DOI: 10.29302/Pangeea 18.02

RATING TECHNOLOGICAL APPLICATIONS BY USING LIFE CYCLE ASSESSMENT

Assoc.prof. PhD ILDIKO TULBURE
University "1 Decembrie 1918" from Alba Iulia, Romania

ABSTRACT: *In order to optimize different technological applications it is necessary to clearly define the rating perspectives of the approached technologies. In order to carry out a holistic comprehensive rating the environmental perspective has to be considered as well, beside technical and economic points of view. Following this constraining conclusion it is necessary to carefully analyse and evaluate environmental impacts of technological applications. Currently there are scientific debates regarding assessing possibilities of different economic activities especially related to concrete methods used in this context. One of the most discussed and used tools is the Life Cycle Assessment (LCA), which will be presented, emphasing the offered possibilities to actually optimise technological applications from different points of view. It will be concluded that with the optimising goal this instrument can be used in different stages and for different phases in the life cycle of a product. Regarding currently car market debates an example will be presented considering a so-called „generic car" by taking into consideration two phases of the whole life cycle, i.e. phase of basic materials fabrication and phase of car utilization. Pollutants emissions in these two phases will be assessed and compared by an Aggregated Emission Indicator, AEI. The obtained results will be discussed and conclusions concerning the application potential of the presented methodology by using life cycle assessment will be drawn.*

Keywords: *life cycle assessment; environmental impact assessment; car market; environmental pollution; aggregated emission indicator*;

1. Introduction

About 50 years before the world started to understand the unwanted impacts of human activities, especially of industrial ones. After the first report to the Club of Rome „The Limits to Growth", 1972 and the Confe-rence for Environment in Stockholm in the same year [7] the mankind has finally understood that besides wanted effects of technological progress, undesired and negative effects can appear. After this time the environmental awareness in the Western world began changing [2]. The created regional and global problems in environmental field have been recognised as being very serious and as implicitly needing to be solved.

2. The Concept of Sustainable Development

The world began to recognize starting with the '70s that beside positive wanted effects of human activities, these usually can hide some undesired effects and unthought dangers, especially when industrial activities are considered [2]. After the Conference for Environment in Stockholm in 1972 and the first report to the Club of Rome „The Limits to Growth" in the same year [3] it was finally understood that besides wanted effects of technological progress, undesired and negative effects can appear. After this time the environmental awareness in the Western world began changing. It was clear that the arised regional and global environmental problems have been very serious and have needed to be solved. Nowadays we confront us with a series of global problems, which can mainly be grouped in three parts: world population growth, growth of the energy and natural resources consumption and environmental pollution, as presented in Figure 1 [2].

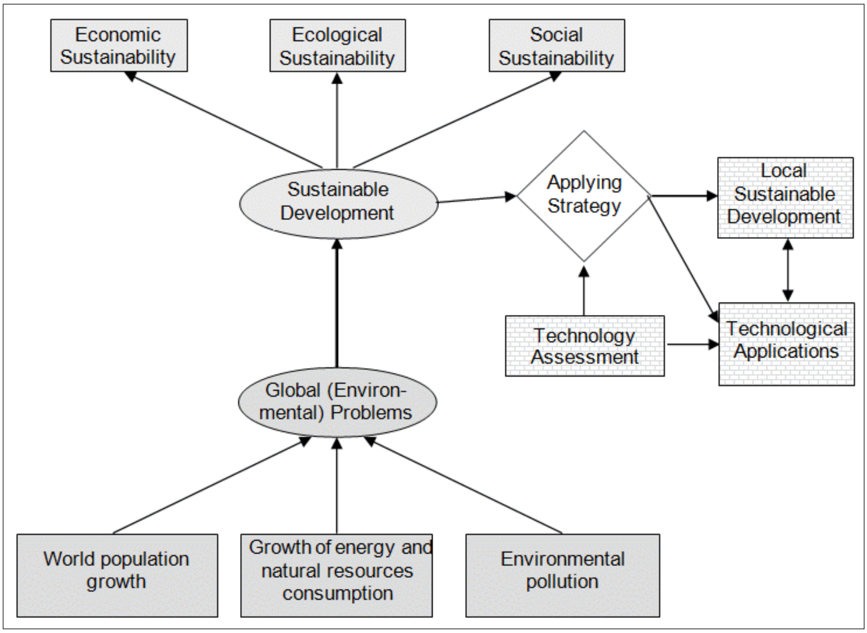

Fig.1. Global problems and Sustainable Development applying strategy on a local level by Technology Assessment.

