Examples of the research works on LCA at Poznan University of Technology

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***Abstract*—**The directions of the world development, as many cases have shown, should be forestalledly assessed. It deals also to the technology and it means that the whole development process, strongly effected by innovation and research, should be monitored and deeply considered. The problem has the complex nature. Therefore the concept of life cycle is supposed to be the best format for this problem solving. In the paper, the research works done in the field of application of the method used in this situation – Life Cycle Assesment (LCA) at Poznan University of Technology (PUT) are overviewed. The Research Group on Ecobalancing and Quality, based at PUT, is the Polish and Central and Eastern European pioneer of the reseach focused on applying the idea of LC concept in development of technical objects. The examples of research works are presented in the paper.

***Keywords*—** design phase, ecobalancing, LCA, Poznan University of Technology, research works,

I. Introduction

The concept of life cycle is supposed to have started in the 1960s. At the beginning the research was concentrated on calculation of cumulative energy requirements for the production of chemical intermediates and products. Later the studies involved the demand for finite raw materials and energy resources have been started. They had form of global modeling studies and were published in "The limits to growth" [17] and "A Blueprint for survival" [1]. In 1969 researchers from Midwest Research Institute did a study for Coca Cola Company to compare different beverage containers and to determine their environmental interactions, particularly consumption of natural resources. In the early 1970s some other companies performed similar studies. Such a processes of quantifying the resource use and environmental releases of products became known as a Resource and Environmental Profile Analysis (REPA) [5]. Since the end of 1970s to early 1980s interest in REPA decreased in United States, but at the same time interest in these processes in Europe rapidly increased.

During that period the Swiss Federal Laboratories for Materials Testing and Research (EMPA) prepared a study on packaging materials for Swiss Environmental Ministry [2]. Improved evaluation procedure and extensive database of EMPA made that this study have been used in many other researches. Within next several years an update of the data was published and new versions of the software developed have been announced [18].

Similar life cycle inventories focused on more qualitative approach have been developed in Germany. They have been called Produkt-Linien-Analyse and have included detailed methodology with comprehensive choice of parameters and even social and economic aspects [18].

In 1990s the most intensive activity by Franklin Associates and Battelle from USA have been observed in area of life cycle assessment, whereas in Europe the studies prepared by Boustead in UK, Sundström in Sweden, Battle in Germany and EMPA in Switzerland have become the most popular. Additionally the Center of Environmental Studies at the Leiden University, Ecobilan in France and the Life Cycle Assessment working group of the Nordic Council of Ministers have worked on methodology development. Some life cycle assessment similar works have been also done in Poland, mentioned in [13]. At the turn of 1980s and 1990s the Society of Environmental Toxicology and Chemistry (SETAC) has taken special place in the progress of life cycle methodology. Both SETAC sub-organizations in USA and in Europe have started to bring life cycle assessment practitioners and users together in the development of life cycle assessment tools [18].

In the beginning of the life cycle concept, analyses based on this methodology had usually environmentally

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oriented character. It was caused particularly by public interest in the environmental issues like shortages or crises in energy economy, consumption of scarce raw materials and solid waste disposal increasing problems. Observed during the last decades activities, carried out by researchers have caused continuous development of life cycle methods, from different points of view, e.g. paper of M. Maletič et al. [15] and M. Ciobanu [3].

II. Life Cycle Assessment

A. Positioning of LCA

The concept of life cycle is defined as a process in which the inputs to the "cycle" and outputs from the "cycle" are evaluated for each step of the object of analysis. The cycle begins at the concept of the object and completes with the recycle or disposal phase [8], [11], [14]. The idea of life cycle is useful especially when considering the product (object) development (Fig. 1).

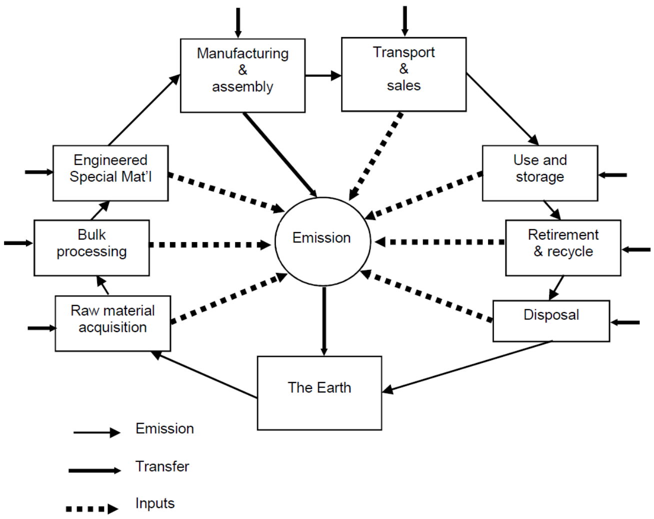

Fig. 1. Life cycle concept stages in the product development system [7], [8], [9]

