

*Application of Life Cycle Assessment
in the Context of Classical Environmental Management System
and with Respect to the Implementation of the EuP Directive*

Volume 1

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Abstract

This thesis presents the results of the research based on the Life Cycle Assessment (LCA), with respect to the application of the Energy-using Products (EuP) Directive and the Environmental Management System (EMS).

In part A, an introduction and hypotheses of the research are given. In general it will be investigated, whether the environmental techniques such as Environmental Management System and Life Cycle Assessment may be used by the company in Poland as a tool for increasing the competitiveness and creation of the green company's image. Furthermore, the applicability of these techniques and tools in the framework of the European directive on the Energy-using Products will be shown.

In order to understand the requirements of the voluntary environmental tools and binding legal framework, a general description of the Environmental Management Systems (based on the ISO 14001 standards), Life Cycle Assessment (described by the ISO standards of 14040 family) as well as the Energy-using Products directive will be given in Part A.

Part B will deal with the results of the LCA based on a case study of a gas-electro cooker produced by FagorMastercook S.A. The LCA evaluation was performed with the help of the SimaPro modelling program. The modelling was divided into two steps. In the first step, only the cooker's influence on the environment was considered, including the production processes. In the second stage, the use phase processes were added, as well as End-of-Life scenarios specific for the Polish market and situation were applied. The evaluation was based on different Life Cycle Impact Assessment methods. As the result, one could observe, that main impact on the environment was caused by the subassemblies and materials with the highest weight. Furthermore, the use of the metals (ferro and non-ferro) was responsible for the majority of the environmental damage. This damage occurred mainly in the categories relating to the natural resource consumption. As for the second modelling stage, cooking and baking processes were pointed out as the main cause of the environmental damage from the life cycle perspective. The cooker itself had a relatively small importance and contribution to the overall impact.

These LCA results were be used as a part of the comprehensive assessment of the environmental performance of the entire company system with the help of Sensitivity Model Prof. Vester (SMPV) software in Part C. The sensitivity analysis was performed in two steps. In the first step, all variables that could influence the functioning of the company (such as financial results, authorities,

customers, environment, inhabitants of the city) were taken into consideration. In the second modelling step, only the variables with the most visible influence on the system were taken into consideration (i.e. price, owner, quality, etc). For both modelling steps, several policy scenarios were developed, taking into consideration various types of interactions between variables and time spans of 15 and 30 years. As the result one could see, that the implementation of the LCA and EMS in the company may help to achieve the strategic goals, such as improvement of the products' quality, creating the green image of the company, minimising costs and negative influence of the company on the environment. On the other hand, decision makers in the company should be aware of the implementation costs, which may cause the increase of the products' price and the decrease of the competitiveness on the internal (Polish) and external (European) market.

Subsequently, summary and conclusions of the results are presented in Part D. Parts A to D are described in the Volume 1 of the thesis. Appendices are presented in the Volume 2.

KEYWORDS: LIFE CYCLE ASSESSMENT, LIFE CYCLE IMPACT ASSESSMENT, ENERGY-USING PRODUCTS, SIMAPRO, SENSITIVITY MODEL PROF. VESTER, SENSITIVITY MODELLING, ISO 14040, ISO 14000, GAS-ELECTRO COOKER, KGE 3490X, FAGORMASTERCOOK, ENVIRONMENTAL MANAGEMENT SYSTEM.

List of terms and abbreviations

AOX	Absorbable organic halogenated compounds
COD	Chemical oxygen demand
DQI	Data Quality Requirements
EDIP/UMIP	LCIA method, Environmental Design of Industrial Products, Danish version: UMIP
EI 99	LCIA method, Eco-Indicator 99
EMS	Environmental Management System
EoL	End-of-Life scenarios
EPS	LCIA method, Environmental Priority Strategies in product design
EU	European Union
EuP	Energy-using product
EuP Directive	Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending the Council Directive 92/42/EEC and directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council
HRAD	High active radioactive waste
IPCC	Intergovernmental Panel for Climate Change; simultaneously, name for the LCIA method
ISO	(<i>Greek</i> : harmony) name of the International Organization for Standardization
ISO 14001	ISO standard describing the EMS, full name: “Environmental management systems – Requirements with guidance for use (ISO 14001:2004); German and English version EN ISO 14001:2004), the newest version: June 2005”
ISO 14040	ISO standard describing the LCA, full name: “Environmental management – Life Cycle Assessment – Principles and framework (ISO 14040:2006); German and English version EN ISO 14040:2006), the newest version: October 2006”
ISO 14044 (Replacing ISO 14041, 14042, 14043)	ISO standard describing the LCA, full name: “Environmental management – Life Cycle Assessment – Requirements and guidelines (ISO 14044:2006); German and English version EN ISO 14044:2006), the newest version: October 2006”

KGE 3490X	Gas-electro cooker produced in Poland by the FagorMastercook company
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LMRAD	Low and medium active radioactive waste
NGO	Non-Governmental Organisation
NMVOC	Non methane volatile organic compounds
SMPV	Sensitivity Model Prof. Vester

PART A

**INTRODUCTION. METHODOLOGY OF THE RESEARCH ACCORDING
TO THE ISO 14040 STANDARDS AND THE EUP DIRECTIVE**

1. Introduction

1.1 Background and statement of the problem

The Life Cycle Assessment is an analytical tool, which determines the environmental impacts of a product or service in the cradle-to-grave approach. Its applications are rapidly developing, because it allows compiling the data concerning the product, service or any other system, and making the best decision concerning the most effective way of minimizing the environmental burden. This decision should be made even before product or service is placed on the market. The LCA may be integrated into the existing or planned Environmental Management System of the company. One can use the results of the LCA also as a basis for the implementation of various management plans and programmes.

The LCA tool is widely applied in the highly developed countries. In Poland, however, it has not widely spread outside the research and educational institutions, where it serves mainly as a starting point for the theoretical discussion. Therefore, for most of the Polish products, no data are available for the LCA research (as i.e. emissions during the production or disposal phases). If such data exist, they are highly fragmented among environmental authorities and companies. The LCA is also extremely rarely performed, when decision makers create strategies for the future developments and check the compliance with the environmental legislation. The question of the assessment of overall environmental performance of the company remains open, as well.

The reason for choosing the research topic was mainly the marginal application of the LCA in the Central-East European countries. The cradle-to-grave approach is a novelty in the Polish companies and authorities. Therefore, the lack of data and modelling factors for the region can be observed, and in most cases, available data originate from the Western Europe and the United States.

It is interesting to perform the LCA studies based on the production data and use phase habits specific for the East European countries, as well as to assess the results and advantages of integration the LCA studies into the environmental management system. Such a comprehensive assessment of the company's environmental performance would be also unique in Polish enterprises.

Currently, the procedures and models aiming at the implementation and integration of the LCA in the Environmental (or Generic) Management Systems, as well as making the LCA studies a basis for the implementation of the EuP European directive, do not exist. This Thesis will present the results of the LCA study of the gas-electro cooker, KGE 3490X produced in Poland by the

FagorMastercook company. Subsequently, they will serve as a basis for the assessment of overall environmental performance of the company, especially with respect to the implementation of the Energy using Products directive (EuP) and the functioning of the currently existing Environmental Management System. As the result, it will be possible to evaluate the possible impacts of introducing large-scale LCAs for all company's products with respect of environmental regulation, financial results, market image of the company, cost savings, etc. Such wide-ranging assessment is necessary, because one may observe the overlapping of environmental measures, legal issues, and other factors inside the market system of every enterprise. As an example, the overlapping of the EuP directive with the LCA studies as a part of the Environmental Management System (EMS) is shown in fig. 1.1.

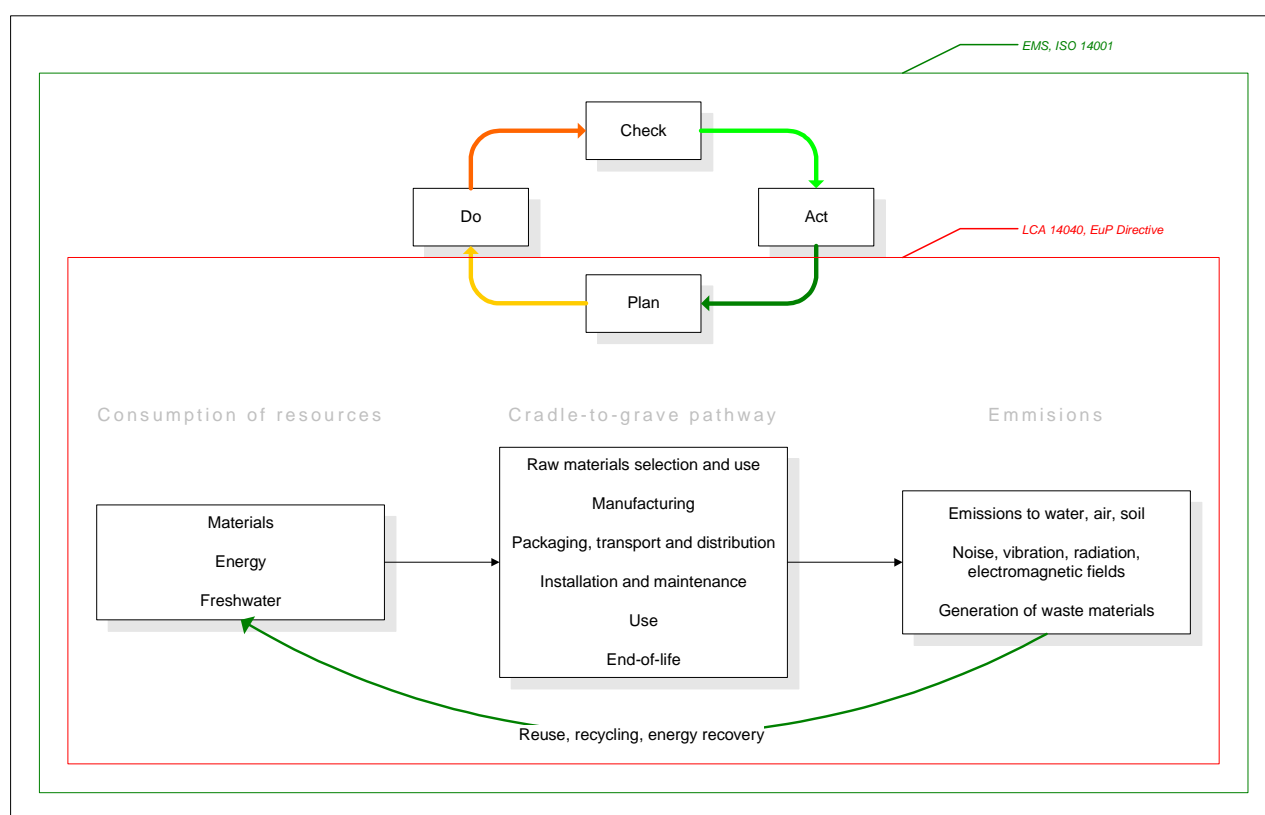


Figure 1.1 Overlapping of EuP directive with ISO standards for LCA and EMS.

The implementation of the LCA into existing company practices may be a time consuming and complicated process. To show the potential advantages and existing obstacles from different points of view, the research was divided into two major milestones: the Life Cycle modelling and the evaluation of its impact on the company system.

In the first phase of the project, inventory data were collected and compiled for the purposes of the LCA studies of the gas-electro cooker. The adaptation of existing software materials and processes was done. Additionally, new End-of-Life (EoL) scenarios and use-phase processes were created.

Their assumptions are appropriate for the Central-East countries, based on the Polish market experience and practice. Distribution and analysis of questionnaires, as well as cooperation with the FagorMastercook, database and web-based research were crucial in this step of the research.

Afterwards, the SimaPro modelling software was used for the determination of the environmental impacts. With the help of SimaPro, the impact assessment of the product life cycle was performed, using such Life Cycle Impact Assessment methods as the Eco-indicator 99, CML 2, EDIP/UMIP, EPS 2000, the Ecopoints 97, the Cumulative Energy Demand, the IPCC greenhouse gas emission models. Application of the various Life Cycle Impact Assessment methods aimed at the comparison of results coming from different methodological approaches.

In the second major part of the research, the broad impact and interrelationships of the LCA, the EuP directive, and the EMS existing inside the company were analyzed. The interrelationships and influence of the external variables, such as i.e. authorities, were also taken into consideration. The use of powerful software package, namely Sensitivity Model Prof. Vester (SMPV), was necessary at this stage of the research. The SMPV modelling, using the concepts of fuzzy logics, allows better understanding of the functioning and interrelations between the elements of the system, without gathering of extensive amounts of statistical data.

1.2 Hypotheses

The following hypotheses will be investigated:

- The LCA tool such as the SimaPro may be used in a very flexible way for the support of the decision process;
- SimaPro may provide a sound basis for the implementation of the EuP directive at the reasonable cost and time expenditure, thus facilitating environmental protection while maintaining economical competitiveness;
- Application of environmental tools, such as the LCA, may strengthen the position of the company on the internal and external market;
- The LCA and the EMS are crucial parts of company's activities, that may not be ignored when making decisions in a modern company.

1.3 Significance of the research and its findings

The significance of the research is based on the fact, that it delivers unique results for the development of the LCA technique on the Polish and European scale. No results for the LCA of Polish products are available for a scientific comparison. Furthermore, the first assessment of the Polish cooking habits has been made for the purpose of the environmental studies.

Secondly, the comprehensive sensitivity analysis of the Polish enterprise model is exceptional. The insight into the functioning and interrelationships of such a model is of crucial importance for the future development of environmental techniques and tools in Polish enterprises. It also allows making improvements and avoiding mistakes, when planning the implementation of measures such as the Energy-using-Product directive.

2. Requirements of the ISO standards and the EuP directive

2.1 Introduction

Scientists and decision makers recognized the significance of the environmental issues in the early 1960's and 1970's. Since then, many articles and books have been published, that described ongoing trends in the environmental management issues and helped to establish sound base for today's environmental assessments.

This chapter will focus on the description of the most important standards and laws, used in the research, including some historical background of their development. First, the description of the Environmental Management System (EMS) will be given, including the importance of the ISO 14000 international standard framework. This description is crucial for the understanding of the company functioning; simultaneously, it gives an idea and insight into the complexity of enterprise systems. The knowledge about the EMS will be important for the sensitivity modelling in the SMPV. At the same time, the ISO 14001 standards were a starting point for the development of the ISO 14040 family standards, dealing with the LCA.

The Life Cycle Assessment standards with numbers 14040 to 14044 were a basis for the LCA research, performed in cooperation with the FagorMastercook. These standards describe in detail, which steps and techniques have to be used, when modelling the product's LCA. Furthermore, the detailed level of description facilitates avoiding errors in LCA study. Therefore, these standards will be described in detail.

Subsequently, the EU framework directive concerning the Energy using Products (EuP) is described. The description of the EuP directives shows, how a practical approach to the LCA tool is translated and becomes a binding law in the European Union. Large variety of products offered on the market forced the initiators of this directive to specify only main guidelines and requirements for the LCA. Therefore, the EuP directive may be fully understood only if used concurrently with the ISO 14040 standards. Description of the EuP directive, identically as in case of the EMS ISO standards, serves as a basis for the sensitivity modelling in the SMPV.

In Part A (especially sections 2.4 to 2.6, presenting in detail the ISO standards and the EuP directive), mainly primary sources of guidelines and laws are used. Other literature resources, such as books and articles, usually refer to these ISO standards and European laws, or describe the results of the LCA studies not relevant for the research. Therefore, as secondary sources of information, these books and articles were omitted.

One has to make an important remark on the various versions of the ISO standards. The ISO organization amends and improves the standards continuously. In the course of research, the ISO published updated versions of the standards. Since some older versions of standards were used as a basis for investigations, updated and outdated versions of standards are mentioned simultaneously in the literature description. However, the introduction of updated standards did not influence the results of the research. The newer standards only simplify and unify the description of the LCA studies and the EMS. The core and essential meaning of the standards remains unchanged.

2.2 History and the development of environmental management system

According to Morelli (1999), the history of the environmental management can be traced to the nineteenth century, when environmental issues have been focused on the proper use of the land resources and maintaining the natural areas (table 2.1).

Table 2.1 Development of the Environmental Management Standards. Source: Morelli (1999), modified.

Years	Phase of the development
1890 – 1950's	“Land Preservation Era”: proper use of land resources and the importance of maintaining natural areas.
1962 – 1990's	“Pollution Control and Cleanup Era”: substantial environmental quality improvements, the base of knowledge of environmental impacts dramatically expanded.
1990's – 2000	“The Era of Global Environmental Responsibility”: acknowledgement of the environmental responsibility as a part of doing business.
2000 – up to now	“The Era of Institutionalized Environmental Responsibility”: the environmental management and its tools implemented as legal requirements of doing business.

The next period of the environmental management followed from the 1962, and was originated by the publication of Rachel Carson's book “Silent Spring” (Carson 1962). Her book showed the excessive use of pesticides and elevated national awareness and concern to give rise to pollution control and cleanup problems. This second phase of the environmental awareness lasted for two decades, and the efforts to improve the quality and the environmental performance dramatically expanded the base of knowledge of environmental impacts. People started to care about the fate of waste materials; the issues of the product responsibility and accountability emerged.

This evolution of knowledge and thought gave the rise to the third era of environmental management, namely the era of global environmental responsibility. Nowadays, the environmental

management is implemented as a legal requirement and has become a natural part of companies' activities. This last phase of the environmental management development may be characterized by the increased acknowledgement of the environmental responsibility by the private sector. It recognizes Environmental Management System as the legitimate part of doing business; simultaneously private enterprises include significant environmental issues in the assessment of the environmental impacts either on their domestic markets and abroad (Morelli 1999).

2.3 Features and targets of the EMS with respect to the ISO 14000 standards

The most widely recognized Environmental Management Standards were developed by the International Organization for Standardization (ISO). This non-governmental organization is a federation of the national standards bodies of 157 countries, from all regions of the world, including developed, developing and transitional economies (source: <http://www.iso.org/>, accessed on 05.10.2006).

According to the official ISO web page (<http://www.iso.org/iso/en/iso9000-14000/understand/inbrief.html>, accessed on 05.10.2006), the ISO 9000 and the ISO 14000 families are among the ISO's most widely known standards ever. The first one relates to the quality management standards, the latter concerns environmental management. As the ISO organization states, the ISO 9000 and the ISO 14000 standards are implemented by more than 800000 organizations in 161 countries. The quality standard ISO 9000 has become an international reference for quality management requirements in business-to-business dealings, and the ISO 14000 is well on the way to achieving as much, if not more, in enabling organizations to meet their environmental challenges.

The "Management system" term is used for the description of the organization's structure for managing its processes or activities, which aim at transforming inputs of resources into a product or service which meet the organization's objectives, such as satisfying the customer's quality requirements, complying to regulations, or meeting environmental objectives (source: <http://www.iso.org/>, accessed on 05.10.2006). The fulfilling of the targets is usually done in a closed-loop systematic way, which usually means an iterative cycle of processes, as depicted in fig. 2.1. As one can see, "plan-do-check-act" cycle covers various levels of company's activities and involves workers from different departments. This fact will be important for the sensitivity analysis. The detailed description of the ISO management system procedure will be given in the following subchapter.

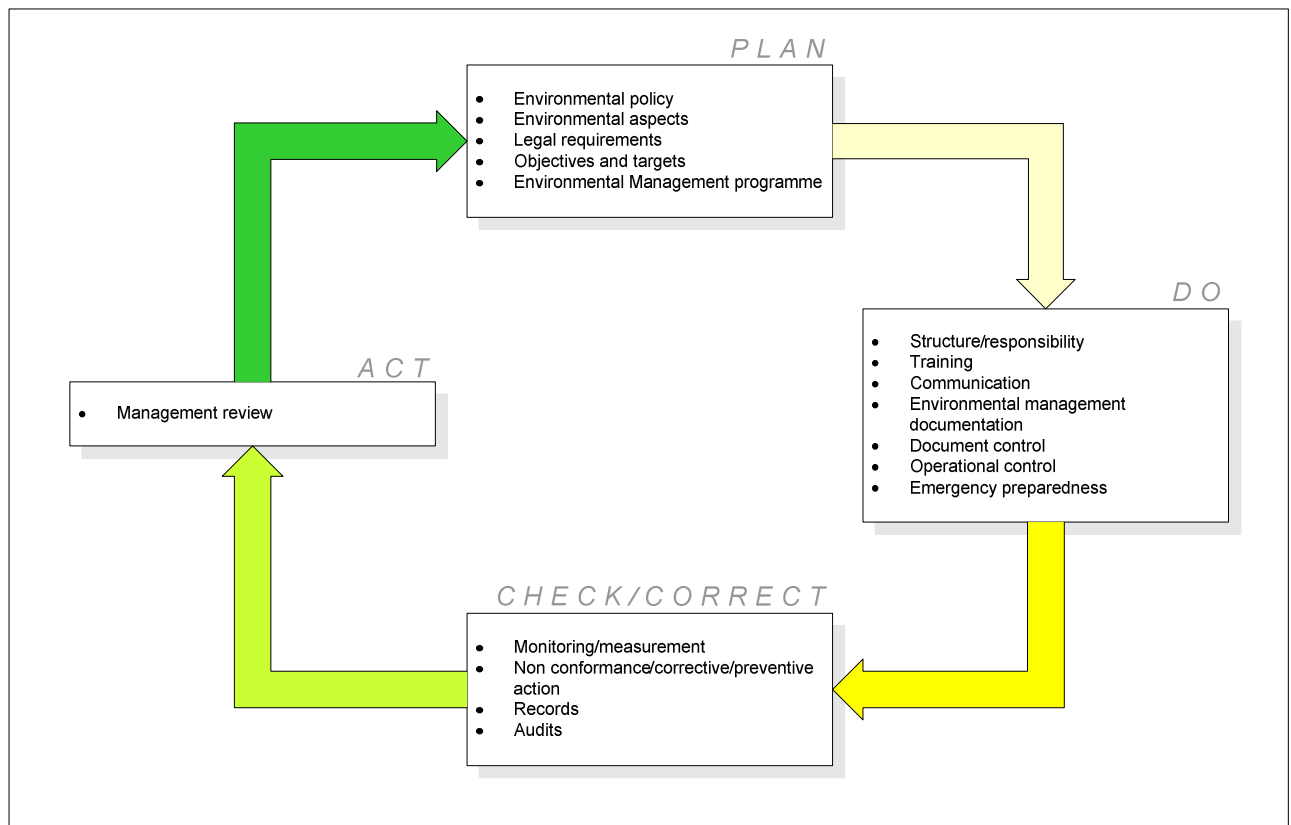


Figure 2.1 Phases of the environmental management system. Source: <http://www.agrifoodforum.net/practices/ems.asp>, modified (accessed on 04.10.2006).

2.4 EMS according to the ISO 14001 standard

2.4.1 Introduction, definitions and general requirements of the EMS

In the recent decade, an increasing environmental consciousness among customers and decision makers has been observed. The growing number of buyers decides today to choose the products manufactured by companies with a recognized green image. In many cases, decision makers prefer the enterprises with an EMS in place. For example, when applying for the European grants, some additional points in the submission process are given for the existing EMS. If one talks about small and medium size enterprises (SMEs), they have greater chances in signing i.e. supply contracts with the bigger companies, which monitor the meeting of the environmental standards by the suppliers.

One has to mention, that the existing EMS does not guarantee the best environmental performance, since this is not a measure of environmental performance. The existing EMS indicates the environmental awareness of the company or an organization.

Two main EMS systems are known in Europe. The European Union developed the first one called EMAS (the Eco Management and Audit Scheme). This EMS is more oriented towards performance of the system. The ISO 14001 system has been developed by the ISO organization, and focuses on

setting rather a general framework than specific performance of the EMS. Table 2.2 presents the main differences between two management systems applied in Europe.

Table 2.2 Main differences between EMAS and ISO 14001. Source: http://ec.europa.eu/environment/emas/pdf/factsheet/fs_iso_en.pdf, modified (accessed on 22.01.2007).

Element of EMS	EMAS	ISO 14001
Preliminary environmental review	Verified initial review	No review
External communication and verification	Environmental policy, objectives, environmental management system and details of organization's performance made public	Environmental policy made public
Audits	Specified frequency and methodology of audits and of measuring the environmental performance	Audits of the environmental management systems (frequency or methodology not specified)
Contractors and suppliers	Required influence over contractors and suppliers	Relevant procedures are communicated to contractors and suppliers
Commitments and requirements	Employee involvement, continuous improvement of environmental performance and compliance with environmental legislation	Commitment of continual improvement of the EMS rather than a demonstration of continual improvement of environmental performance

The sensitivity analysis presented in chapter 5 will take into consideration requirements of the ISO 14001 standard. This type of the EMS is applied in Poland more often than the EMAS. For example, FagorMastercook decided to certify its management system in compliance with the ISO standards. The leading position of the ISO 14000 may be associated with its essential features:

- Flexibility of application – EMS may be introduced by companies, NGO's, travel agencies etc.;
- It is recognized worldwide;
- Implementation of the ISO 14000 is not very difficult and expensive;
- The green image of the company is being built;
- It accommodates diverse geographical, cultural, and social conditions.

The experts in the ISO 14001 recognize also other advantages of the EMS. It may:

- Improve the organization's net income through improved environmental performance;

- Enable an organization to achieve and systematically control its level of environmental performance;
- Trigger procedural and technological changes that can reduce production costs;
- Drive more productive use of all inputs, including raw materials, energy and labour (through the requirement for continuous improvement in environmental impacts);
- Reduce pollution means improved productivity and more efficient use of resources (Perry Johnson Registrars, <http://www.pjr.com/>, accessed on 09.01.2007).

According to the ISO 14001 standard, the requirement of the organization is to establish and maintain the environmental management system including the following elements:

- Environmental policy;
- Planning;
- Implementation and operation;
- Checking and corrective action;
- Management review elements.

Fulfilling the requirements of the standard aims at the formulation of policy and objectives taking into account legal requirements and information about significant environmental impacts (EN ISO 14001:1996, EN ISO 14001:2004). Important feature of the EMS implementation is the enterprise's responsibility for the environmental aspects; the ISO 14001 applies only to those of them, which the organization can control or can have the influence over.

The general plan of implementation of the EMS according to the ISO 14000 family standards is shown in figure 2.2 (compare fig. 2.1, page 27). The framework set by the ISO organization includes the use of the EMS tools such as the Life Cycle Assessment (described in further detail in subchapter 2.5). In the following sections, the detailed description of the EMS according to the ISO 14001 will be provided.

2.4.2 Environmental policy

The environmental policy is defined by the top management of the organization. This policy shall be available to the public, and fulfil the requirements of being documented, implemented, maintained and communicated to all employees.

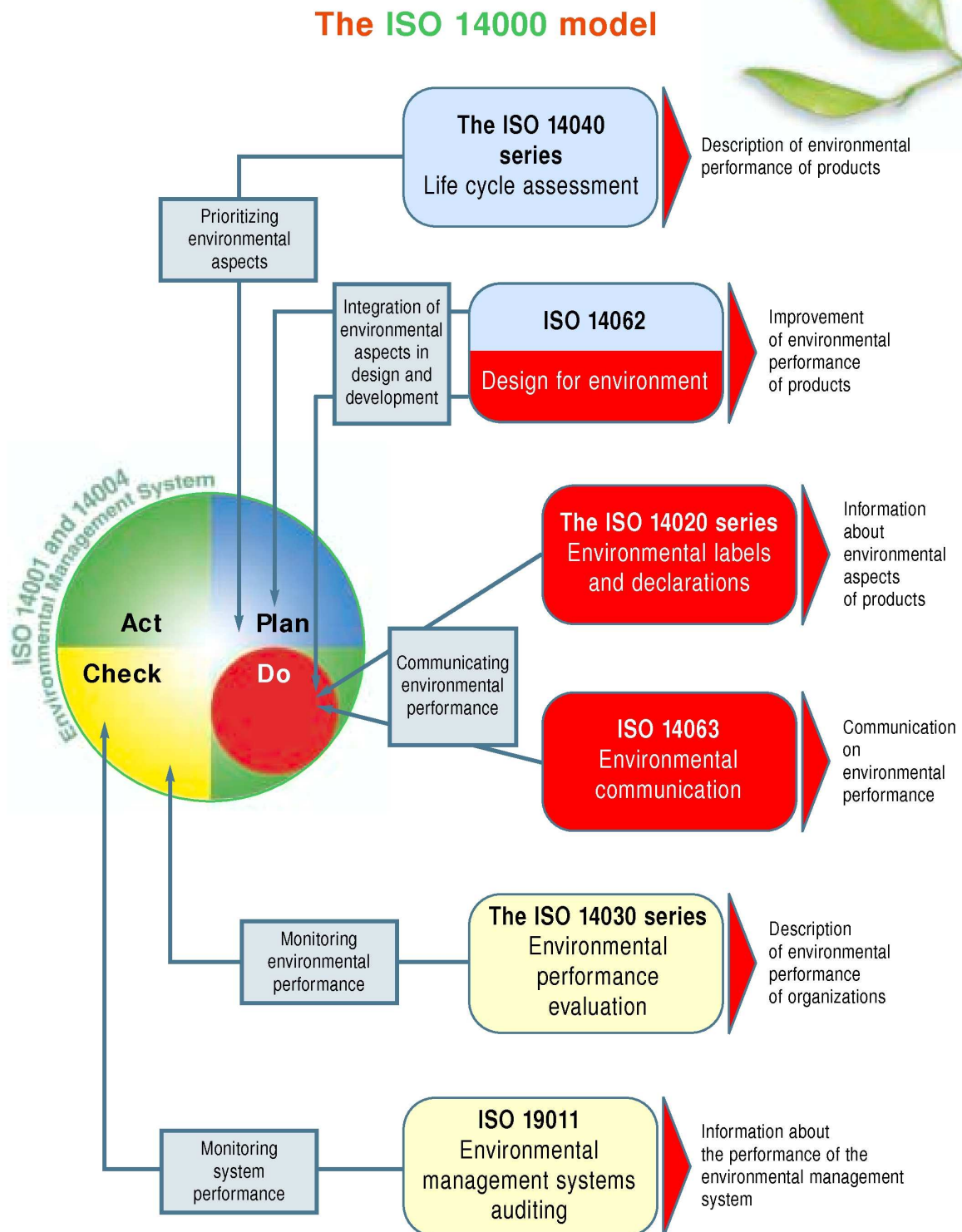


Figure 2.2 The ISO 14000 model. Source: <http://www.iso.org/iso/en/prods-services/otherpubs/iso14000/model.pdf> (last accessed on 22.01.2007).

The statements of the environmental policy should reflect the nature, scale and environmental effects of the organization's activities or products. The commitment to continual improvement, prevention of pollution and compliance with relevant environmental regulations and legislation shall be included. Environmental policy should also provide the framework for setting and reviewing environmental objectives and targets (EN ISO 14001:1996, EN ISO 14001:2004).

2.4.3 Planning

Having an environmental policy in place, an organization can start the next phase of the ISO 14001 implementation, explicitly planning. The planning activities are organized along the logical pathway of determination of environmental issues, recognizing the legal requirements, setting objectives and targets, and finally establishing programmes necessary to achieve them (fig. 2.3).

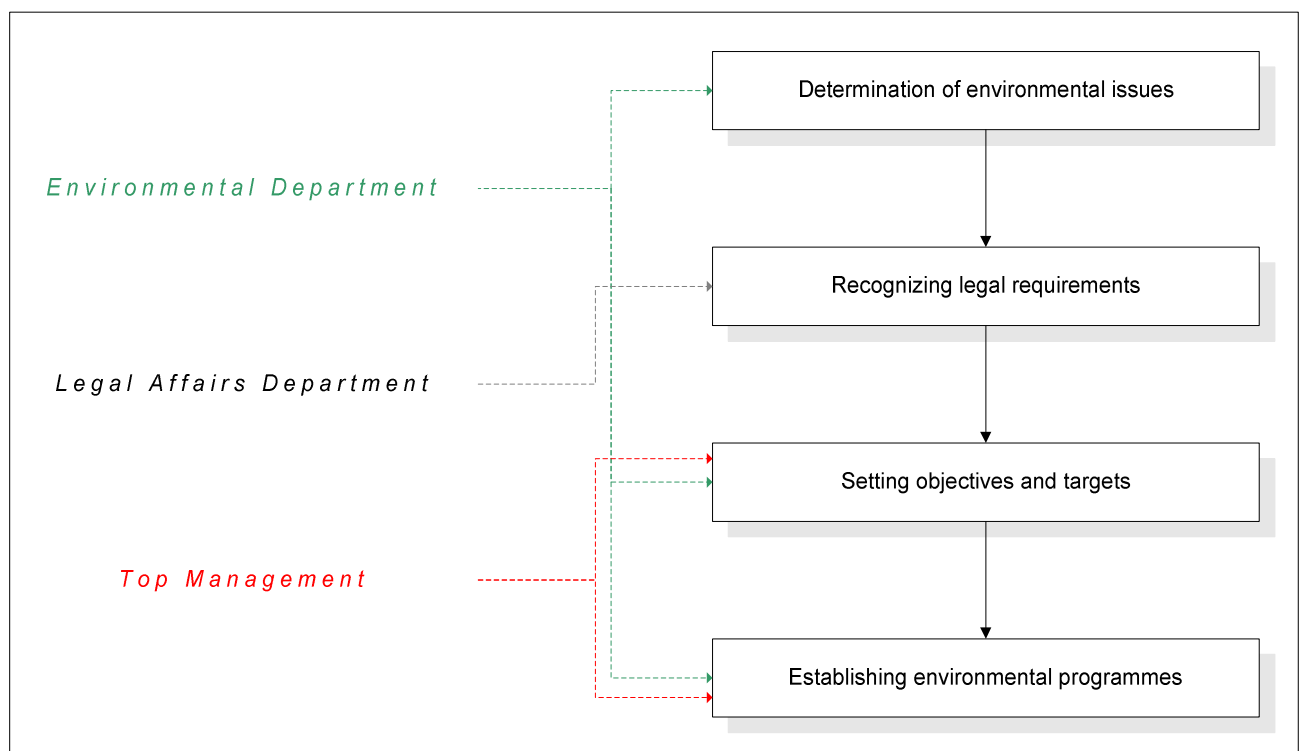


Figure 2.3 Planning phase in the implementation of ISO 14001 system. The main responsibilities of the organization's departments are shown with the dashed arrows. Source: EN ISO 14001:1996, EN ISO 14001:2004, modified.

The procedure for identification of environmental aspects of activities, products or services shall ensure taking into consideration all environmental issues that an organization can control and over which it has an influence. The information about environmental aspects shall be kept by the organization up-to-date.

The special procedure shall ensure the identification and access to the legal and other requirements to which the organization subscribes.

In the third step of planning, the organization's management sets objectives and targets at each relevant function and level of the organization. The legal and other requirements, significant environmental aspects, available technical options, as well as financial, operational and business requirements shall be taken into account. This broad spectrum of issues has to be considered in the planning phase. These aspects will also be covered in the sensitivity analysis in chapter 5. Once again, objectives and targets have to fulfil the essential statements of the environmental policy, especially the commitment to the prevention of pollution.

An environmental management programme allows organization to achieve its objectives and targets. The requirements for this procedure are designating the responsibility and setting the means and periods unambiguously. For the existing programmes and new developments, the ISO 14001 standard necessitates making the amendments, which ensure application of the environmental management (EN ISO 14001:1996, EN ISO 14001:2004).

2.4.4 Implementation and operation

The next section of the ISO 14001 deals with requirements concerning the implementation of the EMS according to the ISO standards. This stage requires creation of the largest amount of new procedures in the management system. The following items of the EMS are being determined:

- Structure and responsibility;
- Training, awareness, and competence;
- Communication;
- EMS documentation;
- Operational control;
- Emergency preparedness and response.

The ISO 14001 requires a clear definition of roles, responsibility and authorities. They shall be defined, documented and communicated. The management shall provide all essential resources essential to the implementation of the ISO 14001, such as human resources and specialized skills, technology and financial resources. Moreover, organization's top management appoints representative(s), which is responsible for the establishing, implementing, and maintaining the EMS. This person is also responsible for the reporting activities.

Furthermore, the standard recognizes the need for a proper training of the employees and management, especially those whose work may create a significant impact upon the environment. The procedure of training shall guarantee, that employees at each relevant function and relevant level will be aware of the importance of the:

- EMS, environmental policy and procedures;
- Significant environmental impacts related to their work activities;
- Their roles and responsibilities;
- The potential consequences of non-conformance with specified operating procedures (EN ISO 14001:1996, EN ISO 14001:2004).

The ISO 14001 emphasizes the role of the appropriate education, training and experience of the employees performing the task which can cause significant environmental impacts. It also highlights the importance of establishing and maintaining procedures for internal communication (between the various levels and functions of the organization) and external communication (with interested parties).

All information concerning the EMS system shall be available in paper or electronic form. This documentation shall describe the core elements of the management system and simultaneously provide direction to the related documentation. The procedures relating to the document control shall ensure that the documents:

- Can be located;
- Are periodically reviewed, revised and approved by an authorized personnel;
- The current versions of relevant documents are available at all locations where operations essential to the effective functioning of the EMS are performed;
- Obsolete documents are promptly removed from all points of issue and of use, or otherwise assured against unintended use (EN ISO 14001:1996, EN ISO 14001:2004).

An operational control is important for the operations and activities associated with the identified significant environmental aspects. These activities shall be carried out under conditions specified by the ISO 14001.

Specifically speaking, the organization shall establish and maintain documented procedures, which cover the situations where their absence could lead to the deviations from the environmental policy, objectives and targets. Secondly, the organization shall stipulate operating criteria in the procedures.

Finally, procedures related to the identifiable significant environmental aspects of goods and services used by the organization shall be established and maintained. The external communication with suppliers and contractors regarding the relevant procedures and requirements shall take place (EN ISO 14001:1996, EN ISO 14001:2004).

A separate subsection of the ISO 14001 is devoted to the emergency preparedness and response. As in the other cases, special procedures shall be established and maintained to assure that:

- Potential for accidents and emergency situations is recognized;
- Respond to them is clearly specified;
- Prevention and mitigation of the environmental impacts associated to accidents and emergencies take place.

2.4.5 Checking and corrective action

Checking and corrective action includes the following elements:

- Monitoring and measurement;
- Handling the non-conformance, corrective and preventive action;
- Maintaining records;
- Performing the EMS audit.

To assure the proper working of the EMS, ISO 14001 requires from the organization setting up and maintaining documented and evaluated procedure for monitoring and measurement. This shall include the key characteristics, operations and activities of the EMS, that have an impact on the environment. Clear responsibilities and authorities shall be defined. Again, the conformance with the organization's environmental objectives and targets is required.

According to the standard, any action taken shall be appropriate to the magnitude of the non-conformance; the resulting changes in the procedures implemented by the organization have to be documented.

The environmental records (including training records, audits and reviews) shall be:

- Legible;
- Identifiable;
- Traceable to the activity, product or service involved;
- Ready retrievable;

- Protected against damage, deterioration or loss.

Furthermore, the organization has to perform periodically an environmental management system audit. This procedure is necessary for:

- a) Determination whether or not the EMS:
 - conforms with the planned arrangements for environmental management including the requirements of the ISO 14001 standard,
 - has been properly implemented and maintained;
- b) Provide the information on the results of audits to the management (EN ISO 14001:1996, EN ISO 14001:2004).

2.4.6 Management review

The management review, conducted periodically at intervals determined by the organization's management, has the goal to assure continuous suitability, adequacy and effectiveness of the EMS. The review shall be documented and shall address:

- The possible need for changes to the policy, objectives and other elements of the EMS;
- Changing circumstances;
- Commitment to the continual improvement (EN ISO 1996:1996).

2.4.7 Summary

The ISO 14001 standard specifies a general framework for setting up and maintaining the EMS. From these requirements one can see, that many aspects (financial, legal, technical, etc) and interesting parties (top management, employees, third parties, etc.) are involved in the process of an enterprise management. All these activities have to be monitored and corrected, if necessary. The means for measurement and control of these (and other) aspects of company's performance will be proposed in chapter 5, dealing with system sensitivity analysis in the SMPV.

Having the EMS in place, a company may think about an introduction of a more specific environmental tool, namely the Life Cycle Assessment. This tool allows user to predict the environmental impact of product, even before it is placed on the market. With the help of the LCA results, one can minimize impact stemming from products, with reasonable time and money investments. The ISO organization prepared a set of standards that allows performing sound and the comprehensive LCA. These standards will be described in the next section.

2.5 LCA and the ISO 14040 framework

2.5.1 Introduction into the ISO 14040 family standards

According to the ISO 14040, the LCA is 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.

LCA studies evaluate the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from a raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences (EN ISO 14040:1997(E)).

As the ISO 14040 standard states, the Life Cycle Assessment may be seen as a very helpful tool for:

- Identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
- Decision-making in industry, governmental or non-governmental organizations (e.g. a strategic planning, a priority setting, a product or a process design or a redesign);
- Selection of relevant indicators of an environmental performance, including measurement techniques, and marketing (e.g. an environmental claim, an ecolabelling scheme or an environmental product declaration).

One has to mention, that the LCA is a young analytical tool, which still undergoes a continuous improvement. Therefore, it is not a perfect tool to study all the environmental impacts resulting from a product or an activity. For instance, the LCA does not cover social or economical issues. These aspects are covered by sensitivity analysis (chapter 5). Other limitations of the LCA technique are the following:

- The nature of choices and assumptions made in the LCA (e.g. system boundary setting, selection of data sources and impact categories) may be subjective;
- Models used for inventory analysis or to assess environmental impacts are limited by their assumptions, and may not be available for all potential impacts or applications;

- Results of the LCA studies focused on global and regional issues may not be appropriate for local applications, i.e. local conditions might not be adequately represented by regional or global conditions;
- The accuracy of the LCA studies may be limited by accessibility or availability of relevant data, or by data quality, e.g. gaps, types of data, aggregation, average, a site-specification;
- The lack of spatial and temporal dimensions in the inventory data introduces uncertainty in impact results. This uncertainty varies with the spatial and temporal characteristics of each impact category (ISO 14040:1997(E)).

Summarizing, the ISO 14040 standard family specifies a general framework for conducting the LCA studies, which should be used as a part of a much more comprehensive decision process. Comparing results of different LCA studies is only possible, if the assumptions and context of each study are the same. These assumptions should also be explicitly stated for reasons of a transparency.

Figure 2.4 shows the most important phases of the LCA based on the ISO standards. In the first phase, the goal and the scope of the study shall be defined. Subsequently, inventory analysis should take place, followed by an impact assessment and interpretation of the results. The LCA may be used for various purposes (such as product development and improvement, marketing, strategic planning, public policy making, etc.); they lay, however, outside the scope of the ISO 14040 family standards.

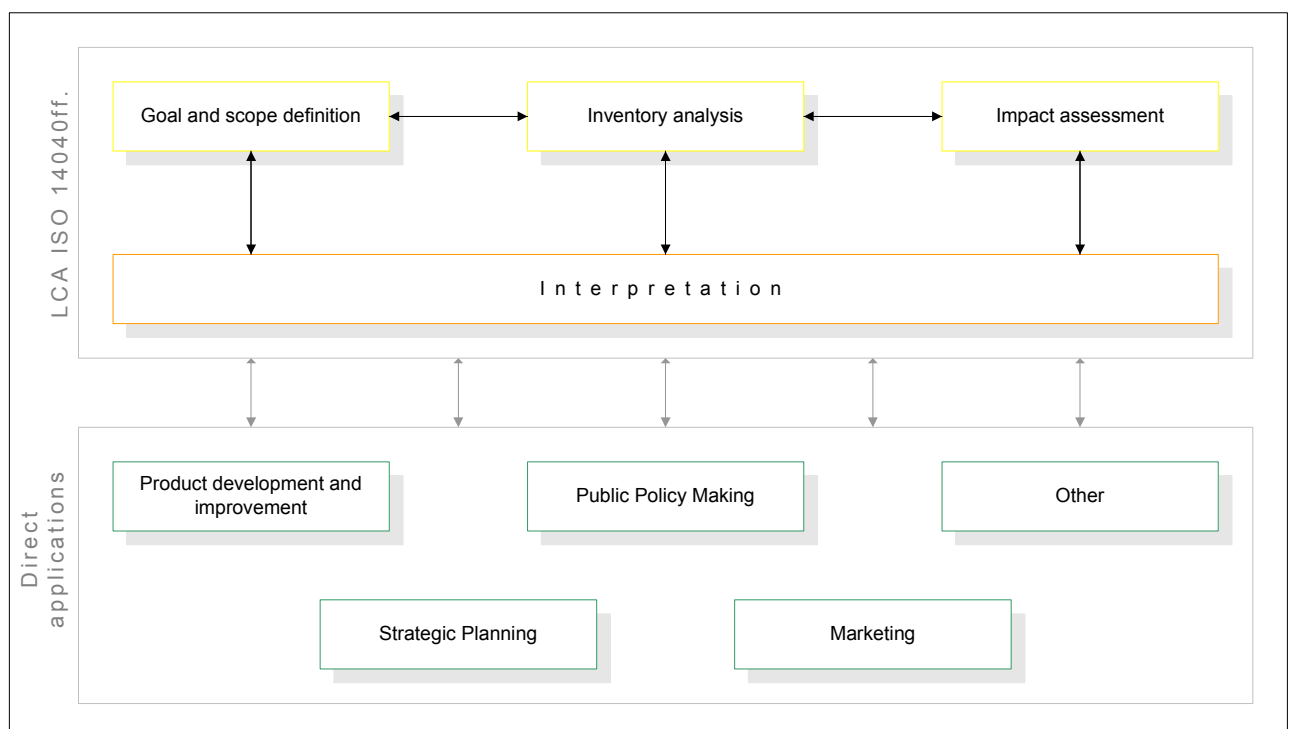


Figure 2.4 Phases of an LCA. Source: EN ISO 14040:1997(E), EN ISO 14040:2006(E), modified.

The LCA study performed in cooperation with the FagorMastercook was based on the ISO 14040 standards. Therefore, following subchapters will present their detailed description, being simultaneously the description of methodology used for the research. The results of the gas-electro cooker LCA were used mainly for product improvement and strategic planning. The experience from the LCA modelling was also integrated into the sensitivity modelling of the entire company system.

2.5.2 Goal and scope definition

The goal and scope definition is the first phase in conducting the LCA study. According to the ISO 14040 and the ISO 14044, the goal and scope of an LCA study shall be clearly defined and consistent with the intended application.

Both standards underline, that the goal of an LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience. One has to consider and clearly define the following items:

- The functions of the product system, or, in the case of comparative studies, the systems;
- The functional unit;
- The product system to be studied;
- The product system boundaries;
- Allocation procedures;
- Types of impact and methodology of impact assessment, and subsequent interpretation to be used;
- Data requirements;
- Assumptions;
- Limitations;
- Initial data quality requirements;
- A type of a critical review, if any;
- A type and a format of the report required for the study.

If the scope is sufficiently well defined, it will ensure that the extent, depth and the detail of the study are compatible and sufficient to address the stated goal. Nonetheless, one has to remember, that LCA is an iterative technique. Therefore, as data and information are collected, various aspects

of the scope may require modification, thus enabling to meet the intended goal. In some cases, even the goal may be changed due to the unforeseen limitations or constraints. It is important to document such changes in the goal and scope duly (EN ISO 14040:1997(E), EN ISO 14040:2006(E), EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

2.5.2.1 Function and functional unit

The basic aspects to be defined in the scope of the study are the function of the product and the functional unit.

The functions of the product are related to its performance characteristics. Functional unit is a measure of the product performance (output), which primary purpose is to provide a reference to which all inputs and outputs are related. In a mathematical sense, functional unit results from a normalization of all input and output data. It shall be consistent with the goal and scope, as well as clearly defined and measurable. The secondary purpose of the functional unit is to provide a common basis to compare different LCA studies. In some cases, when the product system has multiple possible functions, the choice of the functional unit is dependent on the definition of the goal of the study (EN ISO 14040:1997(E), EN ISO 14040:2006(E), EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

2.5.2.2 System boundaries, inclusion of inputs and outputs

Setting the system boundaries is of a crucial importance for performing the LCA study. This phase determines, which unit processes shall be included within the LCA. Factors determining the system boundaries are: the intended application of the study, the assumptions made, cut-off criteria, data and cost constraints, and the intended audience. Moreover, the selection of inputs and outputs, the level of aggregation within a data category, and the modelling of the system shall be consistent with the goal of the study. All criteria used in establishing the system boundaries shall be well documented (EN ISO 14040:1997(E), EN ISO 14040:2006(E)).

Nonetheless, very rarely there is enough time, data, or resources to perform such detailed LCA studies. If a decision concerning the exclusion of some unit processes or inputs/outputs has to be made, one has to clearly state and describe it. The criteria used in establishing the system boundaries usually dictate the degree of confidence in ensuring that the results of the study have not been compromised and that the goal of a given study will be met. Moreover, in many cases there is a need to refine the boundaries because of the outcome of the preliminary work (EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

Several life cycle stages, unit processes and flows should be taken into consideration, when defining the initial system boundaries, e.g.:

- Inputs and outputs in the main manufacturing/processing sequence;
- Distribution/transportation;
- Production and use of fuels, electricity and heat;
- Use and maintenance of products;
- Disposal of process waste and products;
- Recovery of used products (including reuse, recycling and energy recovery);
- Manufacture of ancillary materials;
- Manufacture, maintenance and decommissioning of a capital equipment;
- Additional operations, such as lighting and heating (EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

As for the criteria concerning the initial inclusion of inputs and outputs, it is often not practical to model every input and output into the product system. It is an iterative process to identify the inputs and outputs which should be traced to the environment, i.e. to identify which unit processes producing the inputs or which unit processes receiving the outputs should be included in the product system under the study (EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

As the ISO 14044 suggest, one should use the following criteria of inclusion of the inputs and outputs:

- Mass: the inclusion in the study of all inputs that cumulatively contribute more than a defined percentage to the mass input of the product system being modelled;
- Energy: the inclusion in the study those inputs that cumulatively contribute more than a defined percentage of the product system's energy inputs;
- Environmental relevance: including the inputs that contribute more than an additional defined percentage to the estimated quantity of individual data category of the product system.

2.5.2.3 Data categories and data quality requirements

In the LCA studies, various data sources may be used for the assessment. Data may be collected from the production sites associated with the unit processes (within a system boundary), or it may

be obtained or calculated from existing databases or other published sources. Thus, one obtains the mixture of measured, calculated, or estimated data, where reliability and quality has to be assessed (EN ISO 14040:1997(E), EN ISO 14040:2006(E)).

To estimate the quality of the calculation results, several data quality requirements should be specified. These requirements should address at least:

- Time-related coverage: the desired age of data (e.g. within the last five years) and the minimum length of time (e.g. one year) over which data should be collected;
- Geographical coverage: geographical area from which data for the unit processes should be collected to satisfy the goal of the study (e.g. local, regional, national, continental, global);
- Technology coverage: technology mix (e.g. weighted average of the actual process mix, best available technology or worst operating unit) (EN ISO 14040:1997(E), EN ISO 14040:2006(E), EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

ISO standards specify also other parameters (like i.e. precision, completeness, representativeness, consistency and reproducibility) that may be used depending on the goal and scope. If the LCA study is used to support a comparative assertion that is disclosed to the public, above-mentioned data quality requirements shall be addressed.

2.5.2.4 Comparisons between systems and critical review

If the systems are compared in the LCA, the comparison shall be performed using the same functional unit and equivalent methodological considerations, such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluating inputs and outputs and impact assessment. If any difference between the compared systems occurs, it should be identified and reported. For the results, which are disclosed to the public, a critical review process needs to be carried out. Furthermore, impact assessment shall be performed (EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

2.5.3 Inventory analysis

2.5.3.1 Introduction

Inventory analysis is a very crucial step in the LCA study. During this phase, the data for the LCA modelling are collected and calculated, when necessary. All relevant inputs and outputs of the product system are identified. As the ISO 14040 standard reveals, these inputs and outputs may

include the use of resources and releases to air, water and land associated with the system. Interpretations may be drawn from these data, depending on the goals and scope of the LCA. These data also constitute the input to the life cycle impact assessment.

One has to mention the iterative character of conducting the LCI. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures, so that the goals of the study will still be met. Sometimes, issues may be identified that require revisions to the goal or scope of the study (ISO 14040:1997(E)).

Procedures for data collection and adaptation vary according to the scope, unit process or intended application of the study. Since data collection can be a resource-intensive process, practical constraints on data collection should be considered in the scope and documented in the study report (EN ISO 14040:1997(E), EN ISO 14040:2006(E), EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

2.5.3.2 Components of the Life Cycle Inventory

In the LCA, one has to make a distinction between product system, and the unit process. This should facilitate the identification of the inputs and outputs, the overall understanding and the transparency of the modelling.

According to the ISO 14041, a product system is a collection of unit processes connected by flows of intermediate products, which perform one, or more defined functions (fig. 2.5). A product system description includes unit processes, elementary flows, and product flows across the system boundaries (either into the system or out of the system), and intermediate product flows within the system. A distinction has to be made between the meaning of the system with respect to the LCA study (production and use of some product), and a system in the meaning of an entire matrix, in which the enterprise functions (sensitivity analysis in the SMPV).

Unit processes comprise the essential parts of the product system (fig. 2.6). They are linked to each another by flows of intermediate products and/or waste for treatment, to other product systems by product flows, and to the environment by elementary flows (EN ISO 14041:1998(E)).

One has to remember, that the product system is a physical system, therefore each of its units has to obey the physical laws, such as law of conservation of mass and energy. As the standard suggests, mass and energy balances provide a useful check on the validity of a unit process description.

