The concept of monitoring of LCM results based on refrigerators case study

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Abstract The paper presents the concept of new approach in measurement and evaluation of results in life cycle assessment of products as a result of implementing LCM methodology in companies, based on an exemplary product of a major household equipment producer in Poland. The new approach is established on a complex analysis of economical, environmental and social consequences of an objects' life cycle. Evaluation is generated by an unification of Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Assessment (SLCA) methodology. Obtained results were registered into a matrix, enabling the identification between undertaken development operations and their results. This created a possibility to determine alterations on economical, environmental and social levels of a products' indicators. Consecutively, the range of modifications allowed a comparison between the current "state of an art" solution and the one proposed by interested parties.

1 Introduction

Life cycle management and implementation of the environmentally oriented design are the main topics of the project realized since the beginning of 2006. At the first phase, the project was financed by Polish Ministry of Science and Higher Education. It is carried out by two scientific institutions: Poznan University of Technology and Poznan University of Economics. There is also a partner from the industry, which is one of the largest manufacturers of household equipment on the Polish market. More details about the project can be found in [1].

The company involved in the project is one of the national business leaders in taking environmental image into account of its activities. Further product-oriented improvements are continually a significant part of its policy. To achieve goals of continuous improvement of the products and to improve the organization of production processes, some initiatives have been undertaken. It clearly shows that this is a very good example of an organization engaged in building a base for introduction of LCM approach into practice.

In 1994 the company implemented the Quality Management System compliant with ISO 9001 standard. Later on (in 1997), as the first Polish company, it successfully certified management systems based on ISO 14001 (Environmental Management Certificate) and the Occupational Health and Safety Certificate according to the PN-N-18001 and OHSAS 18001 standards (in 2001). Along with some other types of certificates, it allows the company to mark its products with the CE symbol.

There is a special *Eco-management and Work Safety* department in the company, where an interdisciplinary team works. It is responsible for environmental protection issues in a broad sense. In its activity, the company follows the principle of sustainable development, integrating the technical progress with the care for the environment. Management system promotes activities that:

- increase ecological awareness of the staff and highlight the environmental issues (through various publications, meetings, trainings etc.),
- facilitate a fully documented estimation of the factory's influence on the environment,
- allow a complex monitoring of activities connected with the most important effects that the factory causes for the environment,
- let reduce the negative environmental influences of the factory and allow for counteraction,
- prevent pollution of all elements of the environment,
- meet expectations of the customers concerning protection of the environment,
- increase the ecological reliability of organization.

2 Beginnings of the LCM case study

One of the goals of the project was to establish guidelines and principles of environmental and economical improvements of refrigerators for the need of life cycle management [1-3]. To achieve this goal, a large studies based on LCA and LCC of chosen refrigerator has been carried out. Because of the still discussed methodology of Social Life Cycle Assessment (SLCA), social aspects were not considered during the studies. In consequence, the main aim of the research was the evaluation and quantification of all potential environmental impacts generated during the whole life cycle of one refrigerator, chosen from a group of several models. In a similar way, the economical aspects of the refrigerator life cycle were analyzed.

The aim of the first stage of the analysis was to find answers to the following questions:

1) can changes in material composition improve results in environmental and economical dimensions of the refrigerator's life cycle?
2) can changes in the production processes reflect a decrease of the environmental impacts and lower the costs?
3) what activities should be implemented in the project to minimize environmental burdens and overall costs in the life cycle of refrigerator?

The data from the inventory analysis, including aggregated data concerning manufacturing operations of each element of the refrigerator, have been processed according to detailed LCA and LCC. In cases of use phase and final disposal, some simplifications have been applied at this point. It was assumed that on the base of obtained results, collection of more detailed data will be decided.

The results have been analyzed separately for different life cycle stages: manufacturing, use (operation) phase and disposal. The calculation of environmental aspects was based on the end-points methodology and in consequence results were expressed as the damage indicators for eleven impact categories and – after grouping – for three damage categories (see also [4,5]).

Based on the results, the elements of the refrigerator's life cycle were ranked according to the size of generated costs and environmental impacts. Data matrix was created to show economical and environmental aspects in the composition of these components.