the Conference for Environment and Development in Rio de Janeiro 1992, known as "Rio-Conference", as well as in the closing document „Agenda 21" [2]. Many actions after this time have emphasized that the evolution of technical, economic, social and ecological systems has to be analysed in synergetic relation. Among such actions to be especially mentioned are the follow-up conferences, "Rio + 10" – Conference in 2002 in Johannesburg and "Rio + 20" – Conference in 2012 again in Rio de Janeiro, as mentioned at the Sustainable Development Knowledge Platform [11]

Worldwide began discussions on scientific, economic and socio-political levels in order to find solutions for the problems shown above. Searched solutions should be applicable by regional differences to the developed as well as to the developing countries. The Brundtland Report of the World Council on Environment and Development, published 1987, represented a result of these worldwide political discussions, actually defining for the first time the concept of sustainable development [1]. This concept has been quite fast worldwide accepted as a possible solution for the global complex ecological, economic and social problems. The concept of sustainable development was largely discussed during

During the time, in order to make the concept of sustainable development more understandable certain rules, strategies and principles have been defined [2, 6]. The general Brundtland definition was worldwide accepted, but together with the rules, strategies and principles, it does hardly give a concept, which is applicable to the real concrete situations [2]. The need for more concrete strategies has been emphasized, not-neglecting the made progress during the years in this pretty complicated but sensible field [2, 5, 6].

Different development levels in technological field, as well as in economic and environmental fields, connected to the socio-political field in various countries have no rarely had as a result serious difficulties in applying the concept of Sustainable Development on a local level by rating for instance environmental impacts of technological applications [5, 6, 7].

In order to operationalise the concept of sustainable development a general and flexible methodology by a systematic approach is necessary to be developed, which has to make possible applying Sustainable Development to each concrete case with the specific conditions of the observed system. An important role in this context play concrete methods and instruments of Technology Assessment for assessing industrial processes from a comprehensive point of view regarding potential economic, environmental as well as social impacts [2, 7].

3. Technology Assessment, TA

The concept of Technology Assessment (TA) is among scientists well known, there are a lot of publications which treat general notions, goals, methods and instruments with respect to this concept. This is the reason why in the following no description of Technology Assessment is made, but only some remarks relevant also in the context of Sustainable Development.

When going through the given methodology for Sustainable Development one can recognize that many steps can be also identified in the phases distinguished in Technology Assessment [2, 7, 9]. Very often a concrete sustainability problem 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.

As it is known there are several levels to apply the concept of sustainable development [2]. On global level means to define general goals for the whole world, things which happenned more or less with the Rio-Conferences. 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 [2, 7]. But what about applying sustainable development on the level of an industrial process or on the level of a product ? In this field the operationalisation of sustainable development means to use instruments of TA. Also many methods which are used in TA are the base for applying sustainable development. In Figure 1 we see mentioned Technology Assessment, in concordance with the methodology for sustainable development operationalisation [2, 7]. In order to verify possible impacts of proposed measures, control and evaluation instruments are needed, for shaping a local sustainable development.

Part of what enginners do is to evaluate developments in technology. Their evaluation has up to now almost without exception been focused on technical aspects, like functionality and safety, and on economic aspects following legal and financial boundary conditions. With respect to sustainability more criteria have to be considered like: environmental quality, social and human values, quality of life. This kind of evaluation needs interdisciplinary cooperation [2, 7].