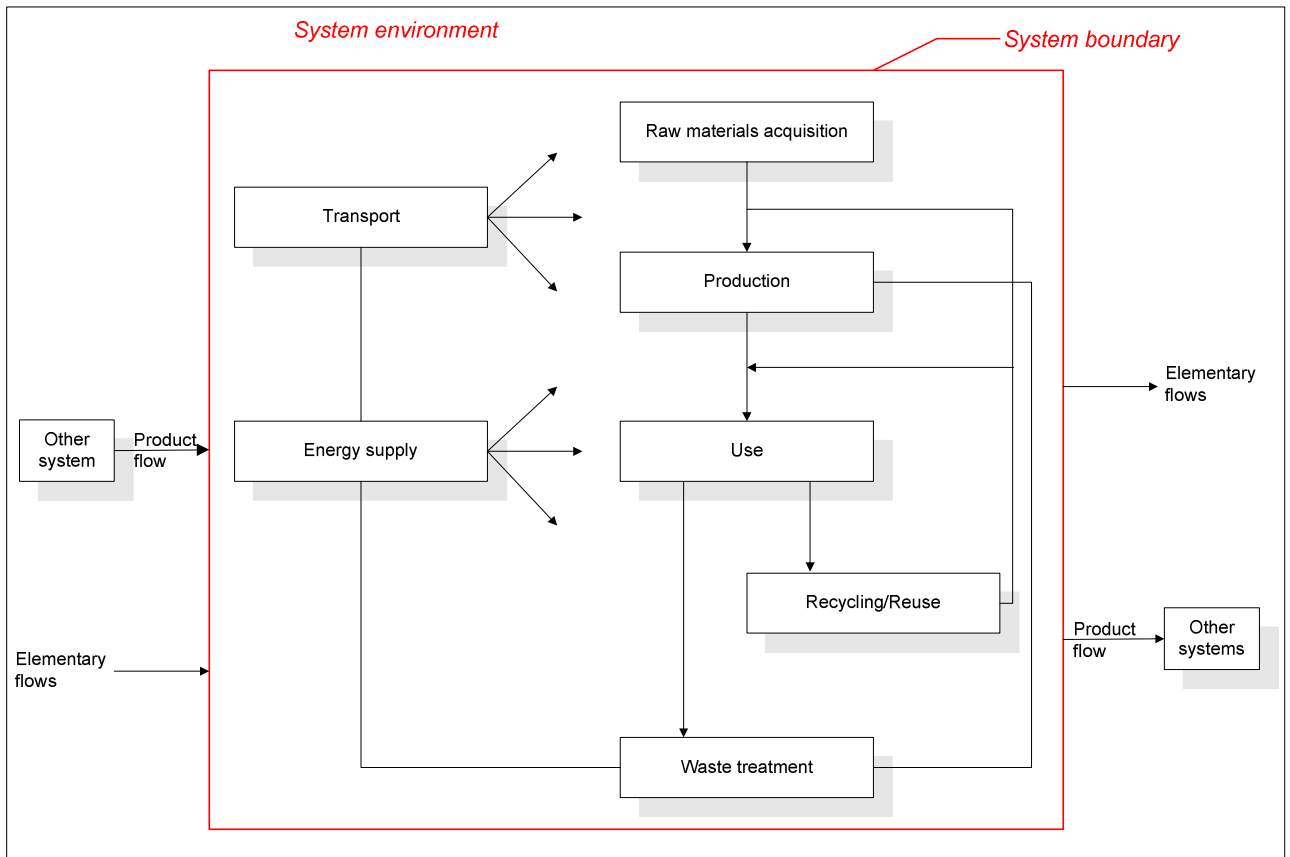


Figure 2.5 Example of a product system for life cycle inventory analysis. Source: EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

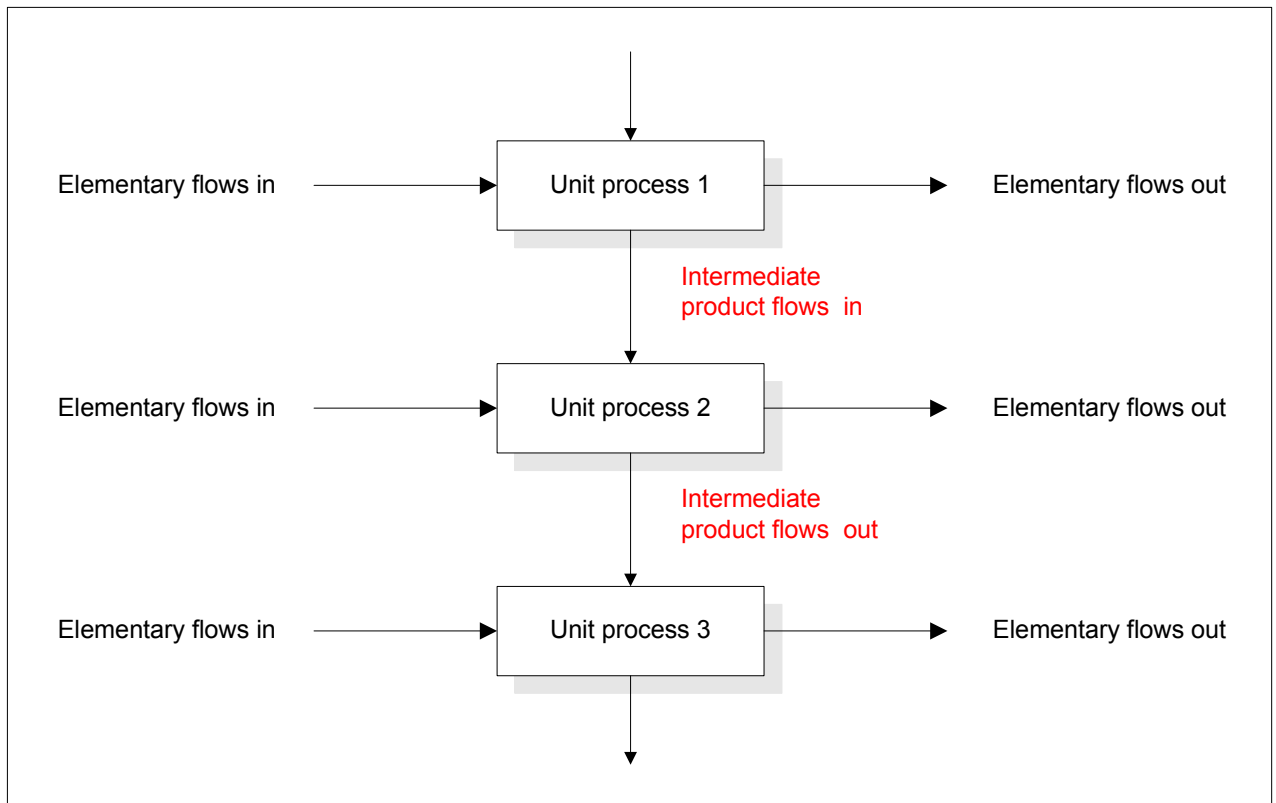


Figure 2.6 Example of a set of unit processes within a product system. Source: EN ISO 14041:1998(E).

The data collected in the Life Cycle Inventory stage (either measured, calculated, or estimated) may be divided into categories and subcategories in a way that allows meeting the goal and scope of the study. They are used afterwards to quantify the inputs and outputs of a unit process. The main data categories are:

- Energy inputs, raw material inputs, ancillary inputs, other physical inputs;
- Products;
- Emissions to air, emissions to water, emissions to land, other environmental aspects (EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

Fig. 2.7 summarizes the detailed procedure of the Life Cycle Inventory. The key elements of physical systems shall be described and modelled. If it is impossible to study all relationships between the unit processes and the product system, or all the relationships between a product system and the system environment, one has to choose the elements to be modelled depending on the goal and the scope of the study (EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

2.5.4 Life Cycle Impact Assessment

2.5.4.1 Introduction

The Life Cycle Impact Assessment (LCIA) is the third phase of the LCA. Its main aim is to evaluate the significance of potential environmental impacts using the results of the life cycle inventory analysis. This process involves associating inventory data with specific environmental impacts and attempts to understand those impacts. The goal is achieved by modelling the selected environmental impact categories, with the help of category indicators to condense and explain the LCI results. This process has an iterative character and depends on the goal and scope definition. In addition, the LCIA prepares the background for the life cycle interpretation phase (EN ISO 14040:1997(E), EN ISO 14040:2006(E), EN ISO 14041:1998(E), EN ISO 14044:2006(E)).

As the ISO 14042 specifies, the LCIA provides a system-wide perspective of environmental and resource issues. At this stage, the LCI results are assigned to impact categories. The final results are presented with respect to the assumed functional unit.

The detailed description of the LCIA phases is given in the following sections. One has to mention the subjectivity of the choices and input data modification due to the calculation procedures and errors. In order to avoid any misunderstandings, all the choices and calculation procedures shall be documented duly.

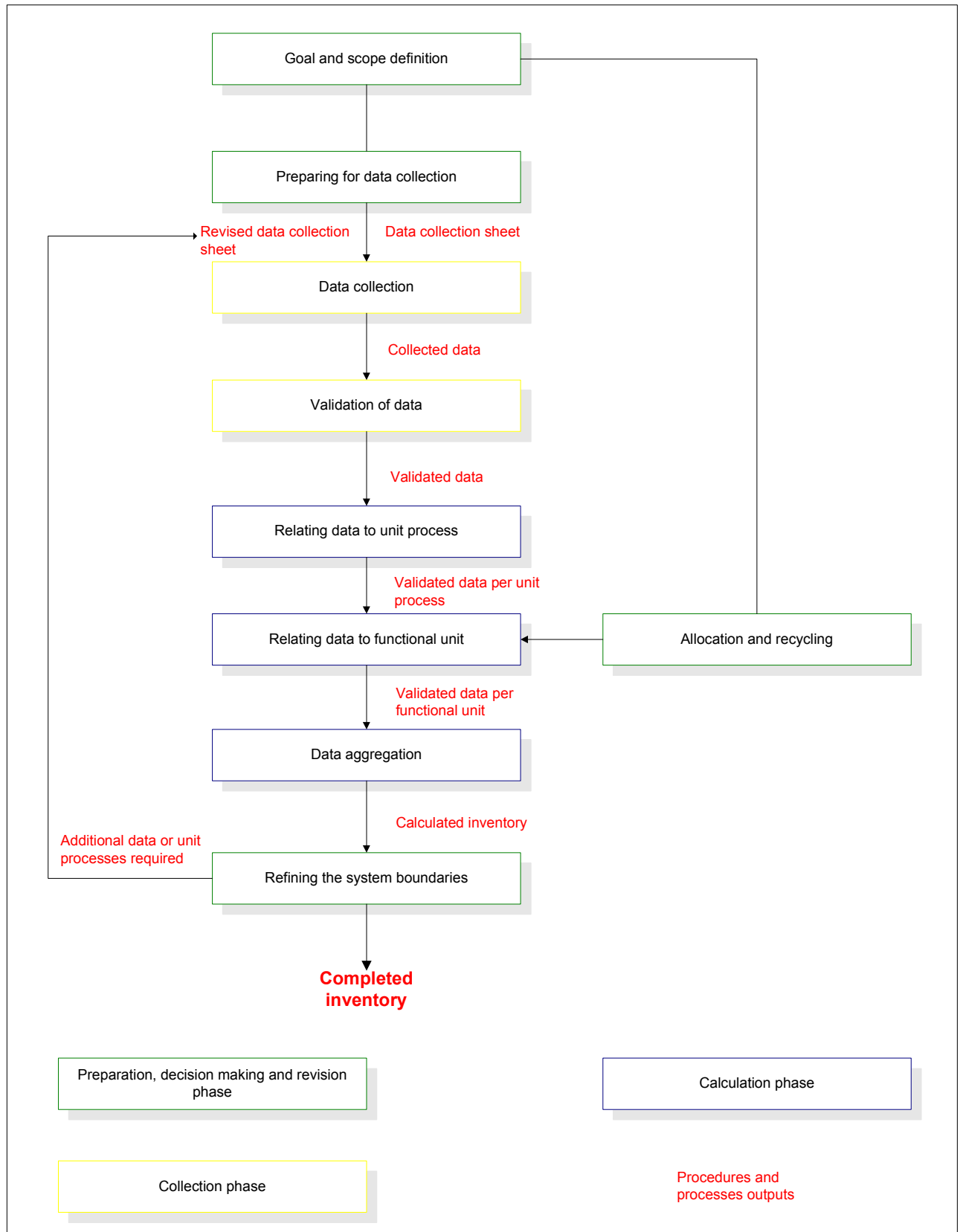


Figure 2.7 Simplified procedures for inventory analysis. Some iterative steps are not shown. Source: EN ISO 14041:1998(E), EN ISO 14044:2006(E), modified.

2.5.4.2 Elements of the LCIA

The LCIA is subdivided into several mandatory and optional steps (figure 2.8), which convert the LCI results into category indicators. Such a division is necessary for the several reasons. For example, it allows to distinct and to define clearly each element or conduct a quality assessment of the LCIA methods. Furthermore, this division facilitates transparency within each element of the LCIA procedures, assumptions, and other operations for a critical review and reporting purposes (ISO 14042:2000(E)).

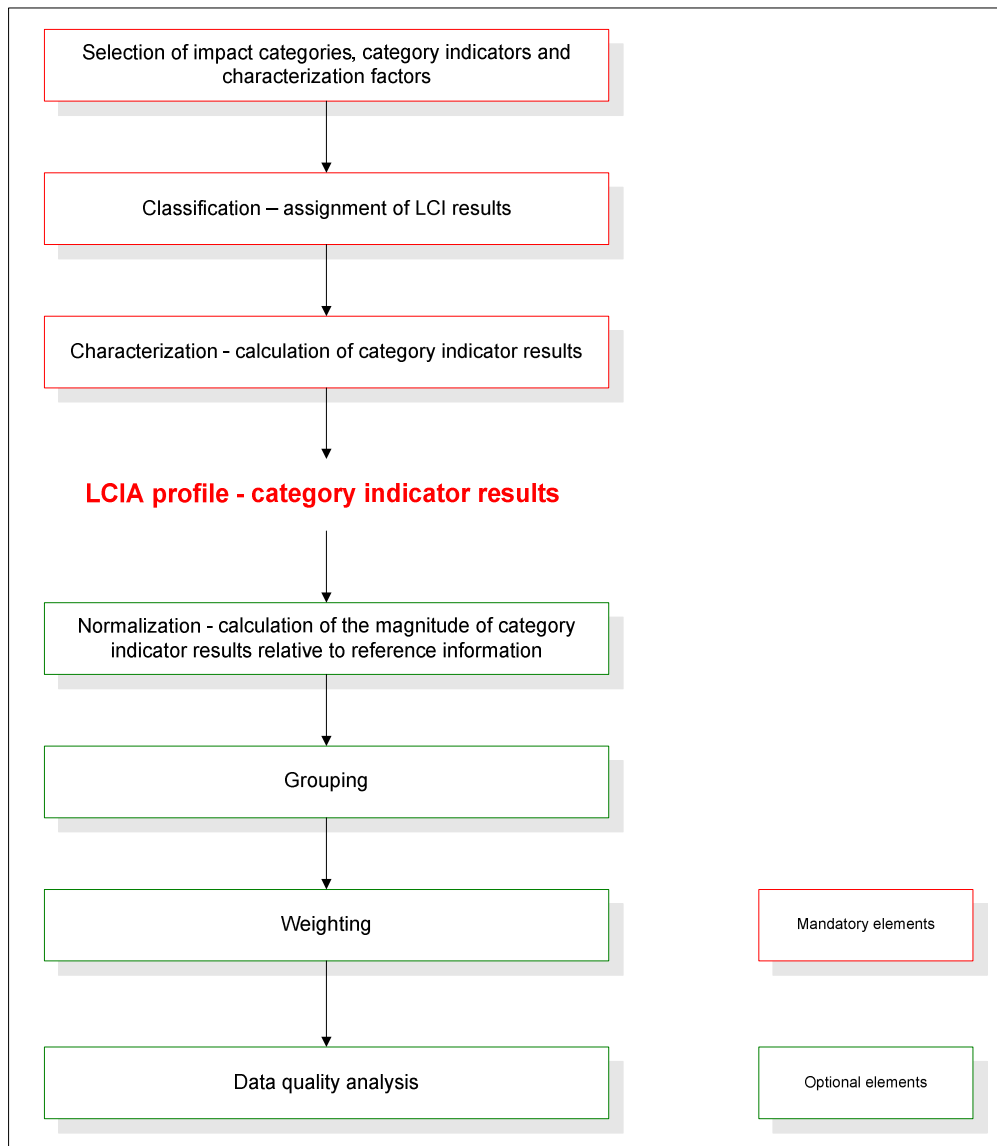


Figure 2.8 Elements of the LCIA phase. Source: ISO 14042:2000(E), modified.

The ISO standards 14042 and 14044 recognize the following mandatory elements:

- Selection of impact categories, category indicators and characterization models;
- Assignment of the LCI results (classification) to the impact categories;

- Calculation of category indicator results (characterization); category indicator results represent for different impact categories the LCIA profile, which is used in the subsequent steps of the LCA modelling.

According to the standards, following elements are optional:

- Calculating the magnitude of category indicator results relative to reference information (normalization);
- Grouping: sorting and possibly ranking of the impact categories;
- Weighting: converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices;
- Data quality analysis.

The detailed description of the mandatory and optional elements is given in the following sections.

2.5.4.3 Mandatory elements

The first step in the LCIA is selection of existing impact categories, category indicators or characterization models. All information concerning the process of selection shall be referenced. In some cases, there is a need to define new impact categories, category indicators, and characterization models, in order to fulfil the goal and scope of the study. As the ISO 14042 and 14044 specify, the category indicator can be chosen anywhere along the environmental mechanism between the LCI results and the category endpoint(s).

Especially important for the understanding of the LCIA results is the concept of the category indicators. These are values being the outcome of the calculations made during the mandatory stages of the LCIA, calculated for different impact categories. The calculations are based on various specific environmental mechanisms. Fig. 2.9 presents an example for the calculation of an impact category when an acidification is taken into consideration.

The LCA modelling software (i.e. SimaPro) selects impact categories, category indicators and characterization models semi-automatically. Therefore, detailed procedure of selection, requirements and recommendations will not be presented here. The ISO standard, however, provide a sound basis for manual selection, if necessary.

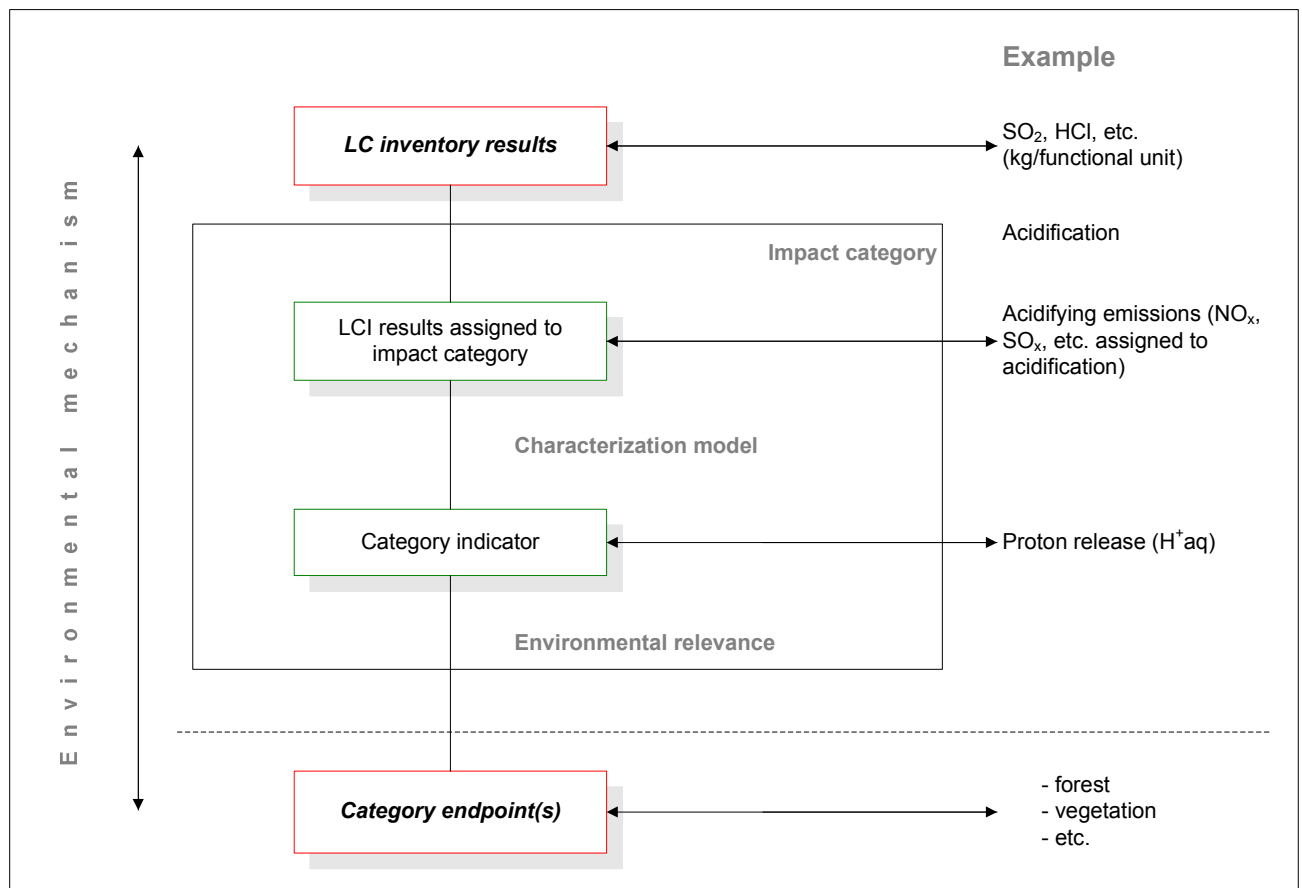


Figure 2.9 Concept of category indicators. Source: EN ISO 14042:2000(E), EN ISO 14044:2006(E).

The fate and transport of the substances shall be part of the characterization model. Moreover, the LCI results other than mass and energy flow data included in an LCA study shall be identified and their relationship to corresponding category indicators shall be determined. Also clear statements for the environmental relevance of the category indicator or characterization model should be made (EN ISO 14042:2000(E), EN ISO 14044:2006(E)).

Classification procedure is based on the assignment of the LCI results to the impact category, originating in scientific knowledge. In this LCIA step, environmental issues related to the LCI can be highlighted. The process should consider:

- Assignment of the LCI results which are exclusive to one impact category;
- Identification of the LCI results which relate to more than one impact category;
- Distinction between parallel environmental mechanisms (i.e. allocation of SO₂ between the impact categories of human health and acidification);
- Allocation among serial mechanisms (i.e. assignment of NO_x to both ground-level ozone formation and acidification) (EN ISO 14042:2000(E), EN ISO 14044:2006(E)).

In characterization step, the calculation of category indicator results takes place. It involves the conversion of the LCI results to common units and the aggregation of the converted results within the impact category. This conversion uses scientifically determined characterization factors, and its outcome is a numerical indicator result (EN ISO 14042:2000(E), EN ISO 14044:2006(E)).

The LCA practitioner should explain every method, simplification, assumption, and value-choice made. One has to mention a trade-off, which usually exists between simplicity and accuracy. As the standard underlines, the variation in the quality of category indicators among impact categories may influence the overall accuracy of the LCA study.

The results of the classification and characterization phases of the LCIA may be used for the non-mandatory elements of the LCA, namely normalization, grouping and weighting.

2.5.4.4 Optional elements

Normalization denotes a calculation of the magnitude of the category indicator results relative to reference information. Its aim is to facilitate the understanding of the relative magnitude for each indicator result of the product system under study. According to the ISO 14042, calculating the magnitude of indicator results relative to reference information may be helpful for:

- Checking for inconsistencies;
- Providing and communicating information on the relative significance of the indicator results;
- Preparing for additional procedures, such as grouping, weighting, or a life cycle interpretation.

In the normalization phase, an indicator result is divided by a selected reference value. This value can be for example the total emissions or resource use for a given area (global, regional, national or local), the total emissions or resource use for a given area on a per capita basis or similar measurement, or a baseline scenario (such as a given alternative product system). The selection of the reference system should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value (EN ISO 14042:2000(E), EN ISO 14044:2006(E)).

As the outcome of the normalization phase, one obtains a collection of normalized indicator results, which represent a normalized LCIA profile. In order to obtain most credible results, the ISO 14042

suggest to perform a sensitivity analysis and to use several reference systems for the normalization purposes.

Grouping phase involves sorting and/or ranking of the results obtained in the previous phases of the LCIA into predefined sets. This value-based sorting may be done on a nominal basis (e.g. by characteristics such as emissions and resources or global, regional, and local spatial scales), or in a given hierarchy of impact categories (i.e. high, medium, and low priority).

Since grouping is based on the value choices, the LCA practitioners may obtain different results, even if they are using the same (normalized) indicator results. In order to avoid misunderstandings, grouping shall be consistent with the goal and scope, as well as it shall be fully transparent (EN ISO 14042:2000(E), EN ISO 14044:2006(E)).

In the weighting process, indicator results of different impact categories are converted with the help of numerical factors based on the value-choices. The aggregation of the weighted indicator results may follow. Two possible procedures are used for the weighting:

- Converting the indicator results or normalized results with selected weighting factors;
- Aggregating these converted indicator results or normalized results across impact categories (EN ISO 14042:2000(E), EN ISO 14044:2006(E)).

The ISO standards require the consistency of weighting procedure with the goal and scope definition, as well as full transparency of the value-choices, assumptions and limitations made. Similarly, the results of the different LCA practitioners may vary depending on the value-choices made, even if the same (normalized) indicator results are being used. In order to get complete and credible results, sensitivity analysis is suggested, including the use of different weighting factors and weighting methods.

The last optional LCIA step, the data quality analysis, helps an LCA practitioner to understand better the significance, uncertainty and sensitivity of the LCIA results. The purpose of the data quality analysis is to help distinguish if significant differences are or are not present, to remove the negligible LCI results, and guide the iterative LCIA process, if necessary. As the ISO 14042 emphasizes, the need for and choice of techniques depend upon the accuracy and detail needed to fulfil the goal and scope of the LCA study. Moreover, due to the iterative procedure of LCA, the result of the data quality analysis may further guide the LCI phase, e.g. refining cut-off criteria or collecting the additional data.

Table 2.3 presents the specific techniques of the data quality analysis and their purposes.

Table 2.3 Techniques and purposes of the data quality analysis according to ISO 14042/14044 standards.

Technique	Description
Gravity analysis	Statistical procedure, which identifies those data having the greatest contribution to the indicator result. These items may then be investigated with increased priority to ensure that sound decisions are made.
Uncertainty analysis	Description of the statistical variability in data sets in order to determine if indicator results from the same impact category are significantly different from each other.
Sensitivity analysis	Measuring of the extent to which changes, e.g. in the LCI results, characterization models, etc., influence the indicator results. Likewise, the extent to which modifications in the calculation procedures influence the LCIA profile can be examined.

2.5.4.5 Limitations, reporting and comparative assertions

The LCIA is a scientific process that possesses some restrictions and limitations. One has to mention such limitations, as i.e.:

- The use of value-based choices in mandatory and optional steps of the LCIA;
- Exclusion of spatial, temporal, threshold and dose-response information, and combination of emissions or activities over space and/or time;
- Variation of category indicators in precision among impact categories, due to differences:
 - Between the characterization model and the corresponding environmental mechanism, e.g. spatial and temporal scales,
 - In the use of simplifying assumptions,
 - Within available scientific knowledge;
- The LCIA results do not predict impacts on category endpoints, exceeding of thresholds, safety margins or risks (ISO 14042:2000(E)).

The ISO 14042 and 14044 describe in detail some additional requirements for LCAs being disclosed to the public, especially in the form of comparative assertions. Such LCA studies should i.e. use category indicators that are be internationally accepted, scientifically and technically valid (i.e. using a distinct identifiable environmental mechanism and/or reproducible empirical observation), and environmentally relevant (i.e. have sufficiently clear links to the category endpoint(s) including, but not limited to, spatial and temporal characteristics). In addition, the requirements for reporting of such studies are set. Since the LCA study is made for the purposes of scientific thesis, the reporting of the results will be made in chapter 4 according to scientific requirements.

2.5.5 Interpretation

The interpretation phase is the last step of the LCA covered by the ISO 14040 family standards. In this step, findings from the inventory analysis and the impact assessment are combined together, consistent with the defined goal and scope in order to analyse results, reach conclusions, explain limitations and provide recommendations. Decision makers may further use these conclusions and recommendations. The life cycle interpretation is intended to provide a readily understandable, complete and consistent presentation of the results of an LCA or an LCI study. The ISO 14040 mentions the iterative character of the interpretation phase. In some cases, its main findings may be used to revise goal and scope definition, and subsequently make changes in the inventory analysis and the LCIA steps (fig. 2.10).

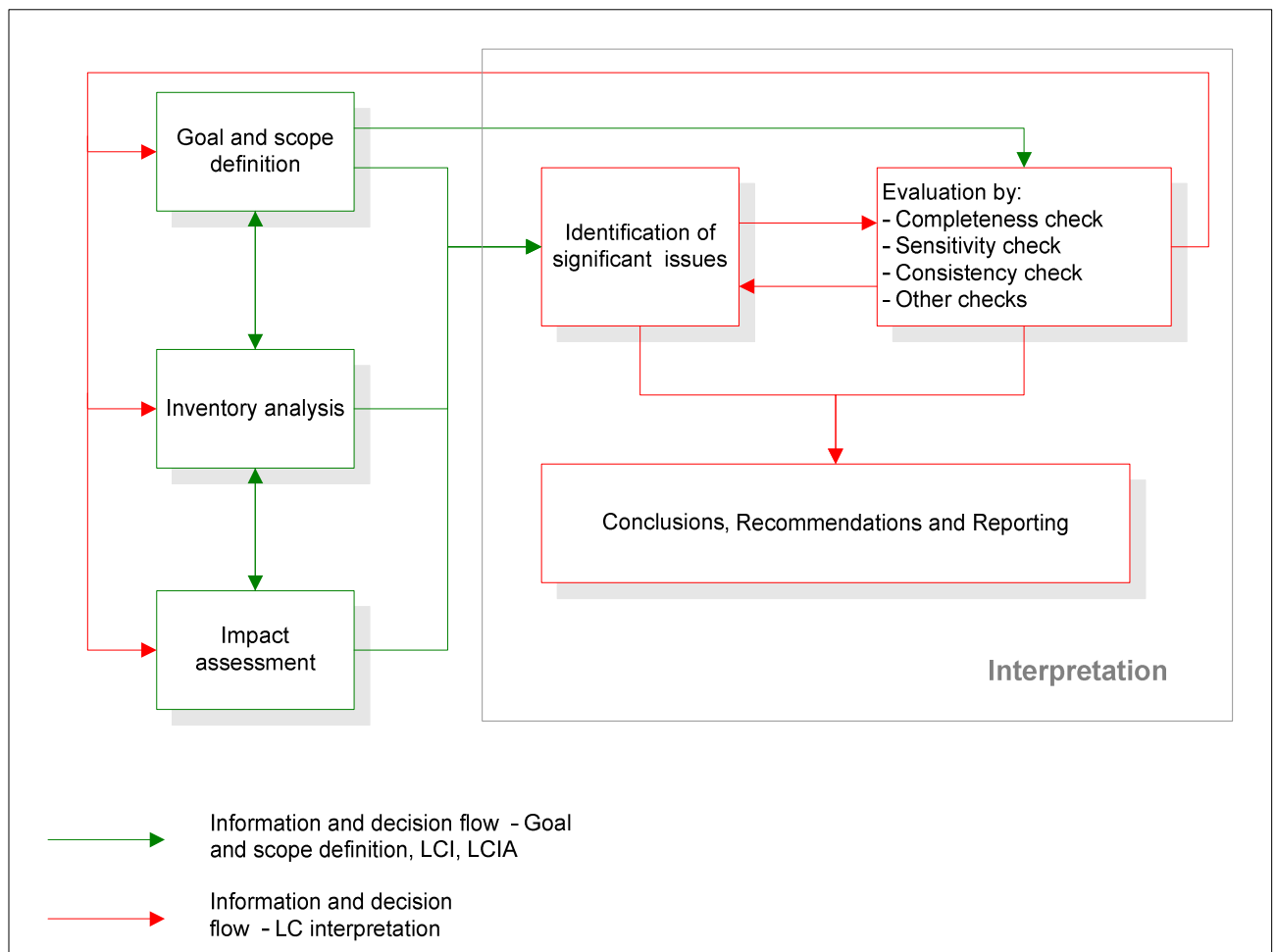


Figure 2.10 Relationships of the elements within the interpretation phase with the other phases of LCA. Source: ISO 14043:2000(E), modified.

The process of the life cycle interpretation may be divided into three main units: identification of the significant issues (based on the LCI and LCIA results); evaluation (considering completeness,

sensitivity and consistency checks); and finally conclusions, recommendations and reporting. All these subunits of the life cycle interpretation are described in detail in the ISO standards.

Table 2.4 presents the most important characteristics of the evaluation techniques.

Table 2.4 Evaluation techniques recommended by the ISO 14043 and 14044 standards. Source: ISO 14043:2000, EN ISO 14044:2006(E), modified.

Technique	Description
Completeness check	<ul style="list-style-type: none"> • Objective: to ensure that all relevant information and data needed for the interpretation are available and complete. • Describing the missing or incomplete information, or revising the preceding LCA phases.
Sensitivity check	<ul style="list-style-type: none"> • Objective: to assess the reliability of the results and conclusions by determining whether they are affected by uncertainties in the data, allocation methods or calculation of category indicator results, etc. • The assessment shall include the results of the sensitivity analysis and uncertainty analysis, if performed in the preceding phases (LCI, LCIA), and may indicate the need for further sensitivity analysis. • For the LCA used in comparative assertion that is disclosed to the public, the evaluation element shall include interpretative statements based on detailed sensitivity analysis.
Consistency check	<ul style="list-style-type: none"> • Objective: to determine whether the assumptions, methods and data are consistent with the goal and scope. • The following questions shall be addressed: <ul style="list-style-type: none"> - Are differences in data quality along a product system life cycle and between different product systems consistent with the goal and scope of the study? - Have the regional and/or temporal differences, if any, been consistently applied? - Have allocation rules and system boundaries been consistently applied to all product systems? - Have the elements of impact assessment been consistently applied?

2.5.6 Reporting

Creation of the LCA report finalizes the LCA project. In order to avoid misunderstandings, the results of the LCA shall be fairly, completely and accurately reported to the intended audience in accordance with the goal and scope definition provisions.

ISO standards call for additional elements with respect to the report, when the results are going to be used for a comparative assertion or communicated to the third party (regardless of the form of communication). In these cases, a third-party report has to be prepared, with the content specified in the standard.

2.5.7 Summary

Section 2.5 presented a detailed description of requirements set by the ISO 14040 family standards for carrying out the LCA studies. Many steps of the LCA are mandatory and have to be done strictly according to the standard, and some of them are voluntary. For all of them, the ISO 14040 standards show clear pathways of completing the environmental assessment. Use of the LCA-specific software, such as the SimaPro package, may greatly facilitate the entire process, by finishing of some steps semi-automatically. Nonetheless, understanding of the LCA process is necessary for any research, and the ISO 14040 standards describe the process in the best possible way. The question arises, how is this LCA research and process translated into the first European law dealing directly with cradle-to-grave approach? The next section will describe the Energy-using-Products directive and underline its importance for the company's functioning from the systemic point of view.

2.6 Energy using Products directive

2.6.1 Introduction

The “Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending the Council Directive 92/42/EEC and directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council” (further on referred to as “EuP directive”) has been adopted on the 6th of July 2005 and published on the 22nd of July 2005 in the Official Journal of the European Union. This directive becomes a very important milestone in the integration of the ecodesign requirements in the internal planning and developing of the new products and services.

The EuP directive sets up the ecodesign requirements for energy-using products offered on the internal market of the European Union by the manufacturers or the importers of the products. The directive is not applicable to means of transport for persons or goods.

According to the directive, member states shall ensure that the products introduced on the market will bear the “CE” marking (fig. 2.11) and will comply with the directive requirements. For these purposes, every member state should define the tasks, powers and organizational arrangements of the competent authorities. These authorities shall be responsible i.e. to take samples from the market and subject them to the compliance tests, to provide the necessary information to the producers and importers, or oblige the manufacturer to recall from the market the non-compliant EuPs. In the absence of the manufacturer, the importer practically bears all the responsibility.



Figure 2.11 CE marking.

Taking into consideration the specificity of the European Market, the EuP directive obliges the member states not to prohibit, restrict or impede placing on the market the products bearing the “CE” marking. However, in some situations, the products may fail to satisfy the requirements of the implementing measures, or the application of the harmonised standards can be incorrect or can show any shortcomings. In this case, the member states (depending on the gravity of the non-compliance) may oblige the EuP manufacturer to make necessary changes, even prohibit of the placing of the product on the market, or decide to withdraw the product form the market. In such cases, the other member states and the EU Commission shall be informed about such decisions.

Not every product is covered by the EuP directive. The criteria of inclusion are the following:

- The number of EuP sold on the EU internal market should be more than 200 000 units per year;
- The EuP shall have a significant environmental impact within the Community;
- The EuP shall present significant potential for improvement in terms of its environmental impact without entailing excessive costs, taking into account in particular the absence of relevant regulation or market self-regulating forces, or a wide disparity in the environmental performance of the EuPs available on the market with equivalent functionality.

All inclusion criteria are met by the products manufactured in Poland by the FagorMastercook.

Customers play also important role in the EuP directive. According to the directive, they should be informed about the role they can play in the sustainable use of the product, and in some cases even about ecological profile of the product and the benefits of the ecodesign.

The EuP directive should be seen only as a strict guideline for the implementation of the specific laws in the Member States, called implementing measures. It is important to mention, that the following criteria should be met by those measures:

- There shall be no significant negative impact on the functionality of the product, from the perspective of the user;
- Health, safety, and the environment shall not be adversely affected;

- There shall be no significant negative impact on the industry competitiveness;
- Setting the ecodesign requirements shall not have the consequence of imposing proprietary technologies on manufacturers;
- No excessive administrative burden shall be imposed on manufacturers.

The annexes to the EuP Directive provide more detailed knowledge of what should be done and assessed when considering the environmental impacts of the products. Table 2.5 presents the annexes and their content. More detailed description will be given in the next subchapters.

Table 2.5 Annexes of the EuP Directive and their content. Source: Directive 2005/32/EC.

Annex	Content
I	Specifies method for setting the Eco-design requirement
II	Deals with the method for setting specific ecodesign requirements
III	Presents CE marking
IV	Refers to the internal design control
V	Speaks about management system for assessing the EuP directive conformity
VI	Shows which elements must be included in the EC declaration of conformity
VII	Specifies the content of the implementing measures
VIII	Presents non-exhaustive list of indicative criteria that may be used for the evaluation of admissibility of self-regulating measures in the context of the directive

2.6.2 Method for setting the generic ecodesign requirements

Generic ecodesign requirements are supposed to set the overall targets in minimising the environmental impact of an EuP, without specifying the number values for these targets. According to the EuP directive, the significant environmental aspects related to the product life cycle phases shall be identified. As the Annex I specifies, the phases that should be covered are the following (fig. 2.12):

- Raw material selection and use;
- Manufacturing;
- Packaging, transport, and distribution;
- Installation and maintenance;
- Use;
- End-of-life (when the EuP is reaching its first use until it is disposed off).

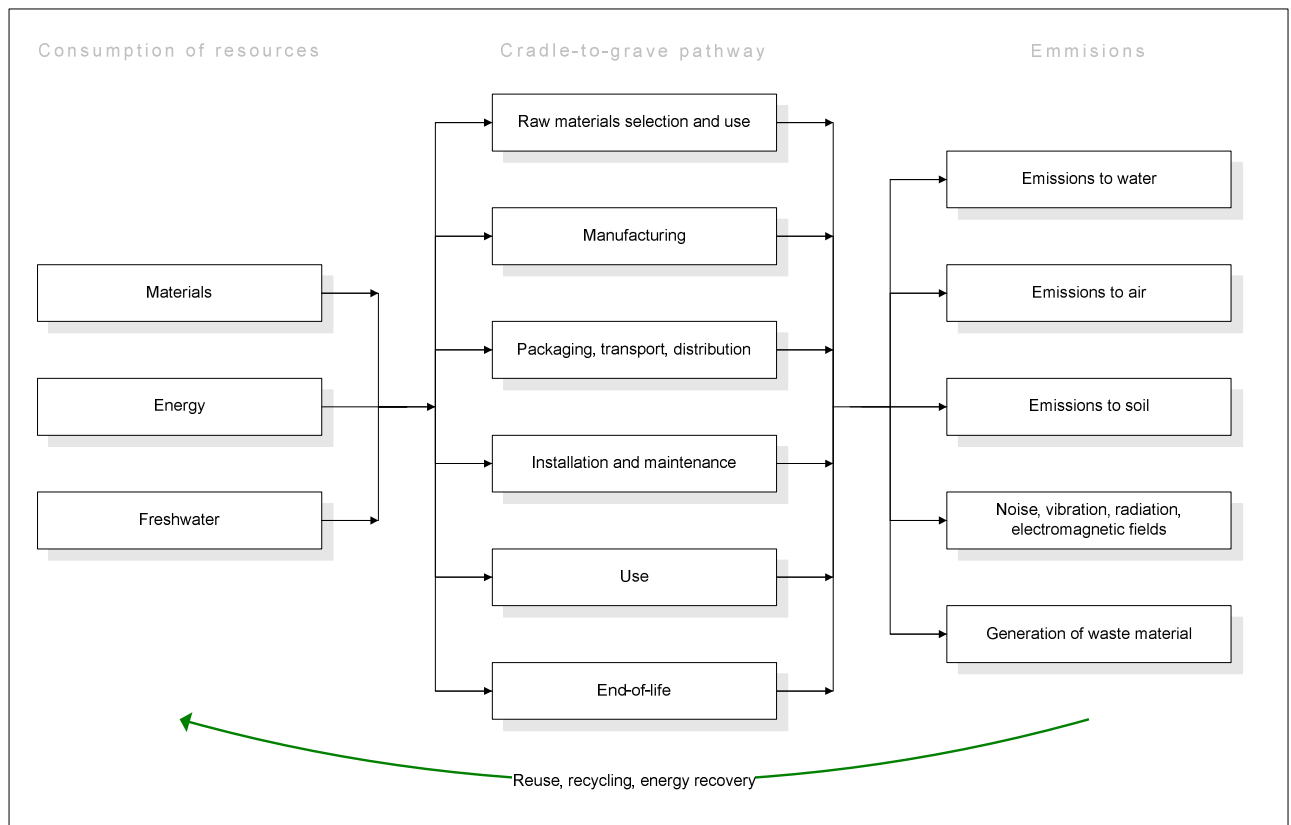


Figure 2.12 Life cycle phases and environmental aspects related to them, as mentioned in the EuP directive. Source: Directive 2005/32/EC, modified.

For each of the life cycle phase, the designers should assess various environmental aspects, such as predicted consumption of resources (materials, energy, fresh water, etc.), anticipated emissions to water, air and soil, pollution through physical effects (i.e. noise, vibration, radiation, electromagnetic fields), expected generation of waste material, as well as possibilities for reuse, recycling, and recover of energy or materials. All these phases are covered in the LCA study and described in chapter 3 and 4.

The EuP directive also specifies which parameters shall be used for evaluating the potential for improving the environmental aspects mentioned in the previous paragraph. The LCA practitioners and decision makers shall concentrate on:

- Weight and volume of the product;
- Use of materials issued from the recycling activities;
- Consumption of resources throughout the life cycle;
- Use of hazardous and dangerous materials;
- Quantity and nature of consumables needed for proper use and maintenance;
- Ease for reuse and recycle;

- Incorporation of used components;
- Avoidance of technical solutions detrimental to reuse and recycling of product or its parts;
- Extension of lifetime;
- Amounts of waste and hazardous waste generated;
- Emissions to air, water, and soil.

The manufacturer should supply all information, that may influence the way the product is handled, used, or recycled by parties other than manufacturer. The information may include i.e. information from the designer relating to the manufacturing process or information for treatment facility concerning disassembly, recycling, or disposal at the end-of-life.

An important target group for the information are consumers. They should be informed about significant environmental characteristics of the product, accompanying the product when it is placed on the market. Consumers can use this information as a basis for comparison with other products' characteristics. Another type of information for customers relates to the proper installation and maintenance of the product, aiming at minimisation of the impacts on the environment, and ensuring an optimal life expectancy. The customers shall also be informed, how to return the product at the end-of-life, as well as what is the period of availability of spare parts and which possibilities of upgrading are available.

The responsibility to perform an LCA assessment is given to the manufacturer. This assessment shall be based upon realistic assumptions about normal conditions and purposes of use. The environmental aspects identified as being capable to be influenced in a substantial manner through product design, shall be addressed. Based on the assessment, an ecological profile shall be established. Manufacturers are also obliged to evaluate alternative design solutions and the achieved environmental performance of the product against benchmarks identified by the European Commission. Since the EuP studies for cookers are not well established, such benchmarks are not available yet. Thus, the LCA performed and described in detail in chapter 4 may be seen as unique one.

2.6.3 Specific ecodesign requirements

In some cases, the specific ecodesign requirements (taking a form of i.e. limit on the use of a specific resource in the given life cycle phase) may be implemented. In such case, the procedure presented in fig. 2.13 shall be applied. Setting the specific requirement aims at improving a selected

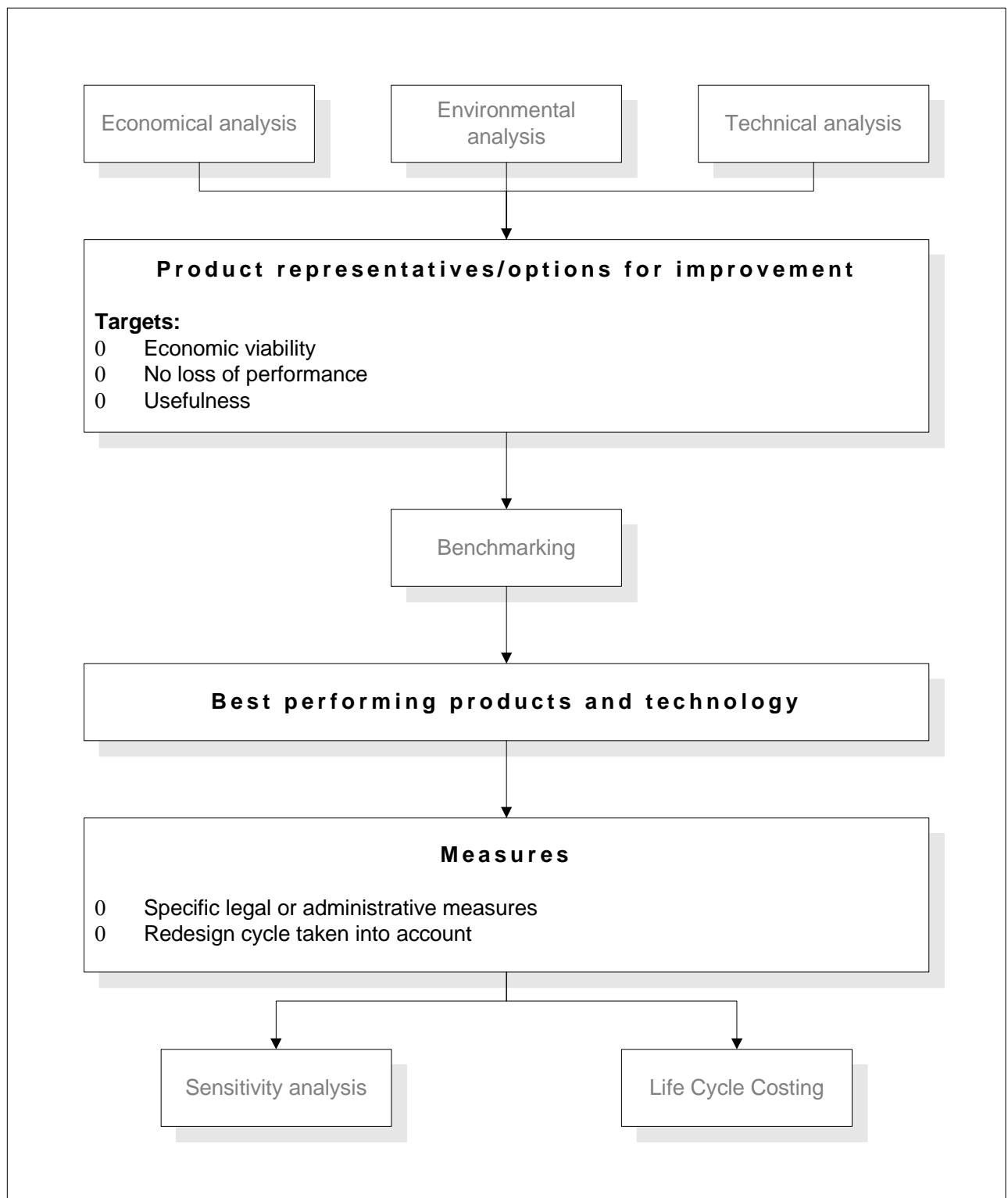


Figure 2.13 Procedure to establish the specific ecodesign requirement according to EuP directive. Source: Directive 2005/32/EC, modified.

environmental aspect of a product. As one can see, taking into consideration economical, environmental and technical aspects is necessary; these aspects will be incorporated in the sensitivity analysis study (chapter 5).

In first step of the above-mentioned analysis, one should select a number of product representatives and identify the technical options for improvement, taking into consideration economic viability and avoidance of significant loss of performance or usefulness of a product. This analysis should identify the best performing products and technology available on the market. The comparison with European markets and legal benchmarks set in other countries should be also taken into consideration.

On the basis on the analysis, the concrete measures shall be taken. A life-cycle costing and the sensitivity analysis with respect to price of energy or resources, the cost of raw materials, discount rates, etc. should be also performed. The implementation of the specific requirements should take into account the redesign cycle for the product (Directive 2005/32/EC).

2.6.4 Internal design control

Annex IV gives an insight into the procedure applied by the manufacturer or its authorised representative when ensuring and declaring, that the EuP satisfies the requirements of the implementing measure. The manufacturer must keep a technical documentation file, which should consist of all crucial documentation, including i.e.:

- General description and intended use of an EuP;
- The results of relevant environmental assessment studies or references to the literature or case studies, which were used by the manufacturer in evaluating, documenting, and determining product design solutions;
- The ecological profile, if necessary;
- Elements of the product design specification relating to environmental design aspect of a product;
- List of the European harmonised standards applied in full or in part, and description of solutions adopted to meet their requirements;
- A copy of information prepared for the consumers, or third-party treatment or repair facility, in accordance to Annex I Part 2 (Supply of information) in the EuP directive;
- The results of measurements on the ecodesign requirements carried out, including the necessary details about conformity of these measurements with the applicable implementing measures (Directive 2005/32/EC).

As Annex IV of the EuP Directive specifies, it is the responsibility of the manufacturer to ensure, that the products are manufactured in compliance with the design specifications and the requirements of the measure, which apply to it.

2.6.5 Management systems for assessing the conformity

Annex V of the Directive underlines the role of incorporation of the EuP directive rules into company's management system. The management system may be used for the conformity assessment with the directive. As a prerequisite, the system has to contain the following environmental elements: the environmental product performance policy, planning, implementation and documentation, and checking and corrective action.

The environmental product performance policy aims at providing a framework for setting and reviewing environmental product performance objectives and indicators with a view to improving the overall environmental product performance. All measures undertaken to achieve this goal have to be documented in a systematic and orderly manner in the form of written procedures and instructions.

The planning part of the management system requires establishing and maintaining procedures for creating the ecological profile of the product, environmental product performance and indicators (taking into consideration technical and economic requirements), as well as a programme for achieving these objectives.

Implementation and documentation must clearly define the responsibilities and authorities in order to ensure effective environmental product performance and reporting on its operation for review and improvement. Documents need to indicate the design control and verification techniques implemented, as well as processes and systematic measures used when designing the product. The manufacturer is also responsible for establishing and describing the core environmental elements of the management system and the procedures for the controlling all documents required. Annex V of the EuP directive specifies, which documents relating to the EuP shall be created and maintained in the framework of the managements system.

Checking and corrective action consists the crucial part of the EMS. The EuP directive requires the manufacturer to take all measures necessary to ensure that the EuP is manufactured in compliance with its design specification and with the requirements of the implementing measure. The procedures of investigation and respond to the non-conformity play a significant role in the process, together with the implementation of changes in the documented procedures resulting from the

corrective action. At least every three years manufacturer is obliged to carry out a full internal audit of the management system with regard to its environmental elements.

2.6.6 Contents of the implementing measures

The EuP directive needs to be translated into national laws in the Member states in the form of implementing measure. Annex VII may be seen as guidance for the lawmakers in the Member states when implementing the directive into national laws. It stresses the necessity to specify in the implementing measure some specific information, like i.e. exact definition of type or types of the products covered by those measures, or generic and specific ecodesign requirement.

2.6.7 Indicative criteria for assessing the admissibility of the self-regulating measures

In some case, self regulatory incentives of the industry may be more effective than setting the legal requirements. The directive presents in Annex VIII the non-exhaustive list of indicative criteria that may be used to evaluate the admissibility of the self-regulatory initiatives as an alternative to an implementing measure. Table 2.6 presents those criteria and their short description.

Table 2.6 Indicative criteria to assess the admissibility of the self-regulating initiatives. Source: Directive 2005/32/EC, modified.

Criterion	Description
Openness for participation	Openness for third-country operators in preparatory and implementation stages.
Added value	Delivery of added value in terms of improved overall environmental performance of the EuP.
Representativeness	Industry and associations taking part shall represent a large majority of the relevant economic sector, with ensuring the respect for competition rules.
Quantified and staged objectives	Setting clear and unambiguous objectives and indicators for the monitoring of the compliance and objectives in affordable and credible way.
Involvement of the civil society	Involvement either in a passive way for the sake of transparency as well as invitation to stakeholders to comment on self-regulatory measures.
Monitoring and reporting	A well-designed monitoring system, with clearly identified responsibilities. The plan of monitoring and reporting shall be presented.
Cost-effectiveness of administering a self-regulatory initiative	A disproportionate administrative burden should be avoided, as compared to the scope of the regulation and other available policy instruments.
Sustainability	Necessity to respond to the policy objectives of the directive, as well as consistency with the economic and social dimensions of the sustainable development; the protection of the consumers' interests.
Incentive compatibility	Consistency with policy in order to deliver the expected results and avoid sending the contradictory signals to participants in the commitment from other factors and incentives.

2.6.8 Summary

The EuP Directive sets requirements that are more general for performing the LCA studies than the ISO 14040 standards. At the same time, these requirements point out the actors and factors, that have to be taken into consideration when setting the binding laws. All these factors will be taken into consideration, when assessing the impact of implementing the LCA and the EuP directive for Polish enterprises in chapter 5.

2.7 Summary and conclusions – ISO standards and the EuP directive review

Chapter 2 presented theoretical background of the research. The requirements set by internationally recognized standards and laws are ranging from more generic ones (such as standards for the Environmental Management System or implementation of ecodesign in European countries), to very detailed ones (i.e. procedures to perform the LCA study according to the ISO 14040 standards). All these documents set up a basis for the research on the two levels of aggregation:

- Detailed LCA study of the gas-electro cooker produced in Poland;
- The assessment of the environmental performance of the company in the holistic approach towards environmental protection.

The next chapter will give some insight into the methodologies used for data collection, analysis, and software applied for these two steps of environmental assessment.

3. Procedures and methodology

3.1 Description of the company and the product

FagorMastercook S.A. is one of the most important producers of household appliances in Poland. The history of the company has originated in year 1946. During the communistic time, it was one of the most important enterprises of the Polish economy. After the democratic turnover in 1989, it managed to maintain the position of one of the biggest home appliance producers. In year 2006, the company has changed its name from Wrozamet S.A. to FagorMastercook S.A. This alteration reflected changes of ownership and the structure of the company. Table 3.1 presents the most important facts from the history of the enterprise.

Table 3.1 Summary of the historical development of the FagorMastercook company. Source: <http://www.wrozamet.pl> (accessed on 24.09.2006), modified.

Year	Event
1946	Company was established in place of former German "Cast Iron and Metal Foundry", previously called "K. Knauth" which was taken over by the state.
1976	The company took a new name – "PREDOM-WROZAMET" – the Heating Equipment Company. A company in Wąsosz was acquired as a out-of-town production department.
1988	Production of electric cookers was introduced.
1993 –	Various prizes and awards granted for the outstanding quality and innovative solutions (e.g. Domexpo 1993 – Golden Medal, Poland Now award in 1994, JEEN award in 1999).
1998	Introduction of the Quality Management System, in accordance with ISO 9001 standard.
IX 1999	Spanish companies: Fagor Electrodomesticos S. Coop. and MCC Inversiones S. Coop became a strategic investor of "Wrozamet" S.A.
2001	Introduction of an Integrated Quality and Environmental Management System in accordance with ISO 9001 and 14001 standards.
VII 2005	The signing of the final documents with the Government of the Republic of Poland, the City of Wrocław and the Walbrzych Special Economic Zone with regard to new investment projects to be carried out in Wrozamet in 2005-2008 (the construction of a new washing machine and refrigerator factory and the expansion of the cooker factory).

The scope of the FagorMastercook products ranges from washing machines, dishwasher, fridges, cooker hoods, and cookers to electric water heaters. All types of appliances are offered in the classical (freestanding) and integrated versions. The company is very well known and recognized

on the Polish market due to the high quality of products confirmed by certificates recognized worldwide and prestigious awards and medals.

In this study, the cooker KGE 3490X has been chosen for the modelling and research purposes (fig. 3.1). It consists of two main functional parts: a cooker plate (with four gas burners) on the top and an electric oven (for making cakes etc.).



Figure 3.1 Gas-electro cooker KGE 3490X. Courtesy of FagorMastercook S.A.

The following points shortly characterize the KGE 3490X:

- The outer material is mainly the stainless high alloy steel;
- Energy outputs of the burners: 1100W (one auxiliary burner), 2000W (two standard burners), 3100 W (one large burner);
- Automatic burner ignition units located in the burner knobs;
- 8-functional oven with hot air convection;
- Timer with an electrical steering unit;
- Grill with 2000 W output power inside the oven, connected with an additional circular grill spring;
- Maximum achievable inside temperature of 250°C;

- Oven dimensions: 330x375x425 mm (high x width x depth, respectively), 53 L of volume;
- Cooker dimensions: 850x500x600 mm (high x width x depth, respectively);
- Energetic class A; nominal power of 2.0 kW, 230V.

The aggregation of cooker's parts in subassemblies was based on the original data provided by the FagorMastercook company. According to this classification, the entire cooker (as produced and passed to the end consumer) consists of the following subassemblies:

- A Insulation;
- B Protective wiring harness;
- C Glass plate;
- D Control knobs;
- E Packaging;
- F Grill;
- G Side wall;
- H Electrical system screen;
- I Electrical chimney;
- J Door;
- K Drawer;
- L Black base;
- M Gas installation;
- N Ignition packet;
- O Trade fasteners;
- P Special fasteners;
- R Back wall;
- S Shelf;
- T Oven;
- U Nomenclature;
- V Decorative angle;
- W Equipment;

- Y Cleansing milk;
- Z Cardboard pad.