Likewise, LCM-oriented recommendations have been proposed for further development at this stage of the project. They are oriented particularly on:

- decrease of the energy consumption in the use phase,
- reduction and recovery of the end-of-life byproducts,
- substitution of hazardous substances.

In detail, a set of rules has been established, including for example:

- easy access to replaceable components,
- easy separation of contaminated materials,
- easy disassembly to constituent parts,
- implementation of the materials identification system,
- decrease in use of "blended" materials,
- application of recycled materials where it is possible,
- upgrading of refrigerator components.

For the LCM to become a practice, it was necessary to ensure easy access to the results of the analysis and to provide easy means to present them. Analytical results of economical and environmental consequences of an objects' life cycle should be in the center of given attention. Such data was generated as the results of Life Cycle Assessment and Life Cycle Costing studies during refrigerator development [2, 7].

3 The concept of LCM results presentation

The implementation of conceptual LCM started with the definition of [1, 2]:

- the object of the analysis (a refrigerator), recognized as a reference for design procedure oriented towards development in the whole life cycle,
- an idea of a refrigerator that fulfills the requirements of all the interested parties and recommendations formulated as results of LCA and LCC studies,
- a difference in technological advancement of the object that is caused by application of life cycle management.

At the task formulation stage, data including LCA and LCC recommendations and requirements, survey among the interested parties and benchmarking results were thoroughly analyzed. On this basis, following aims have been formulated:

1) achievement of higher energy class (A++) and limitation of energy consumption to the level of 218 kWh/year (13,5% reduction compared to reference refrigerator),
2) reduction in the amount of harmful substances by 25%,
3) reduction of noise level in the operational use to the 38 dB (A) limit,
4) achievement of recovery rate at 80% level,
5) shortening the disassembly time to 30 minutes,
6) weight reduction by 5% compared to the reference refrigerator,
7) ensuring the availability of spare parts for 12 years from the date of manufacture,
8) provision of service for 12 years from the date of manufacture,
9) CE marking of materials,
10) development of an appropriate system for the take-back of used appliances.

This way, a set of technical solutions was determined and evaluated using multidimensional comparative analysis. The development of scenarios for the conceptual design and then detailed solutions was based on 10 variants of the changes [2]. The number and the scale of alterations was an inspiration to develop a transparent tool (matrix) for the presentation of the results of individual variants. The results for the developed scenarios should be presented not only to those responsible for product development, but also to some of the interested parties. In the discussed example, manufacturer’s needs to communicate the results of life cycle management of a refrigerator caused a necessity to develop such matrix (Table 1) to present changes being the result of LCM implementation. Opportunity to present the results of social life cycle assessment of the tested object was also provided.

Tab.1: LCM results presentation matrix

	LCA [Pts.]	**LCC [PLN]**	**SLCA [Pts.]**	**Change in relation to the reference state [%]**
Design	-	-	-	-
Manufacturing	-	-	-	-
Operation (use)	-	-	-	-
Disposal	-	-	-	-
Complete life cycle	-	-	-	-
Change in relation to the reference state [%]	-	-	-	-

The concept of using a matrix to present the results of life cycle analyses carried out on the object can be supported by several important arguments:

- **Ease of use** – this form of presenting the results gives a quick insight into volumes of different categories of impacts on a given phase of a life cycle or the whole life cycle of an object (horizontal analysis of the matrix answers the question of total impacts on a chosen life cycle phase, vertical analysis gives results concerning a given category of impacts in the whole life cycle),
- **Ease of preparation** – previously calculated impact volumes just need to be entered into corresponding cells of matrix,
- **Possibility to illustrate –** results can be presented graphically, e.g. in a 3-dimensional bar graph (with life cycle phases and life cycle assessment approaches in x and z-axis, and results in y-axis); however, the problem of a lack of a common denominator for the incompatible units (environmental and social points, units of currency) needs to be solved;

and until then, the results can only be compared in single categories and in a relative, percentage scale,

- **Recognition of the dynamics of changes –** the matrix shows the shift of impact categories volumes of the altered object, compared to the state of reference (in means of single categories of impact at chosen life cycle phase, total impacts on a selected life cycle phase or total impacts in a given category in the whole life cycle of an object),
- **Identification of adverse effects –** e.g. transferring the environmental impacts generated at a chosen life cycle phase to another,
- **Identification of interdependence of impacts –** influence of changes in one direction (e.g. lowering the environmental impacts in the manufacturing phase) can be positive or negative for other dimensions of life cycle (increasing/decreasing economical and/or social impacts at the same time).