Operationalisation of sustainable development with technology assessment means analysing the stability of complex dynamic environmental, economic and social systems in order to try to discover developments which lead to instabilities. In this context there are many fields where research is needed; after [2] these fields are:

- State description using Sustainable Development Indicators (SDI);

- Dealing with uncertain, unclear knowledge or non-existent knowledge;
- Improvement of methods and instruments;
- Orientation with values and dealing with value conflicts;
- Developing criteria for evaluation and making judgement;
- Modelling and simulation of dynamic systems.

The concept of Technology Assessment equally how it is named, if Technology Evaluation, Innovation Research, System Analysis or others, brings together almost all of the scientific disciplines with the question of how sustainability can be operationalised by using instruments of Technology Assessment, tools for rating environmental impacts of technological applications, as shown in Figure 2.

4. Rating Environmental Impacts

For rating environmental impacts of different technological applications in order to assess potential effects of human activities, especially industrial ones on the environment, several tools can be used [7]. As presented in Figure 2 the commonly applied ones for usual situations are the Environmental Impact Assessment, the Eco-Audit and the Life Cycle Assessment, LCA [2, 7, 9].

4.1. Environmental Impact Assessment

Regarding the Environmental Impact Assessment, EIA, there is since 1985 a legislative framework for it 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 since 1994 a legislative reglementation through the Ordinance of the Minister for Water, Forests and Environmental Protection regarding the examination of potential impacts on the environment of economic and social activities [4]. The analysis of environmental effects has as a goal that activities are planed to be carried out in a way that their environmental impacts are as small as possible [4]. Going into details it should be taken into account that possible consequences of a project have to be searched, described and evaluated and that the analysis results have to be delivered to the authorities which have to decide basing on these results. In order to carry out such an analysis, the project, which has to be certified, must contain information about the project itself, about proposed measures to diminish potential negative effects, as well as about other possible alternatives. The

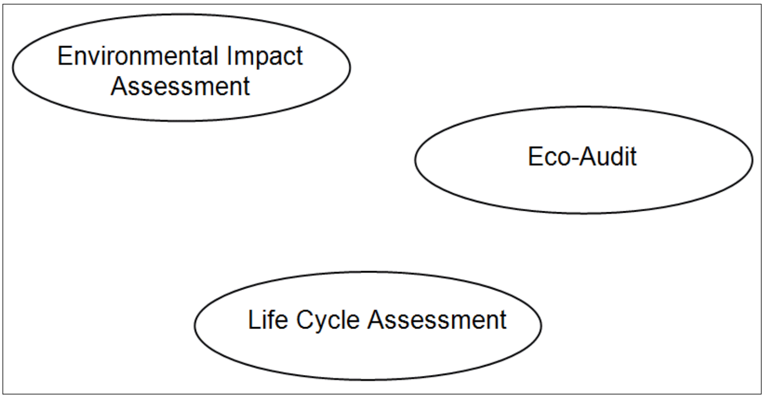

Fig. 2. Tools for rating environmental impacts of technological applications

application domain for such studies is represented generally by public projects. The requirements of a project with respect to EIA are followings: assessments have to be transparent and public, the methods used are to be unified, and the results have to be comparable [7].

4.2. Eco-Audit

As stated in the standard family DIN-ISO 14000, the environmental management in a company is actually representing the totality of measures directed to organise and lead the activities in a company related to environmental protection, also including installations and plants for environmental monitoring and protection [10]. In this regard the Eco-Audit is representing a management tool for systematic, documented, periodic, objective evaluation of the processes regarding the environmental management in a certain company.

With respect to environmental protection the Eco-Audit is working in a preventive way. Carrying out an Eco-Audit in a certain company or institution is supporting to monitor and to emphasise the actual situation in the respective company. The results are stating the potential impact of the production processes or other activities in the considered company or institution with respect to the environmental quality. On the other side an Eco-Audit carried out for a company does inform about the interest of the respective company to respect legislative measures and decrees in the field of environmental protection as well as about the actual goal of the company related to possible impacts on the environment [2, 7]. Taking into account the results of the Eco-Audit it is possible for a company or an institution to improve its environmental protection program by reorganising certain production processes or certain production related activities in the company.