Capital letters at the beginning of subassembly group were added to make a better distinction between most important subassembly groups. Furthermore, every single part, process or group of processes received a number from 1 to 676 (i.e. 10. Austenitic steel ... kg). This special part/assembly/process number was helping the author when discussing the assumptions with the co-workers of the FagorMastercook company.

The original nomenclature of the company was used for the subassembly groups in order to facilitate in the future understanding of the modelling results for the FagorMastercook workers and decision makers.

Some of the subassembly groups mentioned above consisted of only few subassemblies, others included hundreds of parts and materials. That is why some of them were merged into one bigger subassembly group Q – “Other subassemblies”. Thanks to this integration, the results could be presented more clearly. The “Other subassemblies” group consisted of the following subassemblies:

- B Protective wiring harness;
- D Control knobs;
- F Grill;
- H Electrical system screen;
- I Electrical chimney;
- L Black base;
- N Ignition packet;
- O Trade fasteners;
- P Special fasteners;
- R Back wall;
- S Shelf;
- Y Cleansing milk;
- Z Cardboard pad.

Due to the confidentiality of the modelling input data, full list of all 676 subassemblies and materials may not be presented. Nonetheless, section 4.2 (Inventory analysis results) presents the most important materials and emissions taken into consideration in the modelling phase of the LCA.

3.2 Description of the SimaPro and the SMPV software

3.2.1 The SimaPro modelling package

3.2.1.1 Introduction

The SimaPro (current version 7.1.8, fig. 3.2) is one of the most powerful LCA packages available for the LCA practitioners on the market.

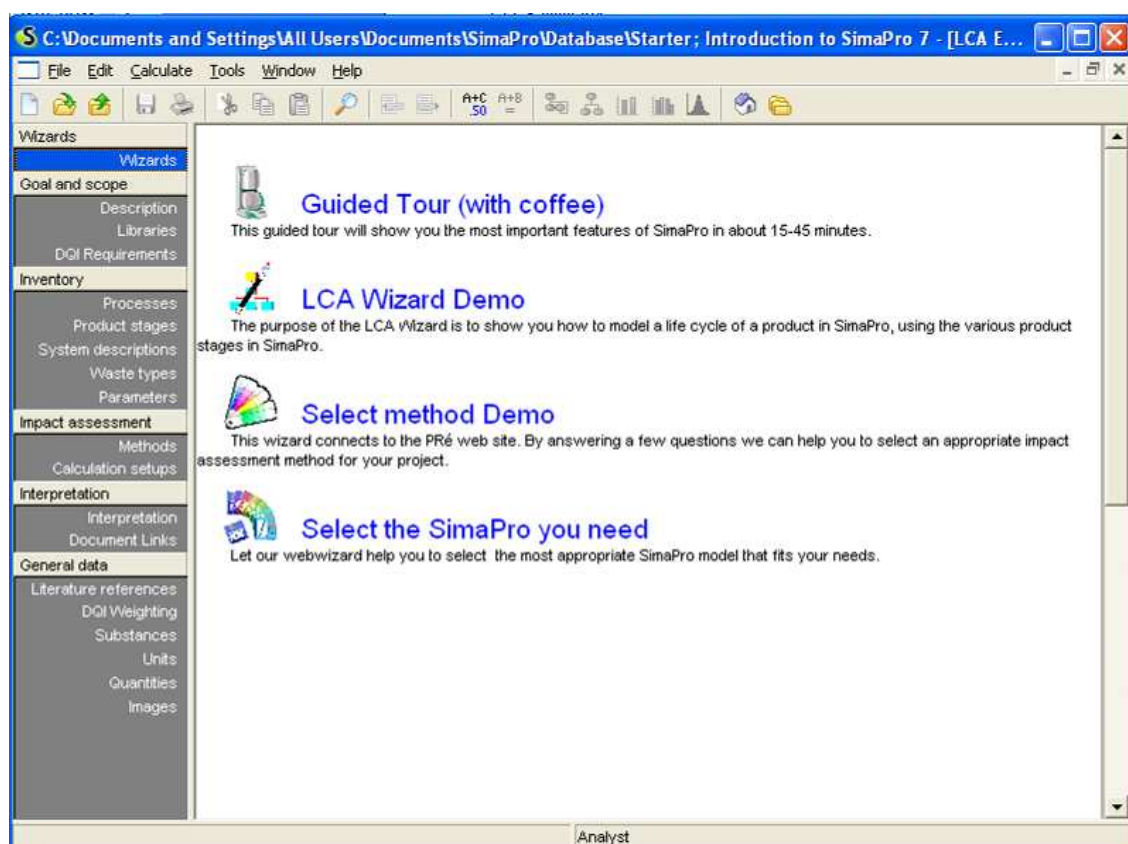


Figure 3.2 Main window in SimaPro.

The main advantages of the SimaPro in comparison to the other types of modelling software are the following:

- Easy to manage user interface, based on most commonly used Windows programmes;
- Organization of input process facilitating the obedience of the general LCA rules (including the ISO 14040 family standards);

- Inclusion of very helpful databases, i.e. BUWAL 250, DK Input Output Database, ETH ESU 96 System Processes and Unit Processes Databases, Franklin USA 98, IDEMAT 2001, Industry data, LCA Food DK, USA Input Output, as well “methods” database;
- Possibility of changing the content of methods and databases, according to the specific needs of the research;
- The SimaPro user may choose among various methods to evaluate the product or service, including CML 1992, CML 2 Baseline 2000, Cumulative Energy Demand, Eco-Indicator 95 and 99, Ecopoints 97, EDIP/UMIP, EPS 2000, Impact 2002+, IPCC 2001, and TRACI. Some of the databases are further subdivided according to different modelling factors and value-based choices used.

High variety of methods and large extent of databases may cause some problems in choice for the LCA practitioner. Therefore, the SimaPro offers a tool for categorization of data from databases, namely Data Quality Indicator (DQI, fig. 3.3). The program user may define the most desirable type of data for the modelling, classified according to time, geography, type, allocation and applied system boundaries. Afterwards, when deciding about choice of substance or process, a coloured bar informs user, whether the process or substance meets the established requirements.

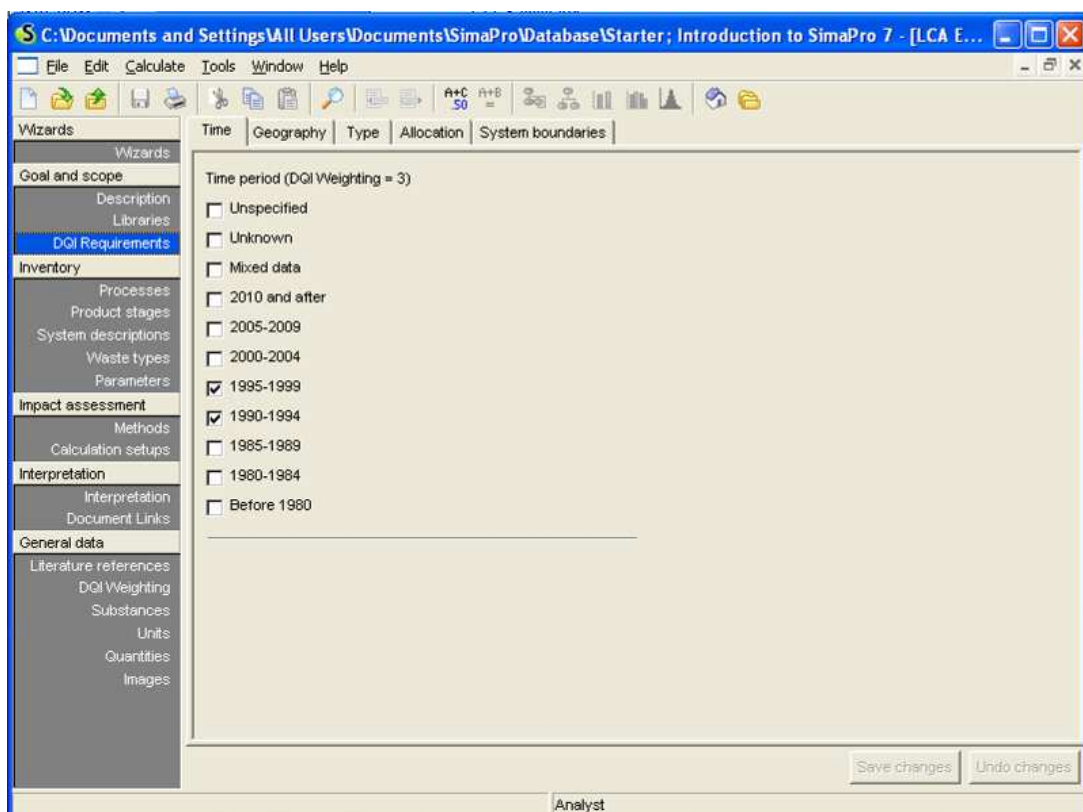


Figure 3.3 Selection of the DQI requirements in SimaPro.

3.2.1.2 Program components

The SimaPro programme is structured very logically and all functions are available intuitively. The menu on the top of the programme window resembles a typical user interface of Microsoft Windows platform. It allows performing actions assembled in the File, Edit, Calculate, Tools, Window, and Help menus. On the left side, additional navigation panel is placed. This navigational menu refers directly to the LCA action plan. At the same time, most important parameters can be viewed and changed there. Left side menu contains the following components:

- Wizards: with the help of pre-programmed wizard a simple LCA study may be performed;
- Goal and scope: the user generates the general description of the LCA study, as well as he chooses the data libraries used and sets the Data Quality Requirements (DQI);
- Inventory group consists of processes, product stages, system description, waste types, and parameters; during the LCA study, this is most often used part of the software;
- Impact assessment: here, various impact assessment methods may be viewed, changed, and created; additionally, calculation setups may be determined;
- Interpretation section allows summarizing the results and providing the document links;
- General Data section provides some useful information about literature references, the DQI weighting, substances, units, quantities and images.

3.2.1.3 Libraries and methods

The libraries and the methods consist the crucial part of the SimaPro. The libraries contain sample data collected mostly in the European countries. Table 3.1 presents most important features of the SimaPro libraries.

Table 3.2 Libraries incorporated in the SimaPro. Source: SimaPro libraries' description, Goedke *et al.* (2004), modified.

Library	Description
BUWAL250	Inventory of packaging materials for the Swiss Packaging Institute, made by the Empa (Swiss research institution). The inventory includes emissions from raw material production, energy production, production of semi-manufactures and auxiliary materials, transports and the production process of the materials. Energy systems are based on ETH (Swiss Federal Institute of Technology) data, without capital goods, plastics data are based on PWMI (PlasticsEurope Association) data.

Library	Description
DK Input Output Database	This Danish input output database is based on the Danish statistical data for 1999 (Danmarks Statistik 2003). A number of modifications/improvements have been made by the SimaPro developers to these basic data in order to make them more relevant for the LCA purposes (Weidema 2005).
ETH ESU System and Unit processes	Inventory data for Swiss and the Western European energy supply situation concerning production and imports of fossil fuels and production and trade of electricity, including emissions from primary energy extraction, refining and delivery, mineral resource extraction, raw material production, production of semi-manufactures, auxiliary and working materials, supply of transport and waste treatment services, the construction of infrastructures and energy conversion and transmission. The data cover the Swiss and Western European situation, and occurs in the form of the system (S) and unit (U) processes.
Franklin USA 98	Inventory data for North American materials, energy and transport (late 1990's). Mostly based on a variety of public and private USA statistical sources, reports, and telephone conversations with experts.
IDEMAT 2001	This database has been developed at the Delft University of Technology, Department of Industrial Design Engineering, under the IDEMAT project. The focus is very much on the production of materials. The data are mostly original (not taken from other LCA databases), and come from a wide variety of sources.
Industry data	This library contains data as collected by industry associations.
LCA Food DK	The LCAfood database provides environmental data on processes in food products' product chains and on food products at different stages of their product chains. It also includes wizards to help analyze the data.
USA Input Output Database 98	The US input-output (IO) database consist of a 500x500 commodity matrix from 1998 supplemented with data for capital goods. The IO commodity matrix is linked to a large environmental intervention matrix. The environmental data have been compiled using several data sources, such as i.e. Air Quality Planning and Standard (AIRS) data of the US Environmental Protection Agency, Energy Information Administration (EIA) data of the US Department of Energy, etc. With the use of the above databases, the impact from small and medium sized enterprises (SME) and diffuse sources such as transport have been added to the environmental intervention matrix.

As for the LCIA, the Eco-Indicator 99 may be used as the reference impact assessment method. Nonetheless, to obtain the complete overview of the product's environmental impact, other LCIA

methods were also used. Most of them present a comprehensive view of environmental load created by the product. Only Cumulative Energy Demand (CED) method focuses on the detailed investigation of energy sources connected with the environmental burden. This method has been used, because one of the key questions of today's environmental protection is maximizing the share of renewable energies in the total amount of produced energy. Therefore, application of CED methodology shows, what is the state-of-the art and the potential of improvement with respect to the use of "green" sources of energy in the production and use of the gas-electro cooker.

The detailed description of all LCIA methods is given in section 3.3 (for Eco-Indicator 99) and in Appendix I (for other methods used).

3.2.1.4 Inventory analysis

Inventory analysis in the SimaPro is done in a very intuitive way. As fig. 3.4 shows, the practitioner may organize assemblies, subassemblies, and materials in a hierarchical way. As for materials, one can create own substances or choose between materials and processes supplied with the databases.

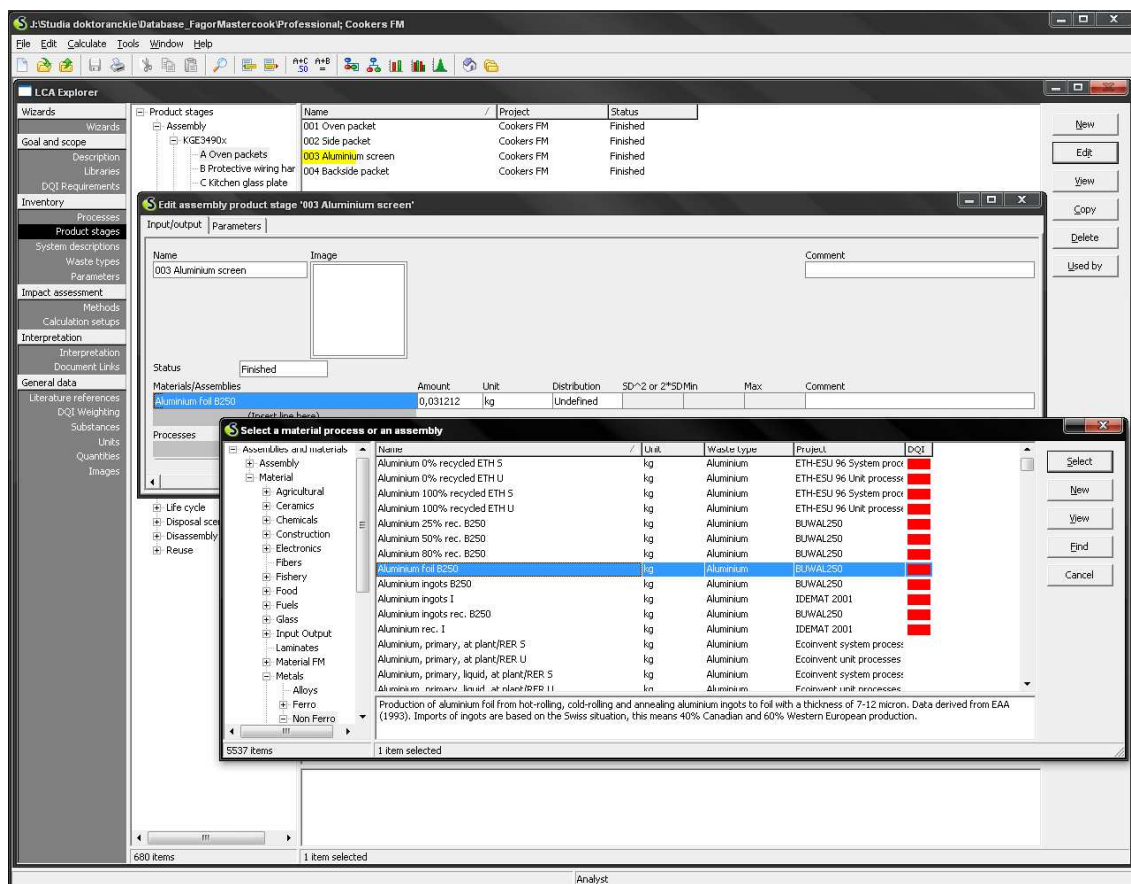


Figure 3.4 Inventory analysis window in SimaPro.

Materials and processes existing in the databases may be also modified according to the specific needs. Furthermore, one has to mention the detailed structure of the gas-electro cooker and its

influence on the modelling speed. In case of the gas-electro cooker, more than 600 substances and subassemblies were used in the LCA modelling. As the result, the calculation of the environmental impact of the product was taking about 40 minutes for every LCIA method chosen. The long time SimaPro needs for the calculation of impacts stemming from such complex products may be seen as shortcoming of the software.

3.2.1.5 LCIA in the SimaPro

The Life Cycle Impact Assessment in the SimaPro is performed in a very easy way. In the first step, one has to choose the product or several products to model and compare. It is possible to model only parts of the entire LCA system (in the meaning of product assembly, entire product, product and additional operations and substances included, as well as product, additional operations, and its end-of-life scenario). After this choice, clicking on the icon “network”, “tree”, “analyze”, or “compare” leads the practitioner to the calculation window (fig. 3.5). Here, the choice of the LCIA modelling method takes place. If desired, one can save the modelling preferences and setups for a later reference.

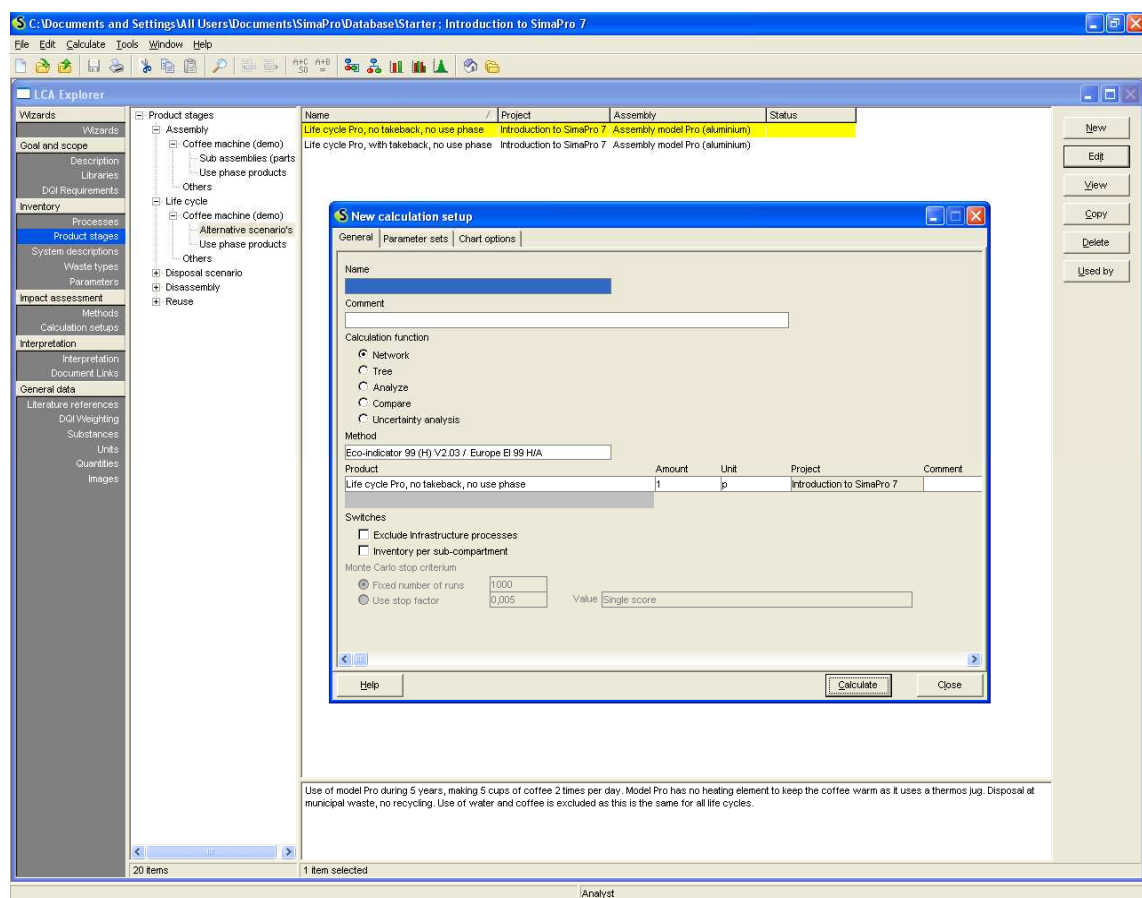


Figure 3.5 Choice of the LCIA method and modelling preferences in the SimaPro.

Subsequently, the SimaPro calculates the results and visualises them in the form of a network, a tree, or a bar graph representation. Examples of network diagrams are shown in appendices VIII and IX. One has to mention the flexibility of the SimaPro when representing the results. The LCA practitioner may choose various options for the results representation, including reference material and the LCA stage for which the diagrams are created. Program user may change the colours of the bars as well as sort them out. Very convenient way to present results is to export them first to an external file (such as Microsoft Excel file with extension of .xls or text file with extension of .txt). Subsequently, one can arrange and sort out results using the possibilities offered also by other software packages.

3.2.1.6 Changes and adjustments in the software and the modelling data

The research was focused on the Polish market to show the environmental impact of the gas-electro cooker. The technology used in the production of the cooker is identical to those used in the western countries of Europe and North America. Therefore, no modification has taken place with respect to the provided values for the materials. Nonetheless, cooking habits of Polish homemakers are very different from those observed in the Western countries. Polish homemakers are preparing many meals by themselves from the raw materials, not the frozen pre-prepared meals. Therefore, the questionnaire has been prepared (Appendix III) to collect the data concerning the use phase of the cooker. The results and additional processes included in the LCA of the cooker are described in section 4.4.2.

3.2.2 The Sensitivity Model Prof. Vester

The Sensitivity Model Prof. Vester (SMPV) is a very powerful program for modelling of the entire systems of many kinds. The developer of the model, Prof. Frederic Vester, aimed at a creation of the model that reflexes the complexity and interconnectivity of the modern world, without a necessity to collect a large amount of statistical data that overwhelms the user and makes the assessment impossible. In the SMPV, user may take into consideration not only quantitative data, but also qualitative data. Thus, the full model description is being made. The concurrent structure and subsequent steps of the program are shown in fig. 3.6. By completing the system description step by step, model developer is able to learn about the system and its internal interrelationships.

The modelling procedure is divided into 9 main steps: describing the system, defining the variables, filling the criteria matrix, defining the interrelations of the variables in the impact matrix, analysis of the systemic roles of the variables, defining the effect system, and finally choosing the partial

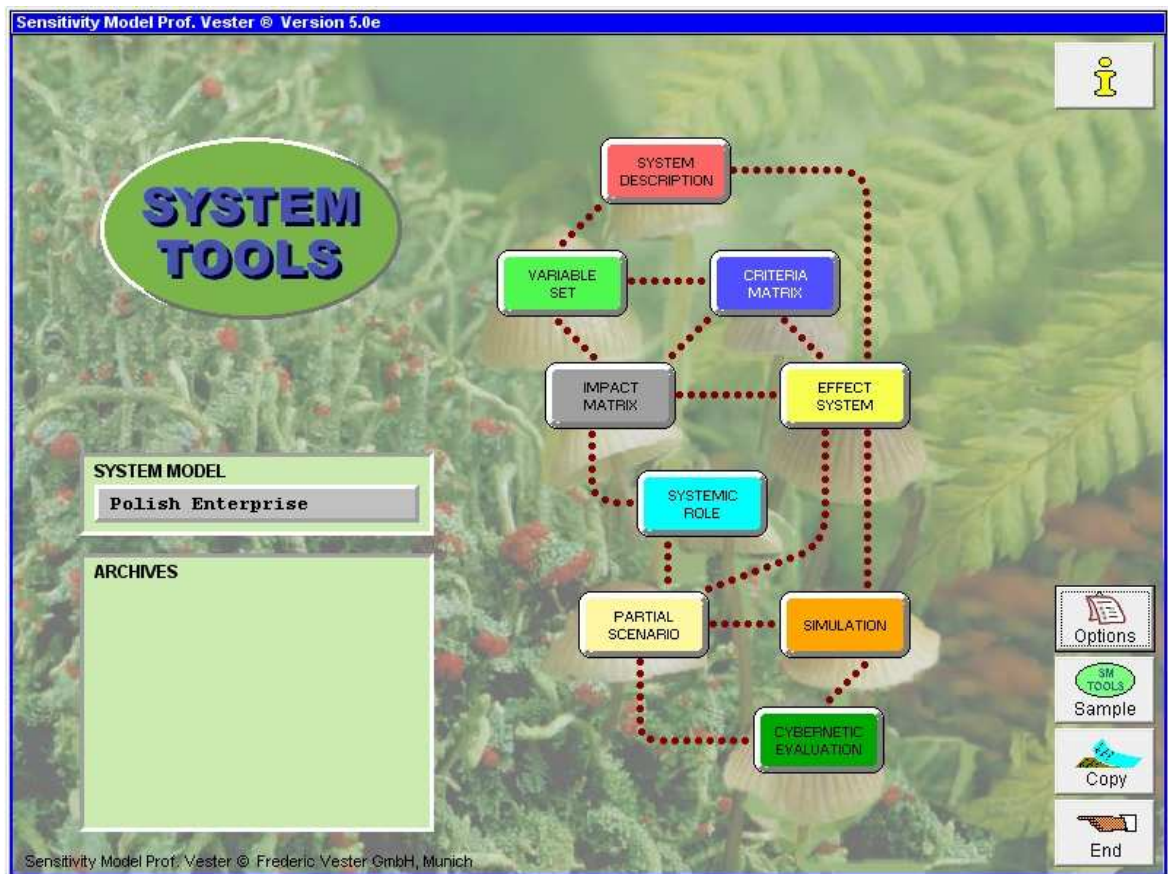


Figure 3.6 Main menu of Sensitivity Model Prof. Vester.

scenarios and their modelling. The last step – cybernetic evaluation – is a kind of final self-check of the feasibility of the defined system and the choices made.

Each of the modelling steps is as a separate module. Inside the module, different functions and sub-modules are available. They will be described in details in chapter 5, using as a case study the system model “Polish Enterprise”.

The important fact to be mentioned here is a cascade character of the model. For example, it is impossible to analyze the effect system of the variables before impact matrix and criteria matrix are finished. Furthermore, the Sensitivity Model developers recommend using it in working groups. Because of the individual character of the dissertation, all modelling steps were completed individually by the author.

3.3 Eco-Indicator 99¹

The Eco-Indicator 99 is an updated version of the Eco-Indicator 95. This is widely applied LCIA method created and developed by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) as the project in the framework of the Integrated Product Policy.

The method consists of several subsequent steps: characterisation, damage assessment, normalisation, weighting, and single score. As in the other methods, the most critical and controversial step is the weighting. The developers suggest minimising the number of subjects to be weighted. Simultaneously, one ought to weight easy-to-explain subjects.

Eco-Indicator 99 recognizes three types of environmental damages (endpoints):

- Human health,
- Ecosystem quality,
- and resources.

In order to link the damage categories with the inventory results, the Eco-Indicator 99 uses specific models. For instance, damages to human health are expressed as DALY (Disability Adjusted Life Years). Models have been developed for respiratory and carcinogenic effects, the effects of climate change, ozone layer depletion and ionising radiation. In these models for human health, four substeps are used:

- Fate analysis, linking an emission (expressed as mass) to a temporary change in concentration;
- Exposure analysis, linking this temporary concentration to a dose;
- Effect analysis, linking the dose to a number of health effects, like the number and types of cancers;
- Damage analysis, links health effects to DALYs, using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL) (Goedkoop and Spriensma 2001).

Damages to ecosystem quality are represented by the percentage of species that have disappeared in a certain area due to the environmental load. The following subcategories are recognized within the Eco-Indicator 99:

¹ Unless otherwise specified, according to: Goedkoop, M. and Spriensma, R.: The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Methodology Report. Pre Consultants, <http://www.pre.nl>, last accessed on: 14.02.2008.

- Ecotoxicity: the percentage of all species present in the environment living under toxic stress (PAF). This damage is not easily observable, therefore a rather crude conversion factor is used to translate toxic stress into a real observable damage;
- Acidification and Eutrophication: the damage to target species (vascular plants) in natural areas is modelled;
- Land-use and land transformation: based on empirical data of the occurrence of vascular plants as a function of the land-use type and the area size. Both the local damage on the occupied or transformed area as well as the regional damage on ecosystems are taken into consideration (Goedkoop and Spriensma 2001).

The last damage category, resource extraction, is related to a parameter that indicates the quality of the remaining mineral and fossil resources. In both cases, the extraction of these resources will result in higher energy requirements for future extraction.

Fig. 3.7 presents the more detailed insight into modelling procedure applied in the Eco-Indicator 99.

One has to mention the assumptions and limitations of the model, specifically that in principle all emissions and land uses are occurring in Europe and that all subsequent damages occur in Europe. Furthermore, data uncertainties (related to technical problems of measuring and assessing factors) and model uncertainties (referring to the uncertainty of the model) are recognized. In some cases, especially for toxicity, these uncertainties are substantial.

In order to cope with these uncertainties a system, Cultural Theory has been used to separate three versions of the damage model.

In an Egalitarian model, long time perspective is represented. Here, even a minimum of scientific proof justifies inclusion. Individualist version is based on the short time perspective. In this model, only proven effects are included. A Hierarchist version (being at the same time the model default one) refers to the balanced time perspective. In the Hierarchist version, consensus among scientists determines inclusion of effects.

3.4 Assumptions and limitations

The LCA study and the sensitivity analysis performed in the SMPV required to make many decisions on the modelling variables and methods. The resulting limitations, that have to be mentioned, are the following:

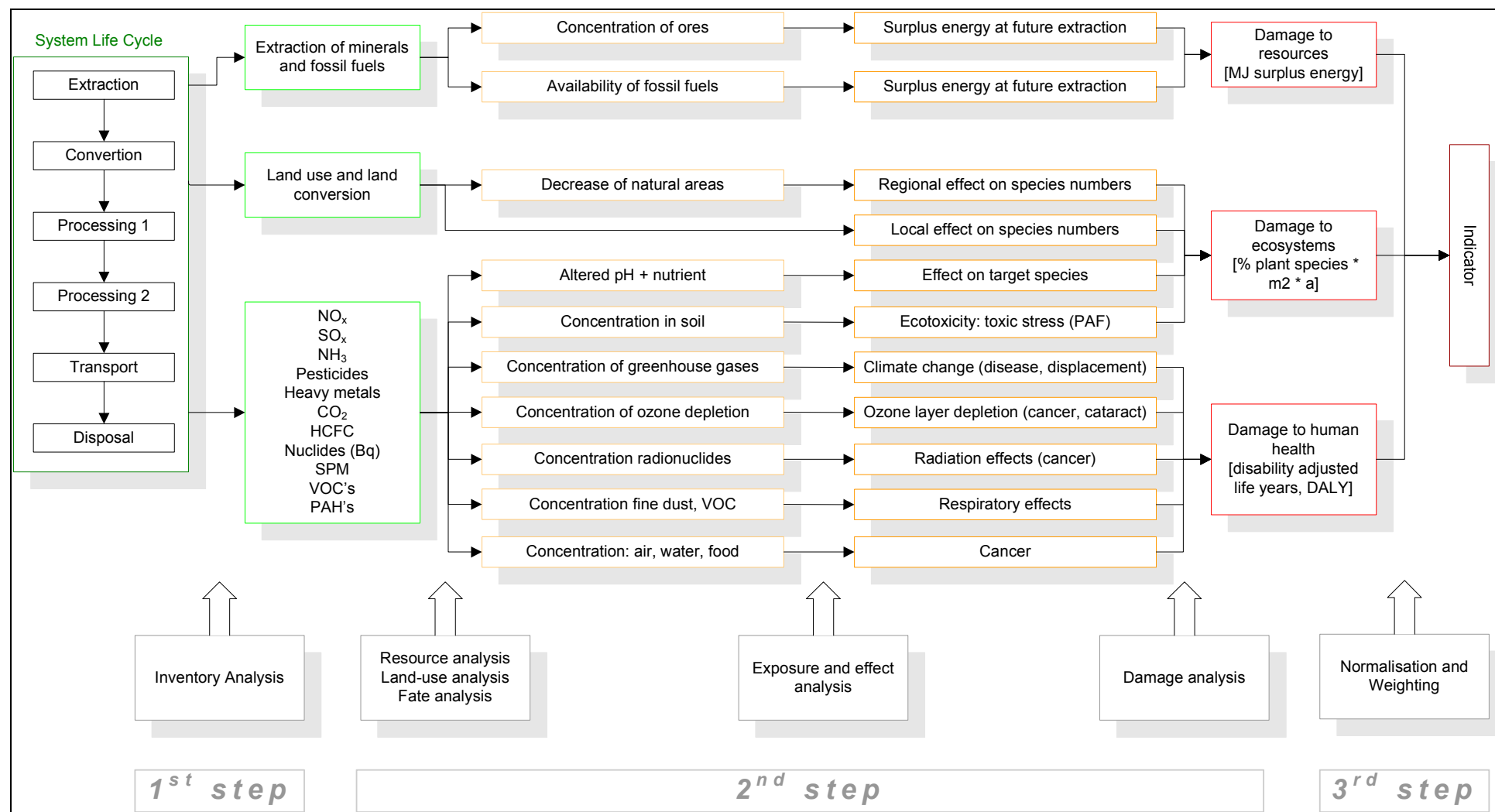


Figure 3.7 Methodology of result calculation in the Eco-Indicator 99. Source: Goedkoop and Spriensma (2001).

- Not all materials identified in the Life Cycle Inventory were available in the SimaPro; therefore, a substitution with similar materials had to be made;
- Some processes and subassemblies had to be aggregated, in order to present clear results; furthermore, cut-off levels in the modelling were used (i.e. for the presentation of the LCIA in form of network diagrams);
- Data collection on Polish cuisine was restricted to one focus group, namely parents and families of children attending the primary school in Lubawka, Poland;
- In the use phase, only the gas and electricity consumption related to the preparation of meals was taken into consideration; the LCA cycles of ingredients and i.e. cleaning of dishes was excluded from the boundary of the LCA;
- Sensitivity analysis was made on the basis of author's knowledge, experience and observation; the group work was not performed.

More specific assumptions are mentioned in the chapters dealing with modelling and result description.

3.5 Data collection and treatment

The collection of data for the research was based on the following sources:

- Analysis of the company's internal databases and documents, such as i.e. technical drawings;
- Laboratory measurements in the FagorMastercook;
- Analysis of the technical documentation;
- Literature research;
- Internet database and web page research;
- Personal observation;
- Interviews with the company's employees;
- Questionnaire analysis.

Subsequently to the data collection, input data were inserted in the models (the SimaPro and the SMPV) and adjusted to fit the software requirements. As for the questionnaires, simple statistical methods were used, such as calculation of mean, standard deviations, minimum and maximum

values, first and third quartile, etc. The values from these operations were helpful to create and “average” use of the cooker and estimate consumption of the gas and the electricity.

The estimation of the Life Cycle Impact Assessment was performed using various methodologies. They are described in Appendix I and section 3.3.

PART B

LCA ANALYSIS

4. Presentation and analysis of the LCA results

4.1 Introduction

As mentioned in chapter 3, the input data for the modelling stage were very detailed. The KGE 3490X structure consisted of more than 600 positions (materials, subassemblies, production processes). For every process and material, the corresponding substitute had to be found in the SimaPro databases. These time-consuming activities were necessary in order to obtain reliable modelling results. Some assumptions made and limitations of the choices were presented in section 3.4.

In the first stage of the LCA modelling, only cooker and production processes were analyzed (including transportation and recycling processes). In the second modelling stage, the entire LCA was performed, including also use phase processes and the three End-of-Life (EoL) scenarios. Section 4.2 includes description of the KGE 3490X, use phase (cooking and baking processes), and EoL scenarios. Sections 4.3 and 4.4 deal with the results of the LCIA modelling for the above-mentioned two modelling phases. Section 4.5 will show, how the environmental impact is changing, depending on the EoL scenario used. In section 4.6, the analysis of the obtained results will take place. Interrelations of the results and their possible impacts on the company's position and functioning with respect to the EuP Directive and the EMS system will be depicted in section 5.1.

One has to mention the question of functional unit, used for possible future comparisons between products:

- In the first modelling phase, the functional unit will be simply 1 gas-electro cooker;
- In the second modelling stage, functional unit will be “cooking and baking in one average Polish household during one year, including respective amount of materials used in the production of one gas-electro cooker”.

The frequencies of meal preparations and corresponding gas and electricity consumptions are described in section 4.2.2.3.

Last remark concerns the clarity of the results. Due to high amount of input data, it was necessary to set cut-off levels at 3-6%, depending on the methodology chosen and the LCIA step. That means impacts on environment from sources contributing less than cut-off level set were not presented on the graphs. However, they were taken into consideration when calculating the overall result. This restriction was necessary for clear and transparent presentation of the results due to the very detailed input data.

4.2 Inventory analysis results

4.2.1 Materials and parts

Table 1 in Appendix II presents the most important materials used by the modelling software for the evaluation of the Life Cycle impact of the gas-electro cooker. One has to remember, that the full list of materials and processes used for the production of the KGE 3490X counts more than 600 positions. Due to the confidentiality of the data, detailed inventory data may not be presented.

Fig. 4.1 summarizes in the form of the pie diagram the most important materials used in the production of the KGE 3490X.

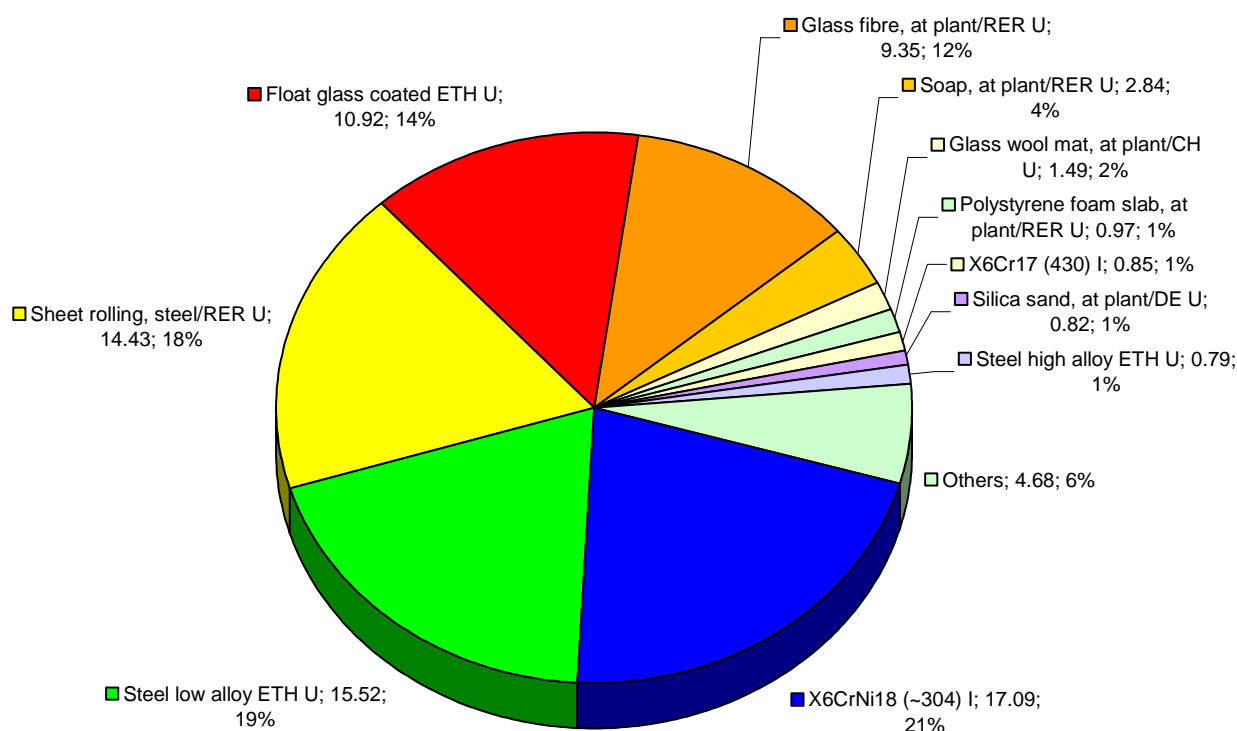


Figure 4.1 Materials used in the modelling of the gas-electro cooker. Numbers represent kg of substances and their percentage. Percentage values do not take into consideration the sheet rolling process.

Production of some materials and substances involves some additional materials, not collected and used as the input data by the SimaPro user. However, the SimaPro calculated the environmental impact from these materials, as well. As the results, full number of substances taken into consideration in the LCA of the gas-electro cooker reached more than 2300, including substances indirectly incorporated in the LCA (i.e. being the part of the ore extraction etc.).

The visualization of subassemblies, their weights and the percentages of the total weight of the product is shown in fig. 4.2.

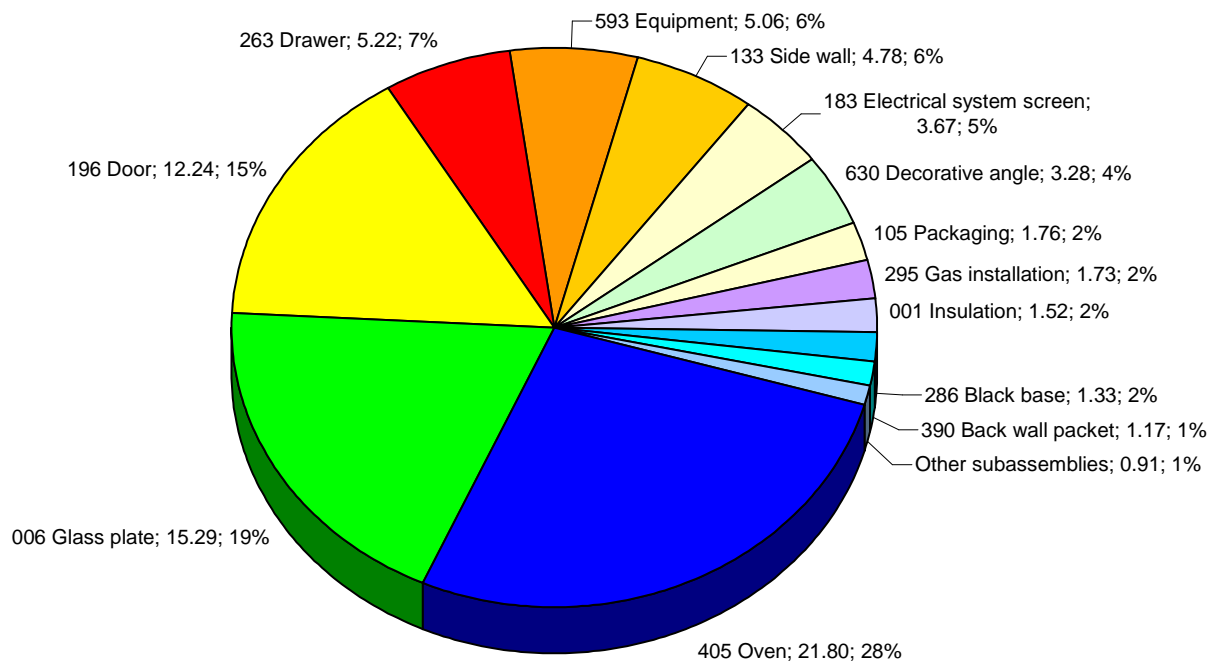


Figure 4.2 Subassemblies of the KGE 3490X. Numbers represent mass of subassemblies in kg and the percentage of their weight in the total mass of the product (including sheet rolling process).

Furthermore, following additional processes and emissions were included in the LCA modelling of the cooker:

- Resource consumption: water (100 L), natural gas (5m³);
- Electricity consumption of an approximately 0.03 kWh;
- Transport by delivery van smaller than 3.5 t (1500 kgkm, assuming the weight of the appliance being 50kg, transported over the distance of 30 km);
- Transport by 40 t lorry (3500 kgkm, assuming the weight of the appliance being 50kg, transported over the distance of 70 km);
- Waste by-products: synthetic rubber, plastics (HDPE, LDPE, PA6, PB, PE, PP, PVC), steel high and low alloy, packaging carton, corrugated board base, core board, paper, lubricating oil, wood board, and electronic scrap (total amount of waste approximately equal to 5 kg);
- Emissions to air: carbon dioxide, carbon monoxide, particulates, polycyclic aromatic hydrocarbons, sulphur dioxide, and nitrogen dioxide (total amount of gaseous emissions of approximately 5 kg);
- Waste treatment processes, namely effluents cleaned in wastewater treatment plant; recycling of paper and cardboard, plastics, steel; disposal of electronics, wood, paint remains, and of incineration of oil.

The assumptions for the above-mentioned processes and materials for the modelling were aggregated into “Production and transportation” module. Finally, this module was added as the input data in the SimaPro. The software calculated the results of the environmental damage for the production and transportation processes and emissions in the same manner as for every other subassembly. Data about these additional materials and processes were based on the information provided by the FagorMastercook, as well as information from the internet and the personal observations.

4.2.2 Data for the modelling of the use phase

4.2.2.1 Introduction

In the use phase modelling, the materials and processes from the production phase were taken into consideration, including the transportation of the cooker from the factory to the end user. Additionally, questionnaires were created and distributed, in order to make real assumptions on the cooking habits in the Polish households.

As the result of the questionnaire analysis, following aspects were added and modified in comparison to the first modelling phase:

- The life span of the product has been defined to be 15 years; The functional unit has been defined to be “cooking and baking in one average Polish household during one year, including respective amount of materials used in the production of one gas-electro cooker”;
- Use processes were defined, based on the questionnaires collected in Lubawka, Poland;
- The three End-of-Life Scenarios were created.

Detailed description of the additional aspects taken into consideration in the modelling is given in the following sections.

4.2.2.2 Questionnaire analysis and the target group

According to the rules of making the statistical analysis, one has to ask the representative number of inhabitants, living in the various locations (villages, small towns, middle towns, and cities), with a different economical background, education, family and social situation, etc. Usually, such research requires an investment of considerable amounts of time and money resources, and focuses on more than 900 to 1000 respondents. In fact, due to the time and financial restrictions, such an assessment was not possible. Therefore, only one target group of the society was investigated, namely families

of children attending the primary school in Lubawka, Poland. Approximately 200 questionnaires (Appendix III) were distributed. The return rate was about 25%, namely 53 questionnaires could be evaluated.

The answers in the first, general part of the questionnaires, give the idea about the type and situation of such families. All answers are summarized in Appendix III, tables 11 and 12.

The “average” respondent was female, around 36 years old, with secondary education. Four people are living in the household. They are travelling twice per year, every third month some guests are visiting family. Most often, they have electrical cooker, produced by Polish company (Amica, Wrozamet, or FagorMastercook). This cooker is approximately seven years old. The average respondent cooks a diner every day. The monthly gas consumption costs 95 PLN (approximately 23 euro), and electricity consumption costs monthly around 50 PLN (13 euro).

One has to remember about high variability of answers in the questionnaires. For the modelling purposes, the median values were used, in order to exclude the most unusual or unexpected results.

4.2.2.3 Cooking habits

The summary of answers is provided in the Appendix IV. For each meal type, specific process in the SimaPro database was created. Subsequently, to facilitate clearness of the results, the meal types were aggregated to the categories of: main course dishes, side dishes, soups, hot beverages, cakes and desserts, and others. For every meal type, the consumption of gas and/or electricity was specified, based on preparation time, and measurements done in the laboratory of the FagorMastercook, as well as the personal observations. Detailed information about the cooking processes, consumption of gas and electricity, and conversion factors used in the modelling, is given in Appendices IV and V. Fig. 4.3 and 4.4 present the bar graphs of the yearly gas and electricity consumption used in the preparation of some selected meal types.

4.2.2.4 End-of-Life scenarios

In all modelling steps, the following End-of-Life scenarios have been used:

- Worst case scenario, based mostly on the incineration of the cooker and its subassemblies;
- Recycling and landfilling scenario, based on the recycling of metal parts and landfilling of remaining subassemblies;
- The best-case scenario, assuming mainly recycling of the cooker after its End-of-Life.

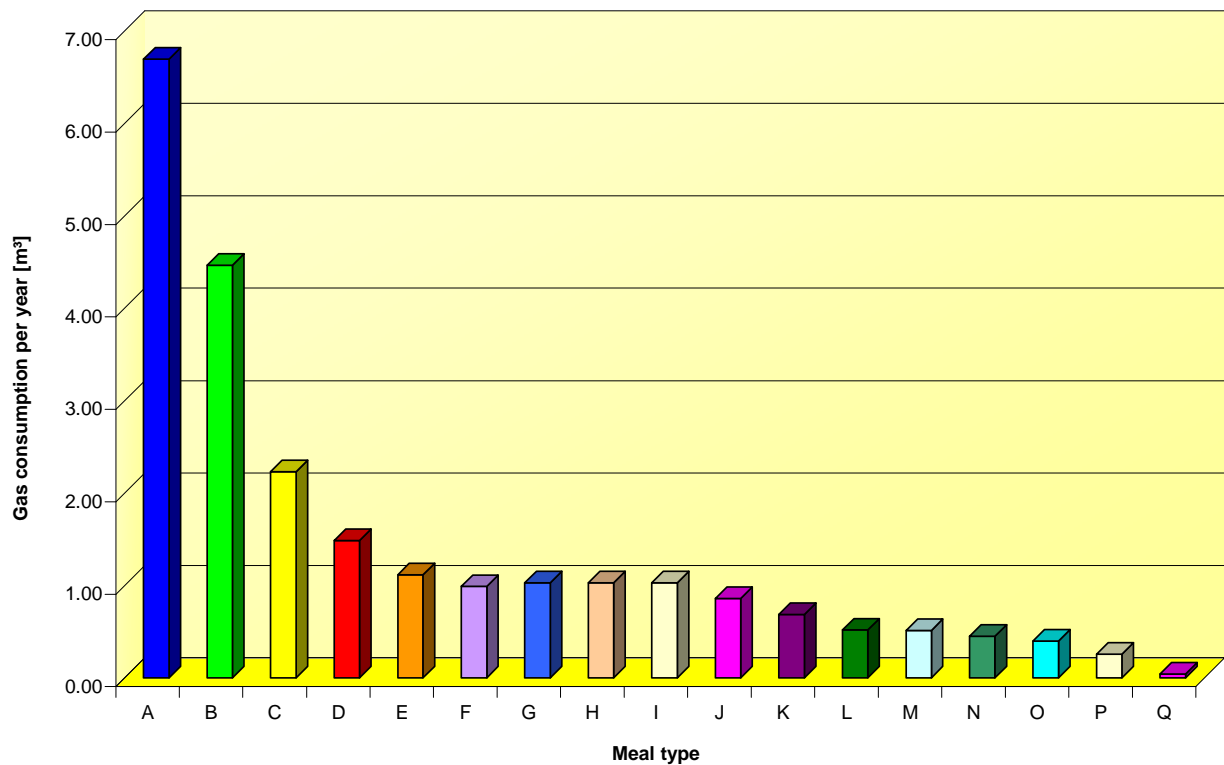


Figure 4.3 Annual consumption of gas for the selected meal types. A – Potatoes, B – Clear chicken soup, C – Breaded pork chop, D – Pasta, E – Milk, F – Fruit/vegetable products, G – Minced cutlet, H – Sour soup, I – Cucumber soup, J – Fried fish, K – Cabbage rolls burner, L – Mushroom soup, M – Goulash, N – Cheap bean and sausage stew, O – Potato pancakes, P – Meatballs, Q – Frozen dough pockets.

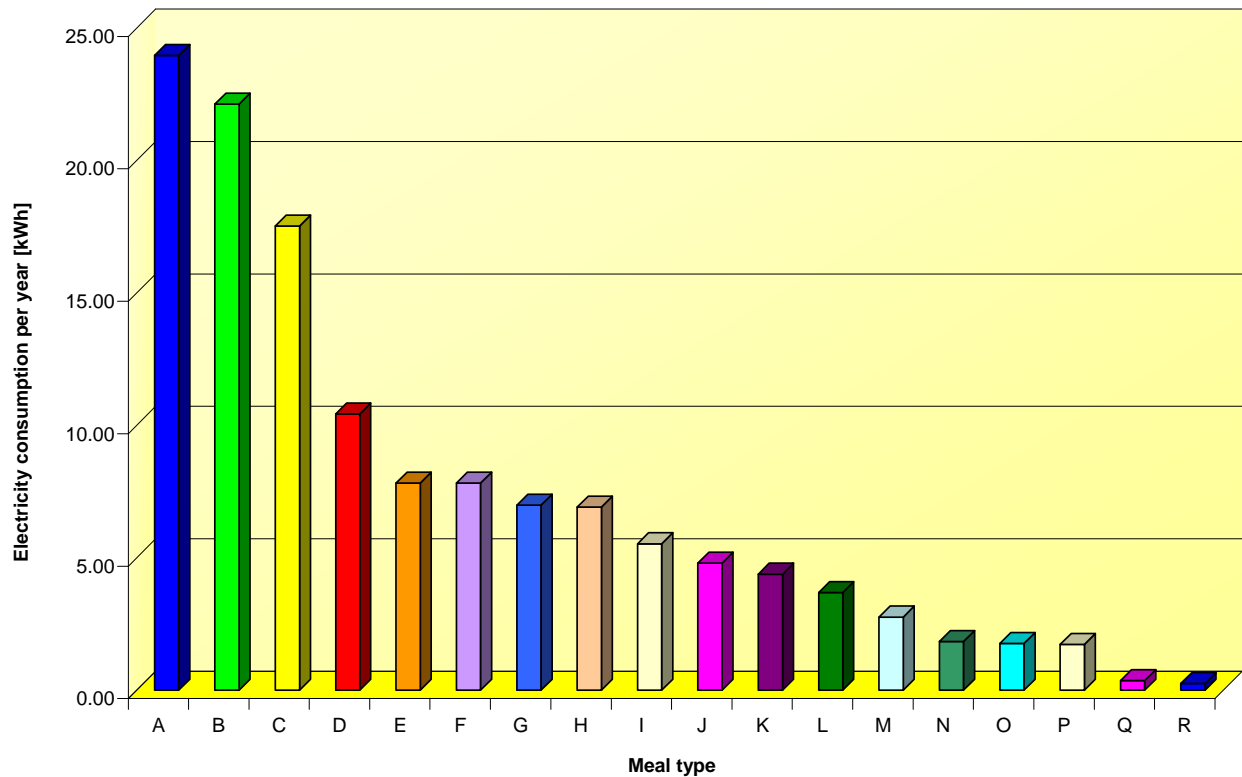


Figure 4.4 Annual consumption of electricity for the selected meal types. A – Cookies, B – Chicken, C – Roast, D – Casserole, E – Pizza, F – Sweatbread/Easter bread, G – Biscuit, H – Cheesecake, I – Apple pie, J – Other cakes, K – Honey pie, L – Yeast cake, M – Toasts oven, N – Poppyseed cake, O – Donuts, P – Gingerbread, Q – Pizza frozen, R – Toasts frozen.

Marek Gawor

Application of Life Cycle Assessment in the Context of Classical Environmental Management System and with Respect to the Implementation of the EuP Directive

The incineration scenario may be considered as purely theoretical one. In reality, nobody is going to incinerate precious metals that may be collected and relatively easy recycled i.e. by refineries. However, one can compare the results of this scenario with the results of other scenarios. The incineration is one of the most environmentally unfriendly methods of waste management. Thus, comparing of incineration scenario with other scenarios may help to understand, how application of environmental measures minimizes environmental burden in the industry.