A LCA of the object:

– is defined as a process aimed at identifying the negative effects of this object,

– quantifies the use of raw materials, energy consumption and emissions,

– evaluates the impact of these uses made of energy and materials as well as emissions into the environment,

– evaluates the relevant improvements in an environmental context.

The standard ISO 14040 describes LCA as a technique for assessing the environmental aspects and potential impacts associated with a product, by:

– compiling an inventory of relevant inputs and outputs of a product system,

– evaluating the potential environmental impacts associated with those inputs and outputs,

– interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

B. LCA structure

The LCA methodology is composed of several interrelated elements:

– goal and scope definition,
– inventory analysis,
– impact assessment,
– interpretation (Fig. 2).

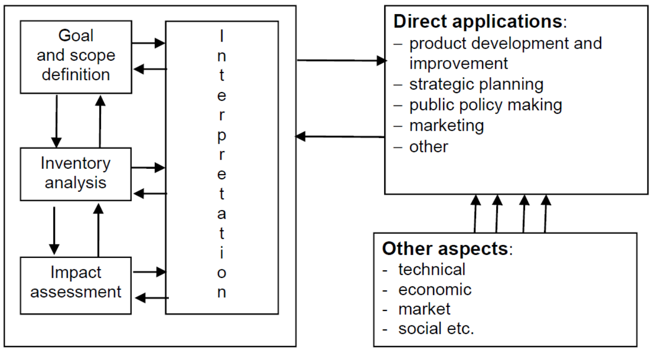

Fig. 2. Structure of LCA [14]

The goal and scope definition is an integral part in the LCA procedure. This step is required at an early stage in the study to gain a clear understanding of the purpose, to specify the system to be studied, and to determine the relevant requirements for peer review and communication of results. These are reasons why the goal and scope definition is placed in the center of the whole structure of the LCA procedure (Fig. 3).

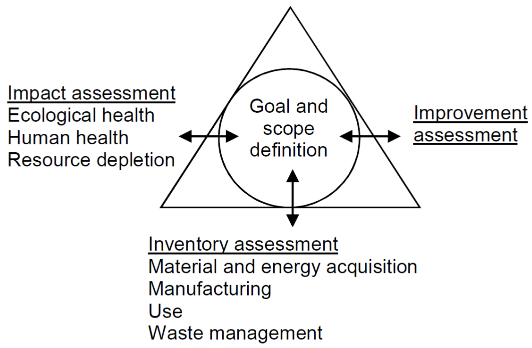

Fig. 3. Technical framework for LCA method [7], [8], [10]

III. Example of Early Poznan University of Technology Works on LCA

One of the first research works on LCA, performed at Poznan University of Technology was environmental valuation of following packaging machines: PCGb01, PCGf02 and PCGi01. Their technical data are presented below (Table I).

Table I. Technical data of analysed packaging machines [10]

Technical data	Unit	Packaging machine		
		PCGb01	PCGf02	PCGi01
Output	bot/h	2300	4500	7000
Consumption power	kW	2,2	2,2	4,8
Quantity of pourers	pieces	20	36	40
Quantity of closing heads	pieces	6	8	8
Pressure of packed fluid	MPa	0,6	0,6	0,8
Pressure of air	MPa	0,5	0,5	0,5
Air consumption	m3/h	4	5	8
CO2 consumption	m3/h	2,8	5,0	7,0
Noise level	dB	85	85	85
Overall dimensions (height × length × width)	mm	2490 × 2080 × 1450	2530 × 2895 × 2125	2860 × 2982 × 2610
Mass	kg	2600	5100	6080

A general aim of this LCA study was a complex environmental comparative evaluation of selected types of packaging machines. As elementary goals there were:

– description and comparison of environmental interactions of given packaging machines,

– identification of the areas of the significant environmental impacts (so called hot spots),

– finding the possible improvement opportunities in the life cycle,

– indication of the directions for whole system of machines optimization.

Data collection processes focused on:

– material production processes,

– energy, transport and wastes.

– composite materials.