The general aim is represented by the fact that companies are actually voluntarily taking part in this process with the conviction of gaining in the end economic advantages. It is to be mentioned that for successfully carrying out an Eco-Audit also a lot of environmental data should be available, which means that a difficult task is represented by shaping an appropriate database [2]. With this goal the steps of collecting, processing and evaluating data and information from companies are relevant, especially regarding production and environment related data [2].

4.3. Life Cycle Assessment, LCA

As a result of the wish to raise the human quality of life, several activities have been carried out especially in the branch of production and in services sector, having as a side effect a smaller or bigger environmental pollution. In order to analyse and assess potential environmental impacts of different technological applications one of the most used tools in this regard is the Life Cycle Assessment, LCA, as stated in the international norm family for environmental management DIN ISO 14000 [10]. As presented in the specific norm, DIN ISO 14040, the Life Cycle Assessment is an analysis which registers all environmental effects of a product during its life, from the production to the consumption and disposal, as well as to recycling [10]. The most important phases in the general life-cycle of a product are presented in Figure 3 [7].

It is to be stated that transport processes are also taken into account in the general life-cycle of a product, besides production and consumption processes, because these can have a relevant environmental impact when assessing the general life-cycle of a product. Transport processes within the life-cycle of a product are emphasised by letter ”T”, as it can be observed in Figure 3 [7]. When going into details it can be remarked that each step has its own importance at a certain stage in the development phase of a certain product [2, 7,

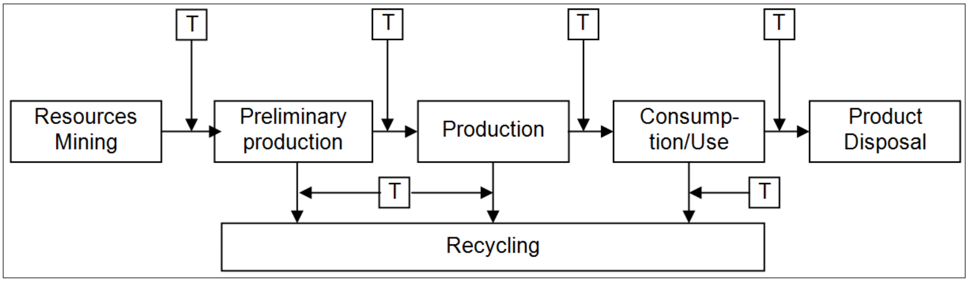

Fig.3. Most important phases in the general life-cycle of products

8]. The process of carrying out a Life Cycle Assessment of a certain product has several steps [7]:

- Definition of goal and scope of the analysis;
- Inventory analysis;
- Impact assessment;
- Interpretation of results.

The first step regarding the Definition of goal and scope shall clearly 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 a Life Cycle Assessment following items shall be considered [10]: functions of the product, functional unit, system boundaries, used methodology for the impact assessment, needs for data requirements, made assumptions as well as necessarily considered limitations. The next phase of Inventory analysis is implying data collection and the establishment of calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources as well as pollutants emissions by the system [10]. The third step of Impact assessment aimes at evaluating the potential environmental impacts using the results of the inventory analysis. The impact assessment may include elements as assigning of inventory data to impact categories, modeling inventory data within impact categories and possibly aggregating the results [7]. It is to be mentioned that the methodological and scientific framework for impact assessment is still in the development phase. Very often in this step of impact assessment aggregated indicators are used in order to enable a transparent evaluation [2]. In the last phase regarding the Interpretation of results the findings from the inventory analysis and the impact assessment are put together. The interpretation should take the form of conclusions and recommendations to decision-makers [2, 4].

In the process of carrying out a Life Cycle Assessment a difficult step is represented by gaining specific relevant data and information about products and production processes [2, 10]. In order to compare different life-cycle stations of a product from the point of view of pollutants emissions there is generally the necessity to use appropriate environmental indicators. Such indicators are used depending on the intended goal of the study regarding the Life Cycle Assessment of a certain product, if the results are to be interpreted on a sectoral, local or regional level. [2, 10]. The process of shaping appropriate environmental indicators is currently still in development [2, 4].