The recycling and landfilling scenario is based on the waste management practices observed in Lubawka. Most of the municipal waste is landfilled. However, metal appliances and parts are collected by poorer people, and sold in the metal collection facility. Afterwards, these metals are sold to refineries and – thus – being recycled. It was assumed that non-metal parts from the cooker will be manually dismantled and they will end up their life cycle in municipal landfill in Lubawka. The prevailing rest of the appliance will be sold in the metal collection centre.

To show the potential of improvement for the current situation, third EoL scenario was created. In this scenario, the entire gas-electro cooker is recycled at the end of its life cycle. However, 100% recycling of the appliance is not very realistic. The recycling facilities in Poland are not located within reasonable distance from each household. Therefore, people prefer to handle white household appliances in the way described in recycling and landfilling scenario.

The results of comparison for the three EoL scenarios are shown in section 4.5. The scenario based on the recycling and landfilling is used in the second step of modelling as the baseline scenario.

4.3 Modelling results SimaPro – cooker without EoL and without use phase

4.3.1 CML 2.03 baseline 2000

Figures 4.5 and 4.6 present the LCIA results for the CML 2 2000 method. As characterization results show, in most of the impact categories, following subassemblies have the highest impact on the environment: equipment, oven, door, glass plate, and decorative angle. These subassemblies have such a high impact mainly due to their composition: high amount of high-alloyed steels and high weight. The damage caused by the packaging is visible in some of the impact categories, such as i.e. fresh water aquatic ecotoxicity, human toxicity, or terrestrial ecotoxicity (fig. 4.5). This impact is caused by the fact, that packaging contains plastic materials causing negative impacts on living organisms during the process of its production.

As for the normalization results, it appears that the marine aquatic ecotoxicity is the impact category, where most of the damage to the environment occurs. As fig 4.6 shows, the cooker has an

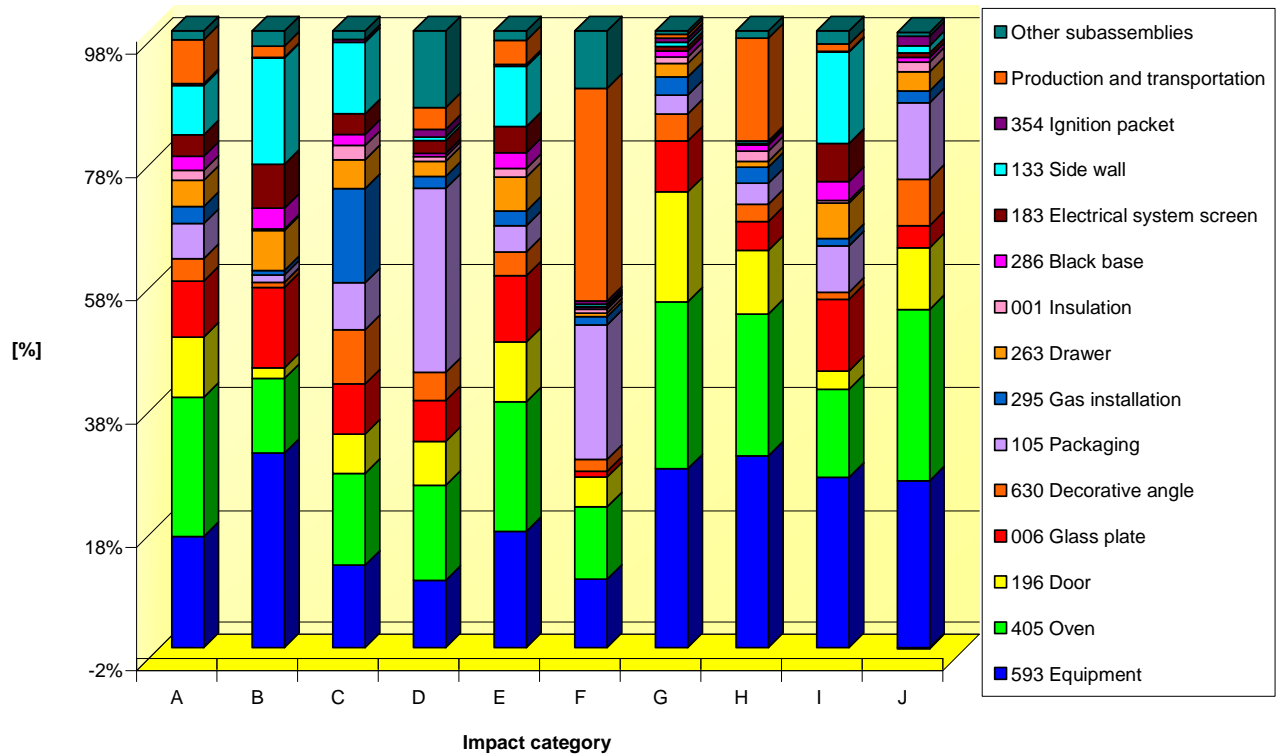


Figure 4.5 Characterization results, CML 2 2000 method. Impact categories: A – abiotic depletion, B – acidification, C – eutrophication, D – fresh water aquatic ecotoxicity, E – global warming potential (GWP100), F – human toxicity, G – marine aquatic ecotoxicity, H – ozone layer depletion (ODP), I – photochemical oxidation, J – terrestrial ecotoxicity.

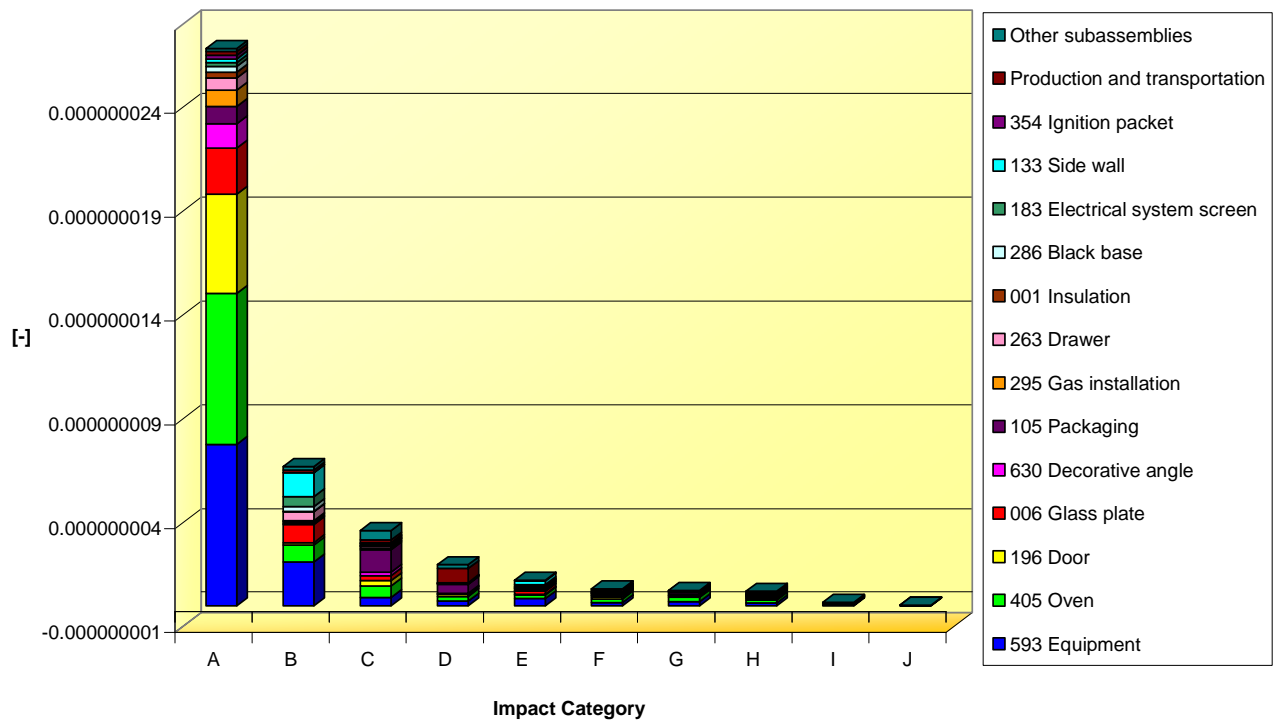


Figure 4.6 Normalization results, CML 2 2000 method. Impact categories: A – marine aquatic ecotoxicity, B – acidification, C – fresh water aquatic ecotoxicity, D – human toxicity, E – photochemical oxidation, F – abiotic depletion, G – terrestrial ecotoxicity, H – global warming potential (GWP100), I – eutrophication, J – ozone layer depletion (ODP).

impact on the environment at least 4-5 times higher in this category, than in any other category. The damage to the environment caused in the categories of acidification, fresh water aquatic toxicity, and human toxicity is smaller, but still considerable. The damage in the remaining impact categories is of smaller importance for the overall result.

Appendix VIII presents in its first section the network diagrams for the CML 2 2000 LCIA method. As it appears, various types of steels and nickel are responsible for the crucial part of the environmental burden in the characterization modelling step. Additionally, production of chromium, float glass, steel low alloy and electricity has to be taken into consideration.

One has to explain the negative values of the y-axis on the bar diagrams. The negative impact of the environmental burden originates from the production and transportation module. In this module, some recycling processes of manufacturing by-products were taken into consideration. Thus, in some of the impact categories, negative values represent avoided emissions. Nonetheless, these values were smaller than approximately 1% of the total result.

4.3.2 Cumulative Energy Demand

Modelling results for the LCIA method Cumulative Energy Demand (CED) are shown in fig. 4.7 to 4.9 (bar diagrams) and in section 2 of the Appendix VIII (network diagrams).

The characterization step of modelling has may be characterized as follows:

- The most important subassemblies for the overall impact are: oven, equipment, glass plate, door and side wall;
- Production and transportation module may be seen as the significant part of the overall impact; according to the CED method, it may reduce the overall impact in some categories;
- I.e. when analyzing renewable biomass energy consumption, the production and transportation module reduces up to 15% of the overall impact due to the avoided emissions; these avoided emissions are stemming from the recycling of the cardboard and wood waste.

As the weighting results have shown (fig. 4.8), the most important source of the energy-related environmental burden is coming from the production of electricity from non-renewable fossil fuels. Nuclear energy production also creates significant burden, although its magnitude is much smaller than in the case of fossil fuel energy. Renewable energy sources create very small damage on environment (water and biomass energy sources), or could be simply neglected due to the marginal

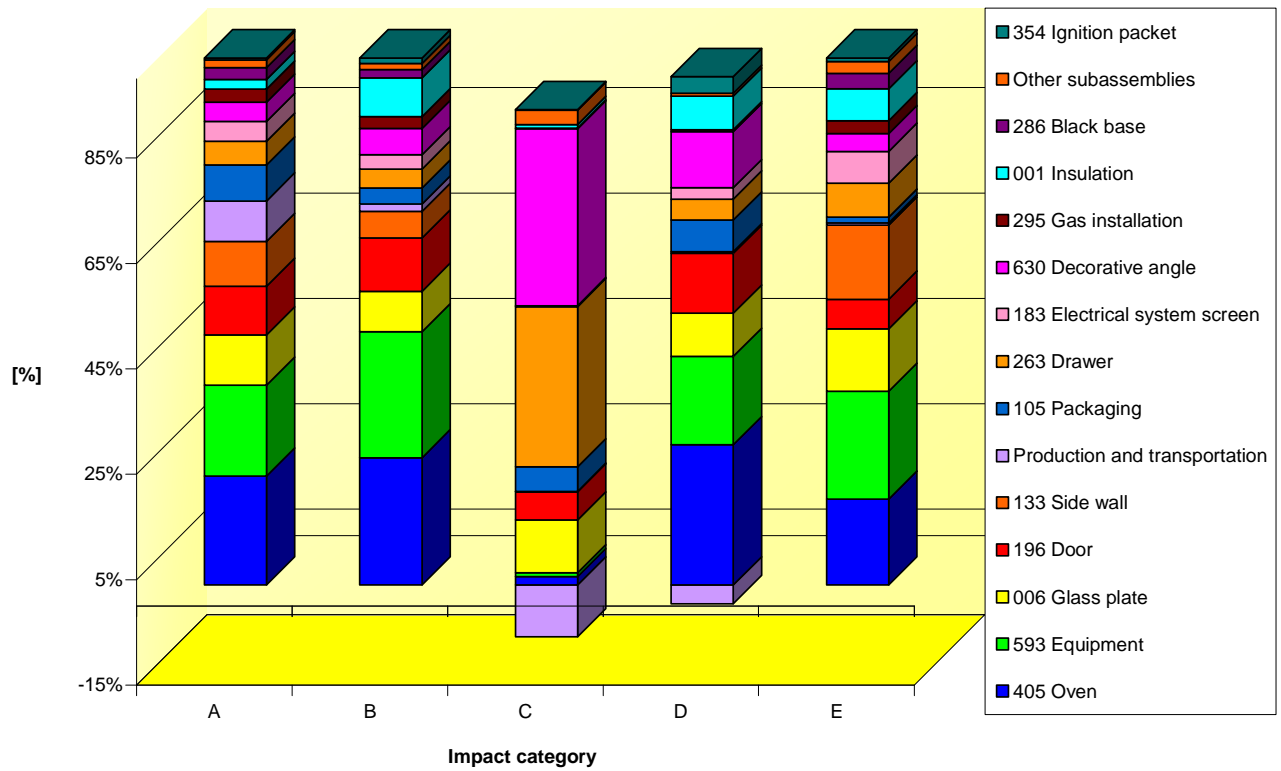


Figure 4.7 Characterization results, the Cumulative Energy Demand. Impact categories: A – non renewable, fossil; B – non-renewable, nuclear; C – renewable, biomass; D – renewable, wind, solar, geothermal; E – renewable, water.

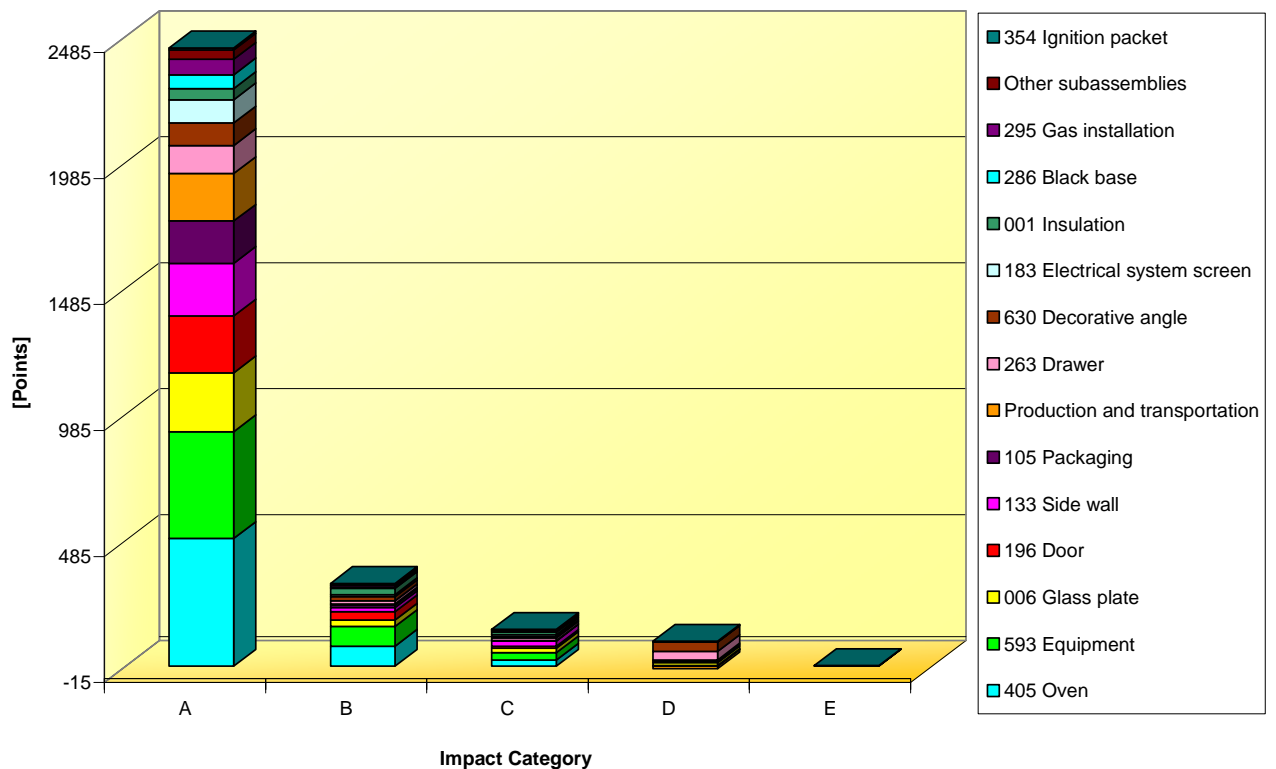


Figure 4.8 Weighting results, Cumulative Energy Demand. Impact categories: A – non renewable, fossil; B – non-renewable, nuclear; C – renewable, water; D – renewable, biomass; E – renewable, wind, solar, geothermal.

influence on the overall result (biomass energy impact category).

Single score results (fig. 4.9), confirm the previous findings. For most of the subassemblies, environmental burden is stemming from the fossil fuel and nuclear energy generation. The highest energy consumption may be associated with the production of oven and equipment subassemblies.

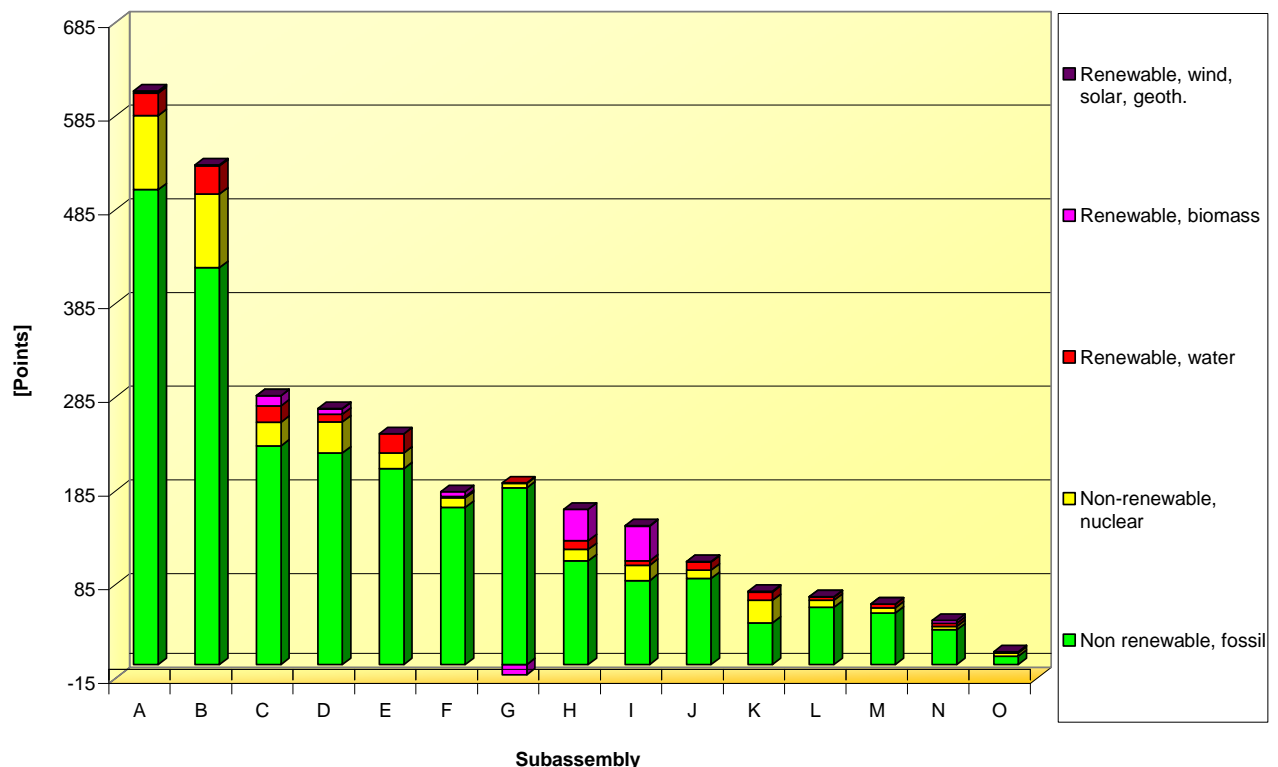


Figure 4.9 Single score results, Cumulative Energy Demand. Subassemblies: A – 405 Oven, B – 593 Equipment, C – 006 Glass plate, D – 196 Door, E – 133 Side wall, F – 105 Packaging, G – Production and transportation, H – 263 Drawer, I – 630 Decorative angle, J – 183 Electrical system screen, K – 001 Insulation, L – 295 Gas installation, M – 286 Black base, N – Other subassemblies, O – 354 Ignition packet.

The energy consumption associated with insulation, gas installation, black base, ignition packet and other subassemblies, may be neglected. Other subassemblies have a middle-range contribution to the overall impact.

Network diagrams demonstrate in general, that the use of steel high alloys create the most of the environmental load with respect to the energy demand (characterization modelling step, section 2 of the Appendix VIII).

4.3.3 Ecopoints 97

The results of the KGE 3490X modelling are presented in fig. 4.10 to 4.13 and in section 3 of the Appendix VIII.

The characterization phase modelling shows that in most of the categories negative impact on the environment has been recorded. The most environmentally unfriendly subassemblies are: oven,

equipment, door, and decorative angle. The results for the specific impact categories, however, show many differences. I.e., in the category of ammonia emissions, previously mentioned subassemblies do not play a significant role. Here, the insulation creates most of the environmental burden (fig. 4.10).

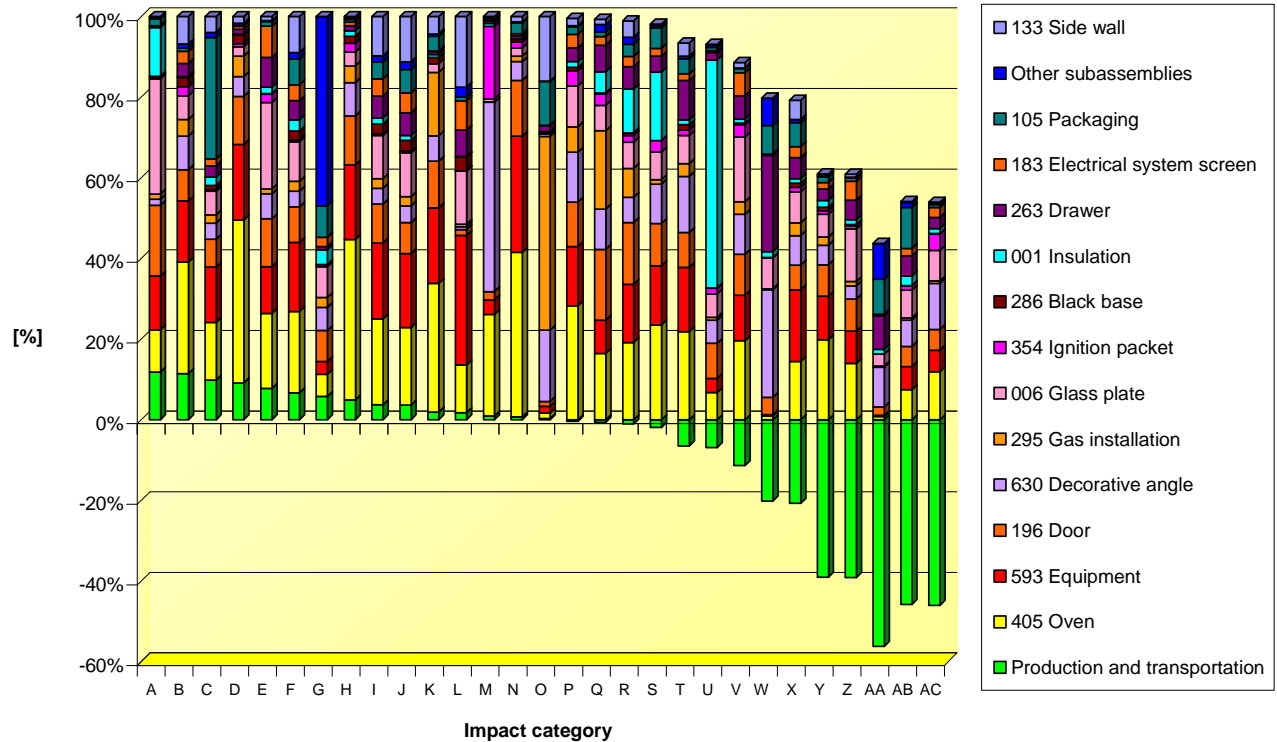


Figure 4.10 Characterization results, Ecopoints 97 method. Impact categories: A – ozone layer, B – Pb (air), C – NMVOC, D – Zn (air), E – Cu (water), F – energy, G – AOX (water), H – Pb (water), I – CO₂, J – NO_x, K – P, L – SO_x, M – metals (soil), N – Cd (air), O – N, P – Cr (water), Q – waste, R – LMRAD, S – HRAD, T – Hg (air), U – NH₃, V – Ni (water), W – nitrate (soil), X – dust PM 10, Y – Zn (water), AA – pesticide (soil), AB – COD, AC – Cd (water).

Furthermore, many impact categories have negative values of the environmental burden, stemming from the recycling processes located in the production and transportation module. That means, the production of the gas-electro cooker is advantageous for the environment, with respect to these impact categories. For example, impact of pesticides on the soil environment has an overall positive value (impact category “pesticide soil”). This is also true for the Chemical Oxygen Demand category (COD), zinc, or release of the heavy metals (cadmium and mercury).

Very interesting are the results of the normalization. According to the Ecopoints 97 methodology, only the emission of the CO₂ has a considerable impact on the environment. The environmental burden in other categories is neglectable (fig. 4.11). In the category of CO₂ emission, one should

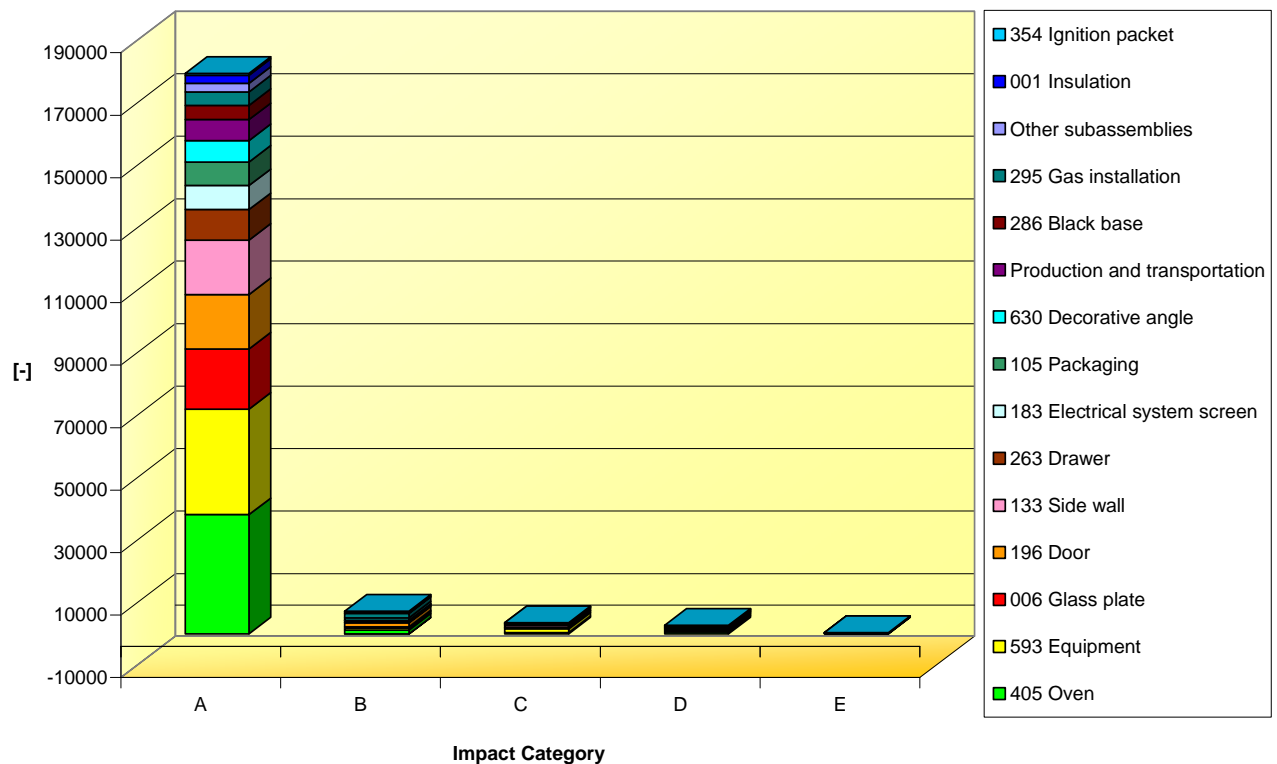


Figure 4.11 Normalization results, Ecopoints 97 method. Impact categories: A – CO₂, B – waste, C – SO_x, D – energy, E – NO_x. Impact calculated for other impact categories was negligible.

take into consideration oven, equipment, glass plate, door, side walls as the elements causing the highest environmental burden.

Interesting fact may be observed after application of the weighing factors in the Ecopoints method. More explicitly, weighting changes the rank of the impact categories with the highest environmental burden (fig. 4.12). Here, the SO_x emissions play the significant role in the overall burden. However, the CO₂ and NO_x emissions have to be also considered.

The single score results (fig. 4.13) may be seen as a good summary of results for the Ecopoints 97 method. As one can see, the highest environmental burden is caused by the equipment, oven, side walls, and glass plate. One should consider the emissions of SO_x, CO₂, and NO_x as having the most important consequences for the natural environment. The recycling processes applied in the production and transportation module are of a smaller importance for the overall result.

The network diagrams presented in Appendix VIII section 3 underline that the materials causing the highest environmental burden are: steel high alloy and austenitic steel. In some cases, the electricity production have to be also considered.

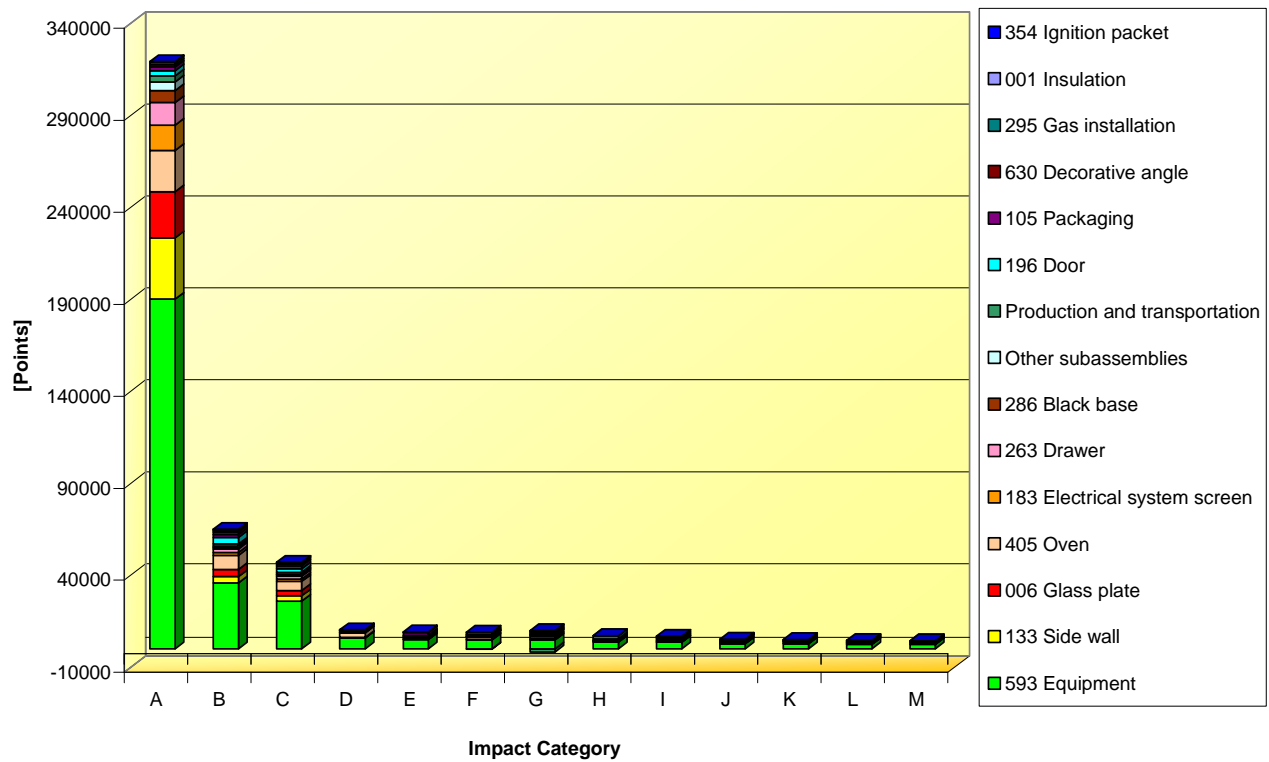


Figure 4.12 Weighting results, Ecopoints 97 method. Impact categories: A – SO_x, B – CO₂, C – NO_x, D – Cd (air), E – NMVOC, F – HRAD, G – dust (PM 10), H – N, I – waste, J – Cu (water), K – energy, L – LMRAD, M – P. Impact calculated for other impact categories was negligible.

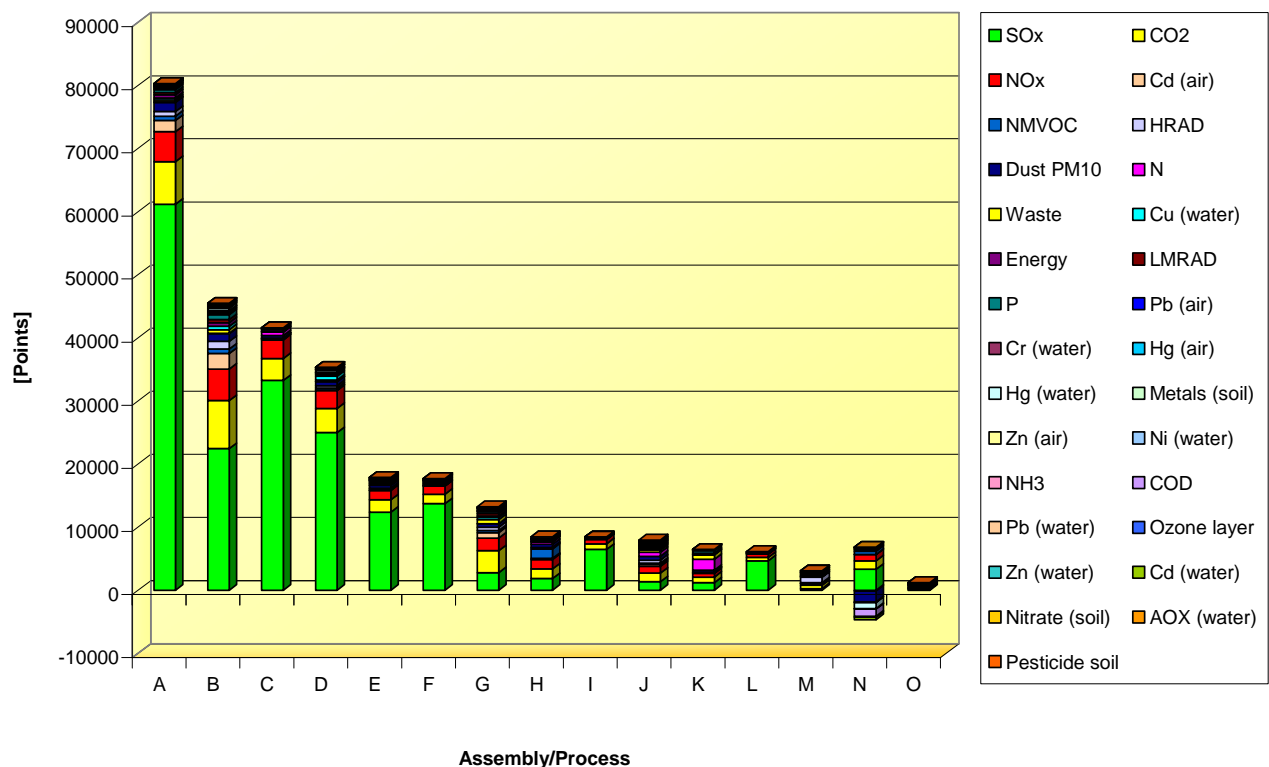


Figure 4.13 Single score results, the Ecopoints 97 method. Assemblies/Processes: A – 593 Equipment, B – 405 Oven, C – 133 Side wall, D – 006 Glass plate, E – 263 Drawer, F – 183 Electrical system screen, G – 196 Door, H – 105 Packaging, I – 286 Black base, J – 630 Decorative angle, K – 295 Gas installation, L – Other subassemblies, M – 001 Insulation, N – Production and transportation, O – 354 Ignition packet.

4.3.4 EDIP/UMIP

Fig. 4.14 to 4.17 illustrate the modelling results according to the EDIP/UMIP methodology. As one can see, recycling processes inside the module production and transportation lower the overall negative impact of the product on the environment.

The characterisation modelling phase proves that the oven, equipment, glass plate, door and side walls contribute to the largest part of the environmental burden generated. However, for the impact categories radioactive waste, ecotoxicity water acute, hazardous waste, human toxicity water and ecotoxicity soil chronic, a part of the burden is balanced by the positive impact of the recycling processes in the production and transportation module. The product impact in the category of ecotoxicity soil chronic category may be even characterized by the overall positive influence on the environment (fig. 4.14).

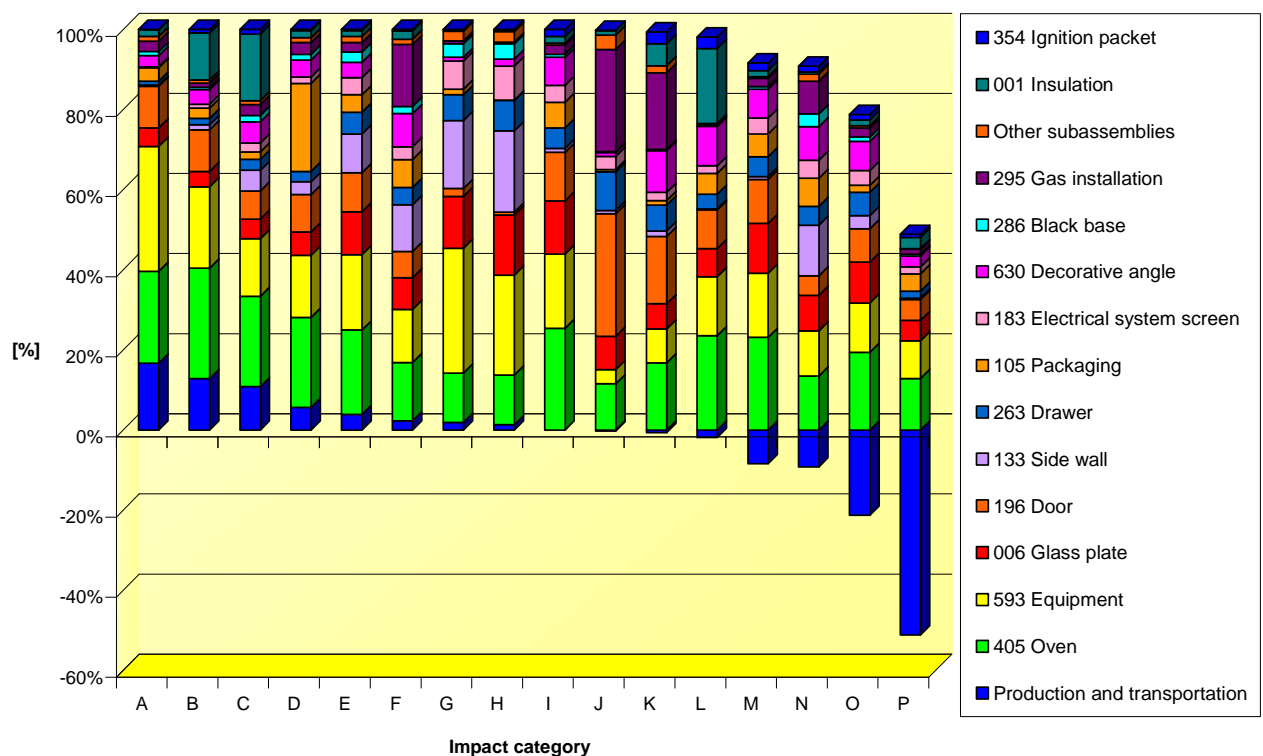


Figure 4.14 Characterization results according to the EDIP/UMIP methodology. Impact categories: A – ozone depletion, B – human toxicity soil, C – human toxicity air, D – photochemical smog, E – Global Warming Potential (GWP 100), F – eutrophication, G – acidification, H – resources (all), I – ecotoxicity water chronic, J – slags/ashes, K – bulk waste, L – radioactive waste, M – ecotoxicity water acute, N – hazardous waste, O – human toxicity water, P – ecotoxicity soil chronic.

As normalization results reveal (fig. 4.15), the gas-electro cooker causes the highest environmental load in the impact categories of ecotoxicity water chronic, ecotoxicity water acute, human toxicity soil, and ecotoxicity soil chronic. In the last category, however, the positive impact of the production and transportation module is well visible. Middle range impact on the environment

occurs in the categories of radioactive waste, acidification, human toxicity water, and the Global Warming Potential 100. The most environmentally unfriendly subassemblies are the oven, equipment, glass plate, door, decorative angle, and packaging.

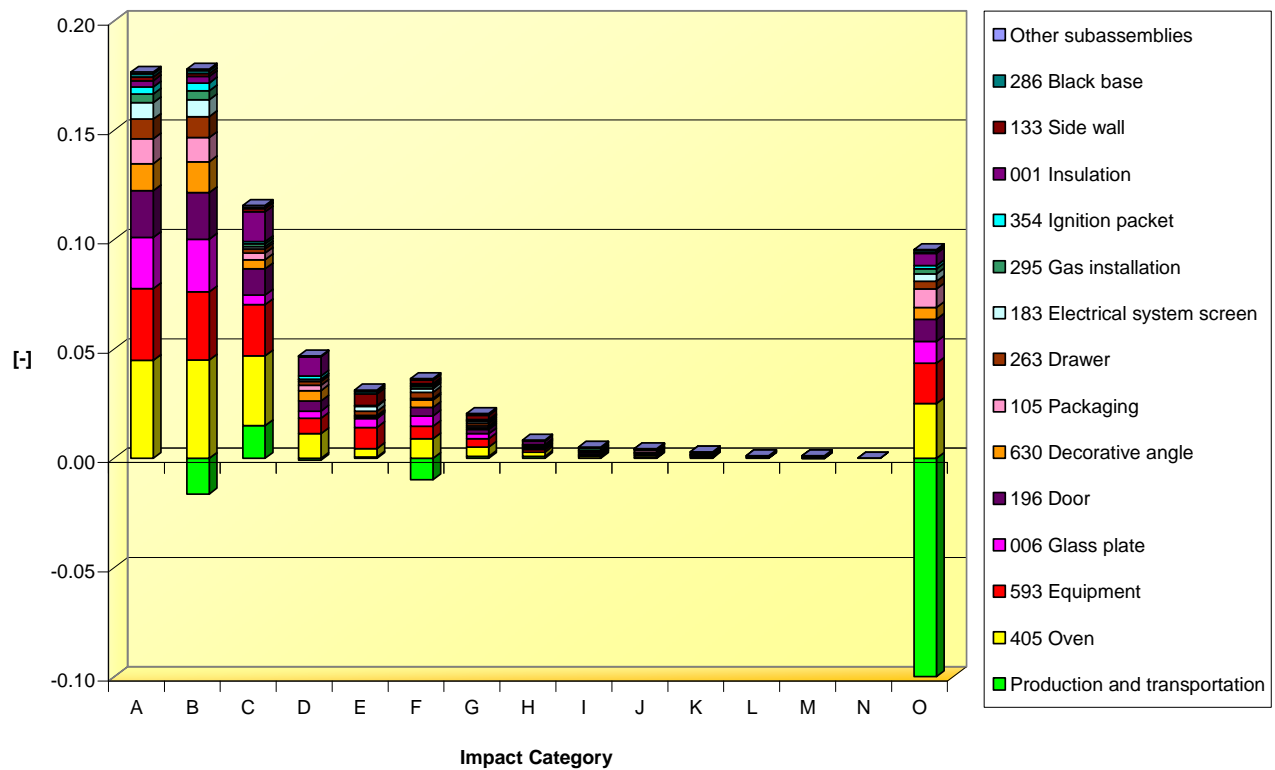


Figure 4.15 Normalization results according to the EDIP/UMIP LCIA. Impact categories: A – ecotoxicity water chronic, B – ecotoxicity water acute, C – human toxicity soil, D – radioactive waste, E – acidification, F – human toxicity water, G – Global Warming Potential GWP 100, H – human toxicity air, I – bulk waste, J – photochemical smog, K – eutrophication, L – slags/ashes, M – hazardous waste, N – ozone depletion, O – ecotoxicity soil chronic.

Weighting results (fig. 4.16) are almost identical with the normalization results. The weighting procedure, however, lowers the results of the impact caused in the category of acidification, radioactive waste, and the Global Warming Potential 100. The calculated impact of the door subassembly is higher than in the normalization phase.

The single score diagram (fig. 4.17) demonstrates the final aggregated values of the environmental load for each specific subassembly of the electro-gas cooker. In total, the highest burden is associated with oven, equipment, door, and glass plate. Other subassemblies possess moderate to low impact on the overall results. The production and transportation module has an overall positive influence on the environment due to the recycling processes of ferro metals.

Network diagrams in section 4 of the Appendix VIII illustrate allocation of environmental burden with respect to the specific subassemblies and materials used. As one can see, steel low and high alloyed, float glass, sheet rolling process, as well as austenitic steel and electricity production, are

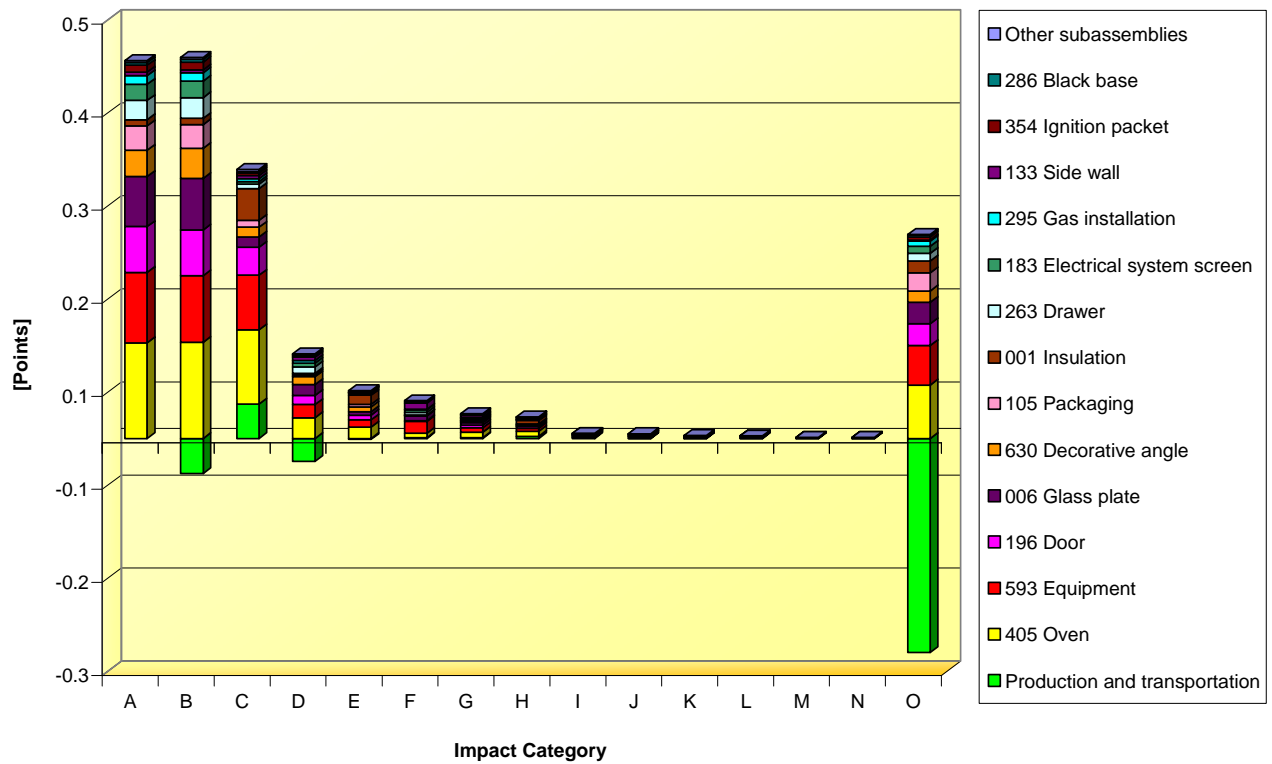


Figure 4.16 Weighting results according to the EDIP/UMIP LCIA. Impact categories: A – ecotoxicity water chronic, B – ecotoxicity water acute, C – human toxicity soil, D – human toxicity water, E – radioactive waste, F – acidification, G – Global Warming Potential GWP 100, H – human toxicity air, I – bulk waste, J – photochemical smog, K – eutrophication, L – ozone depletion, M – slags/ashes, N – hazardous waste, O – ecotoxicity soil chronic.

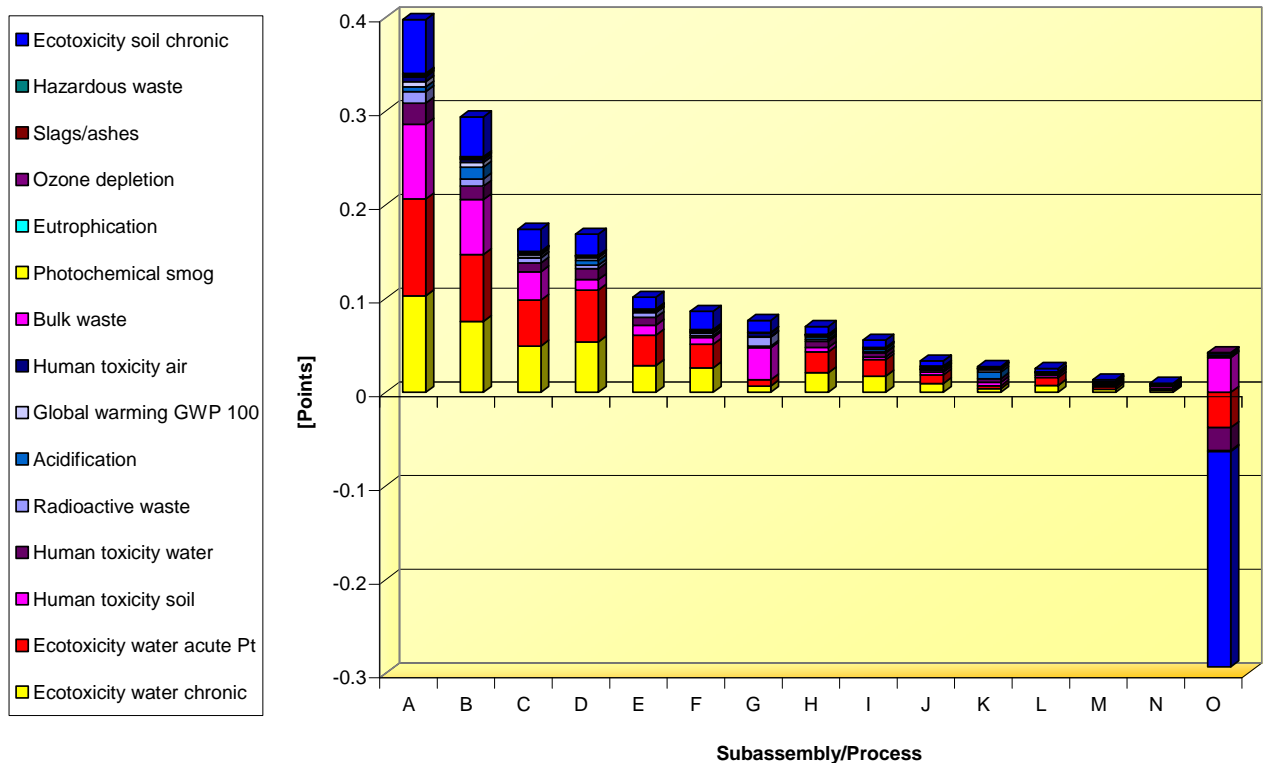


Figure 4.17 Single score results, EDIP/UMIP methodology. Subassemblies and processes: A – 405 Oven, B – 593 Equipment, C – 196 Door, D – 006 Glass plate, E – 630 Decorative angle, F – 105 Packaging, G – 001 Insulation, H – 263 Drawer, I – 183 Electrical system screen, J – 295 Gas installation, K – 133 Side wall, L – 354 Ignition packet, M – 286 Black base, N – Other subassemblies, O – Production and transportation.

responsible for the majority of the environmental burden. This burden may be minimised by recycling of ferro metals scrap.

4.3.5 Eco-Indicator 99

The Eco-Indicator LCIA method is the most comprehensive way to assess the product's environmental load. It consists of characterisation (fig. 4.18), damage assessment (fig. 4.19), normalization (fig. 4.20), weighting (fig. 4.21), and single score (fig. 4.22) steps.

As characterization results demonstrate, one should take into consideration the environmental burden coming from the oven, equipment, door, and decorative angle. They contribute to around 50-70% of the overall environmental burden of the product. For the impact categories carcinogens and land use, some avoided impact has been calculated with respect to the recycling processes used in the production and transportation module.

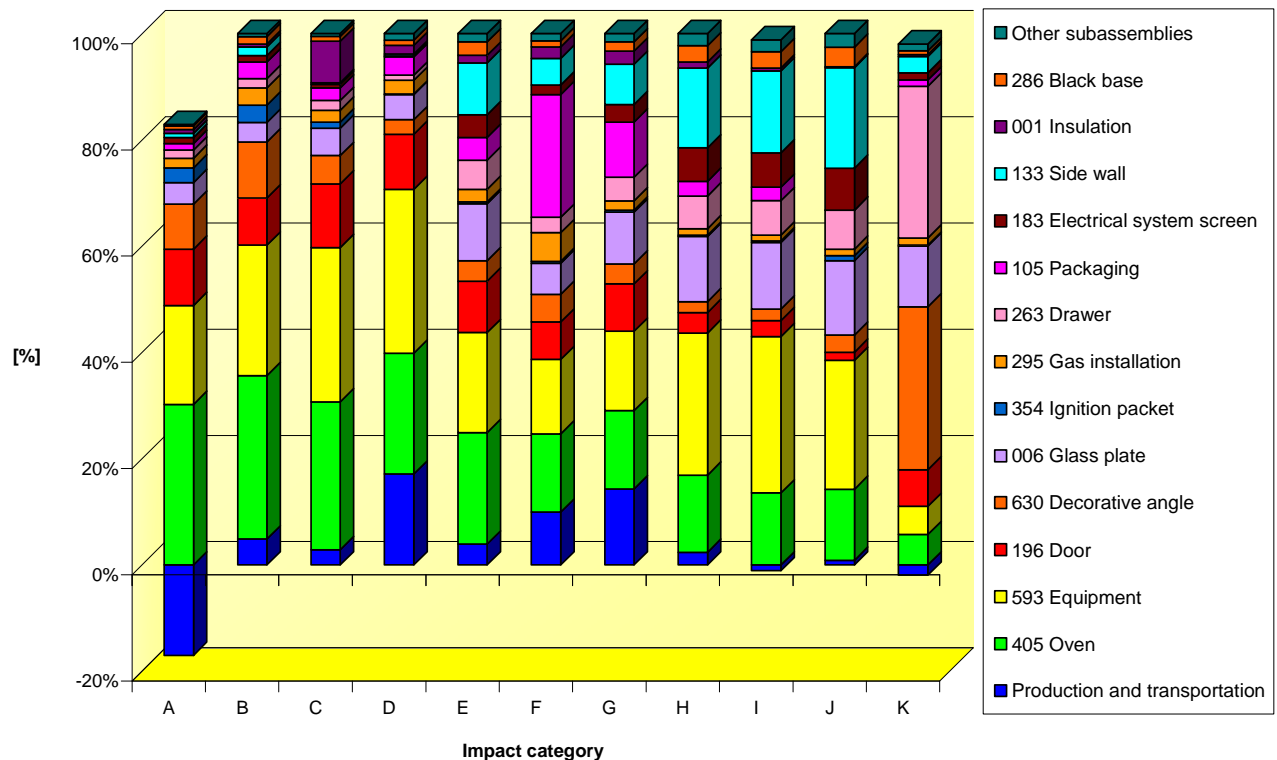


Figure 4.18 Characterization results, Eco-Indicator 99, hierarchist normalization set, average weighting set (H/A). Impact categories: A – carcinogens, B – ecotoxicity, C – radiation, D – ozone layer, E – climate change, F – respiratory organics, G – fossil fuels, H – acidification/eutrophication, I – respiratory inorganics, J – minerals, K – land use.