Functional unit (reference quantity) was the environmental cost of 1000 l beverage filling into the bottles.

Materials used to the production of chosen packaging machines and during the operation period, with reference to the functional unit, are presented respectively in Table II and Table III. Further are presented media used in the whole life of packaging machines (Table IV).

Table II. Materials used to production of chosen packaging machines, with reference to functional unit [g] (part) [10]

Material	Packaging machines		
	PCGb01	PCGf02	PCGi01
St3S			
bars	0,013913	0,013333	0,008096
sheets	0,752187	1,373752	0,935673
St3SX			
bars	2,482361	2,170449	1,132205
sheets	5,154387	4,389882	4,522311
forgings	1,79433	1,736102	0,724694
St5			
bars	0,87731	1,065077	0,519906
sheets	0,898566	0,868347	0,367665
the others	0,929001	0,654581	0,435134
15			
bars	0,005217	0	0,00127
others	0,001256	0,001284	0,000953
45			
bars	1,016153	0,429408	0,507683
sheets	1,292293	0,741391	0,363061
forgings	0	0	0,07239
others	0,637789	0,35998	0,218123

Table III. Materials used in operation period of chosen packaging machines, with reference to functional unit [g] (part) [10]

Material	Packaging machines		
	PCGb01	PCGf02	PCGi01
St3SX	1,410652	0,362449	0,313055
St5	1,8763604	1,170306	0,646113
45	2,5237144	1,550532	1,088708
0H17T	0,2724684	0,040492	0,02413
1H18N9T	0,1565244	0,052837	0,058103
3H13	0,0975862	0,004444	0,01016
Zs60003	0	0,301218	0,136843
B555	0,067634	0	0,02921
BA1032	0,1053158	0	0,010795
MO59	0,0028986	0	0
Hydraulic oil	0,521748	0,335784	0,2921
Transol oil	4,3479	2,91342	0,6985
Compressor's oil	0,927552	0,632064	0,5207
ŁT43 grease	0,77296	0,553056	0,2159
Aliten grease	0,0222226	0,012345	0,00889
Defenzor grease	0,0502424	0,036047	0,025718

Table IV. Media used in the whole life cycle of packaging machines with reference to the functional unit [10]

Medium	Packaging machines		
	PCGb01	PCGf02	PCGi01
Sterile air [m3]	1,15944	0,7407	0,762
CO2 [m3]	0,811608	0,7407	0,66675
Electric energy [kWh]:			
- to production	0,162747	0,084815	0,11639
- to operating	0,63769	0,32591	0,4572

An impact assessment was carried out with the support of SimaPro 4.0 programme, using Ecoindicator 95 procedure.

Subdivision of environmental impact was into ten categories:

– greenhouse effect,

– ozone layer depletion,

– acidification,

– eutrophication,

– heavy metals emission,

– carcinogenicity,

– winter smog,

– summer smog,

– energy depletion,

– solid emissions.

Calculations were carried out with respect to the division of the whole life cycle into:

– production (with further division into metallic and other materials),

– operating period (with further division into materials and media),

– distribution,

– final disposal.

The results of characterization phase and normalization phase for analysed machines, with reference to the functional unit, are presented respectively in Table V and Table VI.

Table V. Results of the characterization phase of packaging machines with reference to the functional unit [10]

Impact category	Unit	Packaging machine		
		PCGb01	PCGf02	PCGi01
greenhouse effect	kg CO2	1,17	0,617	0,827
ozone layer depletion	kg CFC11	4,78E-8	9,08E-9	8,16
acidification	kg SO2	0,0098	0,00618	0,00725
eutrophication	kg PO4	0,000278	0,000151	0,000183
heavy metals emission	kg Pb	1,4E-6	6,49E-7	8,5E-7
carcinogenicity	kg B(a)P	2,16E-8	1,37E-8	1,37E-8
winter smog	kg SPM	0,00823	0,00534	0,00621
summer smog	kg C2H4	7,12E-5	-0,000133	-0,000103
energy depletion	MJ	14,3	5,76	7,55
solid emissions	kg	0,273	0,228	0,209

Table VI. Results of the normalization phase of packaging machines with reference to the functional unit [10]