4 Results of LCM in the case study

Out of the previously developed 10 variants of accepted changes made in the construction of a refrigerator, three were chosen [2]:

- changing the number of chillers (refrigeration systems) (variant 2),
- using different refrigerant (variant 3),
- improving the insulation (variant 4).

Detailed research, including LCA and LCC analyses was conducted on those variants, and the results were presented in a matrix (Table 2, Table 3).
Research outcomes were then distributed into matrices (Table 4, Table 5, Table 6) showing only the comparison between specified version and object of reference life cycle analysis results. Horizontally, the changes in relation to the reference state are presented as LCA result modification/LCC result modification and given in percentages, where the result of LCA/LCC analysis for the object of reference is 100%. Vertically, the result of change is to be understood as a total change, encompassing the whole life cycle of an object, also given in percentages, and with a similar *object of reference = 100%* rule applied. Cells at the intersections of life cycle phases and life cycle analysis modes show the absolute results in units appropriate for the analysis mode.

Tab.2: LCA results of analyzed refrigerator variants

Variants / LCA results [Pts.]				
	Object of reference	Variant 2	Variant 3	Variant 4
Manufacturing	52.09	41.58 (↓20.18%)	51.81 (↓0.54%)	52.07 (↓0.04%)
Operation (use)	148.01	128.49 (↓13.19%)	134.73 (↓8.97%)	136.21 (↓7.97%)
Disposal	-14.8	-13.43 (↑9.26%)	-17.75 (↓19.93%)	-14.80 (↓0.0%)
Complete life cycle	185.30	156.64 (↓15.47%)	168.79 (↓8.91%)	173.48 (↓6.38%)

Tab.3: LCC results of analyzed refrigerator variants

Variants / LCC results [PLN]				
	Object of reference	Variant 2	Variant 3	Variant 4
Manufacturing	644.00	635.00 (↓1.40%)	675.00 (↑4.81%)	660.00 (↑2.48%)
Operation (use)	1186.35	1002.75 (↓15.48%)	1112.15 (↓6.25%)	1078.35 (↓9.10%)
Disposal	60.00	53.00 (↓11.67%)	55.00 (↓8.33%)	57.00 (↓5.0%)
Complete life cycle	1890.35	1690.75 (↓10.56%)	1842.15 (↓2.55%)	1795.35 (↓5.03%)

Tab.4: Life cycle analysis results for variant 2

	LCA [Pts.]	**LCC [PLN]**	**Change in relation to the reference state [%]**
Manufacturing	41,58	635,00	(↓20,18%) / (↓1,40%)
Operation (use)	128,49	1002,75	(↓13,19%) / (↓15,48%)
Disposal	-13,43	53,00	(↑9,26%) / (↓11,67%)
Complete life cycle	156,64	1690,75	(↓15,47%) / (↓10,56%)
Change in relation to the reference state [%]	(↓15,47%)	(↓10,56%)	

Tab.5: Life cycle analysis results for variant 3

	LCA [Pts.]	LCC [PLN]	Change in relation to the reference state [%]
Manufacturing	51,81	675,00	(↓0,54%) / (↑4,81%)
Operation (use)	134,73	1112,15	(↓8,97%) / (↓6,25%)
Disposal	-17,75	55,00	(↓19,93%) / (↓8,33%)
Complete life cycle	168,79	1842,15	(↓8,91%) / (↓2,55%)
Change in relation to the reference state [%]	(↓8,91%)	(↓2,55%)	

Tab.6: Life cycle analysis results for variant 4

	LCA [Pts.]	LCC [PLN]	Change in relation to the reference state [%]
Manufacturing	52,07	660,00	(↓0,04%) / (↑2,48%)
Operation (use)	136,21	1078,35	(↓7,97%) / (↓9,10%)
Disposal	-14,80	57,00	(↓0,0%) / (↓5,0%)
Complete life cycle	173,48	1795,35	(↓6,38%) / (↓5,03%)
Change in relation to the reference state [%]	(↓6,38%)	(↓5,03%)	