The aggregation of the characterization results into three damage categories leads to the damage assessment results (fig. 4.19). The positive influence from the recycling processes is minimized in comparison to the characterization. The main burden-causing subassemblies are again oven, equipment, door, and decorative angle. Additionally, burden stemming from drawer and the

production and transportation modules is highlighted for ecosystem quality and resources categories, respectively.

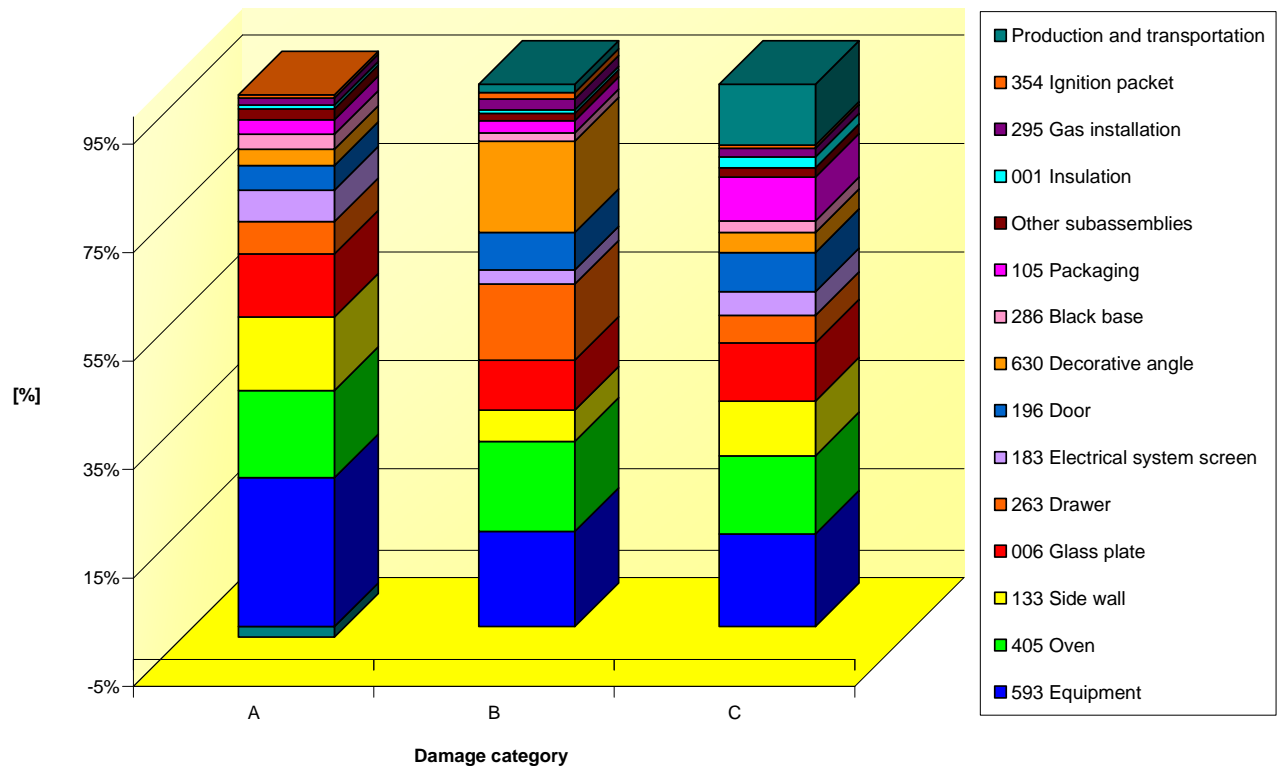


Figure 4.19 Damage assessment, Eco-Indicator 99, hierarchist normalization set, average weighting set (H/A). Damage categories: A – human health, B – ecosystem quality, C – resources.

Normalization results (fig. 4.20) reveal that the magnitude of the environmental burden is the highest in the damage category of resources. Human health may not be, however, omitted. In comparison to the resources and human health, damage to the ecosystem quality is of minor importance for the overall result.

From weighting results (fig. 4.21) one may conclude, that environmental impact is the highest in two impact categories, namely respiratory inorganics and the fossil fuels. Minerals, climate change, land use, ecotoxicity, carcinogens, and acidification/eutrophication do not create very high amounts of environmental load. However, we may not ignore them in the discussion – in total, they influence the result significantly. Radiation, respiratory organics, and ozone layer depletion do not have any importance for the results. According to the weighting results, equipment, oven, side walls, and glass plate are responsible for the biggest part of the environmental load.

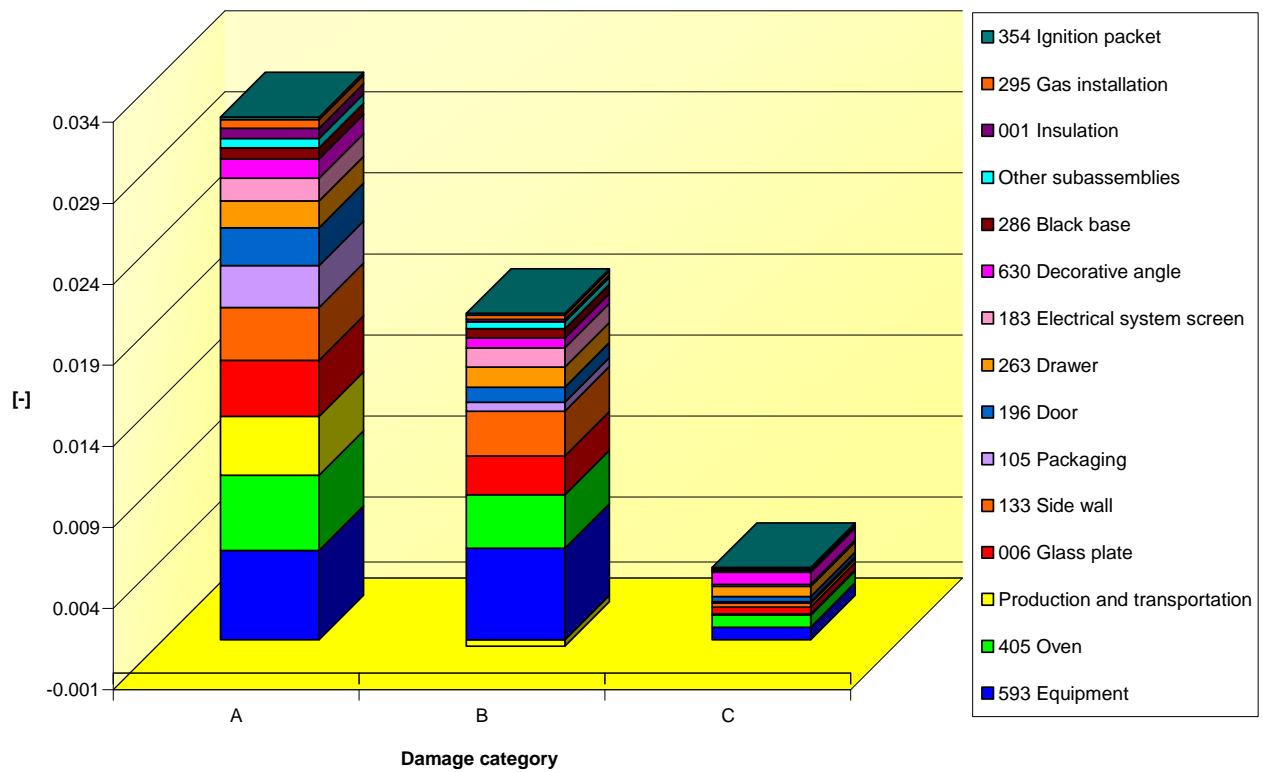


Figure 4.20 Normalization, Eco-Indicator 99, hierarchist normalization set, average weighting set (H/A). Damage categories: A – resources, B – human health, C – ecosystem quality.

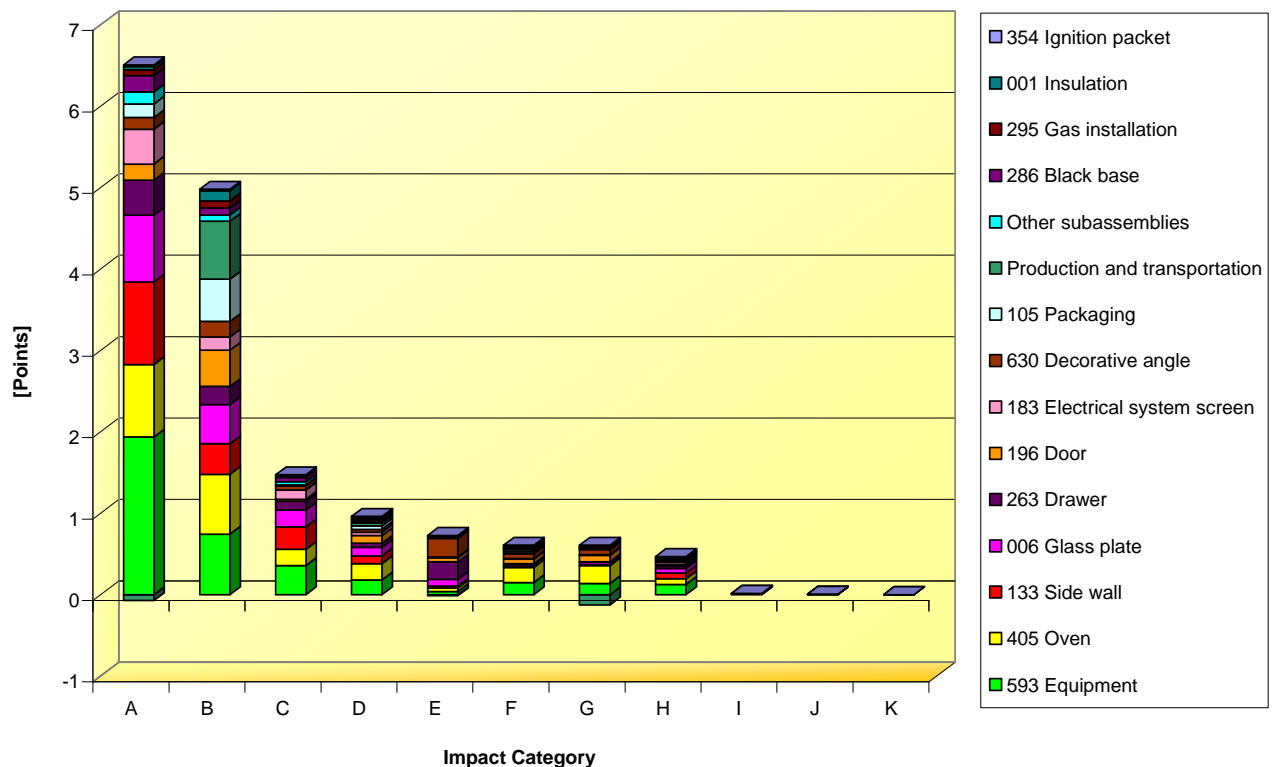


Figure 4.21 Weighting, Eco-Indicator 99, hierarchist normalization set, average weighting set (H/A). Impact categories: A – respiratory inorganics, B – fossil fuels, C – minerals, D – climate change, E – land use, F – ecotoxicity, G – carcinogens, H – acidification/eutrophication, I – radiation, J – respiratory organics, K – ozone layer.

Single score results (fig. 4.22) underline the previous findings with respect to the most important damage categories and damage-causing subassemblies. Network diagrams in section 5 of Appendix VIII show, that the materials causing highest environmental damage are steel low and high alloy, austenitic steel, polystyrene, polyethylene, cleaning agent, natural gas, nickel, glass fibre, and energy production. For some environmental aspects, one should take into consideration wastewater treatment processes.

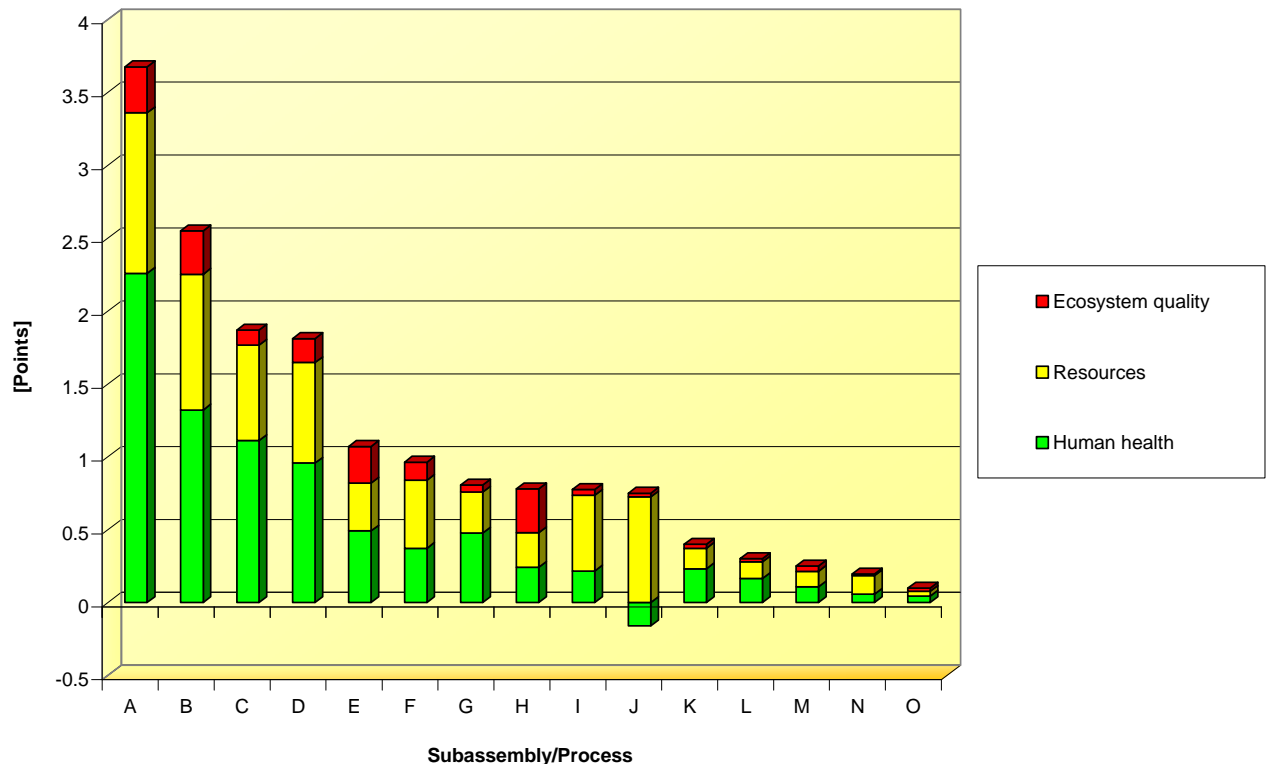


Figure 4.22 Single score, Eco-Indicator 99, hierarchist normalization set, average weighting set (H/A). Subassemblies/Processes: A – 593 Equipment, B – 405 Oven, C – 133 Side wall, D – 006 Glass plate, E – 263 Drawer, F – 196 Door, G – 183 Electrical system screen, H – 630 Decorative angle, I – 105 Packaging, J – Production and transportation, K – 286 Black base, L – Other subassemblies, M – 295 Gas installation, N – 001 Insulation, O – 354 Ignition packet.

4.3.6 EPS 2000

Fig. 4.23 to 4.26 demonstrate the modelling results from different phases of the LCIA calculation according to the EPS methodology. As one can see, for most of the impact categories, the damage is created by production and transportation module, equipment, oven, and glass plate.

In characterization modelling step (fig. 4.23), the values for impact categories fish and meat production and wood growth capacity values are negative. That means, that theoretically the production of cooker helps to avoid environmental damage in these categories. In reality, the negative values come from computational error of SimaPro, associated with small values of numbers (compare fig. 4.24 and 4.25). The error becomes clear, when analyzing the network diagrams in Appendix VIII. The SimaPro software calculated the overall reduction of the

environmental impact stemming from the production of i.e. float glass. This fact is confirmed with the help of green “thermometer” bar in the float glass node (compare the network diagram for the damage assessment step). However, the production of glass creates the environmental damage. Summarizing, the values calculated for the impact categories fish and meat production and wood growth capacity were correct, only the sign should be different.

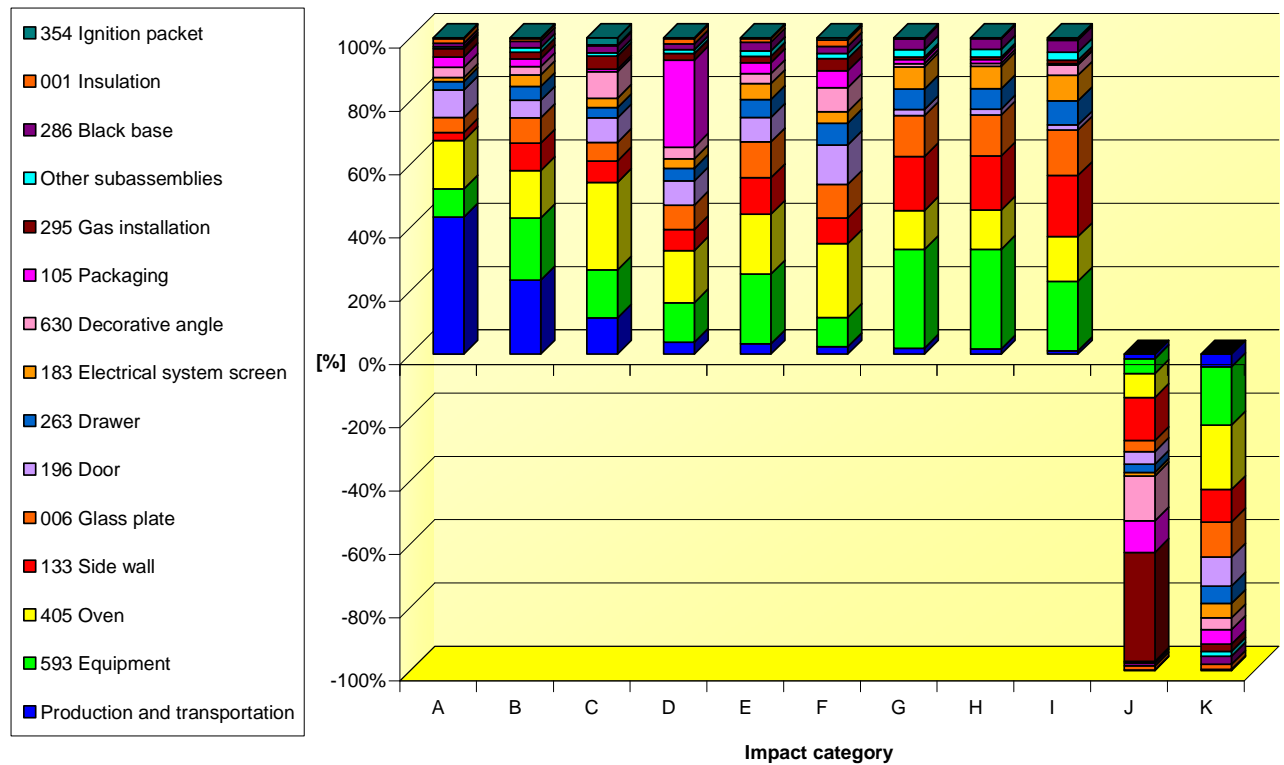


Figure 4.23 Characterization results, the EPS 2000 method. Impact categories: A – severe morbidity, B – life expectancy, C – severe nuisance, D – crop growth capacity, E – morbidity, F – species extinction, G – soil acidification, H – nuisance, I – depletion of reserves, J – fish and meat production, K – wood growth capacity.

In the damage assessment, results of the characterization step are aggregated into more general damage categories (fig. 4.24). For example, above-mentioned categories of fish and meat production and wood growth capacity are aggregated into one single damage category, called ecosystem production capacity. The results with respect to the most environmentally unfriendly subassemblies are similar to those obtained in the characterization step. The environmental impact is created mainly by the production and transportation, as well as equipment, oven, side walls, and the glass plate.

As weighting results (fig. 4.25) reveal, the ecosystem production capacity and biodiversity damage categories do not have any importance for the overall product impact. As one can see, majority of the damage is caused in the category of abiotic stock resource. Very small damage is obtained for the category human health.

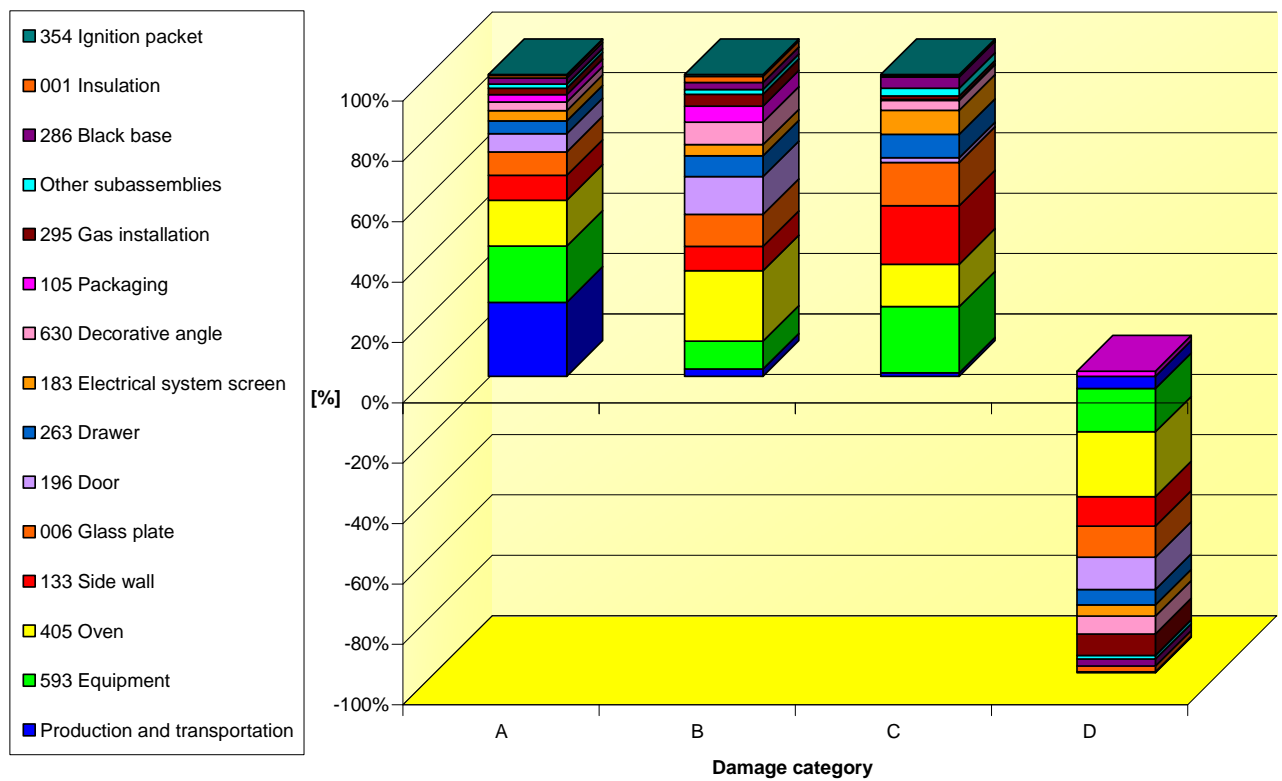


Figure 4.24 Damage assessment results, the EPS 2000 method. Damage categories: A – human health, B – biodiversity, C – abiotic stock resource, D – ecosystem production capacity.

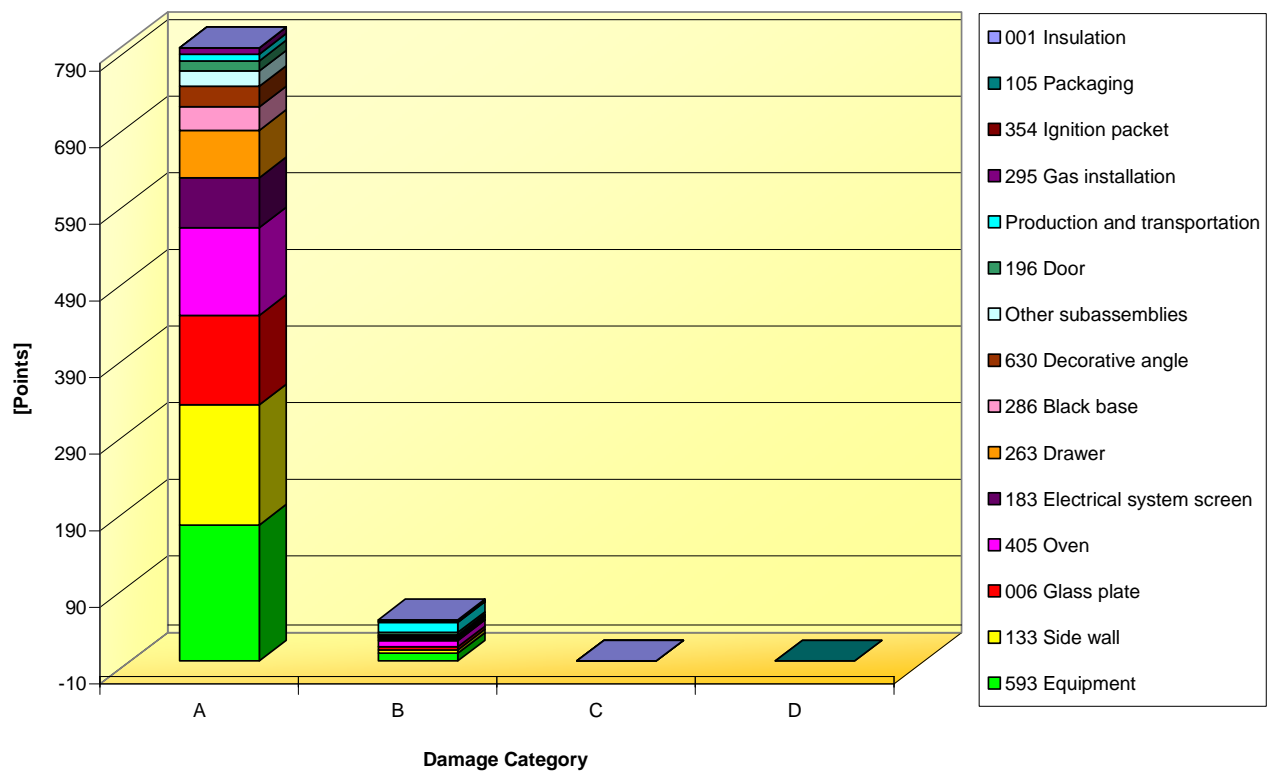


Figure 4.25 Weighting results, the EPS 2000 method. Damage categories: A – abiotic stock resource, B – human health, C – biodiversity, D – ecosystem production capacity.

Division of the weighting results and presenting them in the form of bars for each specific subassembly used gives the single score diagram (fig. 4.26). It is easily visible that considerable impact on the environment occurs only in the impact category of depletion of reserves. Environmental damage in the remaining categories is of minor importance.

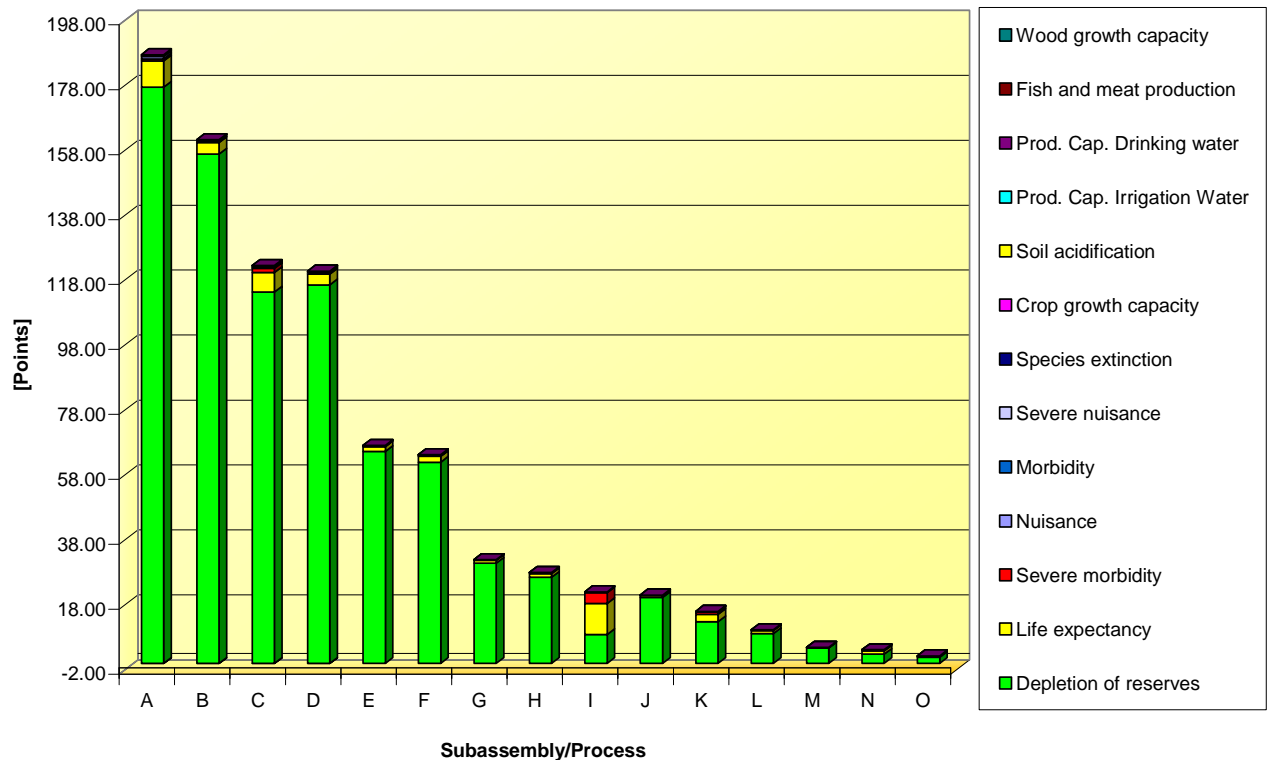


Figure 4.26 Single score results, the EPS 2000 method. Subassemblies/Processes: A – 593 Equipment, B – 133 Side wall, C – 405 Oven, D – 006 Glass plate, E – 183 Electrical system screen, F – 263 Drawer, G – 286 Black base, H – 630 Decorative angle, I – Production and transportation, J – Other subassemblies, K – 196 Door, L – 295 Gas installation, M – 354 Ignition packet, N – 105 Packaging, O – 001 Insulation.

As for all network diagrams, one has to consider steels high and low alloy, austenitic steel, energy production, and float glass, as the materials and processes causing the highest environmental burden.

4.3.7 IPCC

The IPCC method performs the calculation only using the characterisation step (fig. 4.27 and fig. 4.28). The results of calculation using three different time spans (20, 100, and 500 years) are very similar. The oven, equipment, glass plate, door, as well as side walls have the highest influence on the final result – both in terms of the percentage and the mass of CO₂ equivalents.

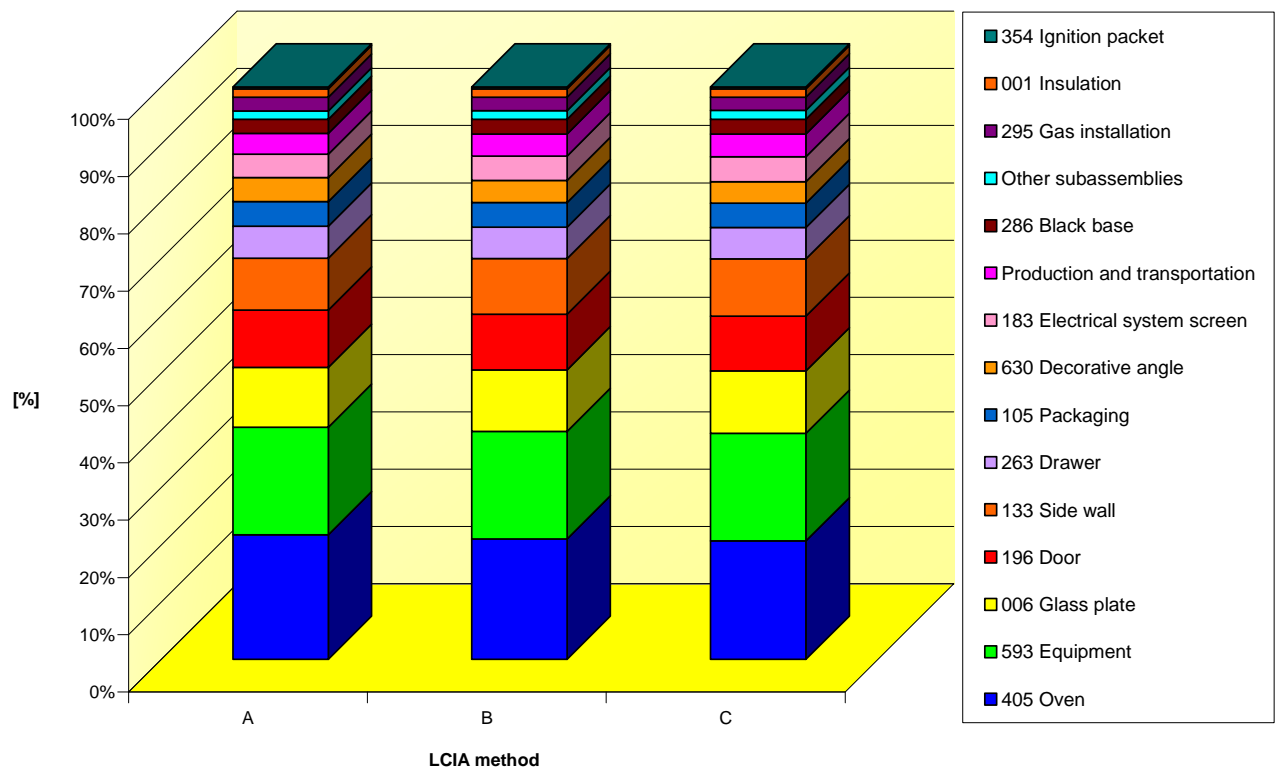


Figure 4.27 Characterization, the IPCC method with 20 (A), 100 (B), and 500 (C) years of time span. Units: percentage.

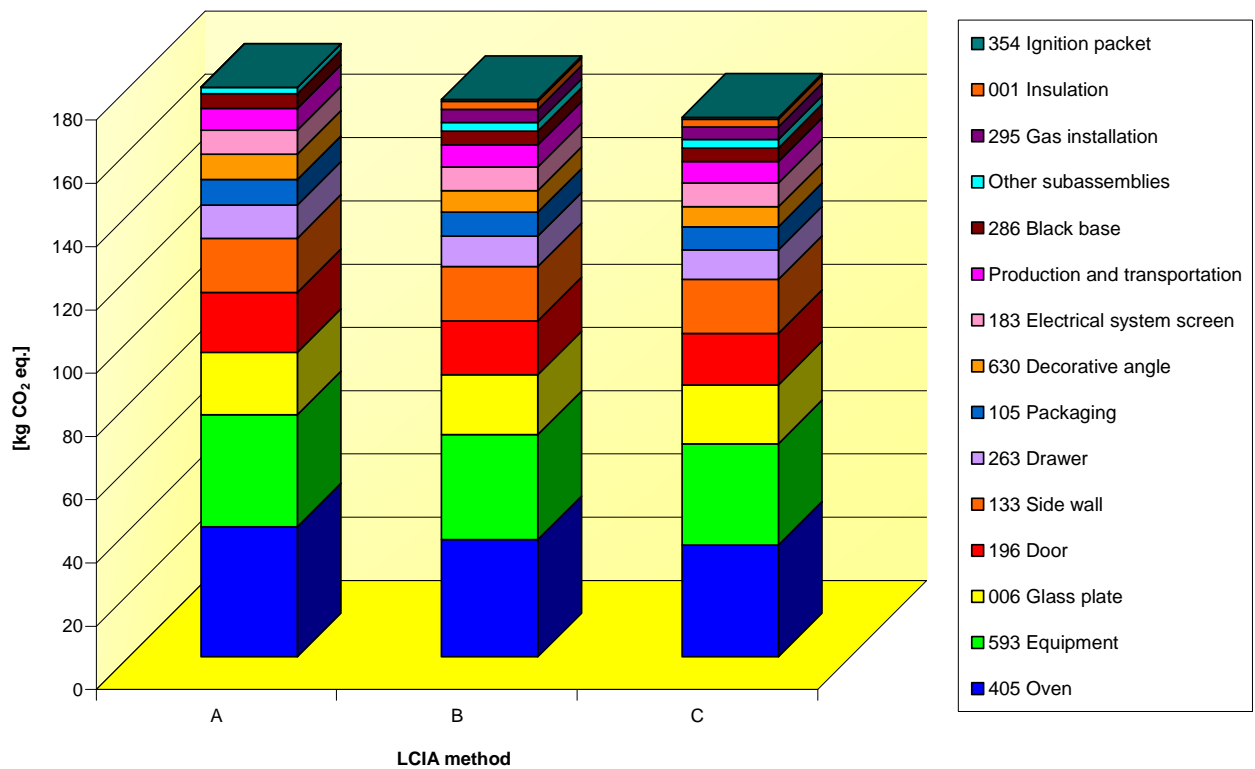


Figure 4.28 Characterization, the IPCC method with 20 (A), 100 (B), and 500 (C) years of time span. Units: kg CO₂ eq.

The distribution of environmental impact among other subassemblies and process is similar in magnitude. Furthermore, one can notice, that the impact on the environment is slightly decreasing with the increasing time span (fig. 4.28). The decrease of environmental burden is most probably due to the regeneration capability of the natural environment after initial disturbance, such as emission of gases.

Network diagrams (Appendix VIII, section 7) for the IPCC method confirm the results from previous LCIA methods, namely the highest environmental burden may be associated with the production of steel high alloy and austenitic steel, float glass, and the generation of energy necessary in the process of steel production.

4.4 Modelling results SimaPro – cooker with EoL and with use phase

4.4.1 CML 2.03 baseline 2000

The results of the LCA modelling for the cooker including the realistic End-of-Life (recycling and landfilling) and the use phase according to the CML 2000 method are presented in fig. 4.29 and 4.30 and in section 1 of the Appendix IX.

According to the characterization results (fig. 4.29), chiefly the cooker itself, preparation of cakes and desserts, beverages, and main courses, cause the major part of the environmental burden. Only slight impact is stemming from the EoL processes and preparation of soups.

In the normalization step, the prevailing burden is created in the category of marine aquatic ecotoxicity (fig. 4.30). Most of this burden may be associated with the baking of cakes and preparation of desserts. In other impact categories (acidification, fresh water aquatic ecotoxicity, abiotic depletion, global warming, eutrophication or ozone layer depletion), the environmental burden is very small or even neglectable. Preparation of other meals and the production of the cooker itself cause very small environmental load. The positive impact on the environment from the recycling processes is not greater than 5 % of the total environmental burden.

As one can see in the network diagrams, from the life-cycle perspective, the main environmental load is stemming from the generation of electricity and the natural gas combustion. Electricity generation causes higher impact than natural gas combustion. For the normalization network diagram, one should take into consideration also impacts from the production of steel high alloyed (section 1, Appendix IX).

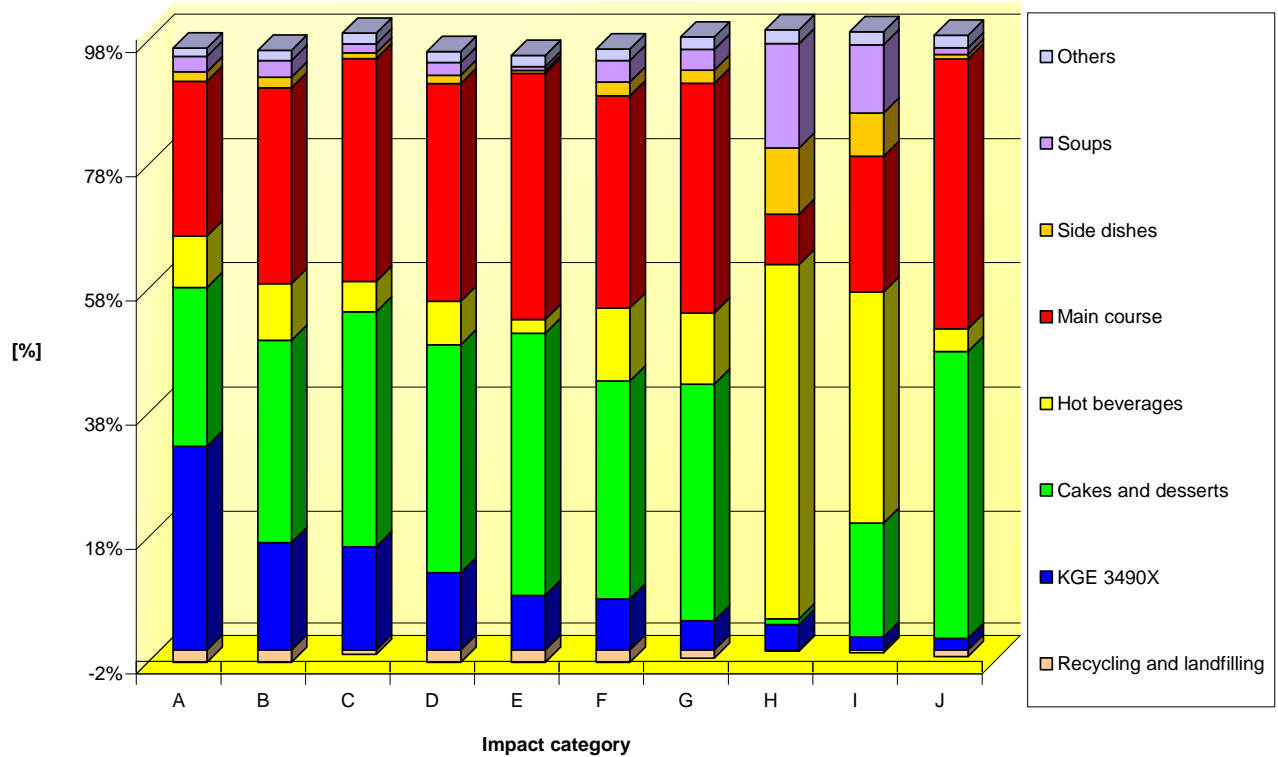


Figure 4.29 Characterization results, the CML 2 2000 method. Impact categories: A – human toxicity, B – photochemical oxidation, C – acidification, D – terrestrial ecotoxicity, E – fresh water aquatic ecotoxicity, F – eutrophication, G – global warming (GWP 100), H – ozone layer depletion (ODP), I – abiotic depletion, J – marine aquatic ecotoxicity.

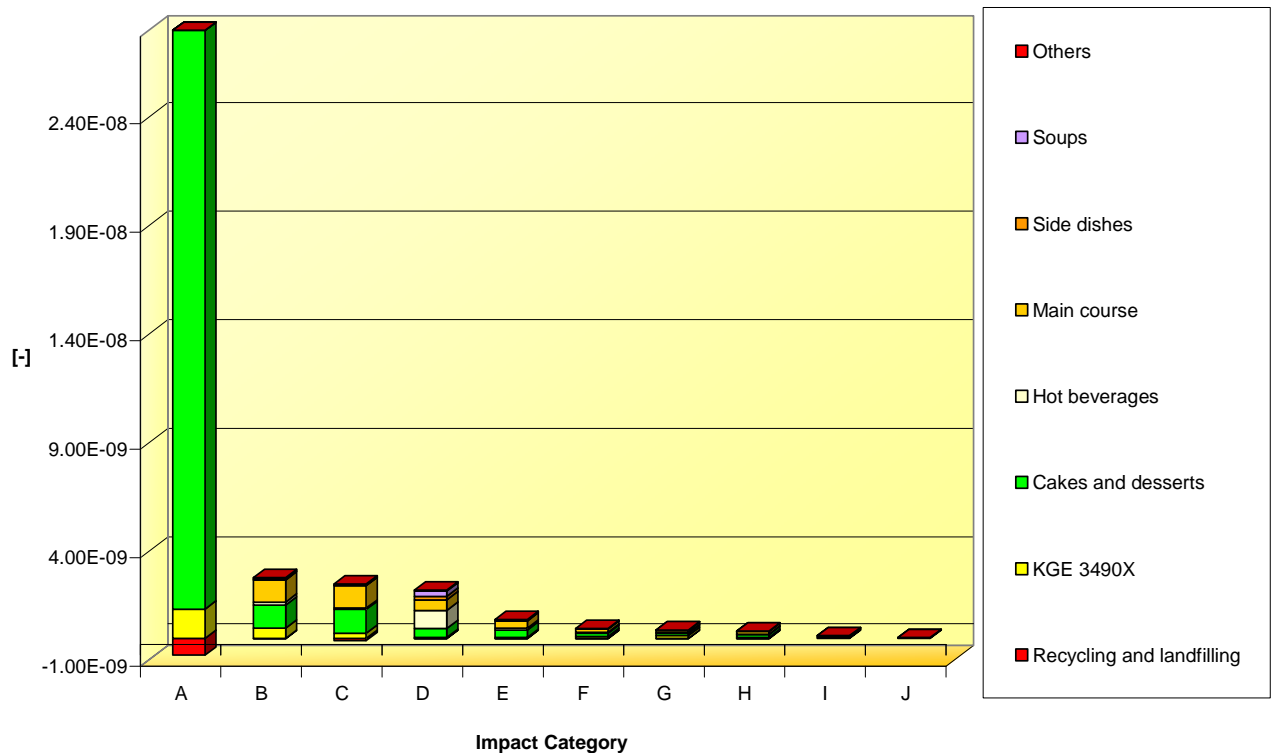


Figure 4.30 Normalization results, the CML 2 2000 method. Impact categories: A – marine aquatic ecotoxicity, B – acidification, C – fresh water aquatic ecotoxicity, D – abiotic depletion, E – global warming, F – photochemical oxidation, G – human toxicity, H – terrestrial ecotoxicity, I – eutrophication, J – ozone layer depletion.

4.4.2 Cumulative Energy Demand

Fig. 4.31 to 4.33 and network diagrams in section 2 of the Appendix IX illustrate the results of the cooker LCA according to the CED methodology.

The characterization results (fig. 4.31) vary with respect to the impact category. I.e. for the renewable energy from water power plants, the highest impact is stemming from the cooker itself (35% of the total environmental damage). Hot beverages and main course are also significant for the overall result.

Quite different are the results for the non-renewable, fossil energy sources. Here, hot beverages cause almost 50% of the total environmental load. Cakes and desserts, main course, and soups are also important for the total result. The cooker itself has an ignorable impact on the overall burden generated.

For all impact categories, the recycling processes contribute to the minimisation of the environmental impact. The magnitude of this minimisation is, however, very small, up to 5% of the overall result.

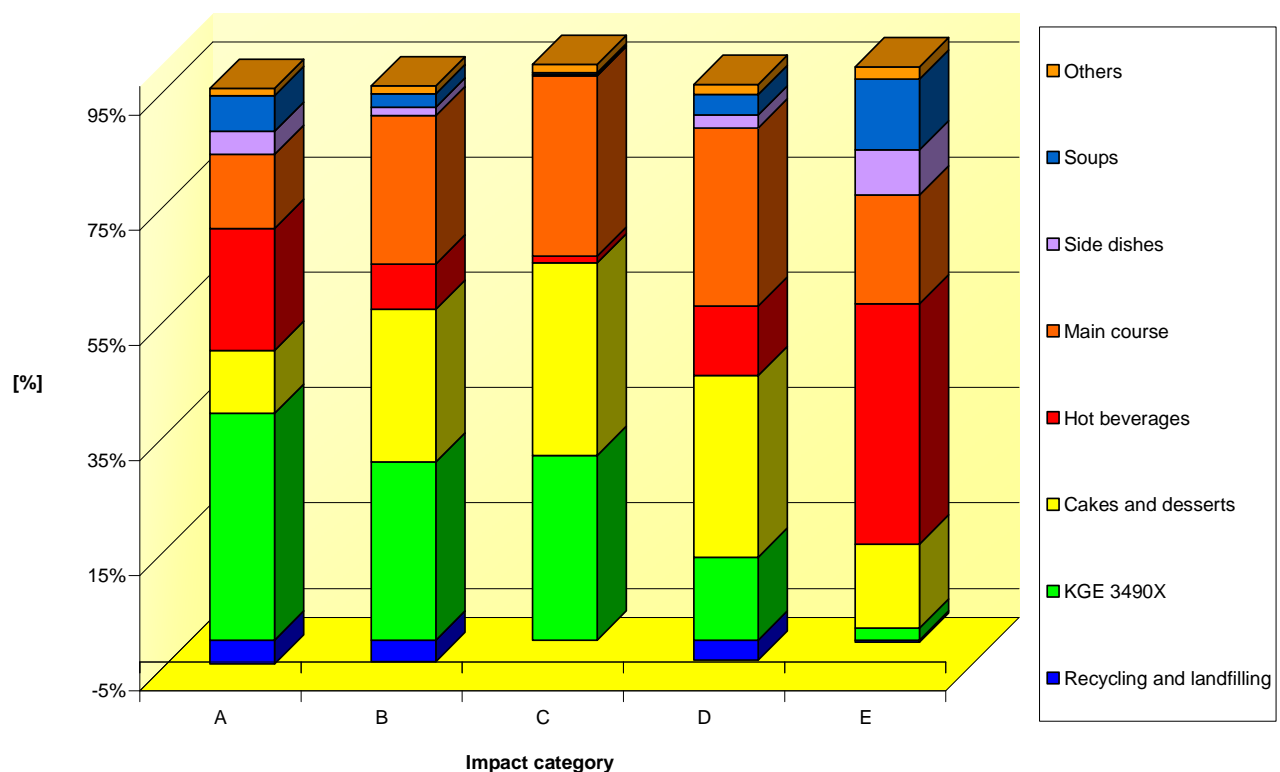


Figure 4.31 Characterization results, the Cumulative Energy Demand. Impact categories: A – renewable, water; B – non-renewable, nuclear; C – renewable, biomass; D – renewable, wind, solar, geothermal; E – non-renewable, fossil.

The weighing results (fig. 4.32) reveal that the highest impact is caused by the non-renewable energy generation. The impacts from the generation of other energy sources may be neglected.

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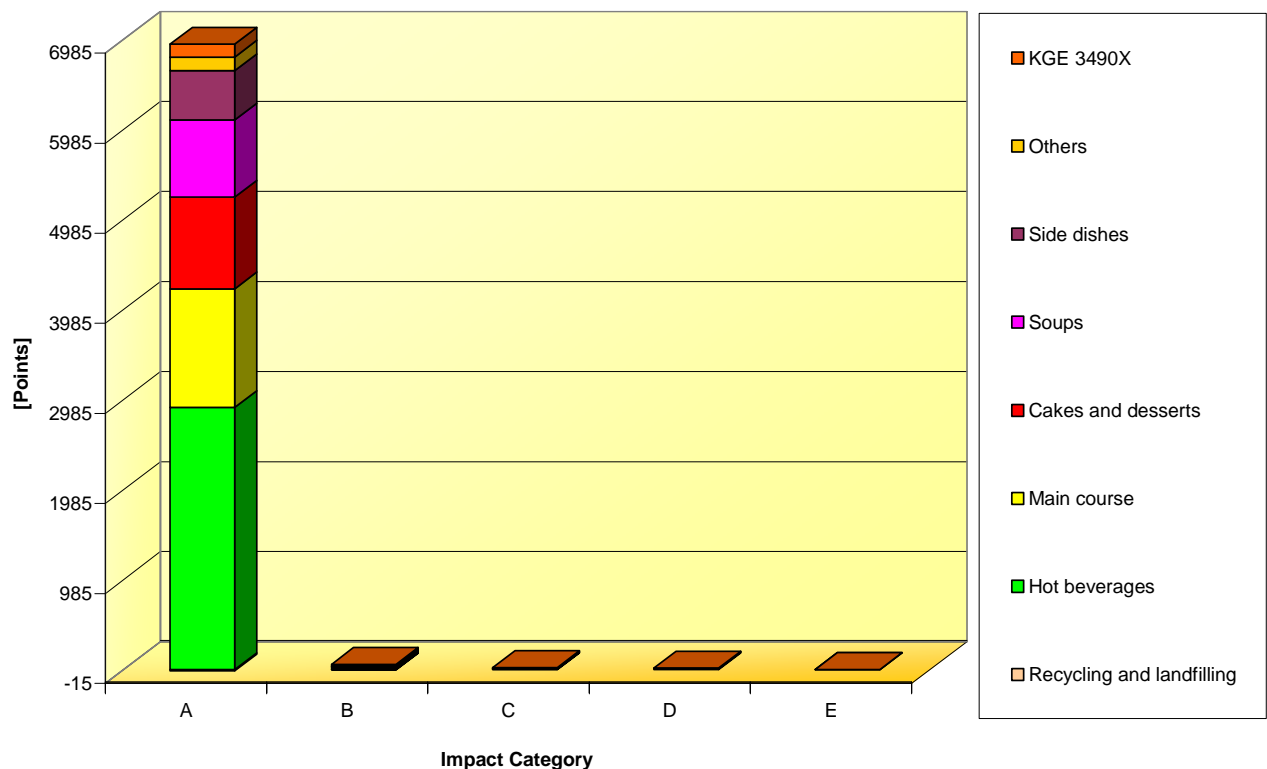


Figure 4.32 Weighting results, the Cumulative Energy Demand. Impact categories: A – non-renewable, fossil; B – non-renewable, nuclear; C – renewable, water; D – renewable, biomass; E – renewable, wind, solar, geothermal.

Fig. 4.33 shows the single score results according to the CED methodology. As one can see, most of the burden may be allocated to the non-renewable, fossil energy generation.

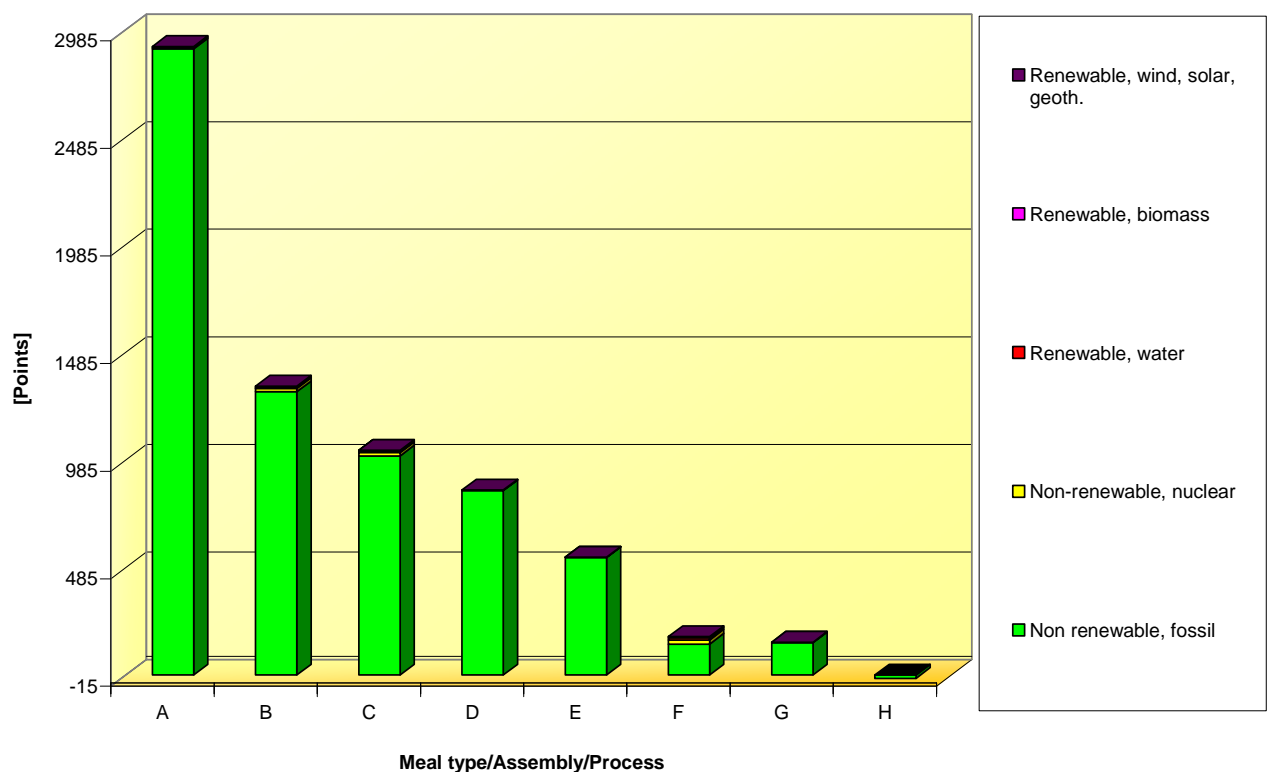


Figure 4.33 Single score results, the Cumulative Energy Demand. Meal type/assembly/process: A – hot beverages, B – main course, C – cakes and desserts, D – soups, E – side dishes, F – KGE 3490X, G – others, H – recycling and landfilling.