Impact category	Packaging machine		
	PCGb01	PCGf02	PCGi01
greenhouse effect	8,99E-5	4,72E-5	6,33E-5
ozone layer depletion	5,17E-8	9,81E-9	8,82E-9
acidification	8,7E-5	5,49E-5	6,44E-5
eutrophication	7,27E-6	3,96E-6	4,8E-6
heavy metals emission	2,57E-5	1,19E-5	1,56E-5
carcinogenicity	1,99E-6	1,26E-6	1,26E-6
winter smog	8,27E-5	5,67E-5	6,58E-5
summer smog	3,98E-6	-7,43E-6	-5,77E-6
energy depletion	8,97E-5	3,62E-5	4,75E-5
solid emissions	0	0	0

The results of environmental analyse of chosen packaging machines show that the most environmentally friendly is the PCGf02 machine. Environmental loads caused by PCGb01 are about 70% and by PCGi01 are about 20% greater than in case of PCGf02 (Fig. 4).

Dominating interactions result in such consequences as: acidification, winter smog and greenhouse effect (Fig. 5).

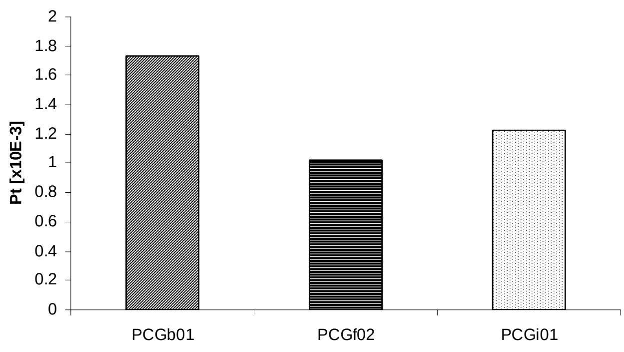

Fig. 4. Comparison of environmental indexes of packaging machines [9], [10]

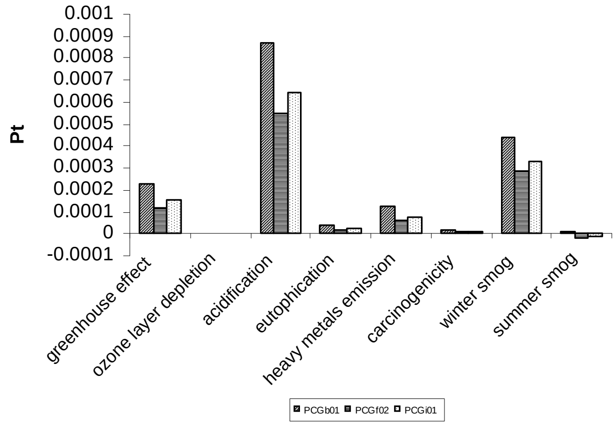

Fig. 5. Environmental profile of packaging machines based on valuation results [9], [10]

Environmental impacts with reference to the division into the main stages of packaging machines life cycle show that the dominating environmental burdens are associated with operating period. Environmental impacts of the disposal stage of packaging machines (about 5,5% of all impacts) diminish the consequences of the rest of harmful interactions (Fig. 6).

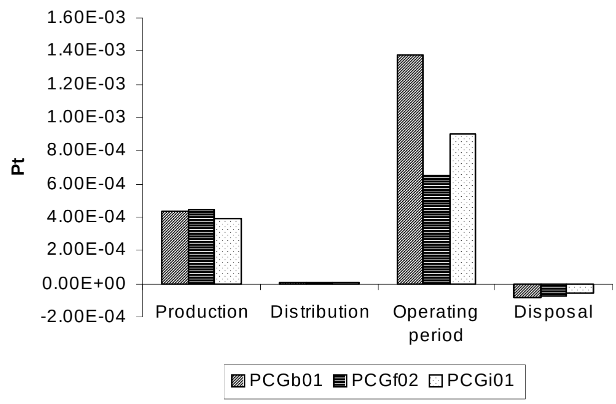

Fig. 6. Environmental indexes connected with stages of packaging machines life cycle [9], [10]

The similar in character the research works were done in other countries, and other, but similar, branches, concentrating for example on refrigeration systems (see work of J.M. Garcia [4].

IV. Hints for designers of technical objects

Early research allows drawing following introductory conclusions [8], [10], [11]:

1) today designers must understand the relationship between a product and the environment before a product can be developed in a truly environmentally sound way,

2) designers have to be able to assess:

– priorities, that they have to know where the biggest gains can be made,

– which design solution is better from the environmental point of view,

3) very often it is possible to reduce the amount of materials by critically looking at dimensions, required strength and production techniques,

4) product design should aim at:

– reducing total material content,

– minimizing the total number of different materials,

– preferring materials which can be recycled, and/or use biodegradable,

– materials to replace non-biodegradable materials,

– minimizing the use of energy-intensive materials,

– minimizing energy consumed in use,

– going for the form of energy with the lowest contribution to green-house gases production where there is a choice of energy supply.

