect to sustainability more criteria have to be considered like: environmental quality, social and human values, quality of life, as emphasised several times in the works carried out at Institute for Technology Assessment and Systems Analysis, ITAS in Karlsruhe, Germany (ITAS). The activities of engineers when evaluating technologies can be sustained by the new discipline called *Technology Assessment* (TA). Although in the last 25 years a lot of progress in the field of technology assessment has been made, especially due to several studies which have been carried out in the USA, Japan, Germany and other European countries, there is still need in developing new integrative methods for technology assessment (Grunwald 2002; Jischa 2005; Tulbure 2013).

As a result of the rapid economic and technological progress in the human society, with all its impacts in different fields, in the economic, technological, environmental as well as in the social field, the necessity to analyze and evaluate these impacts grew up, impacts which could be positive, but also negative ones (Grunwald 2002).

After many tryings to give a complete definition for the pretty complex process of evaluating technological applications, Technology Assessment has been finally defined as being the methodical, systematic, organised process of:

- analysing a technology and its developmental possibilities;
- assessing the direct and indirect technical, economic, health, ecological, human, social and other impacts of this technology and possible alternatives;
- judging these impacts according to defined goals and values, or also demanding further desirable developments;

- deriving possibilities for action and design from this and elaborating these, so that well-founded decisions are possible and can be made and implemented by suitable institutions if need be (VDI-Richtlinie 2000).

Often a concrete sustainability problem especially related to a technological issue is to be solved by carrying out a TA-study. Or a TA-study has as a goal to research if a technology has negative effects on different domains, that means if the effects of a technology application do not conflict with the goals of sustainable development (Grunwald 2002; Jischa 2005). There are several levels to apply the concept of sustainable development. Applying on a global level means to define general goals for the whole world, things which happenned more or less with the Rio-Conference. On national level means to define goals paying attention to the specific conditions of a country. On regional or local level concrete measures represent the content of the Local Agendas 21 (Agenda21 1992). But what about applying sustainable development on the level of companies, of industrial processes or of products? In this field the operationalisation of sustainable development means to use technology assessment tools (Tulbure 2016).

Operationalisation of sustainable development with technology assessment means analysing the complex dynamic environmental, economic and social systems in order to try to discover developments which lead to instabilities (Tulbure 2015). The concept of technology assessment equally how it is named, if Technology Evaluation, Innovation Research, System Analysis or others, brings together almost all scientific disciplines with the question of how sustainability can be operationalised in order to try developing different understanding forms and patterns for assuring the sustainability of our Society (Jischa 2005; Tulbure 2015).

Technology assessment tries to give an answer to the question: Which are the technologies that we need, how are these technologies to be developed and how do they integrate into environment and society? Technology assessment is the concept, which tries to answer exactly such questions. Therefore, a multidimensional assessment problem can be considered as a logical measurement operation. Consequently, one usually has to deal with complex and nonlinear systems, where many non-measurable aspects occur and interactions are at least partially uncertain (Tulbure 2003).

Tools for environmental impact assessment. The legislative framework for environmental impact assessment exists from 1985 in the European countries. In Germany for example the law concerning the examination of different public or private projects was promulgated 1990. In Romania there is as well a legislative reglementation regarding the examination of potential impacts on the environment of economic and social activities (Tulbure 2016). The analysis of the environmental effects has as a goal the assurance of activitites which have as minimal environmental impacts as possible. Going into details the followings have to be taken into account:

- the possible results and consequences of a project have to be searched, described and evaluated;
- the results of the analyses have to be delivered to the authorities which have to decide basing on the results (Jischa 2005).

In order to carry out such an analysis the project which has to be analysed must contain information about the project itself, about the proposed measures to diminish possible negative effects, other alternatives etc. The application domain for these studies is represented by big projects or public projects. The requirements with respect to Environmental Impact Assessment of a project are the following (Grunwald 2002):

- the assessments have to be transparent;
- the assessments have to be public;
- the methods used are to be unified;
- the results have to be comparable.

In order to assess possible impacts of human activities, especially of industrial processes on environment, several tools for environmental impact assessment, so-called *instruments of technology assessement*, can be applied with respect to the questions which have to be answered (Figure 3). The most used and important ones are the following (Tulbure 2013):

- Environmental Management Systems;
- Life-Cycle-Assessment;
- Eco-Audit;
- Ecobalances.

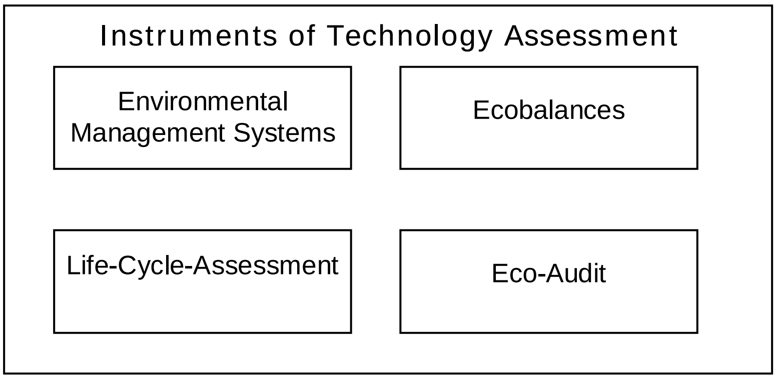

Figure 3. Tools for environmental impact assessment.