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preparation of hot beverages causes the highest environmental damage. Preparation of main course, cakes and desserts, side dishes, and soups has smaller impact on the overall result. The cooker itself together with other meals has a very small impact on the environment. The positive effect of the recycling associated with the EoL processes is marginal.

As the network diagrams show, electricity generation from the hard coal and natural gas combustion are responsible for almost entire impact on the environment. However, contrary to the previous LCIA method (namely CML 2000), the impacts associated with the natural gas are much higher than those related to the electricity generation (Appendix IX, section 2).

4.4.3 Ecopoints 97

Fig. 4.34 to 4.37 and Section 3 of the Appendix IX show the results of the modelling according to the Ecopoints 97 methodology.

The Ecopoints 97 method measures the environmental load in many detailed impact categories. According to the characterization results (fig. 4.34), the most of the environmental burden is created

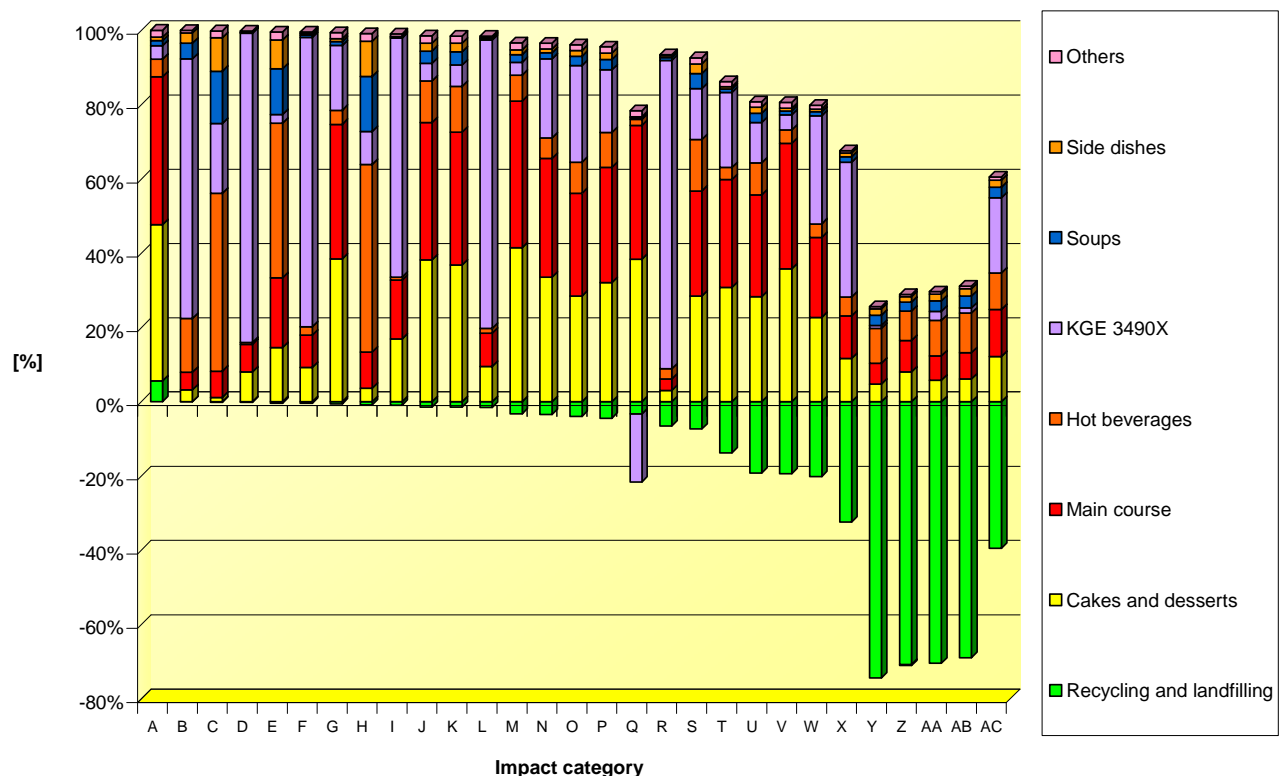


Figure 4.34 Characterization, Ecopoints 97, Recycling and landfilling scenario. Impact categories: A – waste, B – metals (soil), C – ozone layer, D – nitrogen, E – energy, F – AO_x (water), G – SO_x , H – NMVOC, I – nitrate (soil), J – CO_2 , K – NO_x , L – Cd (air), M – Hg (air), N – Zn (air), O – LMRAD, P – HRAD, Q – pesticide soil, R – phosphorus, S – Cr (water), T – NH_3 , U – Ni (water), V – dust PM10, W – Pb (air), X – Cu (water), Y – Cd (water), Z – Zn (water), AA – Hg (water), AB – COD, AC – Pb (water).

by the preparation of cakes and desserts, hot beverages and main course dishes. The recycling processes have minor importance in most of the impact categories. In some of them, however, their positive contribution overbalances the negative impact (i.e. the Chemical Oxygen Demand – COD, or for heavy metals impact on water ecosystems). For most of the impact categories, however, negative impact on the environment may be observed.

Normalization of the results (fig. 4.35) reveals that the highest burden is created by the CO₂ emissions. Waste, energy, and SO_x have a very small impact on the overall result. The impact recorded in other categories is close to zero. Preparation of cakes and desserts, main course dishes, and hot beverages is responsible for more than 80% of the total environmental load.

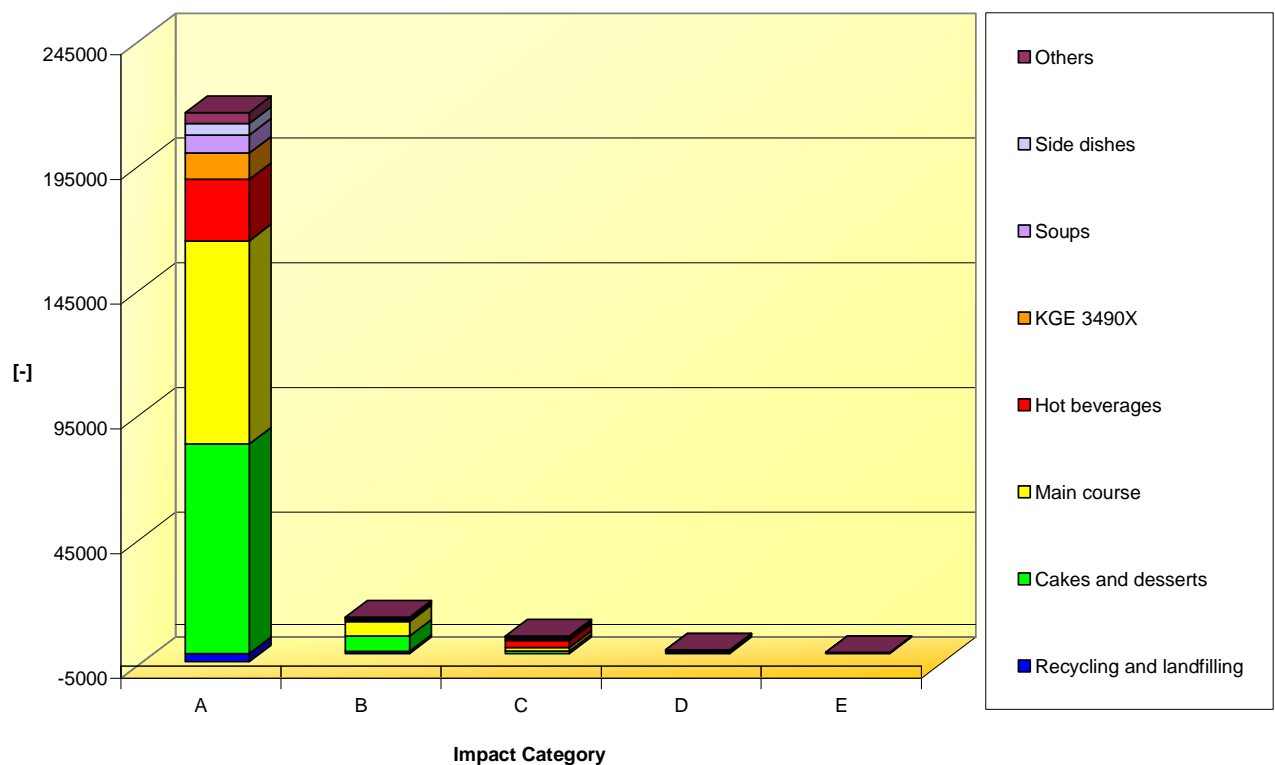


Figure 4.35 Normalization, Ecopoints 97, Recycling and landfilling scenario. Impact categories: A – CO₂, B – waste, C – energy, D – SO_x, E – NO_x. Impact calculated for other impact categories was negligible.

Weighting results resemble those of normalization (fig. 4.36). Nonetheless, SO_x emissions have now the highest importance for the total results. Considerable contribution may be noticed in the categories of CO₂ and NO_x emissions. The environmental impact in other categories is very small or even close to zero. As one can see, cakes and desserts, main course, and the cooker itself have the highest importance for the creation of the environmental load.

Single score results (fig. 4.37) summarize and confirm the previous findings with respect to the impact categories of the highest importance for the final result (SO_x, CO₂ and NO_x emissions), and

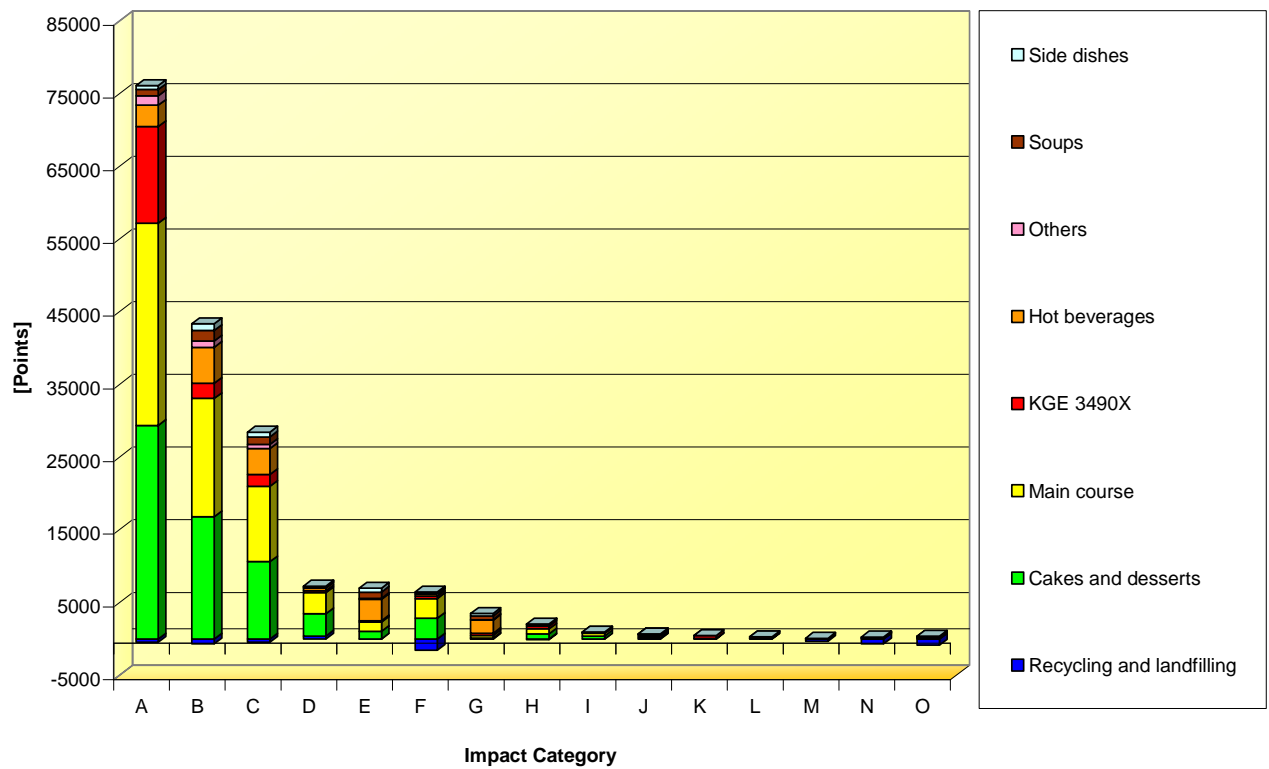


Figure 4.36 Weighting, Ecopoints 97, Recycling and landfilling scenario. Impact categories: A – SO_x, B – CO₂, C – NO_x, D – Waste, E – Energy, F – Dust PM10, G – NMVOC, H – HRAD, I – Hg (air), J – LMRAD, K – Cd (air), L – Nitrogen, M – Cd (water), N – Hg (water), O – COD. Impact calculated for other impact categories was negligible.

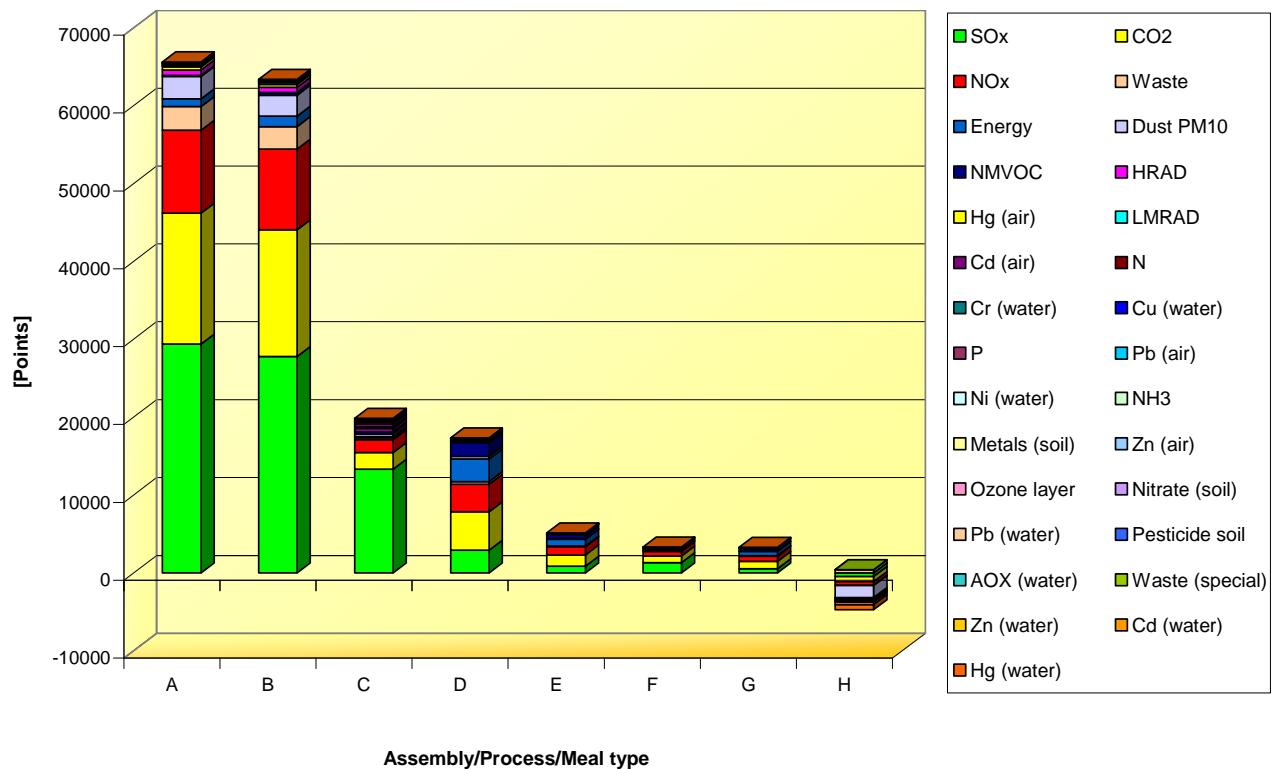


Figure 4.37 Single score, Ecopoints 97, Recycling and landfilling scenario. Assemblies/Processes/Meal types: A – cakes and desserts, B – main course, C – KGE 3490X, D – hot beverages, E – soups, F – others, G – side dishes, H – recycling and landfilling.

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the LCA processes causing the highest environmental load (preparation of cakes and desserts, main course meals, and the production of the cooker).

Finally, the network diagrams in Appendix IX show, that the responsibility for the environmental burden has to be associated with the electricity generation and natural gas production (app. 78% and 18% of the total burden, respectively). One should not omit also the role of the cooker and the burdens related to the production of the high-alloyed steel.

4.4.4 EDIP/UMIP

Fig. 4.38 to 4.41 present the modelling results according to the EDIP/UMIP methodology. Network diagrams may be seen in Section 4 of the Appendix IX.

As for the characterization (fig. 4.38), in most of the impact categories, the environmental damage is associated with the preparation of: cakes and desserts, hot beverages, and the main course. For some impact categories, the damage is minimised by the EoL processes; this is the case for human toxicity air and water, or ecotoxicity water and soil categories.

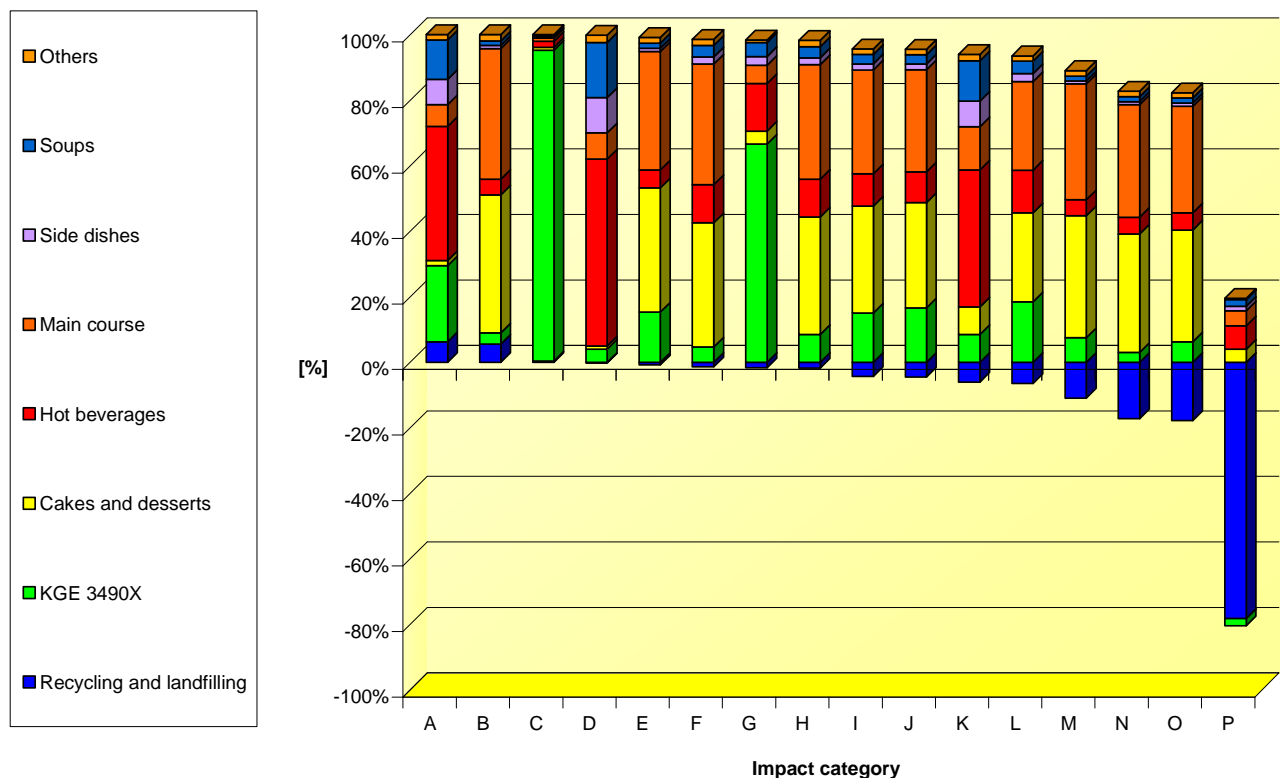


Figure 4.38 Characterization, EDIP/UMIP, Recycling and landfilling scenario. Impact categories: A – hazardous waste, B – bulk waste, C – slags/ashes, D – ozone depletion, E – acidification, F – global warming (GWP 100), G – resources (all), H – eutrophication, I – human toxicity soil, J – radioactive waste, K – photochemical smog, L – human toxicity air, M – ecotoxicity water chronic, N – human toxicity water, O – ecotoxicity water acute, P – ecotoxicity soil chronic.

The normalization results (fig. 4.39) show that the damage occurs in two main impact categories: ecotoxicity water chronic and acute. For some categories (i.e. human toxicity soil and human toxicity water, the Global Warming Potential, or radioactive waste), middle-range impact may be observed. Some impact categories (eutrophication, ozone depletion) have a neglectable impact on the overall result. The minimisation of the impact thanks to the recycling processes in the EoL scenario is up to 10% of the overall impact; however, significant reduction may be observed for the category of ecotoxicity soil chronic. As for the assemblies and meals, which cause the highest burden, one has to mention cakes and desserts, main course, and the gas-electro cooker itself.

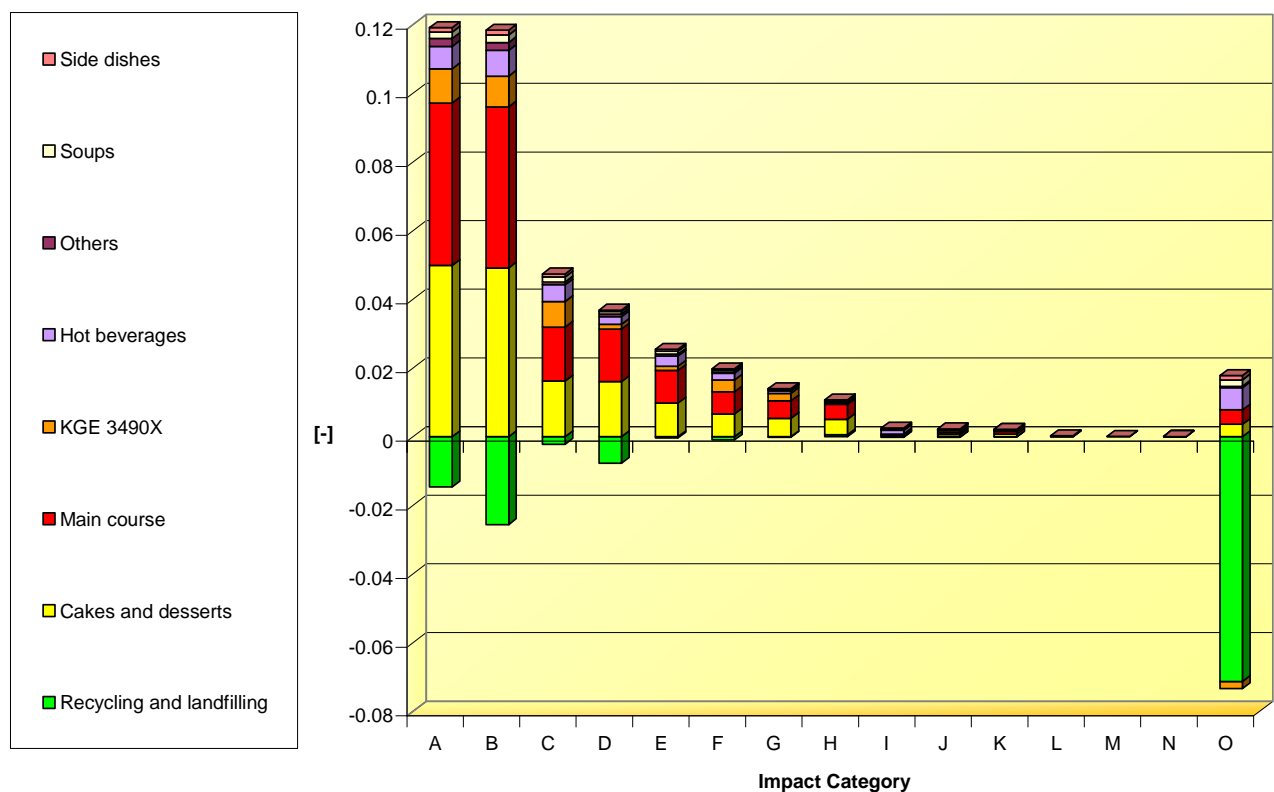


Figure 4.39 Normalization, EDIP/UMIP, Recycling and landfilling scenario. Impact categories: A – ecotoxicity water chronic, B – ecotoxicity water acute, C – human toxicity soil, D – human toxicity water, E – global warming (GWP 100), F – radioactive waste, G – acidification, H – bulk waste, I – photochemical smog, J – human toxicity air, K – eutrophication, L – hazardous waste, M – ozone depletion, N – slags/ashes, O – ecotoxicity soil chronic.

Weighting results (fig. 4.40) are almost identical with the normalization. The main difference is the smaller magnitude of burden in the impact categories of human toxicity soil and human toxicity water, Global Warming Potential, radioactive waste, acidification, or bulk waste.

The diagram for single score according to the EDIP/UMIP methodology (fig. 4.41) underlines the previous statements. The highest burden is caused by the preparation of cakes and desserts and main course dishes. The cooker and hot beverages impact on the overall result is of middle range. Two remaining meal categories: soups and other meals, cause relatively small burden. In all impact categories, the application of the recycling scenario has a positive impact on the environment.

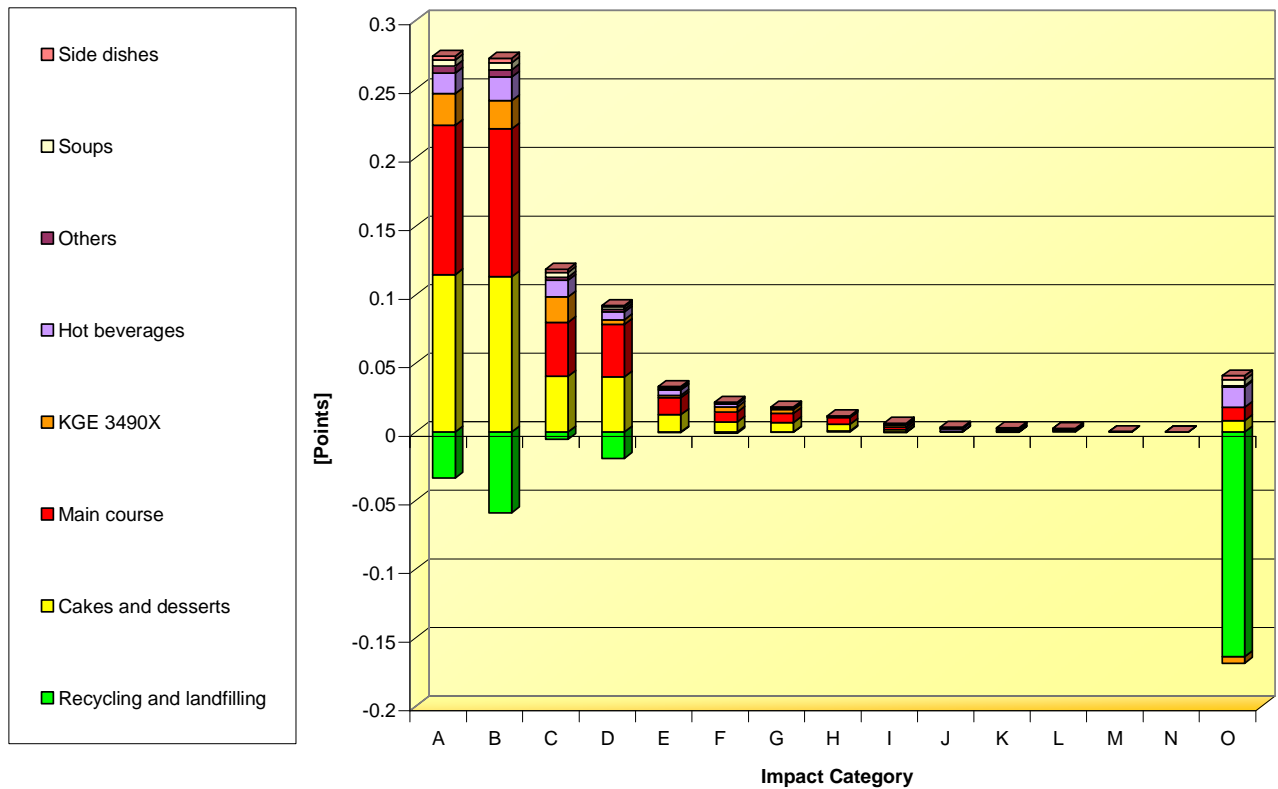


Figure 4.40 EDIP/UMIP, Recycling and landfilling scenario. Impact categories: A – ecotoxicity water chronic, B – ecotoxicity water acute, C – human toxicity soil, D – human toxicity water, E – global warming (GWP 100), F – radioactive waste, G – acidification, H – bulk waste, I – human toxicity air, J – ozone depletion, K – photochemical smog, L – eutrophication, M – hazardous waste, N – slags/ashes, O – ecotoxicity soil chronic.

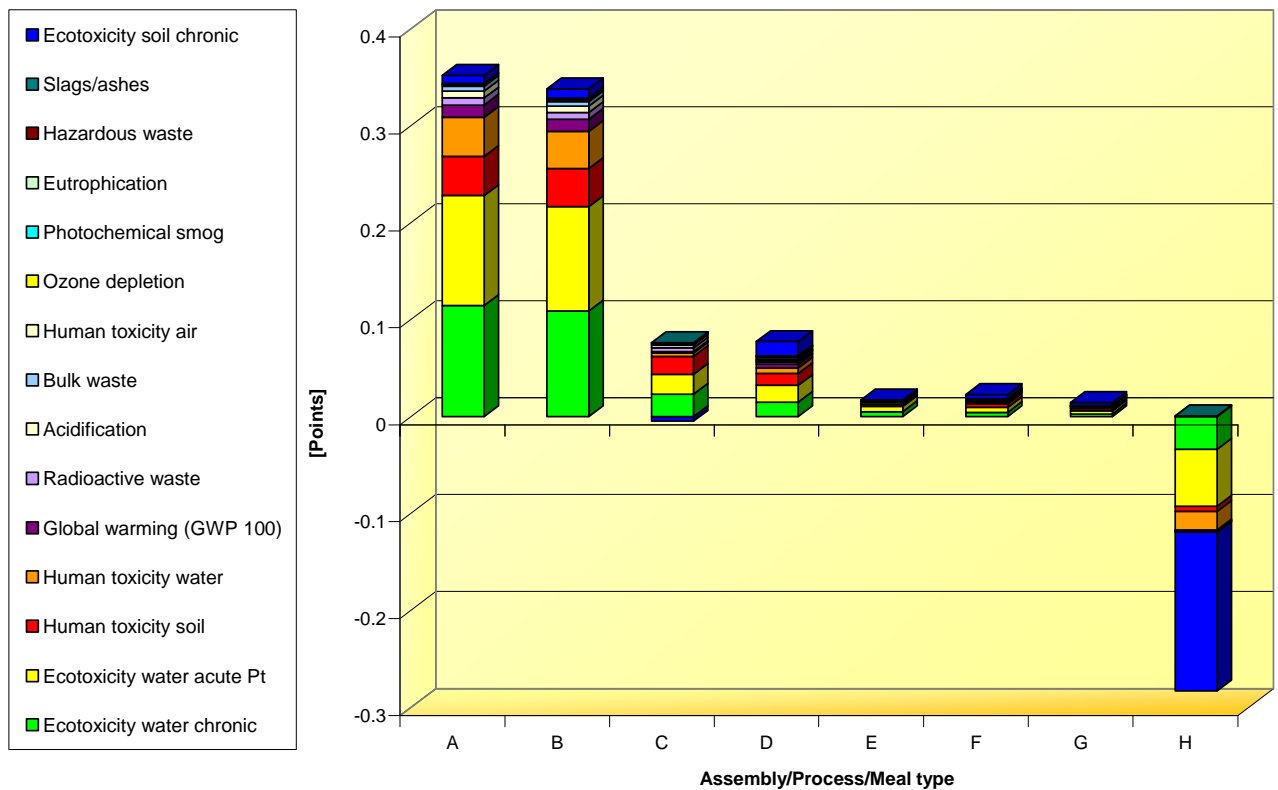


Figure 4.41 Single score, EDIP/UMIP, Recycling and landfilling scenario. Assemblies/Processes/Meal types: A – cakes and desserts, B – main course, C – KGE 3490X, D – hot beverages, E – others, F – soups, G – side dishes, H – recycling and landfilling.

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The overall positive result of characterization with respect to ecotoxicity soil chronic category is easily understood with the help of network diagrams (Appendix IX, section 4). As one can see, the recycling of steel and iron is responsible for the burden minimisation. However, the other network diagrams underline the impacts stemming from the generation of electricity and the combustion of natural gas.

4.4.5 Eco-Indicator 99

Fig. 4.42 to 4.46 and section 5 in the Appendix IX give an insight into the modelling results according to the Eco-Indicator 99 methodology, the hierarchist version with average weighting set.

Characterization modelling step (fig. 4.42) results reveal, that for most of the impact categories, main course and preparation of cakes and desserts cause highest impact on the environment. For some categories (i.e. fossil fuels, ozone layer, or respiratory organics), preparation of the hot beverages is the main process responsible for the environmental burden. In the impact category of mineral extraction, the cooker itself contributes to more than 90% of the total impact.

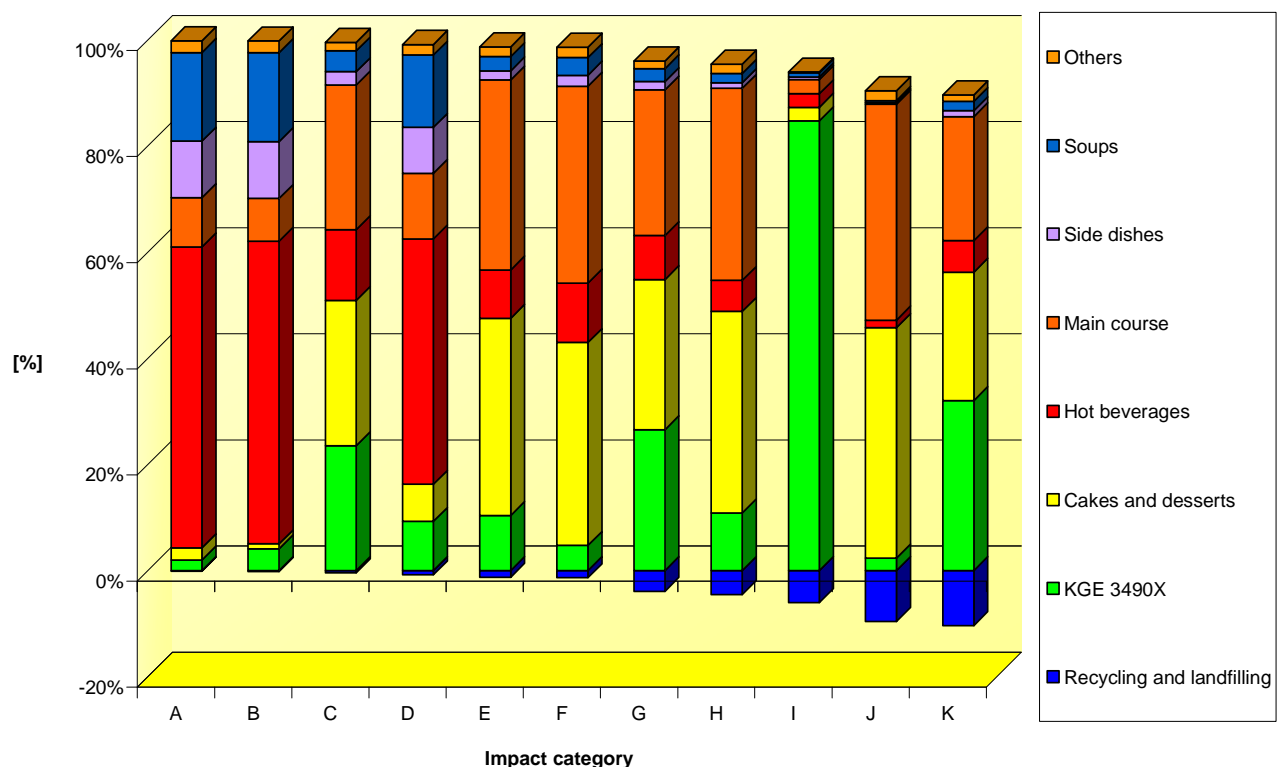


Figure 4.42 Characterization results, Eco-Indicator 99, Recycling and landfilling scenario. Impact categories: A – fossil fuels, B – ozone layer, C – land use, D – respiratory organics, E – acidification/eutrophication, F – climate change, G – radiation, H – respiratory inorganics, I – minerals, J – carcinogens, K – ecotoxicity.

Damage assessment (fig. 4.43) results are similar in the damage categories of the human health and ecosystem quality. Here, main course dishes with cakes and desserts contribute to more than

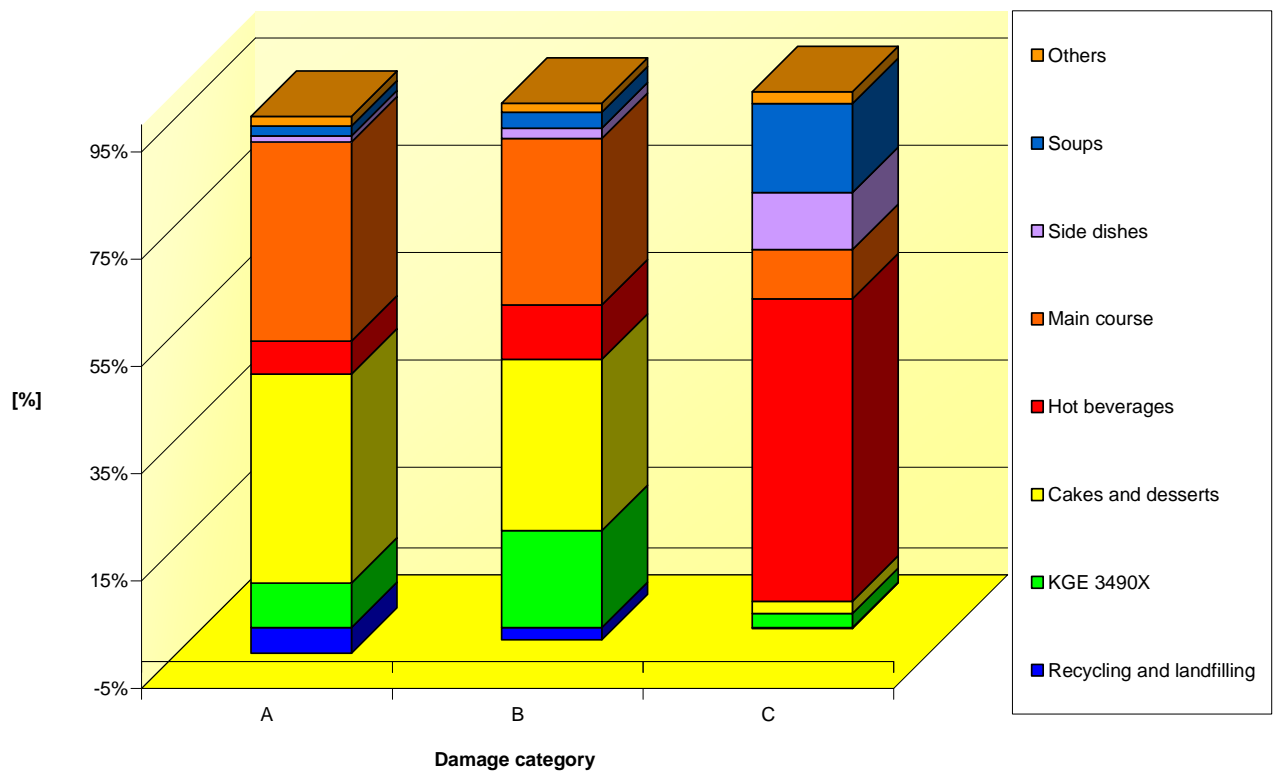


Figure 4.43 Damage Assessment results, Eco-Indicator 99, Recycling and landfilling scenario, per damage category. Damage categories: A – human health, B – ecosystem quality, C – resources.

70% of the overall impact generated. In the category of resources, however, hot beverages and soups are responsible for the biggest part of the environmental impact.

As fig. 4.44 shows, the one should focus mainly on resource depletion, when discussing the impact of the cooker on the environment. The impact in the categories of human health and ecosystem quality is small or very small, respectively.

Weighting results (fig. 4.45) indicate that the burden related to the gas-electro cooker may be associated mainly with the categories of fossil fuels and respiratory inorganics emissions. The impact in other categories is small (i.e. climate change, carcinogens), or even neglectable.

Both normalization and weighting steps point out hot beverages and soups as the processes causing the highest environmental load. This is true especially for the fossil fuel/resources impact category. However, when taking into consideration the results for other categories, one can see, that preparation of the main course, and cake and desserts, also plays a significant role in the overall result. This is especially well visible, when aggregating the results into the single score (fig. 4.46).

Network diagrams (section 5, Appendix IX) give an insight into the role of electricity generation, natural gas consumption, and the burden connected with the production of the cooker. It is worth to mention, that that the rank of importance of the electricity generation and natural gas consumption is changing, depending on the LCIA step applied. According to the network diagram of the single

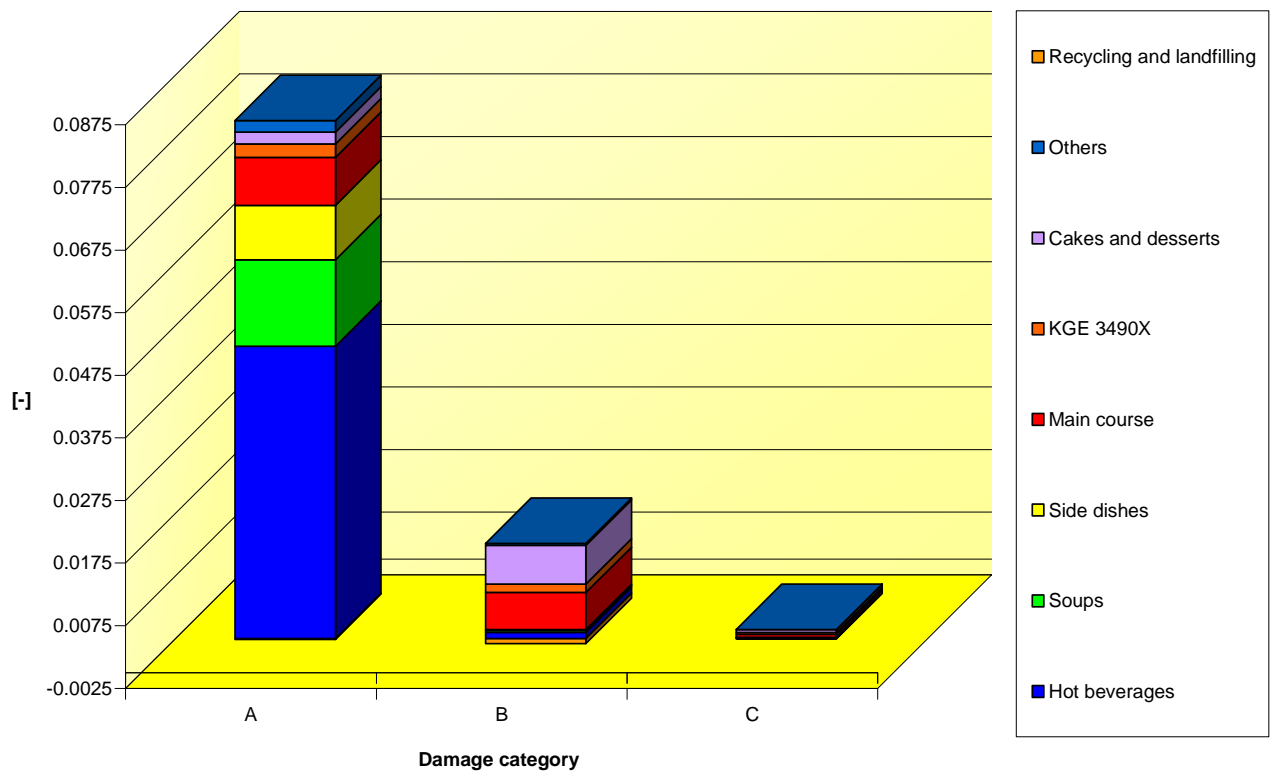


Figure 4.44 Normalization results, Eco-Indicator 99, Recycling and landfilling scenario, per damage category. Damage categories: A – resources, B – human health, C – ecosystem quality.

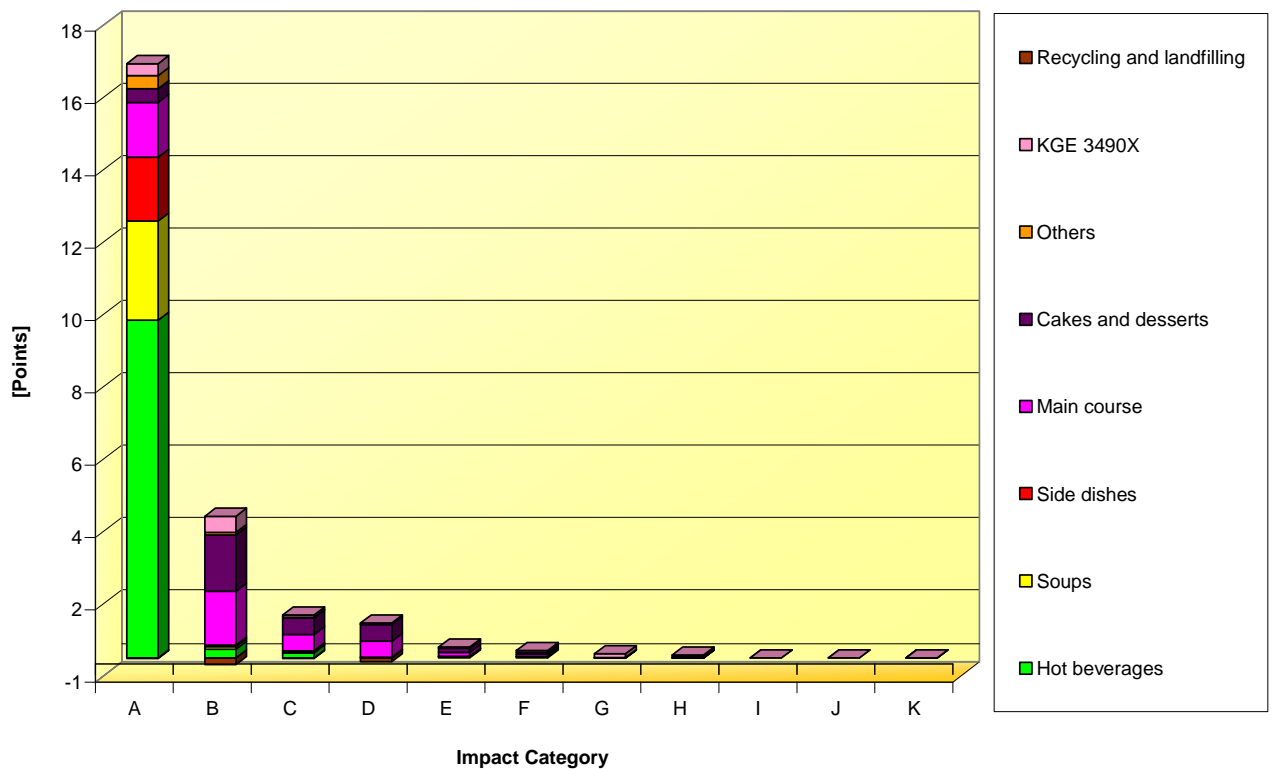


Figure 4.45 Weighting results, Eco-Indicator 99, Recycling and landfilling scenario. A – fossil fuels, B – respiratory inorganics, C – climate change, D – carcinogens, E – acidification/eutrophication, F – land use, G – minerals, H – ecotoxicity, I – respiratory organics, J – radiation, K – ozone layer.

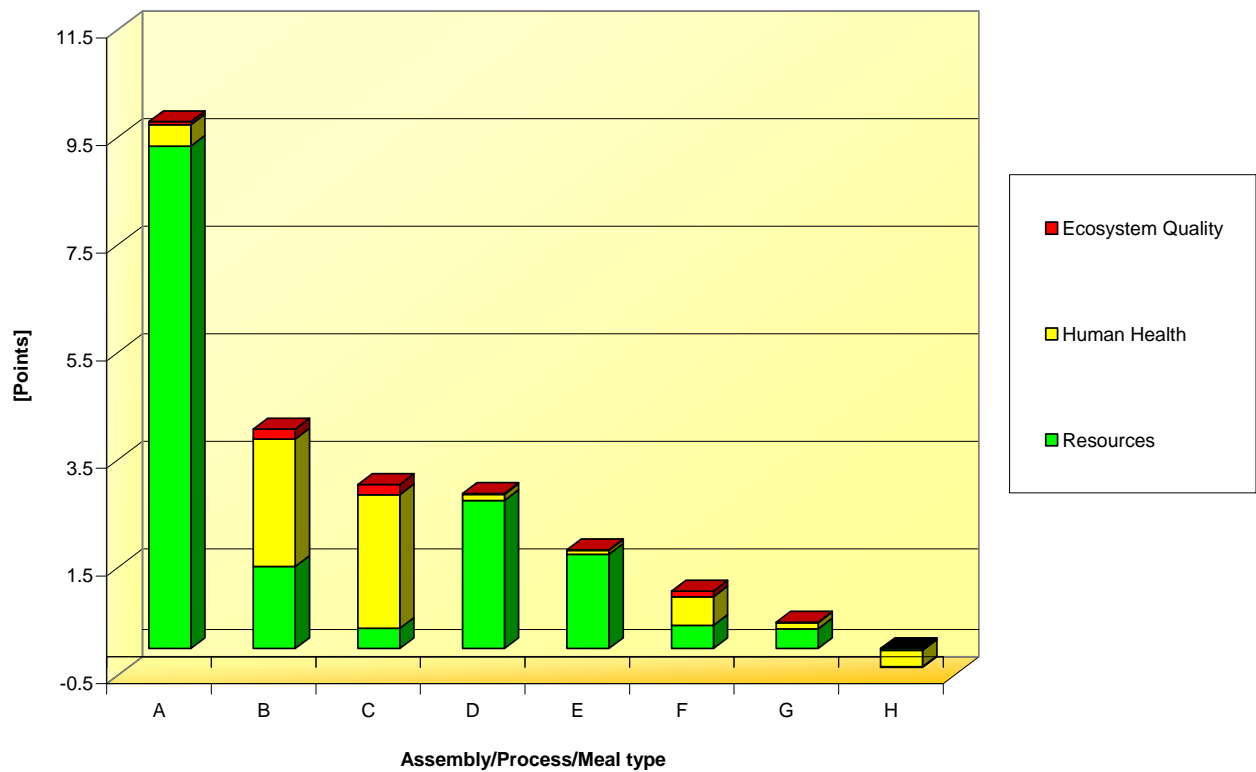


Figure 4.46 Single score results, Eco-Indicator 99, Recycling and landfilling scenario, per damage category. Assemblies/Processes/Meal types: A – hot beverages, B – main course, C – cakes and desserts, D – soups, E – side dishes, F – KGE 3490X, G – others, H – recycling and landfilling.

score results, gas consumption is more important for the overall environmental damage than electricity generation.

4.4.6 EPS 2000

Fig. 4.47 to 4.50 and section 6 of the Appendix IX illustrate the results of modelling according to the EPS 2000 methodology. As in the case of the cooker modelling (compare section 4.3.6) for characterization and damage assessment steps, some modelling factors specified in the SimaPro have wrong sign.

According to the characterization results (fig. 4.47), preparation of cakes and desserts and main course causes the highest environmental impact in most of the categories. The role of cooker itself and hot beverages is better visible in the impact category of depletion of reserves. Landfilling and recycling play a marginal role, except for the impact category of severe nuisance.

The results of damage assessment (fig. 4.48) are very similar for the damage categories human health, biodiversity, and ecosystem production capacity. In these damage categories, cakes and desserts, and main course dishes have the highest environmental impact. For the abiotic stock resources, however, one should focus on the impact stemming from the production of the KGE 3490X and the preparation of the hot beverages.

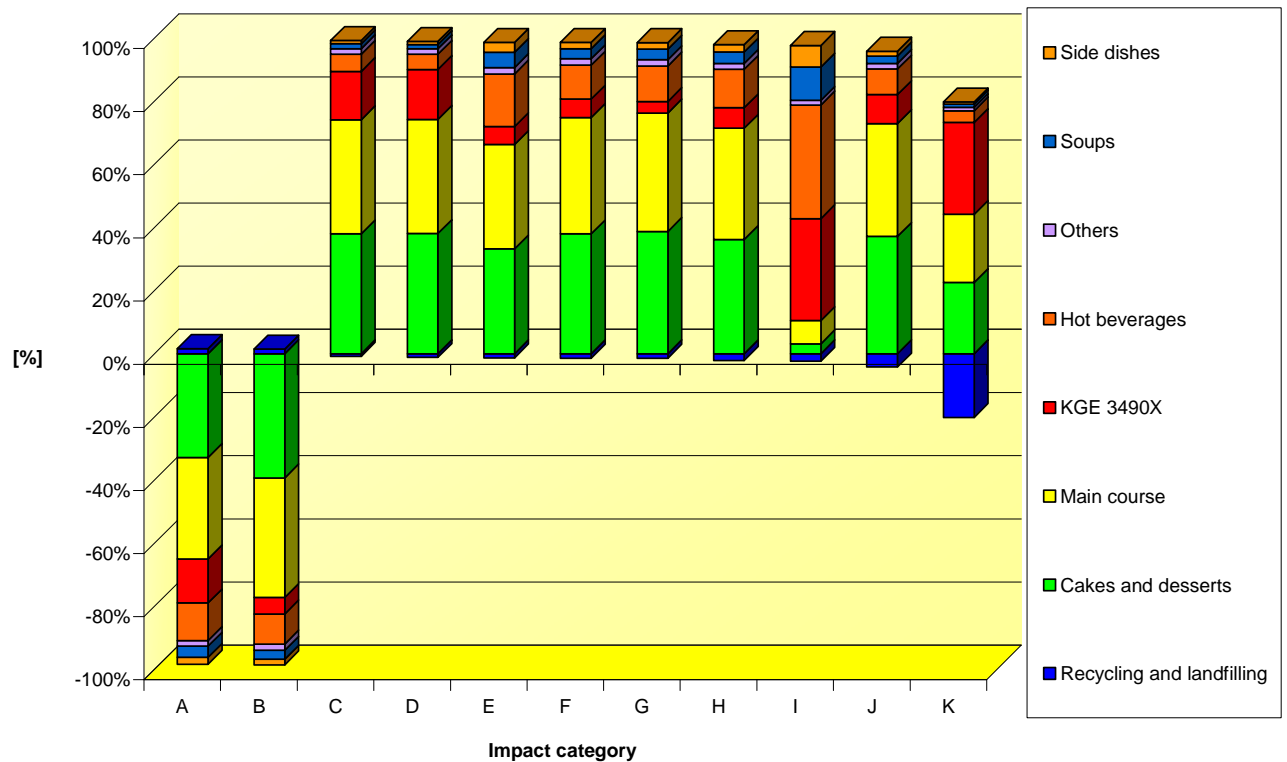


Figure 4.47 Characterization results, EPS 2000 method, Recycling and landfilling scenario. Impact categories: A – fish and meat production, B – wood growth capacity, C – soil acidification, D – nuisance, E – crop growth capacity, F – morbidity, G – species extinction, H – severe morbidity, I – depletion of reserves, J – life expectancy, K – severe nuisance.