As a consequence, from above conclusions the following suggestions arise [7], [9]:

1) to meet above mentioned requirements, it is worth using LCA methodology, which can determine indicators (environmental indices) of existing different materials; environmental indicators (indexes) concern the following groups:

a) construction materials for machines and vehicles: steel (construction, high quality, automatic, stainless etc.), cast iron, plastic, glass, rubber, paper etc.,

b) technological processes (for different materials): casting, welding, forging etc.,

c) electric energy production, in:

– coal power plant,

– lignite power plant,

– oil or gas power plant,

– nuclear power plant,

– hydro power plant,

d) transportation processes, on: road, water, and in air,

2) received environmental indexes are shown in useful units, in case of:

– materials – by 1 kg of materials,

– energy – by 1 kWh of produced energy,

– technology – by 1 kg cast or forging, by 1 m welding joint, by 1 m^2 of surface,

– transport – by 1 km of transported substances.

As an example, the environmental indexes for different technological processes (Table VII) and different means of transportation (Table VIII) are presented below.

Table VII. Environmental indexes for different technological processes [9], [11]

Technological process	Environmental index [Pt]	Unit
casting	0,00657	1 kg of casting materials
forging	5,9E-04	1 kg of forging materials
drawing	1,6E-05	1 kg of drawing materials
plastic forming	2,7E-04	1 kg of plastic
welding	0,0334	1 m of welding
laser cutting	4,2E-04	1 m of welding
machining	2,2E-04	1 kg of machining
injection moulding	3,3E-04	1 kg of injection moulding
MIG welding	0,00899	1 m of welding
turning	2,3E-04	1 kg of machined material

Tab. VIII. Environmental indexes for different means of transportation [9], [11]

Transportation means	Environmental index 1 tkm [Pt]
Truck 28t	1,4E-04
Truck 16t	3,4E-04
Truck (in a city transport)	4,8E-04
Railway (electric)	1,06E-04
Railway (internal combustion engine)	1,32E-04
Barge	5,5E-05
Container ship	5,6E-05
Coaster	2,0E-05
Bulk carrier	3,4E-05
Tanker	9,7E-05

V. Latest Works on LCA at Poznan University of Technology

A. Initial remarks

The main aim of the study performed at the Poznan University of Technology has been identification of the most environment friendly way of beer distribution from the brewery to the consumer. The analysis has been done in co-operation with one of the biggest brewery in Poland, located in Poznan. First of all, quantification of environmental burdens caused by whole packaging process performed in the company has been worked out. An assumption has been made to consider environmental influence of this process independently of consequences of distribution of the product, but against a background of technology process's elementary components. Besides, the need of inclusion of direct and indirect environmental burdens, connected with all environment elements has been noticed. To establish the structure of environmental cost of generated impacts, analysis has been carried out in the module calculations of the system, which consists of analysis of beverage packaging washing, filling and closing process, and distribution by different transportation means. Several configurations of this system's components have been considered. Five types of beverage packaging have been considered separately: glass bottles (refillable and non-refillable), cans and two kinds of casks. The beer packaging have been studied taking into account life cycle of them. Additionally, available distribution ways have been assessed. On the base of results, the variants of the analysed system have been put in order of their environmental interactions, expressed by quantity data, completed by detailed characteristics.

Progress in service sector is the element of the rapidly developing part of economy. It is now reality in developed countries as well in developing ones. In many cases production systems activities are closely related to services. It is visible for example at the interface of beer brewing and offering beer to consumers.

There are two main ways of beer preparation for the distribution: filling the casks to send them to restaurants, pubs, bars or filling the bottles/cans and closing them to send to the distribution centres, shops or shopping centres, where they are bought by clients.

Drinking the beer at home or in the pub we do not even realise how high are environmental burdens connected with the whole beer distribution process, and what is the difference in relation to the another way of distribution.

Let's trace the ways of beer distribution for several possible routes and their environmental consequences. Hopefully that the results of this environmental study will not spoil the taste of beer wherever the beer is consumed.

B. Research goal and scope, materials

The main goal of the research is to find the most environment friendly way of the beer distribution from the mostly used in Poland ways of distribution. The study covers the post production processes of beer: washing, filling and closing the bottles/cans or casks and transportation of them. The materials of packaging, used transportation means and transportation targets are the variables, considered in this study.