The life-cycle of a product takes into account relevant phases in the existence and use of a product, as shown in Figure 3, starting with the extraction of mineral resources used to manufacture the product and ending with the disposal of the product [7, 10]. Regarding the most important steps in the life-cycle of a product it can be recognised when going into details that there are the following ones, as presented in Figure 3 [7, 10]:

- Resources mining;
- Preliminary production;
- Production;
- Consumption or use
- Product disposal.

Recycling is representing a relevant phase in the life cycle of a product, actually playing an important role in different phases of the life cycle of a product, starting with the preliminary production, over production and consumption or use of the certain product, as to be remarked in Figure 3.

The step of resources mining is referring to the extraction of mineral resources, that become the raw material used to manufacture the respective product. The step of preliminary production is including the fabrication of components that will be assembled during production to get the intended final product. In the step of production the components are assembled, resulting the product in its final form. The phase of consumption or use is referring to the happenings after the sale of the product, because thereafter the respective product is entering in the stage of consumption or use. After the usage phase of the product, the product disposal phase is following, that is actually the last stage in its life cycle. In this stage the used product should be directed into the phase of recycling. Parts of the product, which can not be reused or recycled, will be transformed into waste and will enter into the waste processing stage [7, 10].

5. Application Example of Life Cycle Assessment

In order to emphasise the usage possibilities of the presented tools for assessing environmental impacts along the life-cycle of products, it is possible to analyse different steps in the life-cycle of a certain product or to compare the same step in the life-cycles of different products [7, 8, 10].

Aggregated indicators are needed in order to provide a comprehensive assessment of environmental impacts of industrial systems [2, 7]. An application for automotive systems bases on an Aggregated Emission Indicator AEI [7] which consists of the weightened sum of single emissions:

$$AEI = \frac{1}{\sum_i w_i} \cdot \sum_i w_i E_i \qquad (1)$$

where: w_i - weighting coefficients ;
E_i - pollutants emissions

The weighting coefficients are determined depending on the effects of pollutants on health and on ecosphere and on the emitted quantity using a Fuzzy Logic based approach, see for details [7]. The values for weighting coefficients, wi of some pollutants are shown in Table 2. Accordingly to Fig. 3, different life cycle stations of a product can be compared. From the point of view of pollutants emissions in the atmosphere the comparison can be made by using the presented Agregated Emission Indicator, AEI [7, 8].

In this example two life cycle stations of a generic passenger car are compared from the point of view of pollutants emissions. These two life cycle stations are the preliminary production and the phase of use of a car, as presented in Figure 3 for the general case. The basic materials needed in the car (this is the preliminary production) are produced by using first of all different mining based activities for gaining the needed raw materials. For a generic car the emissions data calculated in the phase of material fabrication and in the phase of use are given in Table 1 [2, 7].

The generic car is a car with an average weight of 1000 kg, an average mileage of 150000 km, with emissions calculated as average between diesel and petrol motors [7].

By using the pollutants emissions given in Table 1 in the fabrication process of basic materials for a generic car as well as in the

Table 1: Pollutants emissions in [kg] in the fabrication process of basic materials for a generic car and in the utilisation phase

Phase of basic materials fabrication (Preliminary production)					
Material	Weight [kg]	CO_2- emissions [kg]	NO_x-emissions [kg]	SO_2- emissions [kg]	CO- emissions [kg]
Steel + iron	654	1007,16	0,78	1,18	0,039
Flush	80	48,88	0,016	0,18	0,0008
Plastics	100	189,3	0,51	1,06	0,072
Alumin.	40	292	0,69	2,44	0,36
Rubber	60	134,59	0,16	0,30	0,027
Glass	35	20,65	0,0046	0,00094	0,007
Σ	969	1692,58	2,16	5,16	0,50
Phase of generic car utilisation (Consumption/Use)					
Generic car		29308	189	6,8	804