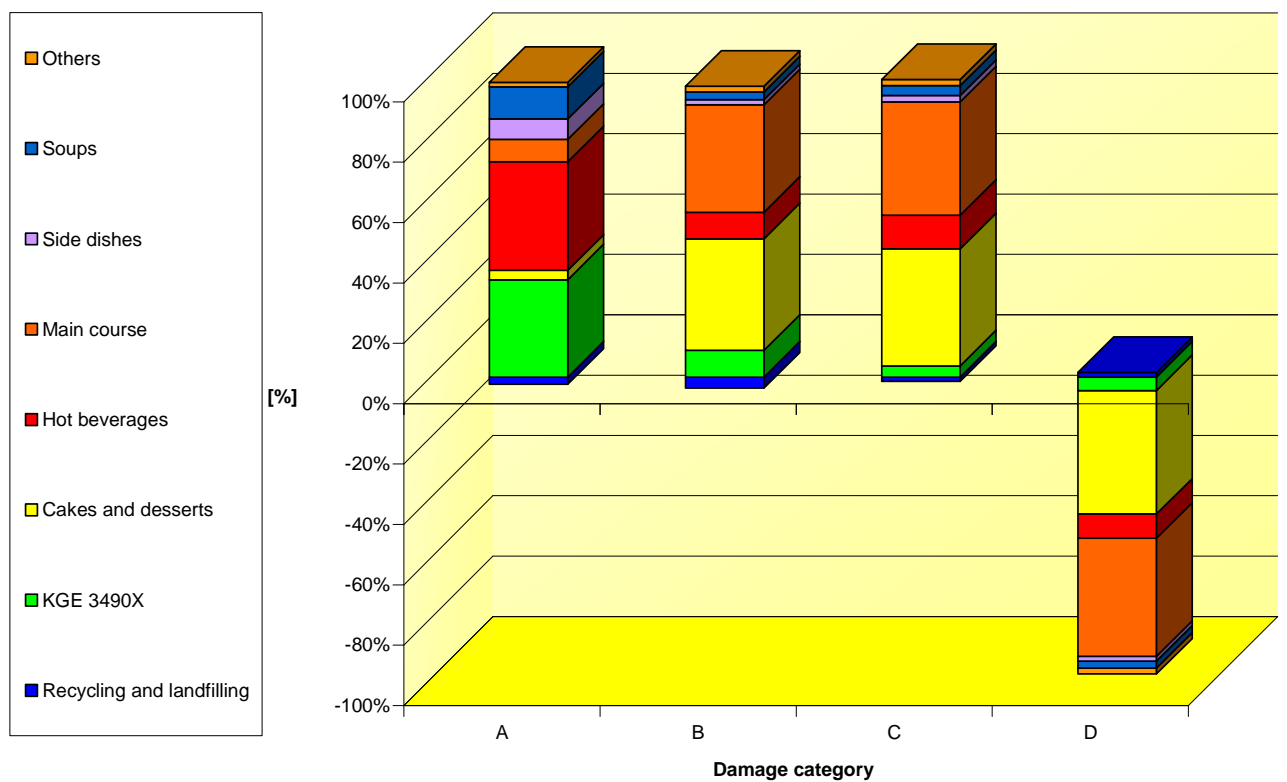


Figure 4.48 Damage Assessment results, EPS 2000 method, Recycling and landfilling scenario; per damage category. Damage categories: A – abiotic stock resource, B – human health, C – biodiversity, D – ecosystem production capacity.

Weighting of the obtained results (fig. 4.49) leads to the conclusion, that the highest damage occurs in the abiotic stock resource category. Human health damage category also contributes to the overall environmental damage. The impact of the cooker and cooking processes on the biodiversity and ecosystem production capacity is marginal.

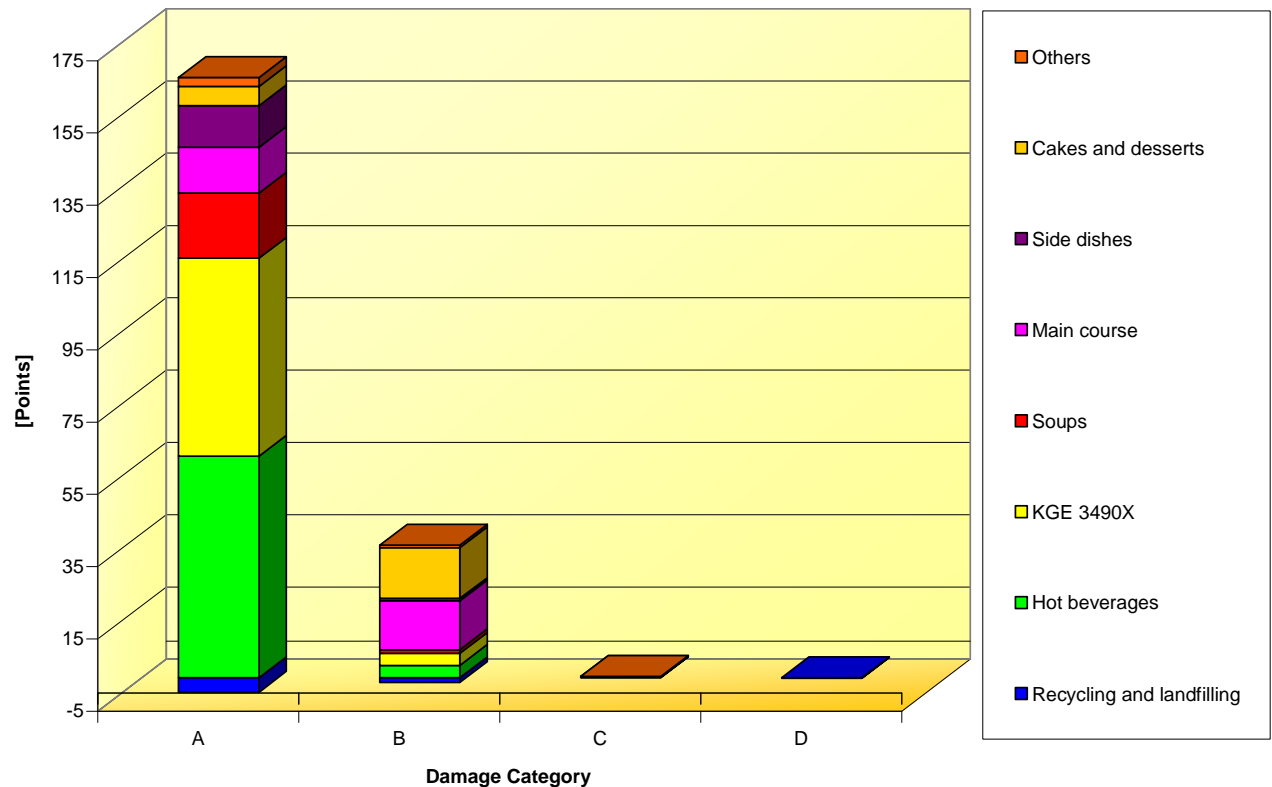


Figure 4.49 Weighting results, EPS 2000 method, Recycling and landfilling scenario; per damage category. Damage categories: A – abiotic stock resource, B – human health, C – biodiversity, D – ecosystem production capacity.

Since abiotic stock resource has the highest importance for the total environmental load, this fact has to find a reflection in the single score results (fig. 4.50). As one can see, depletion of reserves poses the biggest environmental problem. Life expectancy and severe morbidity have much smaller importance. The environmental impact in other categories is minimal. As for the most crucial parts of the product life cycle, one has to mention preparation of hot beverages and production of the materials consisting the cooker. Other processes have a smaller importance for the overall result.

Analysis of the network diagrams shows, that the generation of electricity and consumption of the natural gas is the main cause of the environmental load. Both energy sources contribute to more than 80% or more of the total impact. As in the case of the Eco-Indicator methodology, the percentage of the contribution is dependent on the modelling stage. The single score network diagram points out the combustion of the natural gas as the main cause of the damage. One has to mention also production of the cooker and use of the materials such as steel high alloy. For single

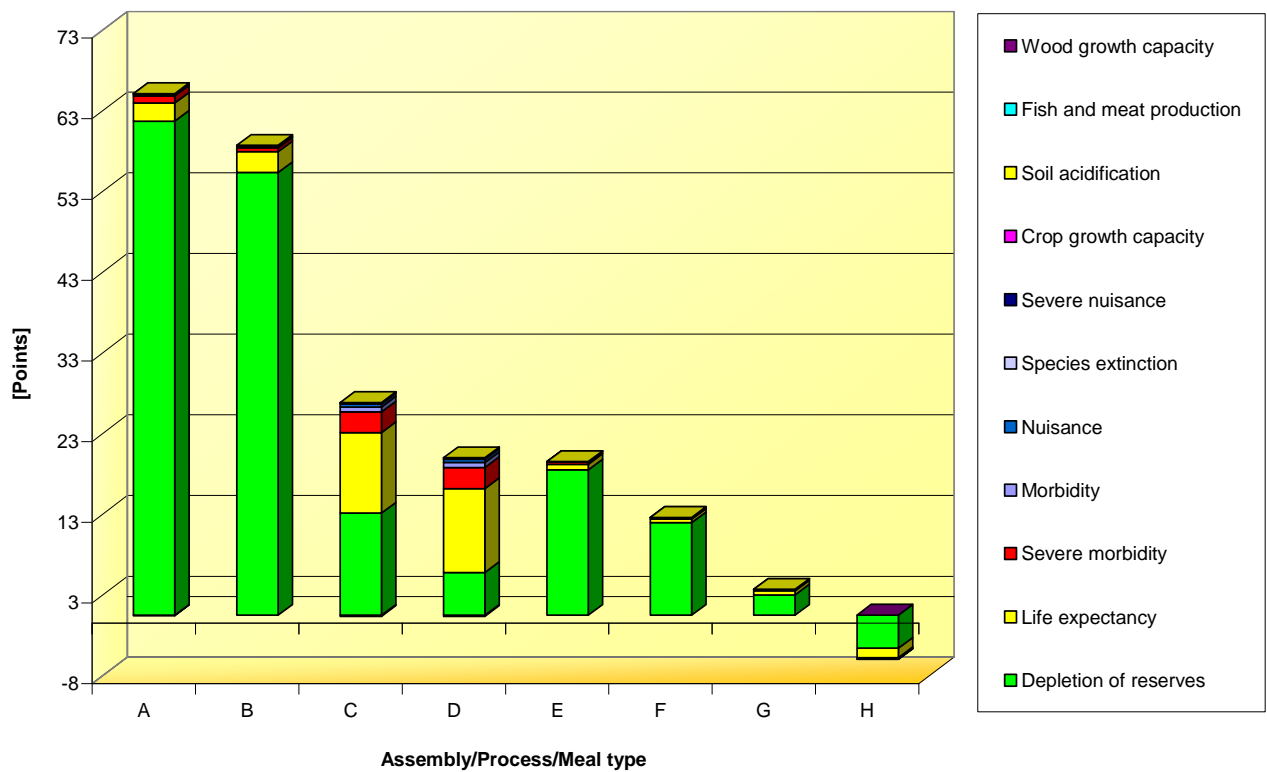


Figure 4.50 Single score results, EPS 2000 method, Recycling and landfilling scenario. Assemblies/Processes/Meal types: A – hot beverages, B – KGE 3490X, C – main course, D – cakes and desserts, E – soups, F – side dishes, G – others, H – recycling and landfilling.

score network, the materials used to produce the cooker contribute to approximately 30% of the total environmental burden.

4.4.7 IPCC

Fig. 4.51 and 4.52 present the comparison of the modelling results according to the IPCC methodology with the time span of 20, 100, and 500 years, characterization phase. As one can see immediately, the results are very similar to each other.

Fig. 4.51 shows the results as the percentage bars. With increasing time span, the contribution of beverages to the overall result declines; the opposite process is visible for the cakes and desserts. In general, cakes and desserts, main course meals, and hot beverages, contribute to more than 80% of the total environmental burden.

Expressing the results in the form of kg CO₂ equivalents (fig. 4.52) leads to the conclusion, that longer the time span, smaller the impact on the environment. This is quite natural, if one takes into consideration the self-cleaning ability of the environment. As pointed out above, preparation of cakes and desserts, main course meals, and hot beverages causes the biggest environmental load. This load is only slightly minimised with the help of recycling processes applied at the End-of-Life.

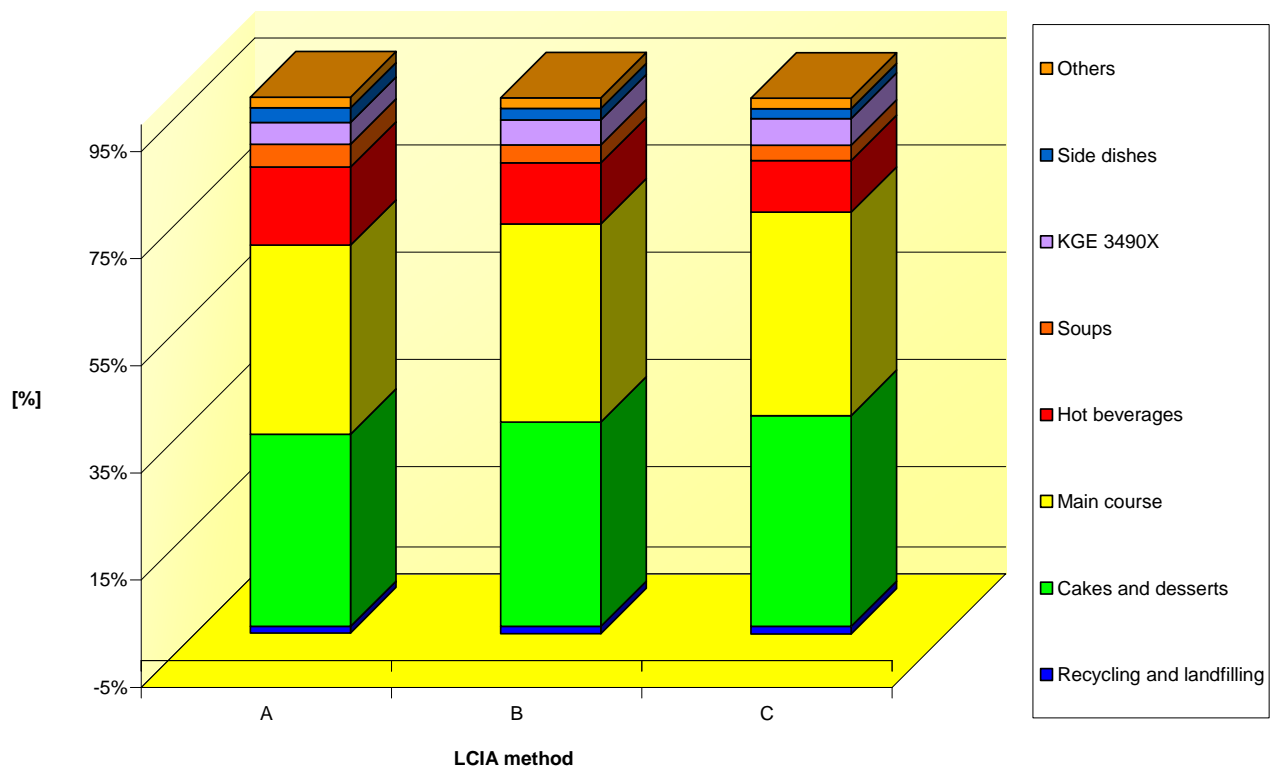


Figure 4.51 Characterization, IPCC method with 20 (A), 100 (B), and 500 (C) years of time span. Units: percentage.

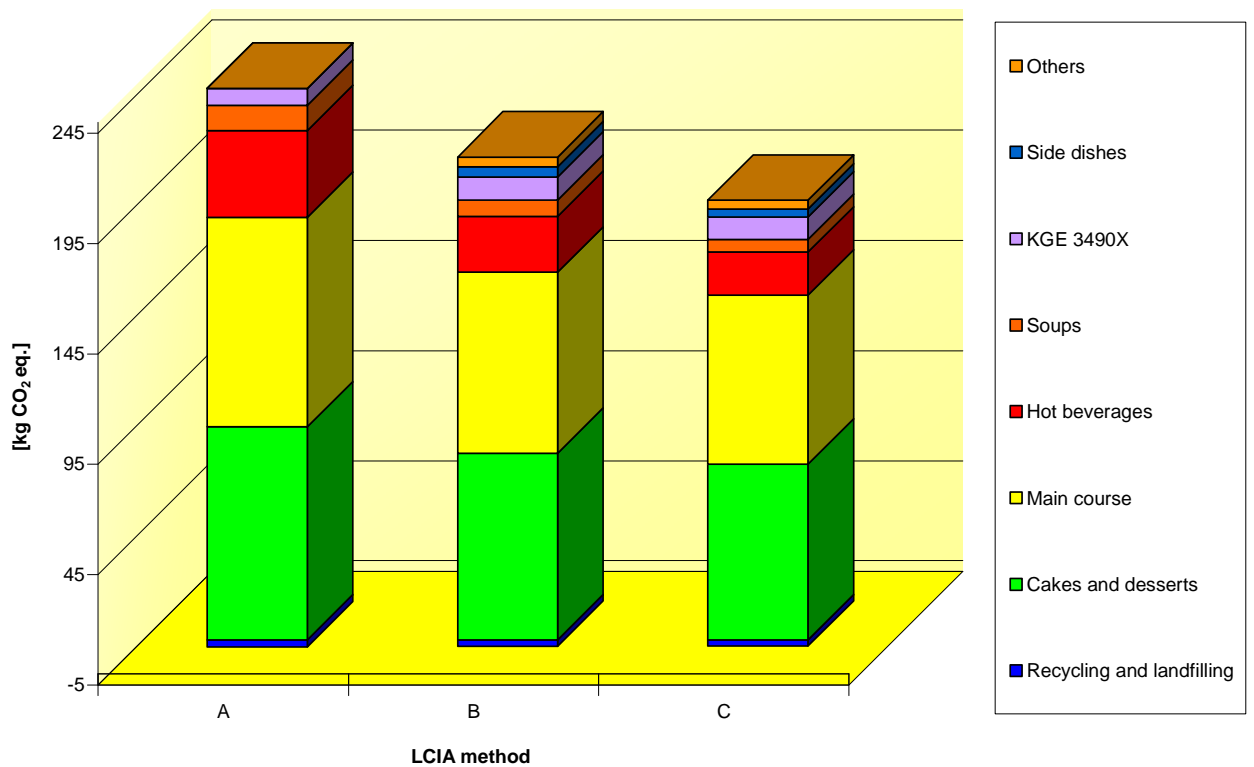


Figure 4.52 Characterization, IPCC method with 20 (A), 100 (B), and 500 (C) years of time span. Units: kg CO₂ eq.

Network diagram in section 7 of the Appendix IX demonstrate, that the generation of electricity is responsible for the approximately 75% of the total environmental impact. The natural gas consumption contributes to 15-25% of the environmental burden generated.

4.5 End-of-Life scenarios and their impact on the overall result

Fig. 4.53 demonstrates the results of modelling of the cooker with various End-of-Life scenarios, using the Eco-Indicator 99 methodology. The smaller the value for the given damage category and EoL scenario, the better. That means, that the scenarios, which results are located closest to the origin of the x, y or z axis, have the best environmental performance.

In total, three scenarios were analyzed (incineration, recycling and landfilling, and recycling). Each scenario was modelled according to the three versions of the Eco-Indicator methodology: individualist, hierarchist, and egalitarian. Furthermore, each version had two different weighting and normalization sets. The application of the Eco-Indicator modelling version depends on the value-based choice.

In the individualist version, only very well proven effects on the environment are taken into consideration. In the egalitarian method, the environmental burden is taken into consideration even, if the scientific studies do not provide a full proof of the damaging effect on the environment. Hierarchist version represents a balanced approach, taking into consideration trade-off between individualist and egalitarian versions.

As one can see in fig. 4.53, the results of the modelling may vary greatly, depending on the value-based choice of the LCIA method. For instance, environmental impact calculated for the recycling EoL with the help of individualist weighing and normalization sets is 2-3 times smaller than the result calculated for the same EoL, but with the help of egalitarian set of modelling factors. However, some general patterns may be observed, namely:

- The best-case scenario is based on the recycling processes (green-coloured signs on the graph) and causes the lowest environmental load with respect to three damage categories used;
- The scenario applied in Lubawka, with major materials being recycled and some being landfilled (black colour), has worse environmental performance, but it is still comparable with the full-recycling option;
- The incineration scenario (red colour) would cause the most significant environmental burden, much higher than in case of recycling and recycling-landfilling scenarios.

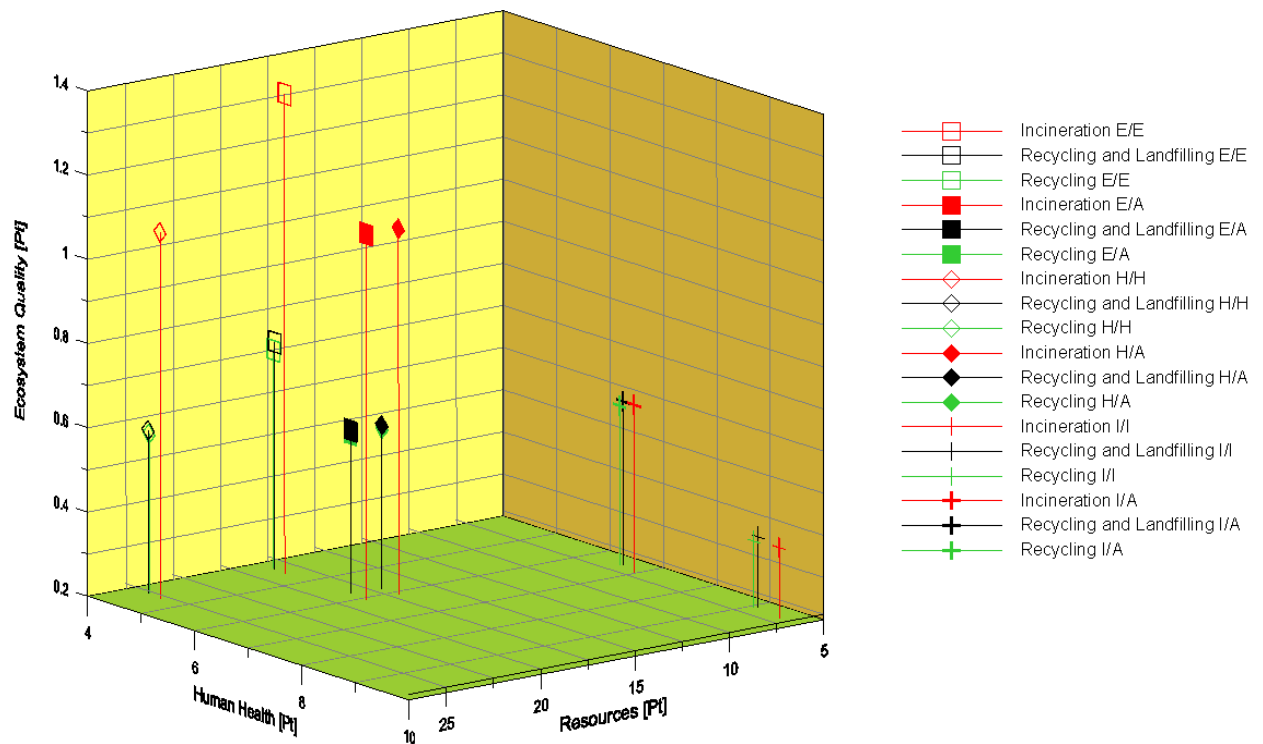


Figure 4.53 Comparison of End-of-Life scenarios and different versions of the Eco-Indicator versions. Weighting/normalization sets: E – egalitarian, H – hierarchist, I – individualist, A – average.

4.6 Results of the modelling and the ecolabelling

The results of this study may serve as a basis for environmental labelling and/or for Environmental Product Declaration (EPD). This ecolabelling may be based for instance on the series of ISO 14020 family standards. These standards distinguish between three types of ecolabels:

- Type I label is awarded by a third party organization. For example, one of the most well known eco-labels is the Blue Angel, created in Germany (fig. 4.54). The requirements for this type of labelling are described in detail in ISO 14024:1999 standard;
- Type II label is created by the company and applied for the products by the self-declaration; as an example, Ricoh Recycle Label may be presented (fig. 4.55). Type II of environmental labelling is covered by the ISO standard 14021:1999;
- Type III ecolabelling is based on the results of LCA modelling. The details of this ecolabelling type are described in ISO 14025:2006 standard. As the result, manufacturer shall create an Environmental Product Declaration (EPD).

The results of the LCA study performed for the gas-electro cooker may serve as a basis for the establishing the ecolabelling schemes in FagorMastercook. This ecolabelling may take the form of



Figure 4.54 The Blue Angel logo. Source: http://www.blauer-engel.de/en/blauer_engel/whats_behind_it/index.php (last accessed on 23.02.2009).



Figure 4.55 The Ricoh Recycle Label. Source: <http://www.ricoh.com/environment/label/type2/index.html>, last accessed on 24.02.2009).

Type II ecolabels (i.e. by creation of specific environmental logo) or Type III ecolabels (by publishing the Environmental Product Declaration i.e. for the gas-electro cooker).

4.7 Summary and interpretation of the results

The results for the different LCIA methods vary with respect to the total amount of environmental load, and the focus point, namely impact categories, where the environmental impact is the highest. This is due to the very detailed input data. As a result, certain substances may influence the results in one method, and in the other, its importance for the final modelling outcome may be marginal. This is true for the materials used in the production of the cooker in smaller amounts. For the main materials comprising the essential part of the appliance mass, their share in the creation of environmental load is taken into consideration in the modelling stages of all LCIA methods.

The LCIA modelling results are summarized and compared in tables 4.1 and 4.2. As one can see, the modelling results for different LCIA method are not contradictory to each other. In general, the following patterns may be recognized for all used LCIA methods:

- The materials with the highest impact on the environment are steels (high alloy, low alloy, austenitic steel), glass, and in some cases other high weight materials;

- Other materials, although present in the inventory results, play a smaller role in the overall impact on the environment;
- These materials, may, however, cause some divergence of results, when comparing outcome of modelling from different LCIA methodologies; their influence determines the environmental performance of the product especially in the less important or neglectably important impact categories;
- Generally speaking, the depletion of abiotic resources and emissions from energy generation play the major role, when discussing the impact of the KGE 3490X on the environment;
- Depletion of resources reflects environmental effects stemming from the extraction of ferro metals and use of gas reserves;
- Gaseous emissions influencing the state of the environment are associated mainly with the production of electricity for the use phase and production of ferro and non-ferro metals;
- The assemblies causing the highest environmental damage are equipment, oven, side walls, glass plate, and decorative angle;
- When the use phase is taken into consideration, the impact from the manufacturing of the product is considerable, but much smaller than the impact of the cooking and baking processes;
- The impact from the cooking processes is stemming mainly from the meals most often prepared in the Polish households (i.e. cooking of potatoes, boiling of water for the hot beverages);
- The impact from the use phase may be only predicted, since large variability of habits is present, even inside one single societal group, responding to the questionnaires;
- Impacts stemming from the usage of the upper part of the cooker (gas burners) is bigger than that of baking in the electrical oven; however, these values are comparable in their magnitudes;
- Application of recycling processes in the production phase, as well as in the EoL scenario, helps to avoid some emissions, thus minimising the total impact of the appliance on the environment.

Part C will present the results of sensitivity modelling, focused on the Polish enterprise in the context of the Environmental Managements System, with respect to the implementation of the EuP directive and the application of the LCA techniques.

Table 4.1 Comparison of the LCIA methods with respect to most important damage and impact categories, subassemblies, and materials; cooker without EoL and without use phase. For all LCIA methods, recycling processes reduced the total environmental impact.

No.	Method	Damage/Impact categories	Subassemblies	Materials/Processes	Remarks
1.	CML 2	Marine aquatic ecotoxicity, acidification, fresh water aquatic toxicity, human toxicity	Equipment, oven, door, glass plate	Steel high alloy, nickel, chromium, float glass, steel low alloy and electricity	-
2.	Cumulative Energy Demand	Electricity production: non-renewable fossil fuels and nuclear energy	Oven, equipment, glass plate, door, side walls, packaging, production and transportation	Steel high alloy, steel low alloy, float glass, nickel, austenitic steel	-
3.	Ecopoints 97	Emission of the CO ₂ , SO _x , NO _x	Oven, equipment, door, glass plate, side walls, electrical system screen, drawer	Steel high and low alloy, austenitic steel, float glass, electricity production	-
4.	EDIP/UMIP	Ecotoxicity water chronic, ecotoxicity water acute, human toxicity soil, ecotoxicity soil chronic	Oven, equipment, glass plate, door, side walls, packaging	Steel low and high alloy, float glass, sheet rolling process, austenitic steel, plastic materials	-
5.	Eco-Indicator 99	Resources; respiratory inorganics, fossil fuels, minerals, climate change, land use, ecotoxicity, carcinogens, acidification/eutrophication	Oven, equipment, door, decorative angle, drawer, production and transportation, side walls	Steel low and high alloy, austenitic steel, float glass coated, polystyrene, polyethylene, cleaning agent, natural gas, nickel, glass fibre, energy production	-
6.	EPS 2000	Abiotic stock resource; depletion of reserves	Production and transportation module, equipment, oven, glass plate, side walls, door	Steel high and low alloy, austenitic steel, energy production, float glass	Negative values for ecosystem production capacity (fish and meat production and wood growth capacity categories)
7.	IPCC	-	Oven, equipment, glass plate, door, side walls, production and transportation	Steel high alloy, steel low alloy, austenitic steel, float glass, generation of energy	Impact on the environment is slightly decreasing with the increasing time span

Table 4.2 Comparison of the LCIA methods with respect to most important damage and impact categories, subassemblies, material and meal types; KGE 3490X with EoL and with use phase. For all LCIA methods, recycling processes slightly reduced the total environmental impact.

No.	Method	Damage/Impact categories	Meal types/Assemblies	Materials/Processes	Remarks
1.	CML 2	Marine aquatic ecotoxicity	Cooker, cakes and desserts, beverages, main course	Electricity generation, consumption of natural gas, steel high alloy	-
2.	Cumulative Energy Demand	Energy generation, non-renewable fuels	Cakes and desserts, hot beverages, main course, side dishes, soups	Electricity generation from the hard coal and natural gas combustion	-
3.	Ecopoints 97	CO ₂ , SO _x and NO _x emissions	Cakes and desserts, hot beverages, main course, cooker	Electricity generation, consumption of natural gas, steel high alloy	-
4.	EDIP/UMIP	Ecotoxicity water chronic, Ecotoxicity water acute	Cakes and desserts, hot beverages, main course, cooker	Electricity generation, consumption of natural gas	-
5.	Eco-Indicator 99	Resources; fossil fuels, respiratory inorganics emissions	Main course, cakes and desserts, hot beverages, soups, cooker	Electricity generation, consumption of natural gas	-
6.	EPS 2000	Abiotic stock resource; depletion of reserves	Cakes and desserts, main course, hot beverages, cooker	Electricity generation, consumption of natural gas, steel high alloy	Negative values for ecosystem production capacity (fish and meat production and wood growth capacity categories)
7.	IPCC	-	Cakes and desserts, main course, hot beverages	Electricity generation, consumption of natural gas	Impact on the environment is slightly decreasing with the increasing time span

PART C

IMPACT ANALYSIS OF INTRODUCING THE LCA IN A COMPANY

5. Sensitivity modelling in the SMPV software

5.1 Introduction. LCA in EMS and EuP

The integration of the Life Cycle Assessment in the activities of the company is not a simple process, taking into consideration financial and resource constraints, as well as legal constraints. The results of the LCA study presented in Part B illustrate how complex the LCA study may be, and how much time has to be invested in the LCA of one single product.

The question that arises for the decision maker is the following: is this investment feasible? Does the company benefit from the LCA? What is the influence of the LCA on the company's image, market situation, etc.?

These questions are not easy to answer, taking into consideration, that system, in which company operates, is multifunctional, complex, and interconnected with many internal and external factors and variables. Many actors and stakeholders play an important role in the functioning of the company. Their role and influence on the company may be different: positive or negative, with various strength, including spatial and temporal variability. Furthermore, the importance of some variables may become visible in specific situations, in others their influence may be marginal. Taking into consideration all these facts, the assessment of positive or negative effects of the LCA on the enterprise may be very difficult. One should also keep in mind the huge amount of data that need to be collected in order to make such an assessment.

One of the possible answers to such challenge is a use of sensitivity analysis. A very interesting model was developed by the frederic vester GmbH company², located in Munich, Germany. The model allows assessing the interrelations and influences of many-variable interconnected systems, based on the concepts of fuzzy logics. Thus, decision maker may learn a lot about the interesting aspects of the system, keeping the time and money investments on an acceptable level (Vester 2007).

Sections 5.2 to 5.10 will present the outcome of the sensitivity analysis performed with the help of the Sensitivity Model Prof. Vester (SMPV) software. As an example, general model "Polish Enterprise" was created. The modelling variables and their interrelationships were chosen to reflect:

- The comprehensiveness of the system;
- The role and interrelations of the LCA, the EMS, and European laws, especially the EuP directive;

² Lowercase used intentionally by the company founders. For more information see <http://www.frederic-vester.de/> (last accessed on 30.03.2009).

- The conditions characteristic for Poland and its internal market.

In the modelling, various sources of the knowledge were utilized, namely the literature description (the ISO 14001 and 14040 family standards, the Energy-using Products directive), experience from the cooperation with the FagorMastercook, results of the LCA studies, as well as specific cultural and scientific background, gained by the author from his education and private life in Poland.

The sensitivity analysis was completed in a series of consecutive steps, explicitly:

- General system description;
- Defining the variable set, criteria and impact matrices;
- Establishing the systemic role of the variables and arranging the effect systems;
- Setting-up partial scenarios and simulation according to various policy tests;
- Self-check using cybernetic rules of system evaluation.

All these steps and the outcomes of specific modelling phases will be presented in detail in the following sections.

5.2 System description

The first step of defining the system is based mainly on discussion and brainstorming. Here, the boundaries are defined, as well as the first definition of the key actors of the system and their interrelationships is being done. For example, one has to define the following constituents of the model system:

- The system boundaries;
- The nature of the influence factors;
- The meaning of the interdependencies between the system elements (variables);
- The sketch of the initial “picture” of the system has to be done, as well as
- The construction of the preliminary effect system.

The key questions were:

- How are the elements of the system functioning?
- Which of the influencing factors are of the highest importance, and which can be neglected?

- Will the introduction of the comprehensive LCA help the company to achieve the goals settled and the improve the overall performance of the system?
- What kind of disadvantages may occur if the company introduces detailed LCA?

To answer these questions, initially very wide boundaries were set up. As the result, many variables influencing the functioning of the enterprise were included in the system modelling. I.e. even the state of the natural environment was taken into consideration. Subsequently, the number of the variables was reduced, in order to obtain clear modelling output.

The initial results of the system definition and the variables taken into consideration are shown in fig. 5.1. In order to avoid overlapping of the information, the details of the system functioning are not described in the system description module. However, the subsequent modules of the SMPV serve as a basis for answering the questions laid down in the system description.

5.3 Variable set

The next step of analysis the system is the choice and description of the variable set. Here, aggregation as well as splitting of some key system elements may occur.

The system was described in terms of 27 main elements, namely: Owner, Financial results, Wages, LCA, EMS, Quality, Price, Employees, Trade unions, Authorities, Customers, Competitors, Educational institutions, Politicians, European Union (EU), Environment, Subassembly deliverers, Resources/Global market, Local infrastructure, Transportation network, Job centres, Health and social care, Inhabitants of the city, Property market, Financial institutions, International organizations, and finally TV and radio stations (fig. 5.1). Some variables were aggregated already at this stage of the research for the sake of results' clarity and keeping the similar level of variable aggregation. For example, the influence of the EuP directive was aggregated into the variable European Union (EU).

The choice of initial variables ranking was not accidental; the most important variables were placed on the top of the list (fig. 5.2). The revision of the variables importance for the entire system was performed after the step "Systemic role". In some cases, like i.e. for the variable "Wages" it appeared that they are not as crucial for the functioning of the system as one might think. Secondly, the importance of the variable was not determined only by its total influence on the system, but also by its importance in this special research. Here, the example may be "LCA" variable.

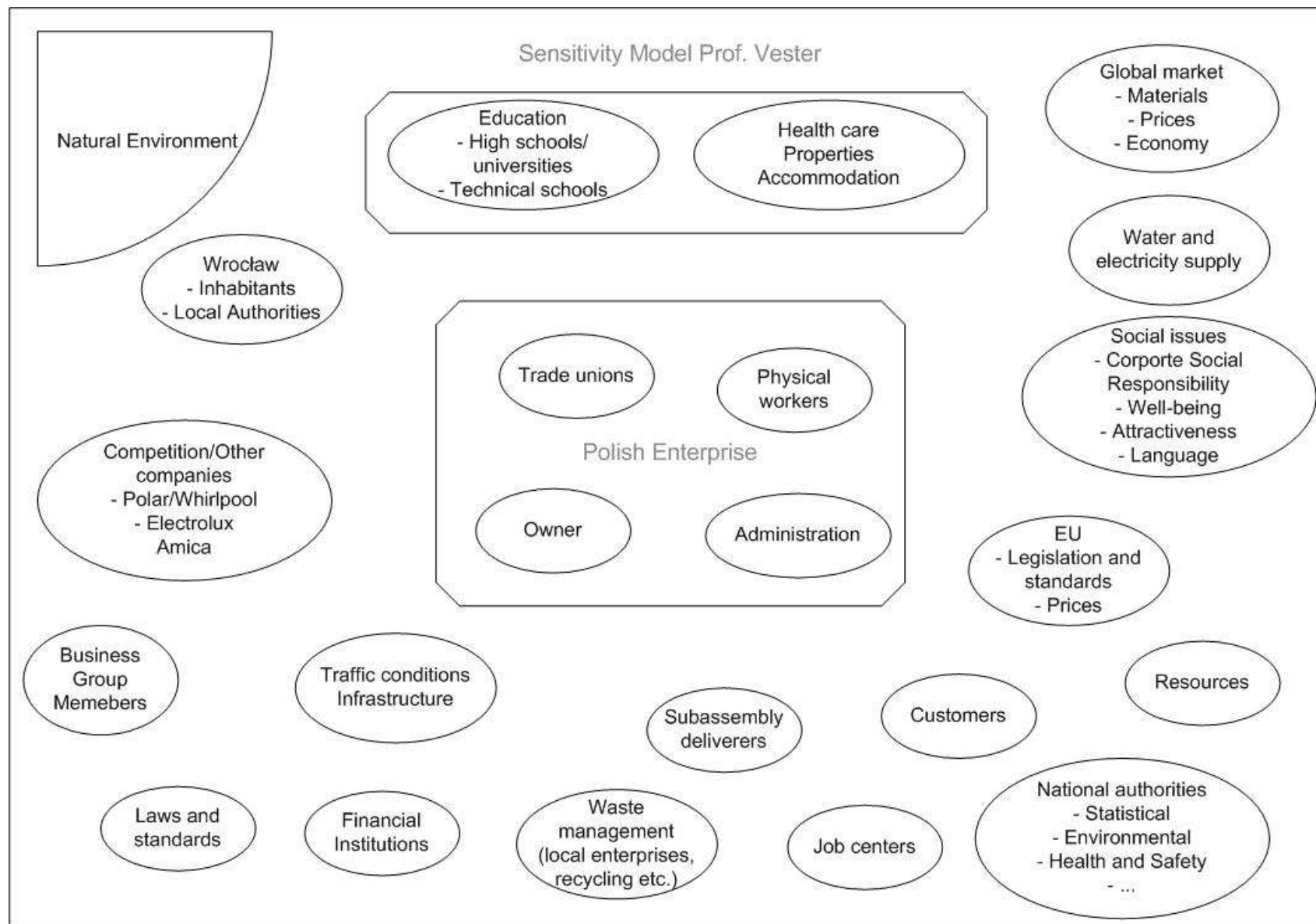


Figure 5.1 Initial definition of the system elements.

Variable Set
System model: Polish Enterprise

List of variables

1	Owner
2	Financial results
3	Wages
4	LCA
5	EMS
6	Quality
7	Price
8	Employees
9	Trade unions
10	Authorities
11	Customers
12	Competitors
13	Educational institutions
14	Politicians
15	EU
16	Environment
17	Subassembly deliverers
18	Resources/Global market
19	Local infrastructure
20	Transportation network
21	Job centers
22	Health and social care
23	Inhabitants of city
24	Property market
25	Financial institutions
26	International organizations
27	TV/radio stations

Description of the variables
1 Owner

Who/what:
Person or corporation that owns the company. May be a private person, a legal person, or the state.

Variables influenced: Financial results, Wages, EMS, Price, Employees, Trade unions, Authorities, Customers, Competitors, Politicians, Subassembly deliverers, Job centers, Health and social care, TV/radio stations

Most important relationships:
Financial results

Total strenght of influence on the system: very high

Optimum: at the top

Maximum: making profits, but also taking care of employees well-being, health and social care, CSR, environment, future development of the company

Upper middle range: focused mainly on making profits, obeying laws and commitment to the standards only if forced by the law

Lower middle range: Focused mainly on making profits, disobeying laws and standards ia for health and safety, as well as environmental issues.

Minimum: Disobeying laws and standards, no commitment towards development of the company, wrong management without making profits

Actual situation: Upper middle range

Total view
HIGH MIDDLE LOW Scaling
Print
Menu

Figure 5.2 List of variables defined for the system model “Polish Enterprise”.

For every variable, a detailed description took place. The classification of information took into consideration the following groups of criteria:

- Criteria relating directly to the variable and its interrelationships with other elements of the system:

- Definition of the variable;
- Most important variables influenced by the variable in question;
- Most important relationships with other variables (with respect to the strength of influence);
- Total strength of influence on the entire system;
- Criteria relating to the scaling of the single variable: optimum position of the variable;
- Detailed description of the maximum, middle range, and minimum positions;
- Actual position of the variable for the system model “Polish Enterprise” (fig. 5.3).

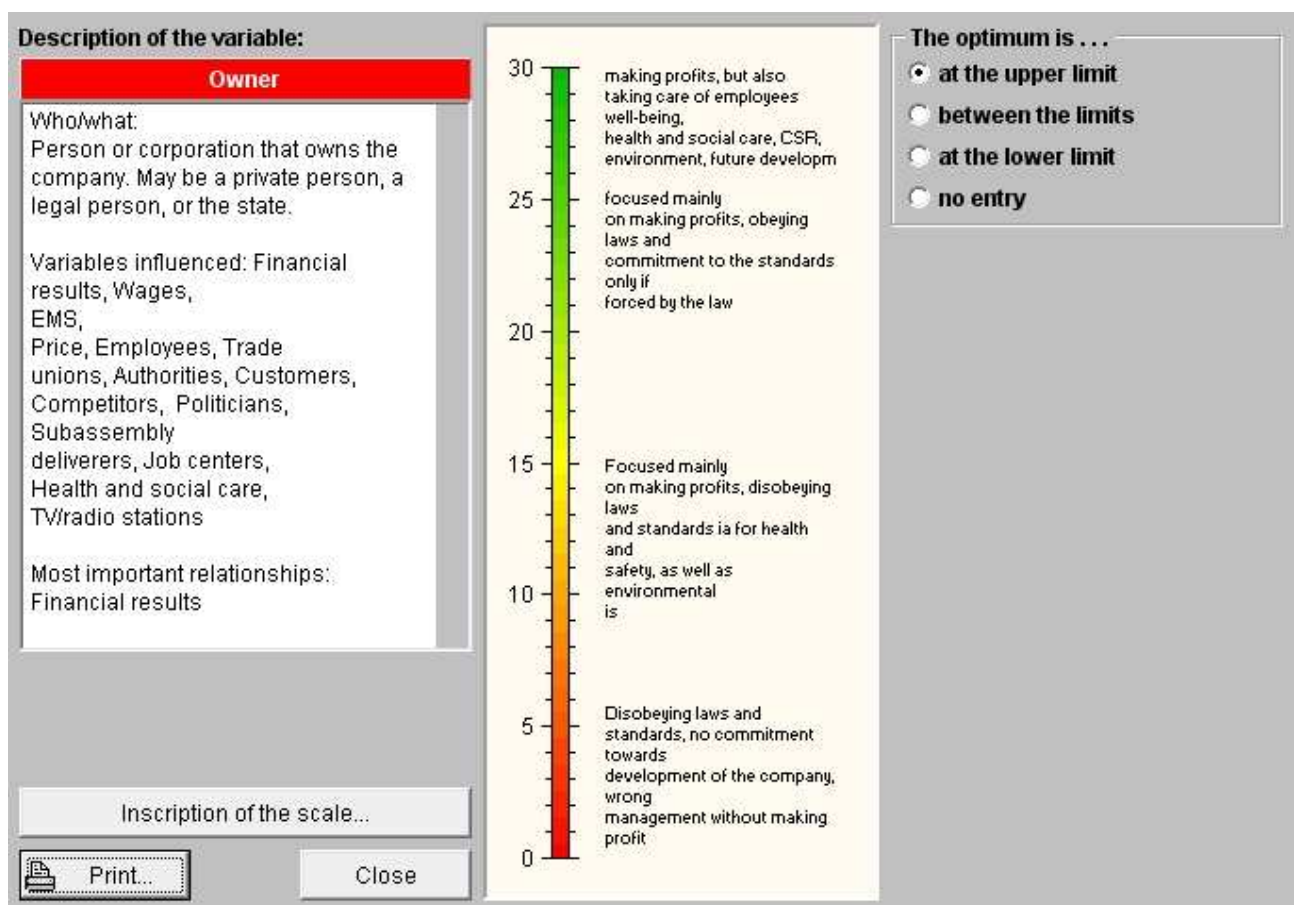


Figure 5.3 Scale of values for the variable “Owner”.

The scaling procedure is of crucial importance for the subsequent partial scenario simulation. It also allows user to understand and better define the nature of the variable. One has to remember, that inscriptions on the scale describe the possible states of the variables in general way. In some cases, however, the state of the variable may be the same for different combinations of external conditions. As an example, the variable EMS can be mentioned. In the middle range the state of the

variable may be described as in table 5.1. However, this middle range state may also mean, that the EMS is implemented, the LCA is included, but no communication to customers takes place, or there is some comparably high impact of the product on the environment.

Tables 5.1 and 5.2 show examples of description for the variables “Owner” and “Financial results” and their scale inscriptions. Full list of descriptions is given in Appendix X. One has to remember, that the optimum positions of variables were described from the point of view of single enterprise, such as i.e. FagorMastercook. From the company’s perspective, the position of competitors shall be as weak as possible. If the system would be modelled from customers’ point of view, the optimum would change.

5.4 Criteria matrix

Next step in the system model evaluation consists of setting the criteria matrix. Here, the evaluation of the variables takes place. As the results, one may estimate the sustainability and completeness of the system in question.

The sustainable and complete system should be described in terms of variables, which relate to the following categories:

- a) Spheres of life: economy, population, space utilization, human ecology, natural balance, infrastructure, rules and laws;
- b) Physical category: matter, energy, information;
- c) Dynamical category: flow quantity, structural quantity, temporal dynamics, spatial dynamics;
- d) System relationship: open system through input, open system through output, can be influenced from outside, can be influenced from inside.

Since the Sensitivity Model serves for the evaluation of various systems, the meaning of the categories and subcategories is very general. In fact, the model user might interpret it in a very flexible way.

Fig. 5.4 presents the system criteria window. Here, the user may specify, which categories may be applicable to the variable in question. The applicability may be denoted with the black-filled circle (fully applicable) or circle without filling (partially applicable).

Table 5.1 Variables and their description in the system model “Polish Enterprise” (excerpt).

No.	Name	Definition	Variables influenced	Most important relationships	Strength of influence
1.	Owner	Person or corporation that owns the company. May be a private person, a legal person, the state or corporation.	Financial results, Wages, EMS, Price, Employees, Trade unions, Authorities, Customers, Competitors, Politicians, Subassembly deliverers, Job centres, Health and social care, TV/radio stations	Financial results	Very high
2.	Financial results	General financial results, including profit and economic efficiency, etc.	Owner, Wages, Quality, Price, Employees, Trade unions, Authorities, Customers, Competitors, Subassembly deliverers, Resources/Global market, Local infrastructure, Educational institutions, Health and social care, Property market, Financial institutions, Politicians	Owner, Wages, Financial results, Price, Employees, Competitors	Very high

Table 5.2 Variables and their description in the scale of values (excerpt).

Variable	Optimum	Maximum	Middle range	Minimum	Actual situation
1. Owner	At the top	Making profits, but also taking care of employees well-being, health and social care, Corporate Social Responsibility, environment, future development of the company	Focused mainly on making profits, obeying laws and standards if necessary, no special commitment in health and safety, as well as environmental issues	Disobeying laws and standards, no commitment towards development of the company, wrong management without making profits	Upper middle range
2. Financial results	At the top	Very high profit, divided "equally" between owner and employees, plus new investments	Moderate profit, returned mainly to the owner of the company, with little investments and little share of employees	No profits or losses	Between upper middle range and maximum. High investments, high profit, little share with the employees

Sensitivity Model Prof. Vester © Version 5.0e

System Criteria

System model: Polish Enterprise

List of variables

- 1 Owner
- 2 Financial results
- 3 Wages
- 4 LCA
- 5 EMS
- 6 Quality
- 7 Price
- 8 Employees
- 9 Trade unions
- 10 Authorities
- 11 Customers
- 12 Competitors
- 13 Educational institutions
- 14 Politicians
- 15 EU
- 16 Environment
- 17 Subassembly deliverers
- 18 Resources/Global market
- 19 Local infrastructure
- 20 Transportation network
- 21 Job centers
- 22 Health and social care
- 23 Inhabitants of city
- 24 Property market
- 25 Financial institutions
- 26 International organizations
- 27 TV/radio stations

Description of the variables

1 Owner

Who/what:
Person or corporation that owns the company. May be a private person, a legal person, or the state.

Variables influenced: Financial results, Wages, EMS, Price, Employees, Trade unions, Authorities, Customers, Competitors, Politicians, Subassembly deliverers, Job centers, Health and social care, TV/radio stations

Most important relationships:
Financial results

Total strength of influence on the system: very high

Optimum: at the top

Maximum: making profits, but also taking care of employees well-being, health and social care, CSR, environment, future development of the company

Assignment of criteria for the variable "Owner"

SPHERES OF LIFE	PHYSICAL CATEGORY	DYNAMICAL CATEGORY	SYSTEM RELATIONSHIP
<input type="radio"/> Economy	Matter	<input type="radio"/> Flow quantity	<input checked="" type="radio"/> Opens system through input
<input type="radio"/> Population	Energy	<input type="radio"/> Structural quantity	<input checked="" type="radio"/> Opens sys. through output
<input type="radio"/> Space utilization	<input checked="" type="radio"/> Information	<input type="radio"/> Temporal dynamics	<input checked="" type="radio"/> Can be influenced f. inside
<input type="radio"/> Human ecology		<input type="radio"/> Spatial dynamics	<input type="radio"/> Can be influenced f. outside
<input type="radio"/> Natural balance			
<input type="radio"/> Infrastructure			
<input checked="" type="radio"/> Rules and laws			

Figure 5.4 System criteria module in the SMPV.

As the result, final criteria matrix may be presented (fig. 5.5). The software calculates automatically the sum of points for every column corresponding to one subcategory. Every circle corresponds to 1 or 0.5 points for filled and unfilled circles, respectively. In case some subcategories are underrepresented in the model, it may be immediately visible in the sum row. In case of the system model, however, the variables chosen cover all-important spheres of sustainable model (fig. 5.5).

Sensitivity Model Prof. Vester © Version 5.0e

Criteria Matrix

System model: Polish Enterprise

Criteria →

- FULLY applicable
- PARTIALLY applicable

	Criteria	SPHERES OF LIFE						PHYS. CATEG.			DYN. CATEGORY			SYSTEM RELATIONS					
		Economy	Population	Space utilization	Human ecology	Natural balance	Infrastructure	Rules and laws	Matter	Energy	Information	Flow quantity	Structural quantity	Temporal dynamics	Spatial dynamics	Opens through input	Opens through outp.	Influenced f. inside	Influenced f. outside
1	Owner	○	○		○			●			●	○			●	●	●	○	
2	Financial results	●						○	○	●	●	●		●	○	●	●	●	
3	Wages	●	●		○			○	●	○		○	○	○	○	○	○	○	
4	LCA	○	○	○	○	●		○	○	○	○	○	○	○	○	○	○	○	
5	EMS	○	○		●	●		●	○	○	○	○	○	○	○	○	○	○	
6	Quality	●			○	○		●	●	●	○		○			○	○		
7	Price	●	○					○		○	○	○	○	○	○	○	○	○	
8	Employees	○	●	○	○			●			○		○		○	○	○	○	
9	Trade unions	○	●		○			○			○		○		○	○	○	○	
10	Authorities	○				○	○	●		○	○	○	○	○	○	○	○	○	
11	Customers	●	●					●	○		○	○	○	○	○	○	○	○	
12	Competitors	●						○			○	○	○	○	○	○	○	○	
13	Educational institutions		●	○		○	○	○			○	○	○	○	○	○	○	○	
14	Politicians		●					○			○	○	○	○	○	○	○	○	
15	EU	○			○	○	○	○	○	○	○	○	○	○	○	○	○	○	
16	Environment		○	●	○	●	○	○	○	○	○	○	○	○	○	○	○	○	
17	Subassembly deliverers	●	○	○			○	○	○	○	○	○	○	○	○	○	○	○	
18	Resources/Global market	●	○				○	○	○	○	○	○	○	○	○	○	○	○	
19	Local infrastructure	●	○	○		○	○	○	○	○	○	○	○	○	○	○	○	○	
20	Transportation network	○	○	●			○	○	○	○		○	○	○	○	○	○	○	
21	Job centers	●	●					○			○	○	○	○	○	○	○	○	
22	Health and social care		●		○			○			○	○	○	○	○	○	○	○	
23	Inhabitants of city	○	●	●	○			○			○	○	○	○	○	○	○	○	
24	Property market	●	●	●			○	○	○		○	○	○	○	○	○	○	○	
25	Financial institutions	●	○					○	○		○	○	○	○	○	○	○	○	
26	International organizations			○	●	●		○			○	○	○	○	○	○	○	○	
27	TV/radio stations	○	○				○				○	○	○	○	○	○	○	○	
Sum:		17.0	15.5	7.0	7.0	6.5	10.0	16.5	10.0	9.0	17.5	10.5	12.5	12.5	9.5	13.5	13.5	12.0	17.0

Minimum

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Figure 5.5 Full matrix of the system criteria.

5.5 Impact matrix

After defining the variables and assigning them to various categories, the evaluation of their influence has to take place. This evaluation allows user to get some knowledge about real importance of the variable for the system. Simultaneously, the behaviour of the variables may be examined.

Fig. 5.6 presents the results of evaluation for the system model “Polish Enterprise”. The influence of every single variable on the other remaining 26 variables was specified. Four values described the strength of influence:

- 3 for strong influence;
- 2 for middle influence,
- 1 to weak influence;
- 0 to no influence.

Those values were used to calculate active and passive sums. Active sum denotes the total number of influence of variable in question on other variables. Passive sum denotes the strength of influence of other variables on the variable in question.