The distribution process consists of two main operations: packing (washing, filling of different containers and closing them) and transportation.

Relating to the filling there are following options:

(1) filling the glass bottles (0,5 l):
- non-refillable (disposable – glass bottle 1),
- refillable (glass bottle 2),

(2) filling the aluminium cans (0,5 l),
(3) filling the casks (30 l and 50 l).

Filling and closing processes are done in special technological lines in plants – breweries, where beer is produced.

Relating to the transportation of containers mentioned in (1), (2) and (3), this process consists of first sending containers by the trucks (16 t) to the distribution centres 250 km away, and then – by delivery vans (3,5 t) on the distance of 25 km – to the shopping centres or shops. The same distances are covered in case of sending beer by train and then by delivery vans (3,5 t). Structure of system is shown on Fig. 7.

The distribution of 0,5 l of beer (average unit volume in shop or pub) is established as a functional unit.

C. Method of the study

The environmental consequences of beer distribution are studied using LCA method. Ten main environmental categories, gathered in three groups, are taken into consideration:

a) human health (HH):
- carcenogenicity,
- respiratory diseases,
- climate change,
- radiation,
- ozone layer depletion,

<u>b) state of ecosystems (*SE*):</u>
- ecotoxicity,
- acidification/eutrophisation,
- land use,

<u>c) natural sources depletion (*NSD*):</u>
- minerals,
- fossil fuel depletion.

For the calculation of environmental consequences the SimaPro software is used.

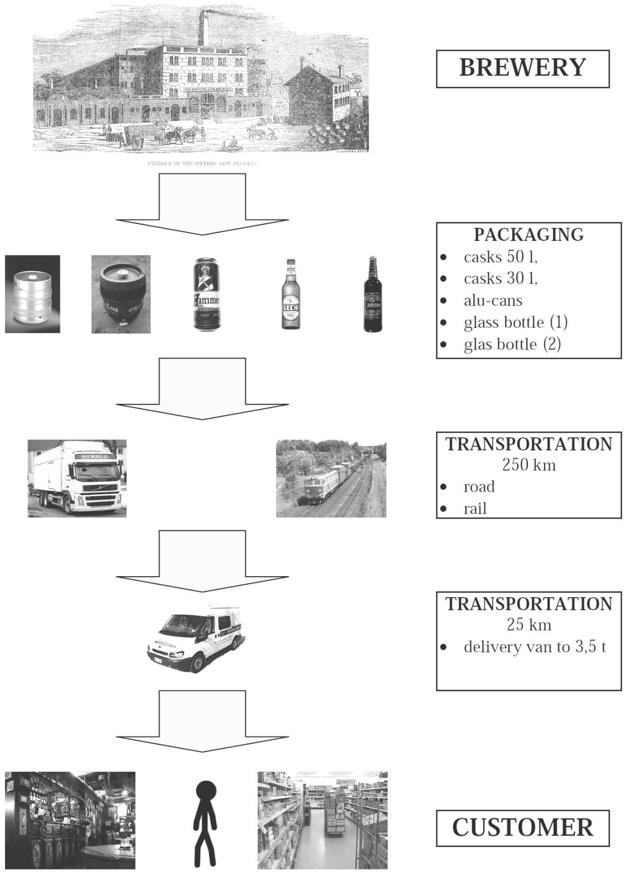

Fig. 7. Beer distribution system structure

D. Main results

The main results of the environmental comparison of different packaging for beer are presented on the Fig. 8 and 9.