The instruments of technology assessment for environmental impact assessment are often used on company level, on local or regional level, depending on the concrete situation (Jscha 2005). Currently the most important one on the company level is the Life-Cycle-Assessment, LCA, which is used in order to minimize the environmental impacts of industrial processes (DIN ISO 14001; Tulbure 2016).

Eco-audit. The Eco-Audit is a management tool for systematic, documented, periodic, objective evaluation of the environmental management in a company. The environmental management in a company as stated in the norms DIN-ISO 14001 represents the whole measures directed to organize and lead the activities in the company related with environmental protection including installations for environmental protection and for environmental monitoring. The Eco-Audit is an instrument which works preventively with respect to environmental protection (Tulbure 2013). By Eco-Audit the actual situation in a company is emphasized. The results state the degree in which the company respects the legislative measures and decrees in the environmental protection field as well as the goal of the company. Taking into account the results, it improves the environmental protection program of the company. It is remarkable that in this case it is aimed that companies take voluntarily part in with the conviction of gaining in the end economic advantages (Grunwald 2002). It is to be mentioned that here a big problem constitutes the database, that means collecting, processing and evaluating data and informations from the company.

Ecobalance. The ecobalance or environmental performance evaluation represents an instrument for systematically analysis of products, processes or even companies or regions regarding environmental impacts (Grunwald 2002). The ecobalance can be performed as a singular study or as a comparative study. The ecobalance registers material and energetical flows when producing something, or within a process or within a company or a region. An ecobalance is to be done in 4 steps (Tulbure 2013): definition of goal and scope; inventory analysis; impact assessment; interpretation of results.

Life-Cycle-Assessment (LCA). The LCA is an analysis which registers all the effects on the environment of a product during its life "from the cradle to the grave", from the production to the consumption and recycling. The general life cycle of a product is given in Figure 4 (VDI-Richtilinie 2000).

Besides production and consumption processes it can be remarked that also transport processes are taken into consideration. With *T* are indicated in Figure 4 transport processes within the life cycle of a product. The life-cycle-analyses is appropriate to improve the production lines of products, to compare different products and to ecologically optimize the life-cycle of products. The LCA is in fact an ecobalance which can be performed as a singular study or as a comparative study (Tulbure 2013).

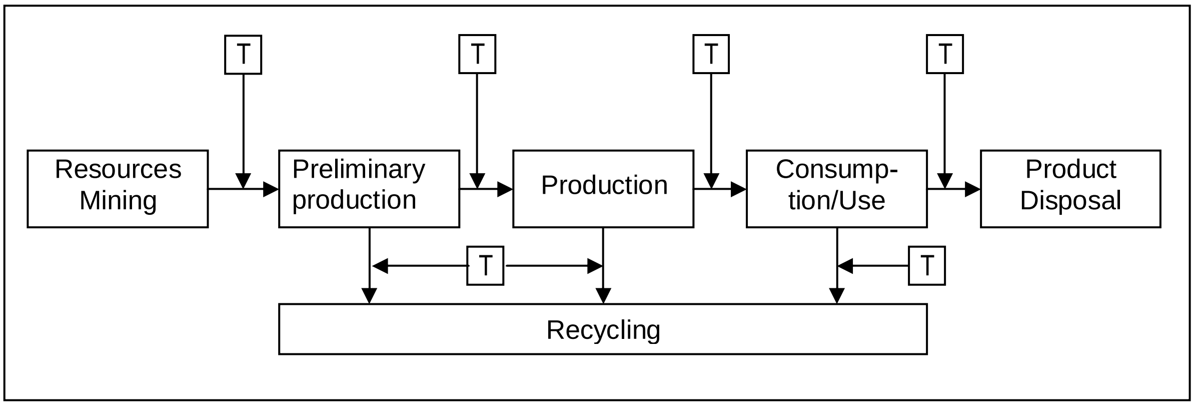

Figure 4. General life-cycle of products.

The ecobalance registers material and energetic flows when producing something, or within a process or within a company or a region. Such an analysis needs several steps (VDI- Richtlinie 2000):

a) definition of goal and scope;
b) inventory analysis;
c) impact assessment;
d) interpretation of results.

a) Definition of goal and scope - The goal shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated. In defining the scope of an LCA study, the following items shall be considered and clearly described: the functions of the product, the functional unit, the system boundaries, methodology of impact assessment, data requirements, assumptions, limitations;

b) Inventory analysis - It involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases into air, water and land associated with the system;

c) Impact assessment - It is aimed at evaluating the significance of potential environmental impacts by using the results of the inventory analyses. The impact assessment may include elements as: assigning of inventory data to impact categories, modelling of the inventory data within impact categories and possibly aggregating the results in very specific and meaningful cases. It is to be mentioned that the methodological and scientific framework for impact assessment is still being developed. Very often in the step of assessment aggregated indicators are used in order to allow a transparent evaluation;

d) Interpretation of results - in this phase the findings from the inventory analysis and the impact assessment are combined together. The interpretation takes the form of conclusions and recommendations to decision-makers, consistent with the goal of the study.