5 Interpretation of results

In most of the categories, the impacts simulated for the versions of the refrigerator are lowered, and this reduction is simultaneous in both categories of impacts. In two examples (variant 3 and 4, Table 6 and Table 7 respectively) there is a negative relation - reducing the environmental burdens at the manufacturing stage raises the costs generated at that life cycle phase. Positive correlation between those two results can be found in variant 2 and that is because it assumes alterations to the original design more advanced than just modifications to the type or amount of materials used, as in the case of the two other variants. This major redesign also contributes greatly to the reduction of overall impacts in the operation phase of a refrigerator's life cycle – for example, cost reduction scale is more than twice when compared to the third variant.

Transfer of impacts is most apparent in the LCA results for variant 4 (Table 6). Insignificant reduction of environmental burdens at the manufacturing phase affects the results for other life cycle phases negatively. This can be interpreted as a certain negative attitude at environmental evaluation of any solution that includes adding weight and volume of materials to the design of an object [6].

Advantages of matrix-based presentation of LCM can also be seen using the overall conclusions as a background [1, 2] (Fig.1). The chart shows a hierarchy of proposed solutions in means of lowering total impacts in a life cycle of analyzed refrigerator – the lower the points for selected variant are, the better a solution in life cycle development context is. But although this form of showing the results is good for putting in order different variants, it does not explain the reasons for such arrangement. Therefore, it is incomplete in means of communicating detailed data for the decision-making process [6]. For example, it does not address the question of reversed scale of environmental and economical impacts reduction for variant 3 and 4. At this level of generality, it is impossible to trace back deficient decisions focused on solving a single impact reduction issue, that affect other areas and contribute to the transfer of impacts across the whole life cycle of an object.

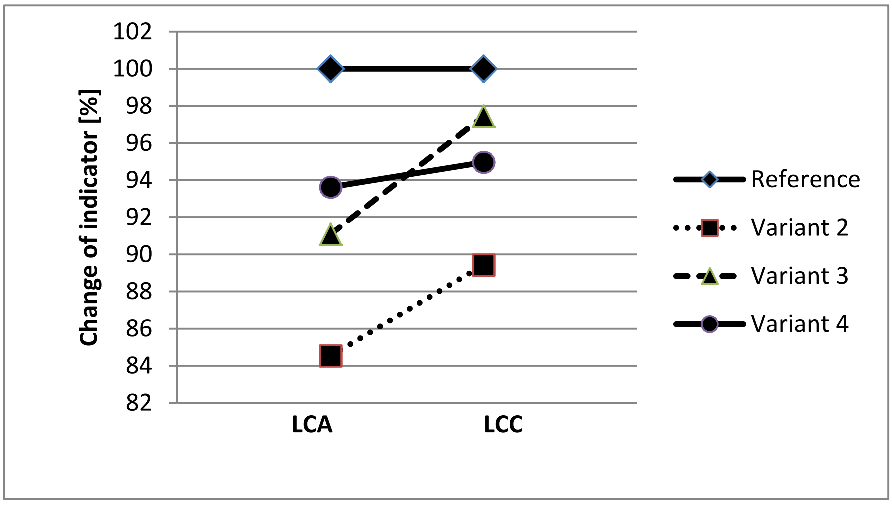

Fig.1: Comparison of LCA/LCC results for different variants of the analyzed refrigerator

6 Conclusions

Results of the conducted analysis of chosen variants show that proposed variant 2, including alterations to the original design of refrigerator should be selected to the stage of research (prototyping, testing, trial production). It is characterized by the highest degree of reduction of environmental impacts and costs that occur throughout the life cycle of analyzed object. The reduction of environmental and economical indicators reaches 15,47%, and 10,56% respectively.

The proposed presentation and monitoring tool is a simple and effective way to illustrate the results of undertaken development procedures (actual or hypothetical). It can be used as an aid in dialogue between performers of life cycle analyses and decision-makers (managers responsible for product development strategies). In LCM, which is a management concept, it is fundamental that the decisions should be made based on facts. Any initiative aimed at improving the availability and legibility of acquired and interpreted data strengthens the position of LCM as default methodology for implementing the ideas of sustainable development at the object level into practice.

7 References

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