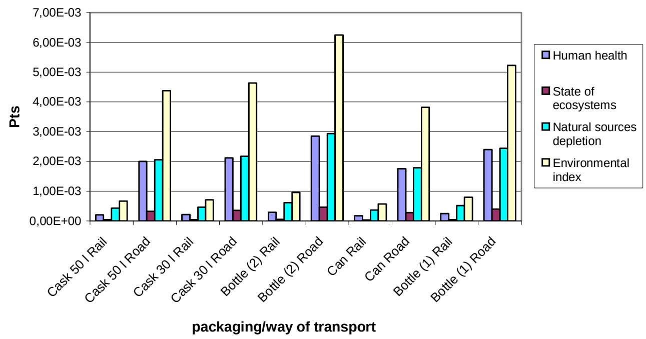

Fig. 8. Environmental impacts of transport means

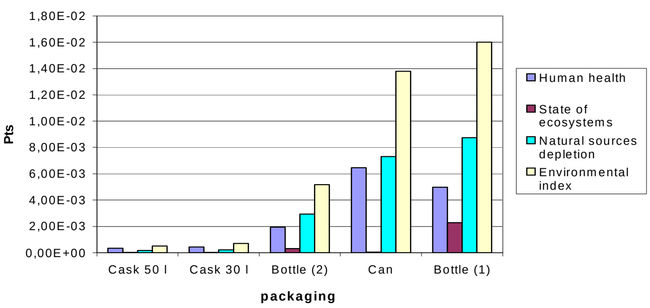

Fig. 9. Environmental impacts of packaging and packaging process

The analysis of obtained results reveals that:

1) The most environment friendly solution is system including packing beer into 50 l casks and its transportation by rail. To pack beer into 30 l casks and transport it by rail is also still acceptable option. The difference between the results is only 20 %.

2) The worst option is to pack beer into non-refillable glass bottle and to send it by truck. The environmental impact of such an option is almost 18 times bigger than the best option mentioned above.

3) In case of refillable packaging (casks, refillable glass bottles) the main environmental burdens are related to the transport processes. The level of environmental impacts connected with packaging and packaging process is lower. It is because of fact that the packaging mentioned above are used many times (glass bottles: 6-10 times, casks: 100-150 times).

4) In case of non-returnable packaging (cans, non-refillable glass bottles) the significant domination of impacts related to packaging appears. In case of non-refillable glass bottles the burdens associated with packaging are even 20 times bigger than the impacts caused by transport.

5) Generally, casks are the packaging which should be strongly preferred from the environmental point of view. Using refillable glass bottles is also a good solution. The environmental impacts caused by cans and non-refillable glass bottles are much more bigger (even 30 times).

Thus, to the environmentally conscious beer fans in Poland, the recommendation reads as follows: go to the pub, bar or restaurant and drink your beer there, instead buying the bottle or can in the shop, and drink it at home.

VI. TOWARDS THE SUSTAINABLE ENOTOURISM – A CASE STUDY

A. Initial remarks

In the last decades, records show the growth of travelling over the world, also in the area of tourism. This branch of economy attracts each year hundreds of million customers. One of the subbranches of tourism is enotourism. By enotourism are defined all the tourist, leisure and spare time activities, dedicated to the discovery and to the cultural and enophile pleasure of the wine. The pillars of enotourism are: wine culture, territory and tourist. It is important to highlight the enological-cultural value of the enotourism product, because the wine culture is the thematic axis of this product. The territory plays a very important part, being defined as a basis for the development of the offers in the wine-making tourism for the destination. The tourist, as a key element of the tourism, should be the point-of-aim of all measures and of all the development accomplished in the area of the enotourist offer. The low number of studies found in the literature shows rather limited awareness of LCA methodology by tourism drivers. Important are also some obstacles like complicated nature of tourism system and lack of specific LCA databases for tourism. The same problems relate to the enotourism.

B. Zielona Gora – enotouristic capital of Poland

Zielona Góra (Fig. 10) is formerly known as the Polish Capital of Wine. It is the unique Polish town cultivating the rich wine traditions, living for todayn in history and culture of the region. The first mention of the vines cultivation dates back from 1314. It is also known, that the friars were the forerunners of the vines cultivation, followed by the noblemen and finally ordinary citizens. And however it is known that the tradition of vintage is almost so long as the vines cultivation, it started to be celebrated recently.

Vintage became the official municipal holiday in 1852, and this fact was formally announced by town hall. Each year the tourists are guided by the god of wine – Bachus – with his retinue. All the visitors can taste the local tipple, enjoy the music and see one of the theatrical performances. However the big encumbrance is the Polish law, not taking into account the the sale of the local vines and mead by farmers.

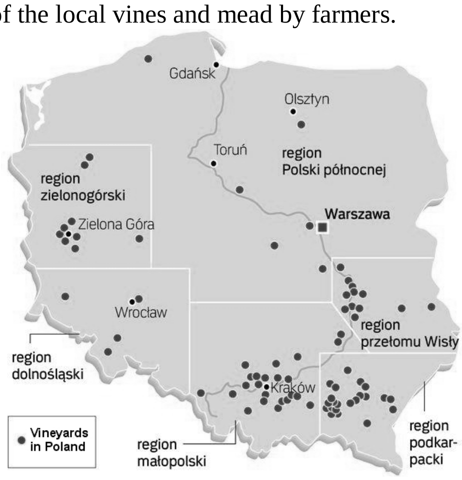

Fig. 10. Vineyards in Poland [19]

C. Method and assumptions

LCA (Eco-indicator 99 procedure, hierarchist approach) is chosen as the method of the study.