Table 2: Matrix of emissions with emissions in [kg], values for the weighting coefficient, wi and calculated AEI for two life cycle stations of a generic car

	CO_2- emissions [kg]	NO_x-emissions [kg]	SO_2- emissions [kg]	CO-emissions [kg]	**AEI** [kg]
w_i	0,67	0,46	0,42	0,33	
Basic materials fabrication	1692,58	2,16	5,16	0,50	**604,98**
Utilisation	29308	189	6,8	804	**10633,76**
Σ	**31000,58**	**191,16**	**11,96**	**804,5**	**11238,74**

utilisation phase, the overall matrix of emissions with relevant data for the analysed application example is given in Table 2.

6. Conclusions

Results emphasise that most pollutants are emitted in the utilisation phase of a car, the value of AEI being much bigger in this phase compared to the phase of basic materials fabrication. On the other side it is interesting to calculate this indicator in other life cycle phases too. In this way problematic points in the production lines can be emphasised and appropriate measures for improving the life cycle of the considered product can be found. The heightened awareness for the possible environmental impacts of different products has increased the interest in the development of instruments for Technology Assessment. Industrial activities have the direct goal to help increasing the quality of life of the population.

Beside positive direct and desired effects of industrial activities these often have also negative, undesired effects on the environment and society.

There are several tools of Technology Assessment for evaluating impacts of human activities. The Life Cycle Assessment, LCA is presently world wide used to assess environmental effects of products, but the evaluation question is still not definitively clarified. An evaluation method based on the Aggregated Emission Indicator, AEI has been presented and applied for an automotive system.

Results emphasize the working way of the presented method and allow an evaluation of different phases in the life-cycle of a product. In the given example the air pollution related to obtaining basic materials needed for producing a car is relevant, but the phase of car utilization produces bigger air pollution than the car production itself. It follows that actually the field of changing human mentality about car utilization is more relevant than obtaining a less pollutant industrial process. From this reason in the future interdisciplinary cooperation is needed for optimizing life cycles of products and minimizing their environmental impacts.

References

[1] Hauff, V. (Ed) (1987), *Our Common Future*, The Brundtland Report of the World Commission on Environment and Development, Oxford Univ. Press, Oxford.

[2] Jischa, M. F. (2014), *Herausforderung Zukunft. SpringerSpektrum*, New Edition, Berlin/Heidelberg.

[3] Meadows, D. and D. (1972), *The Limits to Growth*, Universe Book, New York.

[4] Ministry of Water, Forests and Environmental Protection (1994), *Ordin pentru aprobarea Procedurii de reglementare a activitatilor economice si sociale cu impact asupra mediului inconjurator*, in: Monitorul oficial al Romaniei, Nr. 73, Part I, Bucuresti, 11.04.1994

[5] Prunariu, D. (2017), *Space activities in support to climate change mitigation and climate resilience*, Presentation in South Africa.

[6] Prunariu, D., Tulbure, I. (2017), *Space Activities and Sustainable Development*, in: Proceedings of the 17th International Multidisciplinary Scientific Geocon-ference, SGEM2017, Volume 17, "Nano, Bio, Green and Space – Technologies for a Sustainable Future", Issue 62, pag. 947-954, Albena, Bulgaria.

[7] Tulbure, I. (2013), *Technikbewertung*, (Technology Assessment) - Lecture Notes. Clausthal University of Technology. Clausthal-Zellerfeld, Germany.

[8] Tulbure, I., Sârb A. (2016), *Analysing and comparing different traffic environmental impacts*, Proceedings of the SIMI 2016 Conference, ECOIND, Bucharest.

[9] VDI-Richtlinie 3780 (2000), *Technikbewertung - Begriffe und Grundlagen* (Technology Assessment – concepts and basic notions), new edition, Düsseldorf Used Internet Sites.

[10] ISO Central Secretariat, 2009: *Environmental management* - The ISO 14000 family of International Standards, Genève, Switzerland, http://www.iso.org/iso/theiso14000family_2009.pdf.

[11] *Sustainable Development Knowledge Platform*, https://sustainabledevelopment.un.orgE.