Results and Discussion. With respect to LCA a difficult step is represented by getting on complete data and information about the products and production processes. To compare different life cycle stations of a product from the point of view of pollutants emissions several methods can be used, one of them has been developed at the Clausthal University of Technology and applied especially in technological field for automotive systems (Jischa 2005; Tulbure 2013). The presented tools for environmental impact assessment, the environmental management systems, the eco-audit, the ecobalances, but especially the Life-Cycle-Assessment, are considered to have a great potential in order to be used when assessing the possible environmental impacts of technological applications, especially because of their potentials to integrate different aspects from the production processes into the exact mathematical approaches.

In order to carry out an environmental impact assessment of a certain product, the emitted pollutants have to be considered in which phase P_i in the life cycle of a product, as presented in Figure 4. The emissions of different pollutants are registered in each station of the product life cycle and can be written in a table like given in Table 1, resulting at the end a matrix of emissions of different pollutants (Tulbure 2003). By using such a table the total emissions of each pollutant can be calculated in different stations of the product life cycle and also the weighted sum of different pollutants emissions can be established, called as Aggregated Emission Indicator, AEI, as presented in Table 1 (Tulbure & Ludwig 2000).

Aggregated indicators are needed in order to provide a comprehensive assessment of environmental impacts of industrial systems (Jischa 2005). The concrete applications demonstrate the necessity to work with aggregated indicators in order to draw some relevant conclusions regarding the environmental impacts of different stations in the product life-cycle. Especially applications for automotive systems are demonstrating the necessity to develop in the future so-called aggregated emission indicators, which consists of the weighted sum of single pollutant emissions the possibility to establish such weighting coefficientd has to be clarified (Tulbure & Ludwig 2000). A transparent way to establish weighting coefficients for singular pollutants could be the mathematical method based on fuzzy logic (Tulbure 2003). Accordingly to Figure 4 different life cycle stations of a product could be then compared from different point of views. From the point of view of pollutants emission in the atmosphere the comparison can be made by the already mentioned matrix of emissions as proposed in (Tulbure & Ludwig 2000) and presented in Table 1.

Table 1

Matrix of emissions for different pollutants S_j in different life cycle stations P_i

Phase P_i	*Pollutants S_1 ... S_j .... S_m*					*AEI*
P_1	E_{11}	...	E_{1j}	...	E_{1m}	AEI_1
...	...		...		...	...
P_i	E_{i1}	...	E_{ij}	...	E_{im}	AEI_i
...	...		...		...	...
P_n	E_{n1}	...	E_{nj}	...	E_{nm}	AEI_n
Σ	$E_1 = \Sigma E_{i1}$	...	$E_j = \Sigma E_{ij}$	...	$E_m = \Sigma E_{im}$	AEI

In this way several life cycle stations of a certain product, in the mentioned case of a generic passenger car can be compared from the point of view of pollutants emissions. The generic car is a car with an average weight of 1000 kg, an average mileage of 150000 km and with pollutant emissions calculated as average between diesel and petrol motors (Tulbure/Ludwig 2000).

The concrete results got by such a matrix of emissions could emphasize that the most critical phases in the life-cycle of a certain product from the point of view of most emitted pollutants. It is to be mentioned that considering all phases in the life-cycle of a certain product is a difficult process because of lack of environmental data. It could be interesting to calculate such emission indicators in all life cycle stations of a product in order to make comparisons, as well as for other products too, allowing in this way comparisons and assessments of different products regarding their environmental impact. Such approaches could support finding dangerous and unsafe points in the production lines as well as establishing measures to improve production processes. Such a methodology by using Life-Cycle-Assessment, LCA, together with new aggregated indicators for the step of evaluation could be successfully applied in the future, if the needed data from different production processes would be available.

Conclusions. For industry and engineers the operationalisation of sustainable development could mean to lead technology assessment studies especially environmental impact assessments of technological applications. In the process of operationalisation of sustainable development an important step is represented by evaluating environmental impacts on regional level, in order to carry out local environmental impact assessments. The heightened awareness of the possible impacts associated with the use of products has increased the interest in the development of methods to better comprehend these impacts. Several companies in Western Europe having practiced environmental optimisation of production processes started to recognise that by applying an ecological optimization also economic advantages can be achieved. This gives example to companies in Eastern Europe as well and arises interest for environmental assessments. There are several tools in order to evaluate environmental impacts of industrial activities like life-cycle-assessments, eco-audit, ecobalances or environmental management systems. Life-cycle-assessments, LCA are world wide used to assess environmental effects of products, but the evaluation questions are still not well clarified. This question has been pointed out and the need of using assessment methods based on aggregated indicators has been emphasized. The application way of LCA has been debated, the assessment difficulties and the advantages of applying technology assessment methods for assessing environmental impacts of technological applications have been pointed out.

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