The vineyards of Zielona Gora are located on average in the distance of 150 km from Poznan. The case study encompasses three variants of the transport means (see on the Fig. 11).

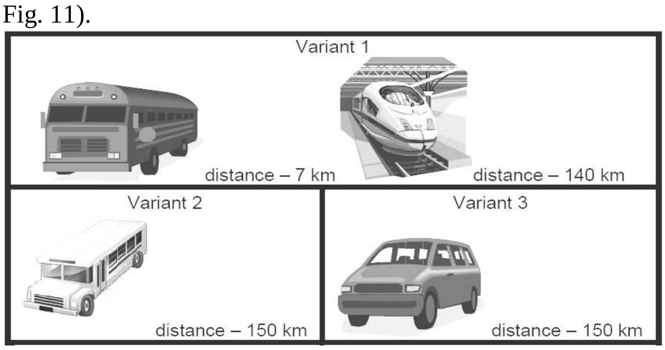

Fig. 11. Different variants of transport from Poznan to the Vintage of Zielona Gora

D. *Main Results*

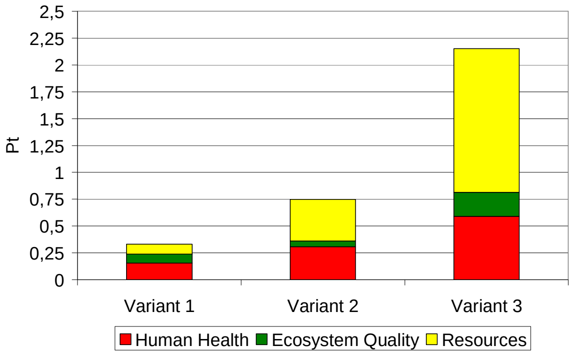

Fig. 12. General comparison between the results of the different ways of transport – groups of damage categories

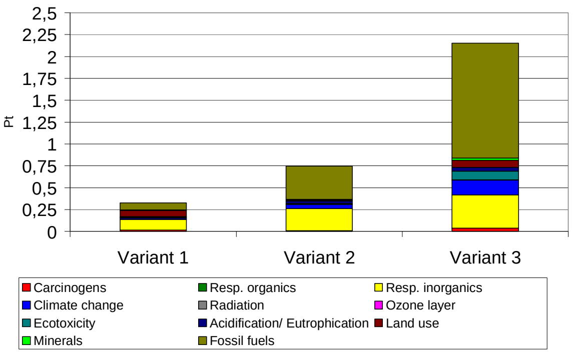

Fig. 13. General comparison between the results of the different ways of transport – 11 damage categories

As it is shown on the Fig. 12 and 13 – the variant 1 is the best from the environmental point of view, however the variant 2 – with the use of coach – is also acceptable. The worst solution is to travel with passenger car – this scenario affects the environment eight time harder that the trip using the train.

Though the environmental costs of travel are obviously not the only costs of the enotourism. One should alse take into consideration the environmental impacts of the whole stay during the Vintage – the accomodation (hotels, private lodgings etc.) and board (restaurants, bars, self-made alimention. The alternative scenario – not included in this case study, but also very interesting and popular – is to travel by bike and to pitch the tent and to camp on the campside. Despite the environmental impacts of all the scenarios everyone can enjoy the famous Vintage of Zielona Gora in September. The ideas presented in this research meet the elements of the model of sustainable tourism, presented in the paper of M.Mazilu [16].

VII. Conclusions

Following conclusions can be drawn:

1) the results of all the case studies show usefulness of this procedure to evaluate analysed objects,

2) research results of the first case study give the clear message which object is the most environment friendly one (PCGf02),

3) it was confirmed that in the case of long working object (10 and more years) the operation period creates the dominating environmental burdens [12],

4) the selection of construction materials concerning environment should be based on two main criteria:

– environment influences of materials, defined by environmental indexes for materials and raw materials,

– environment influences of technological processes, defined by environmental indexes for these processes,

5) presented examples show also the directions of LCA research done in PUT: first of all environmental analyses of technical objects; also creation of the data bases concerning materials and different technological issues, as well as the sustainable, environment friendly processes and attitutes.

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