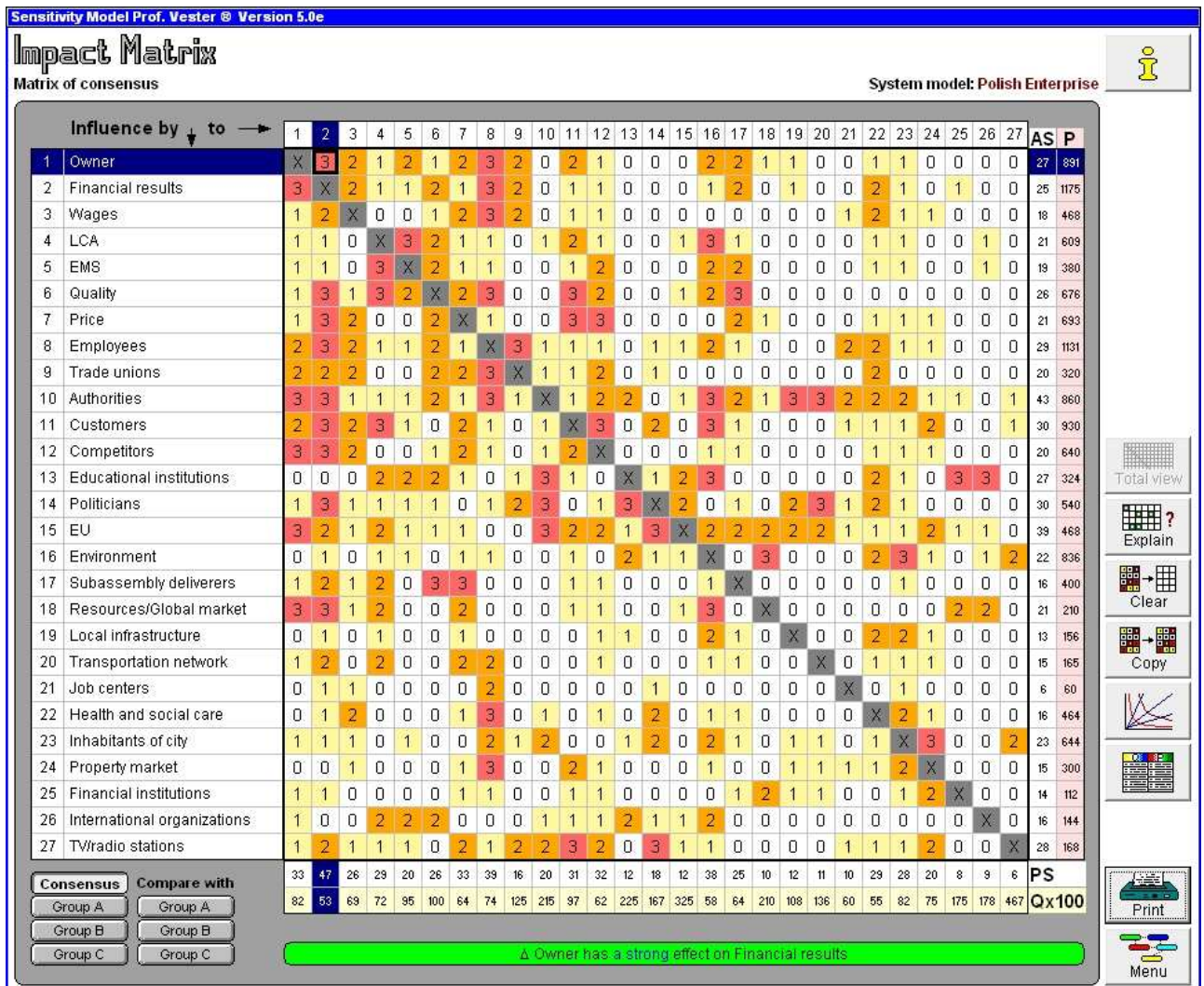


Figure 5.6 Impact matrix for the system model “Polish Enterprise”.

The letter “Q” in the diagram stands for the “Quotient”: the quotient of active and passive sums of the corresponding variable. This index helps the user to estimate, whether the variable in the system behaves actively (influencing other variables) or passively (being influenced by other variables).

The letter “P” in the diagram stands for “Product”: the result of product of the active and passive sum of the corresponding variable. In this way, variable may be evaluated from the point of view of being critical or inert for the system.

The sensitivity model classified automatically variables according to their “Q” and “P” values (fig. 5.7). One can say, for some variables the result was surprising. I.e. some active variables like Educational institutions or the EU have buffering (inert) character for the system. From the indices calculated by the SMPV, the impression about most important variables and their interactions can be derived.

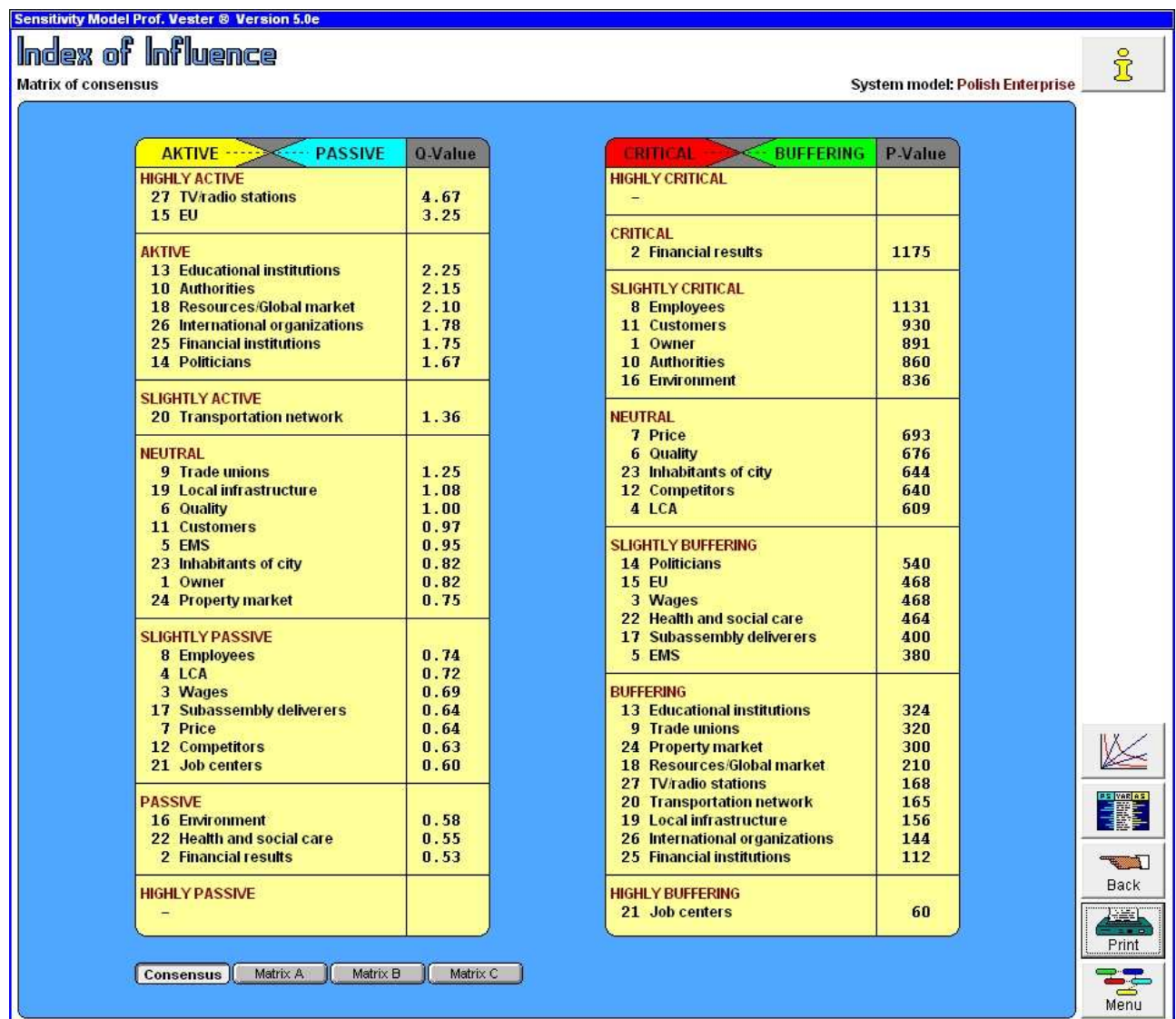


Figure 5.7 Index of influence for the system “Polish Enterprise”.

In general, for the further considerations and modelling, the highly critical, critical and neutral variables were chosen (section 5.8, Partial scenarios). Most of them represented passive, slightly passive, or neutral way of behaviour in the system.

5.6 Systemic role

The results of the impact matrix analysis can be used for the graph visualization of the system variables (fig. 5.8). Here, one can see immediately the position of the variable and its importance for the entire system.

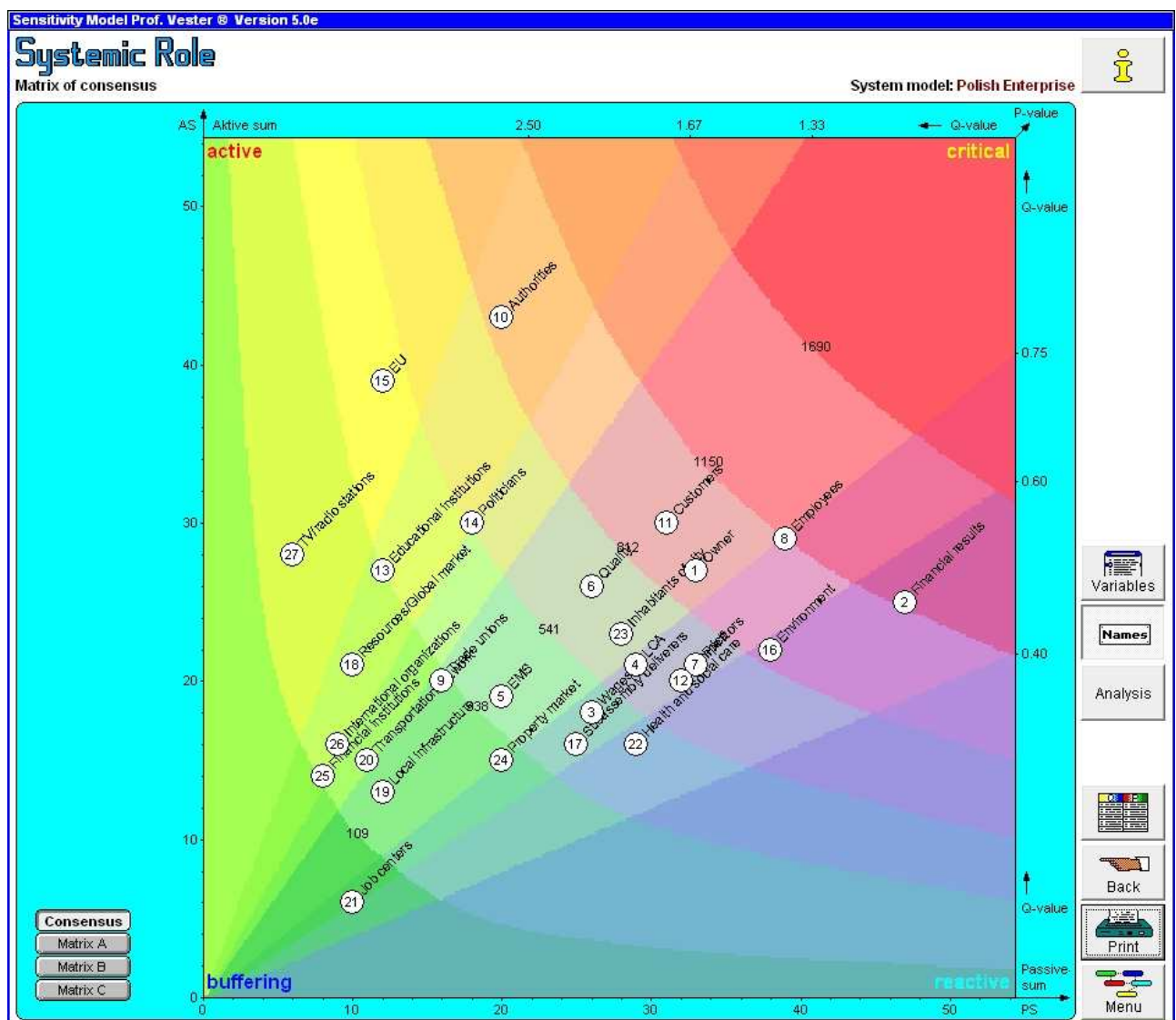


Figure 5.8 Systemic role of the variables in the system model “Polish Enterprise”.

When analysing the graph, one has to keep in mind the meaning of the active and reactive influence of variables on the system. Small changes of active variables results in significant change of the

entire system. Reactive variables are changed, when the system changes. They do not influence the behaviour of the system by their intrinsic changes.

5.7 Effect system

The subsequent step of analysing the system is based on the determination of the effect system and interrelations of the variables. The SMPV user has to define the nature of the influences in terms of negative (opposing) and positive (confirming effects). Negative effects are denoted with the help of dashed arrows, positive with solid arrows (fig. 5.9).

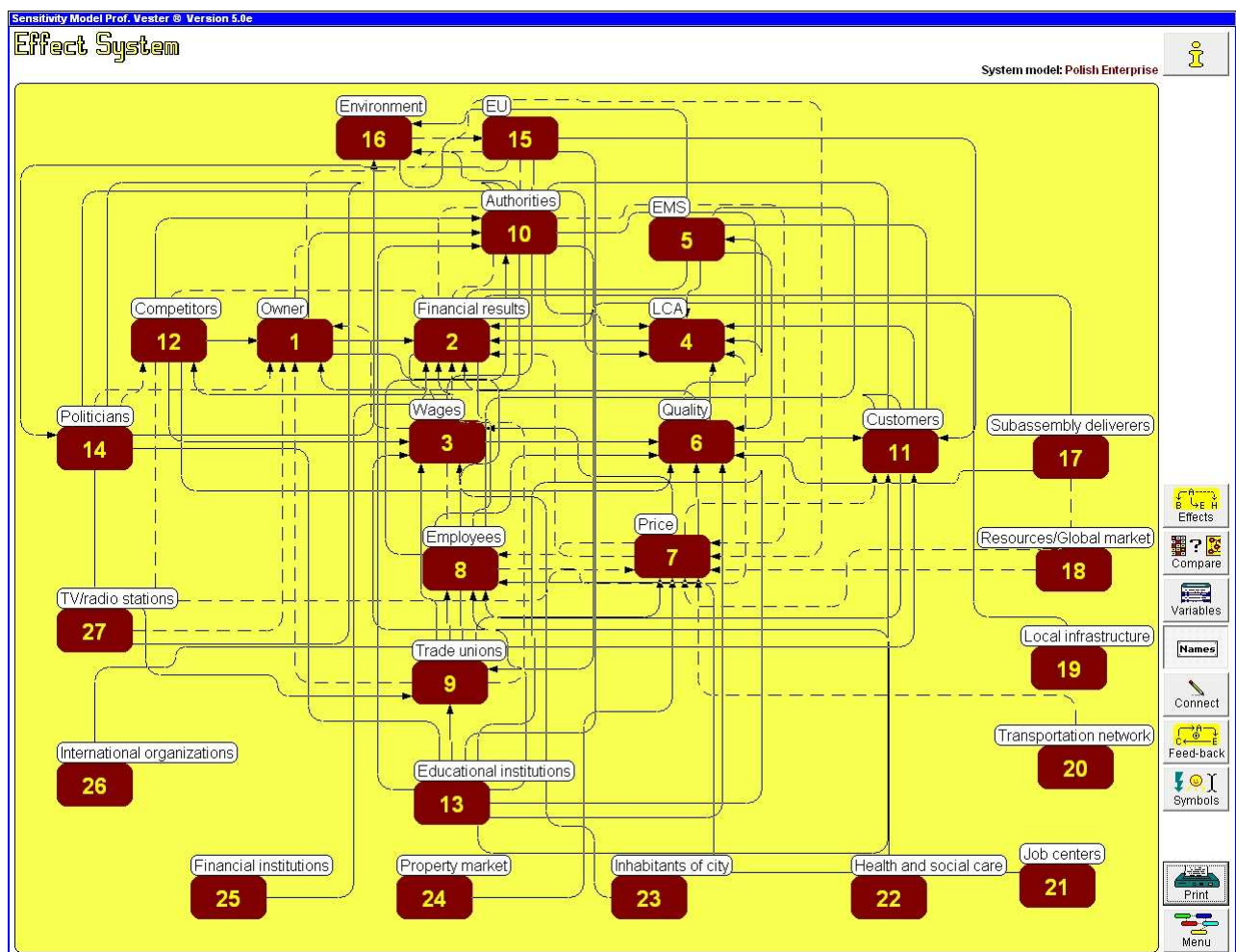


Figure 5.9 Total view of effect system for the model Polish Enterprise.

Positive influence may be seen as directly proportional influence. For instance, higher the price of the product sold, better the financial results of the enterprise. Negative interrelationships have inversely proportional character. For instance, higher the attention of the authorities paid to the company (by means of controls), worse the financial results. The meaning of the “positive” and “negative” may be, however, misleading in the context of the system modelling and feedback

cycles, created by the positive and negative connections of two or more variables. Here, greater the number of the negative feedback cycles, the better self-sustainability and self-controlling of the system in question.

One can explain the self-sustainability of the system with the help of interrelationships price – quality – customers. If two effects are confirming (amplifying) each other, they may explode (higher the price, better the quality; better the quality, higher the price... etc.). Finally, one could obtain the product with infinitely high price of the superior quality. Such a situation may be true for some luxurious brands, but not for a “classical” enterprise. Introducing one negative relationship (higher the price, less consumers; less consumers – lowering the price of the product) may lead to system stabilization. Thus, interrelationships between the variables in question (price, quality, consumers) will be balanced.

The SMPV developers classified positive feedbacks as those with even numbers of confirming effects or opposing effects. Negative (self-regulatory) feedbacks are those with odd numbers of negative effects. Number of variables used in the modelling and the huge number of interrelationships between them created a very large number of positive and negative feedback cycles. Some of them are presented in table 5.3.

Table 5.3 Positive and negative feedbacks inside the effect system (excerpt). Full number of positive and negative feedback may exceed the total number of 2000. There are no correlations between negative and positive feedbacks.

Examples of negative feedbacks	Examples of positive feedbacks
1->2->3->1	1->10->1
1->8->9->1	8->9->8
1->10->3->1	1->8->10->1
1->10->9->1	2->3->6->2
2->8->4->2	2->8->6->2
2->8->9->2	6->11->8->6
2->8->10->2	6->11->10->6
3->8->9->3	6->11->12->6
3->8->10->3	7->8->10->7
7->8->9->7	7->11->10->7
1->2->8->9->1	7->11->12->7
1->8->9->3->1	8->10->9->8

The effect system presented in fig. 5.9 is very comprehensive, but very difficult to model because of its complexity. The sensitivity model offers some features that help to analyse it at this stage of the modelling (i.e. highlighting the incoming and/or outgoing effects of one or several variables, fig. 5.10). However, to discover the details of system functioning, one has to choose the most important variables to focus the research on. Details will be given in the following section.

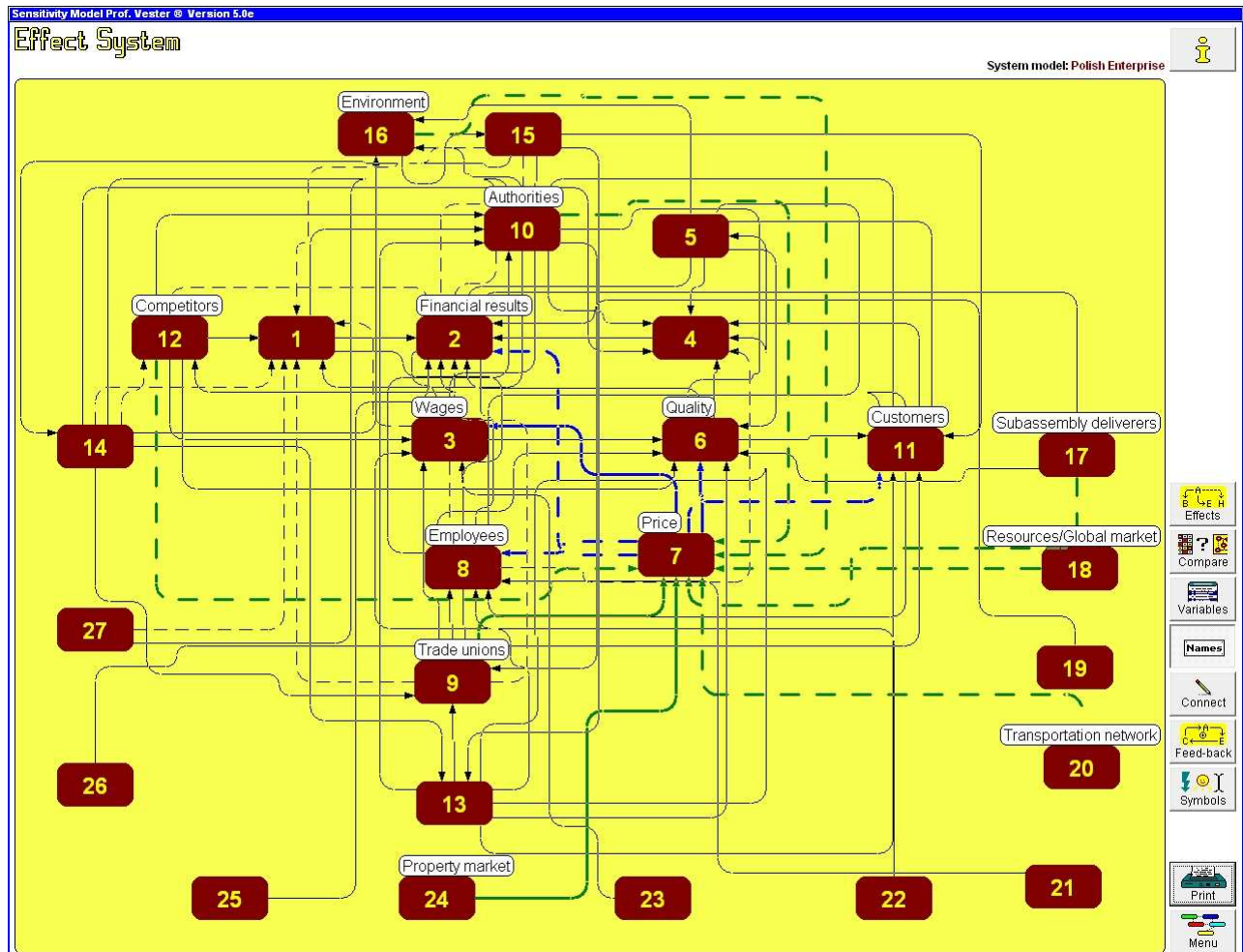


Figure 5.10 Effect system of Polish Enterprise. Incoming and outgoing effects of variable Price are highlighted.

5.8 Partial scenarios

The analysis and evaluation of the system with 27 variables and more than 400 negative and positive feedback loops seems to be almost impossible. Therefore, following variables were merged:

- Authorities and the EU, represented afterwards as “Authorities”;
- EMS and the LCA, represented as the variable “EMS + LCA”.

Furthermore, in modelling of the partial scenarios, only the variables being the core of the system were used, namely Owner, Financial results, LCA and EMS, Quality, Price, Employees, Authorities, Customers, Competitors, and Environment. For the sake of results transparency, other variables were neglected or represented as the controlling variable. Additionally, the opposing and confirming effects were revised.

As the result of the merging and simplifications, the analysis of the system behaviour has been done for two basic partial scenarios.

The first partial scenario investigated the behaviour of the following variables: Owner, Financial results, LCA and EMS, Quality, Price, Employees, Authorities, Customers, Competitors, and Environment. After first simulation runs, additional self-regulation cycles (self-feedback) cycles were applied for the variables Financial results, Price, and Employees (fig. 5.11).

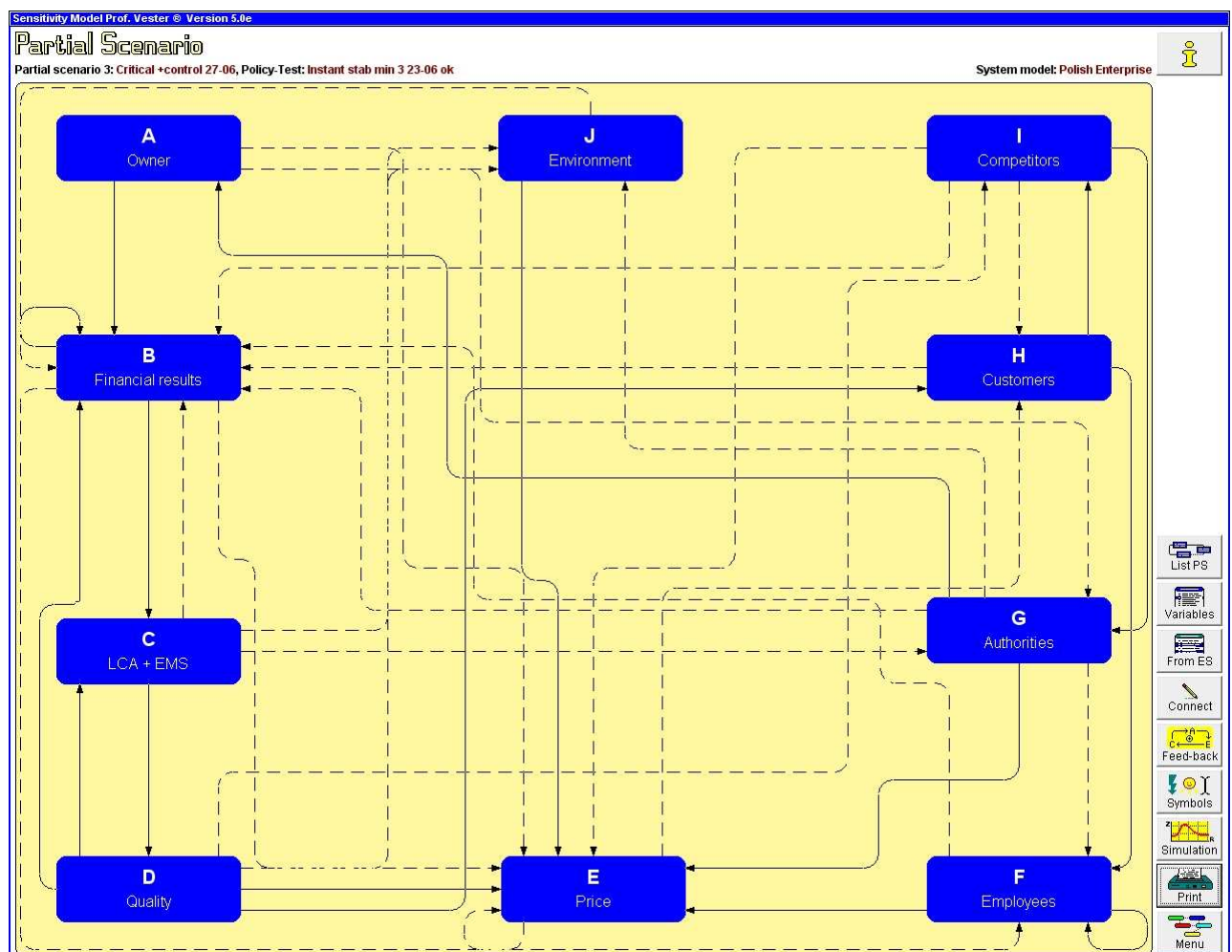


Figure 5.11 Partial scenario for the most important variables in system model “Polish Enterprise”. Self-feedback cycles for the variables Financial results, Price, and Employees were added.

Further refinement of the analysis led to the creation of the partial scenario, in which only the core system variables were taken into consideration: Financial results, LCA+EMS, Quality, Price, and Environment. This scenario was additionally evaluated with the option of self-regulating feedback loop (Fig. 5.12).

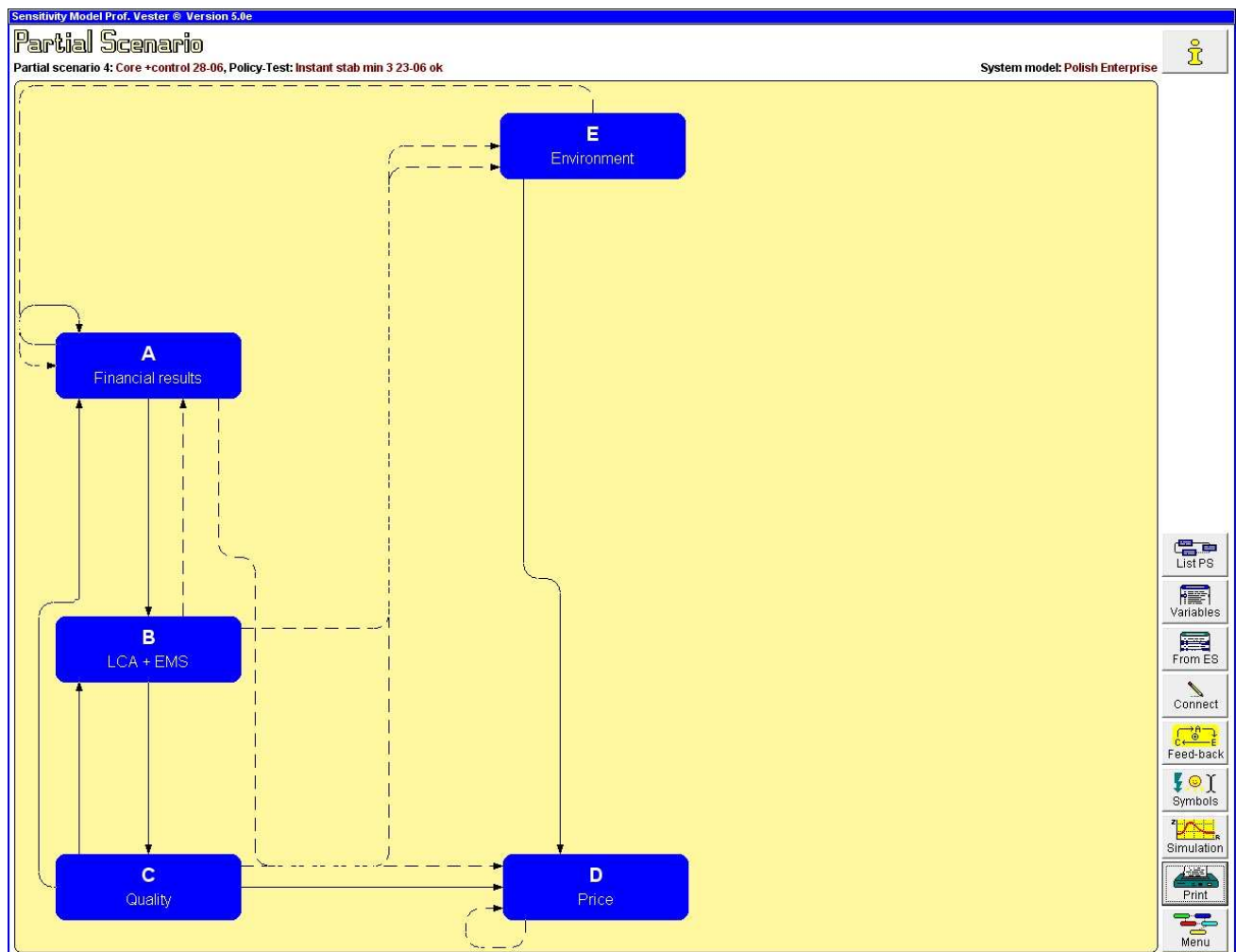


Figure 5.12 Partial scenario with core system variables and self-regulating feedback loops.

One has to mention the overall number of positive and negative loops in the critical and core simulation scenarios. The first one is characterized by the existence of 40 negative feedbacks and 43 positive feedbacks. The latter one includes one negative feedback and four positive feedbacks.

These numbers of feedback loops do not fully represent the real behaviour of variables' interrelationships. In some cases, variable may influence another variable in positive way. In another arrangement, the nature of influence will be negative. Further explanation of this matter will be provided in section 5.9.

5.9 Simulation results

Simulation module constitutes the crucial part of the model. Here, the user has the chance to test the behaviour and interrelationships between the variables.

The modelling of the system proceeds in three major steps, using the knowledge about the system acquired from the previous parts of the system modelling. In the first step, one has to determine the strength and the type (confirming or opposing) of effects between the variables for every interrelationship occurring between them (as specified in module “Partial scenarios”). Subsequently, the course of the modelling is determined. That means one has to specify, which effects occur first, and which as their consequence or simply later. The final step is modelling itself, precisely running the computation for the number and duration of cycles determined by the user.

Fig. 5.13 and 5.14 present the examples of the effects for the relationships LCA+EMS – Financial results and Competitors – Price, respectively. In the first case, one can see immediately, that the result has a prevailing opposing nature. When the LCA and the EMS are implemented, the financial results may be lowered due to costs of implementation. Lack of implementation of the voluntary management tools may also lead to lowering of financial results due to i.e. worse waste management programs or loss of the positive company’s image.

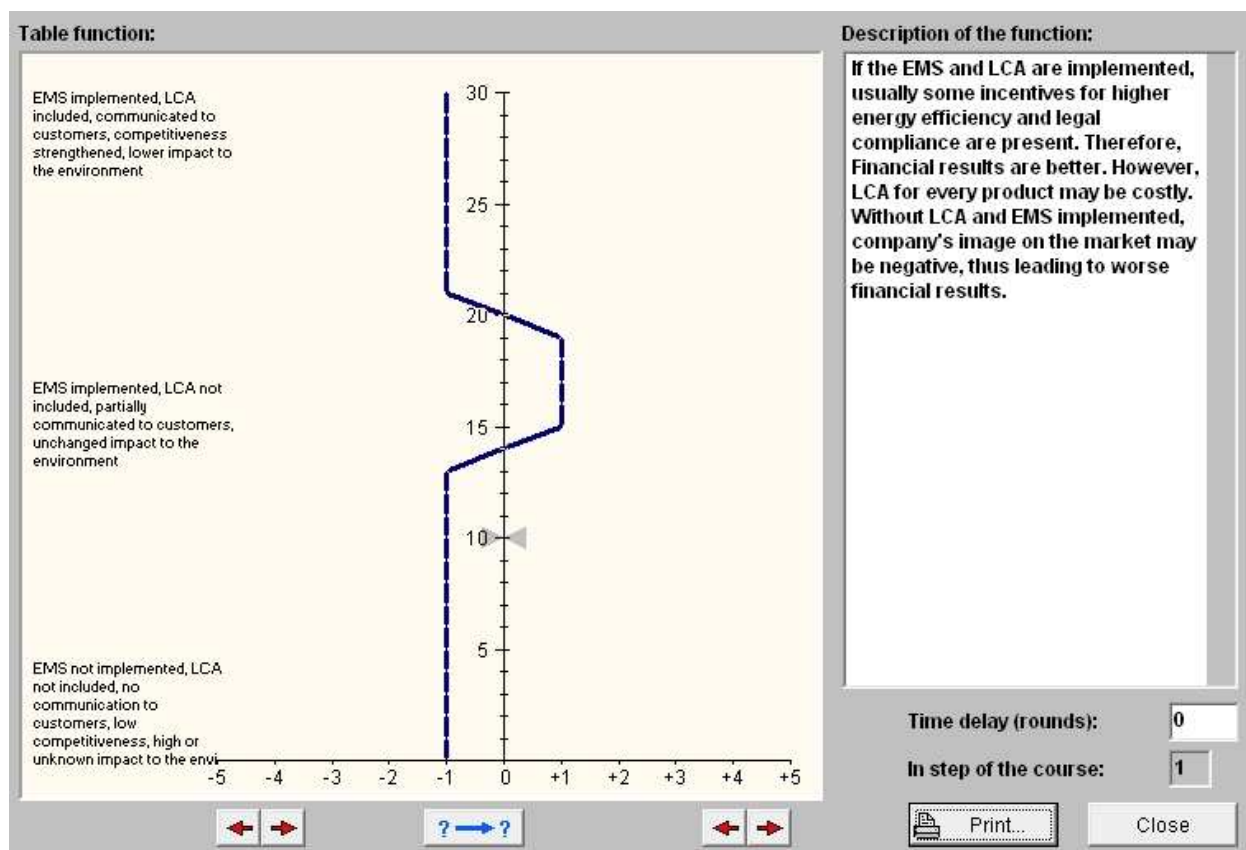


Figure 5.13 Influence of LCA and EMS variables on the Financial results.

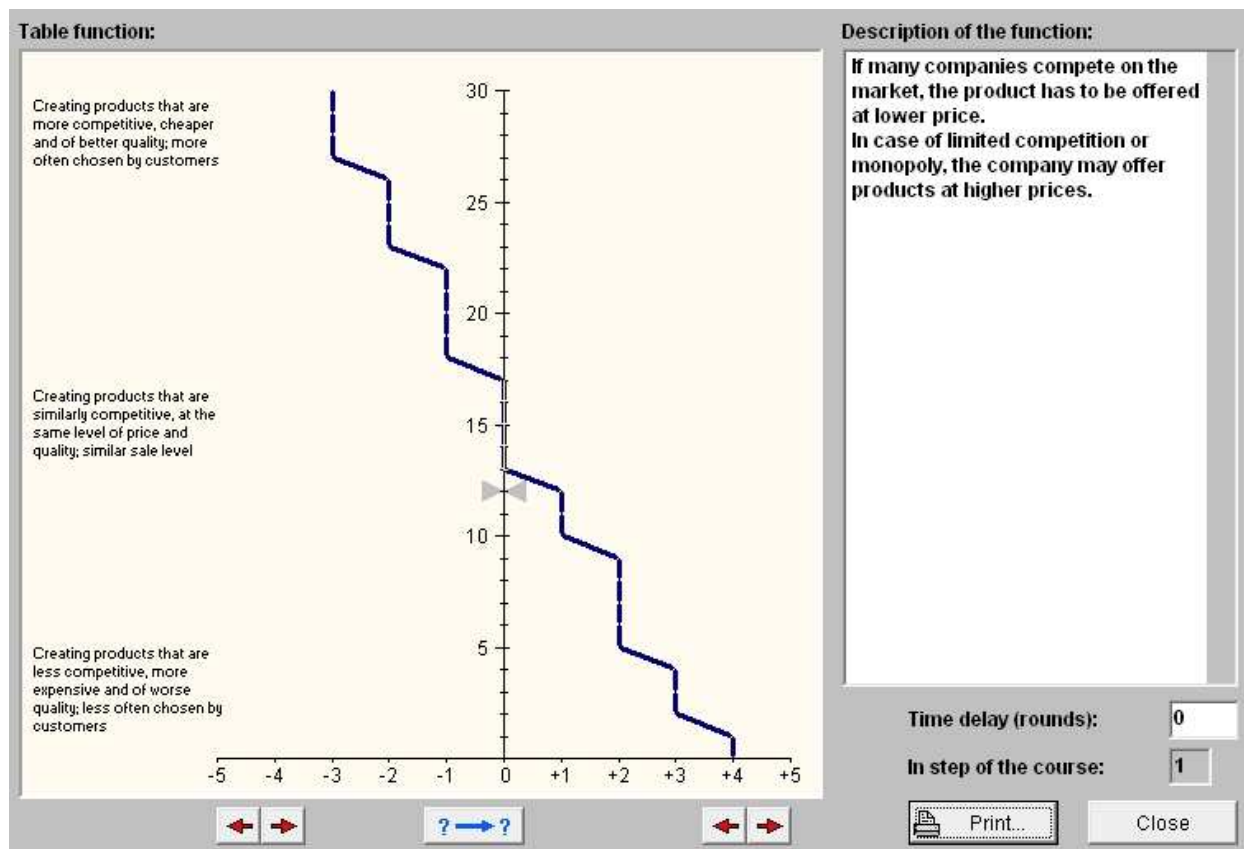


Figure 5.14 Influence of variable Competitors on Price.

In most of the cases, however, it is very difficult to decide, whether the effect is positive or negative. For instance, in some cases, the effect may be negative (fig. 5.14 – existence of many competitors cause price lowering) or positive (lack of competition – like in case of monopoly – may lead to higher product prices).

For that reason, referring to the positive and negative effects and feedback-loops is very difficult in case of real systems. The developers of the SMPV suggest that number of negative feedback loops should prevail over the number of positive feedback loops. This should help to avoid the situation when the system explodes (the values of the variables achieve maximum and remain constant after short number of computation runs) or freezes (the values of the variables achieve minimum or certain value and remain constant after short number of computation runs).

However, as one can see, it is difficult to decide about the nature of the influence. Subsequently, the number of positive and negative feedback loops calculated by the SMPV software may be seen only as a kind of an additional information.

To avoid the situation when the system explodes or freezes, two versions of the variables' interrelationships were created. The first version was represented in the modelling policies called "stable". These policies were based on the assumption, that the interrelationships inside the system

are usually of low strength, and are balancing each other. The second version of interrelationships, represented by the policy test called “fluctuating”, did not restricted the values of the effects to low or middle strengths. In the latter case, however, freezing and explosion of some variables was inevitable. This freezing and explosion of variables occurred in the stable scenarios, as well, but only after several computational steps.

One can ask a question, which types of modelling policies are more representative for the real systems. In reality, the systems explode and freeze very rarely (i.e. in case of bankruptcy or new revolutionary product invention). That would suggest that stable scenarios are closer to the reality. However, it is possible to represent in the modelling only the most important system variables. Maybe in real systems, additional variables are controlling the behaviour of the system, thus not allowing exploding or freezing. As one can imply, both types of scenarios represent the part of the reality.

The disadvantage of the model is its only partially dynamic representation of the real systems. That serves for the simplicity of the modelling. Nonetheless, the variables are behaving only in the way prescribed in the graphs. In reality, if some part of the system is malfunctioning, the decision makers can start acting in the way different from usual. For instance, they may decide to lower the price of the product or spend additional amount of money for a successful advertising. This kind of behaviour may be reflected in the SMPV only partially. The additional partial scenarios with self-controlling feedbacks were created to represent that kind of corrective action. One has to remember, however, that it is only a substitute mean of representation, and does not fully represent the changes in variables’ effects and behaviour.

Appendix XI presents the effect diagrams for the variables and the interrelationships occurring in the modelling scenarios, for stable and fluctuating results.

Subsequent step in the simulation of the system behaviour constitutes of the modelling course determination. The partial scenarios and policy tests were analysed using three options:

- Simultaneous interactions between all variables; all effects have the same priority in the calculation (referred afterwards as “simultaneous” policy test; fig. 5.15);
- The core variables of the enterprise have the priority; they influence other variables first, then the effect of other variables is calculated (step 1: Owner, Financial results; step 2: LCA+EMS, Quality, Employees; step 3: Price, Competitors, Authorities, Customers; step 4: Environment; referred afterwards as “Cascade Enterprise”);

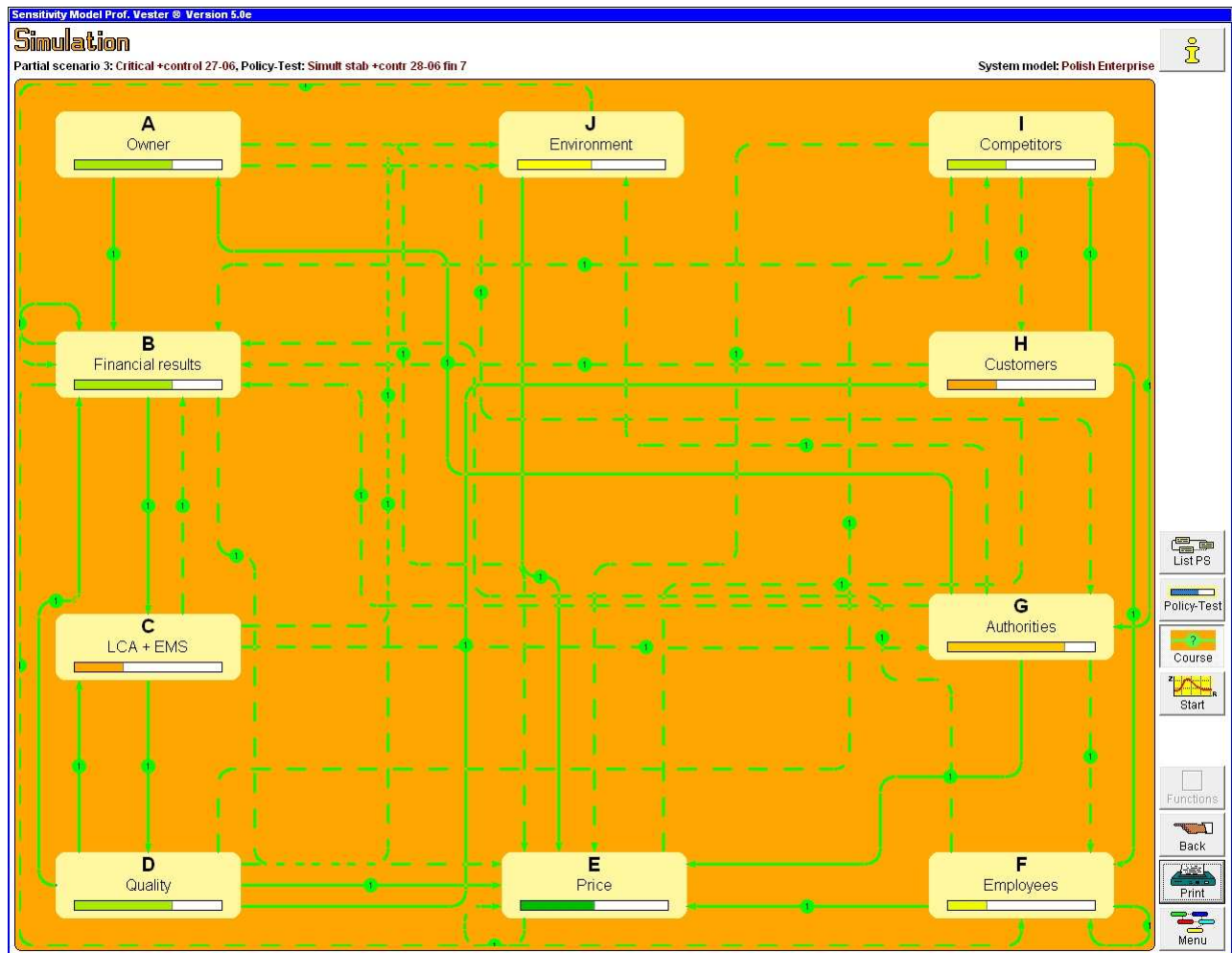


Figure 5.15 Course of interactions for “Simultaneous” policy test.

- The variables outside the enterprise affect the variables inside the enterprise first (step 1: Competitors, Customers, Environment, Authorities, Price; step 2: Employees; step 3: Quality, LCA; step 4: Owner, Financial results, referred afterwards as “Cascade Surroundings”).

Here the question of the real-life course of interactions appears. Most probably, it depends on the size of the company. For bigger enterprises, they have enough power to influence and shape the elements of the system outside themselves. Smaller enterprises, however, are being influenced by the external conditions. From this point of view, simultaneous-interactions-policy seems to be a good trade-off between those two options.

The courses of the modelling for the policy tests focusing on the core elements of the system are the same as mentioned above. The only difference is that only core variables were taken into consideration. For scenarios without self-regulation, the internal feedbacks were excluded.

Summarizing the previous findings and assumptions, the system was analysed in 18 various configurations. All of them are listed in table 5.4. As the starting point for every modelling run, the position of the system variables for the model “Polish Enterprise” has been used (compare Table 5.2, column “Actual situation”).

The last step of the simulation consists of several computational runs. For the research on the system “Polish Enterprise”, time period of 30 years was used (for stable policy tests with self-regulatory internal feedbacks) or 15 years (for all other policy tests). Results of the simulation are presented in the following figures and in the Appendix XII.



















The modelling results suggest, that stable policy tests (fig. 5.16 to 5.18) represent the most probable behaviour of the system. As one can see, the enterprise is on a good way to achieve the success. That means, the level of the environmental burden will be lowered, with increasing level off the LCA and EMS implementation, increasing number of customers and decreasing importance of competitors.

The problems according to the stable policy test results may arise with the rising level of product price, associated with the costs of LCA implementation, as well as implementation of other environmental measures. That means the financial results in the future might be lowered.

As for the enterprise-focused scenario (fig. 5.17), it differs only slightly from the simultaneous interaction policy test. General trends are positive for the enterprise. One can observe the increasing numbers of customers, better implementation of the environmental measures and the EMS, lowered impact on environment, and better quality of the products.

As for the surrounding variable-focused policy (fig. 5.18), the situation is rather different. Here, although the number of customers is increasing, the price of the product strongly decreases, causing also decrease in financial results. One has to remember, that company-external variable focused policy test assumes kind of inertia of the enterprise; it reacts to the changes in external variables, but there is no motivation or means to improve the situation of the company. That results in a weaker overall performance of the company.

Table 5.4 Configurations of modelling scenarios and policy tests for the system model “Polish Enterprise”.

Strength of effects	Partial Scenario	Simultaneous	Cascade Enterprise	Cascade Surroundings	Time span	Remarks
Stable	Critical - self regulation				15 years	Critical variables without self-regulatory feedback, small fluctuations of variable values
	Critical + self regulation				15 + 15 years	Critical variables with self-regulatory feedback, small fluctuations of variable values
	Core - self regulation				15 years	Core variables without self-regulatory feedback, small fluctuations of variable values
	Core + self regulation				15 + 15 years	Critical variables with self-regulatory feedback, small fluctuations of variable values
Fluctuating	Critical - self regulation				15 years	Critical variables without self-regulatory feedback, larger fluctuations of variable values
	Core - self regulation				15 years	Core variables without self-regulatory feedback, larger fluctuations of variable values
		All effects occurring at the same time	Priority given to effects stemming from enterprise-related variables	Priority given to effects stemming from outer-enterprise variables		

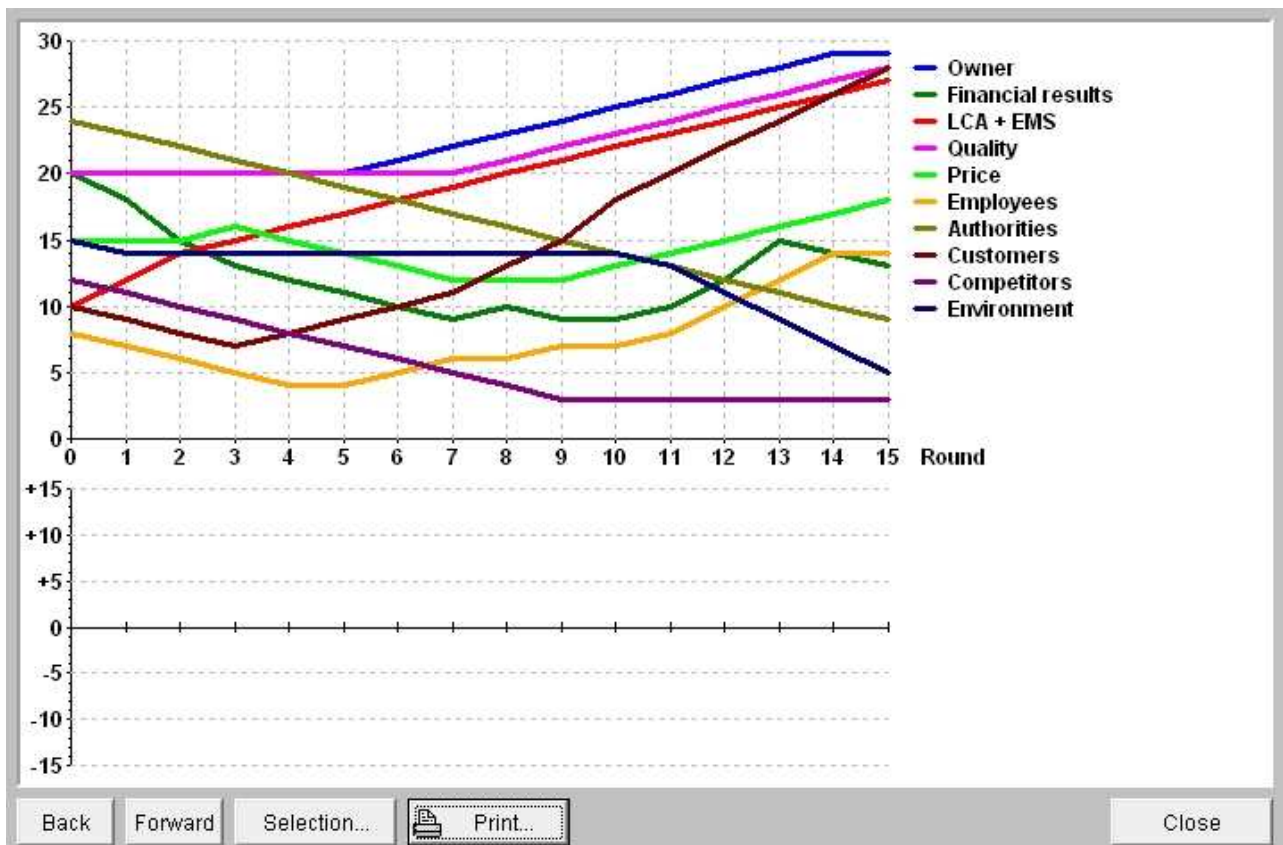


Figure 5.16 Simulation results, critical variables without self-controlling feedback, stable policy test, simultaneous interactions.

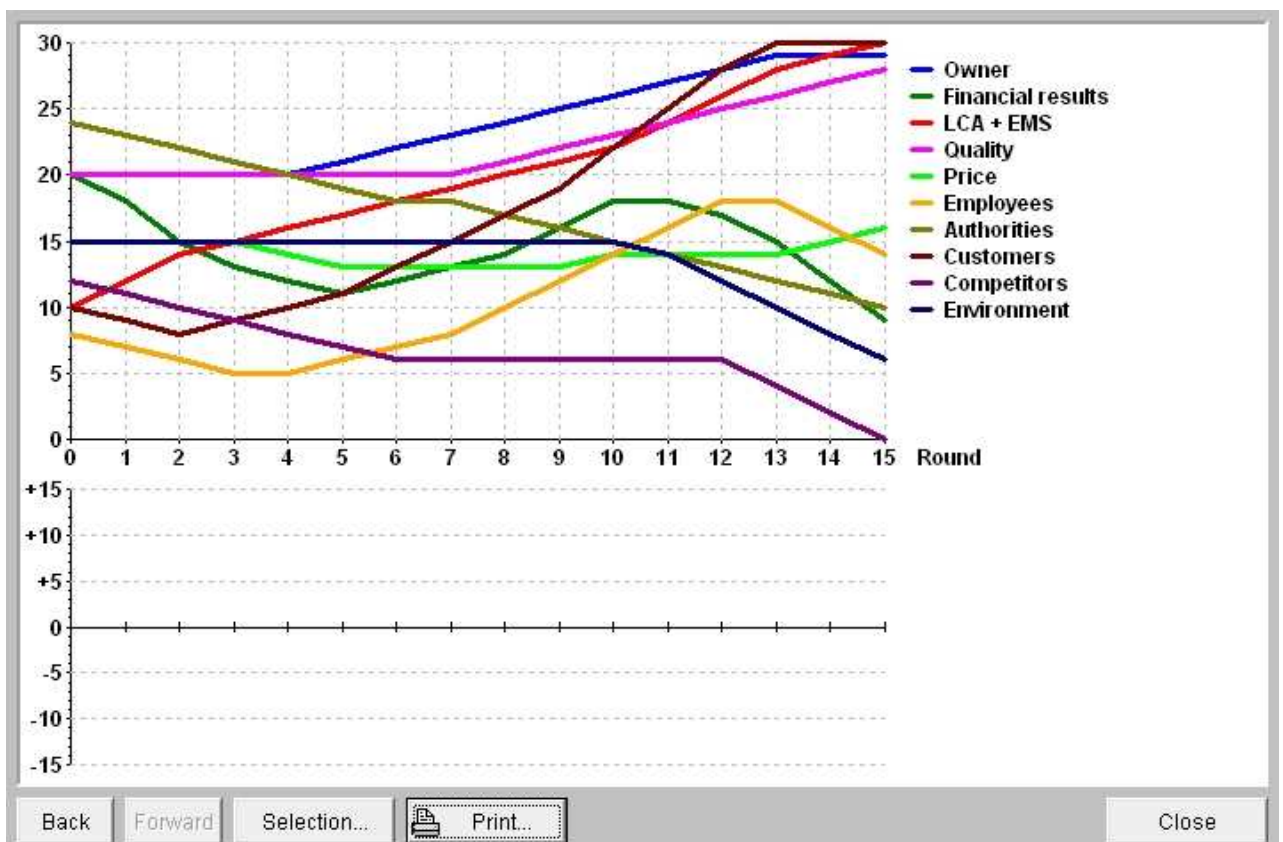


Figure 5.17 Simulation results, critical variables without self-controlling feedback, stable policy test, enterprise-focused interactions.

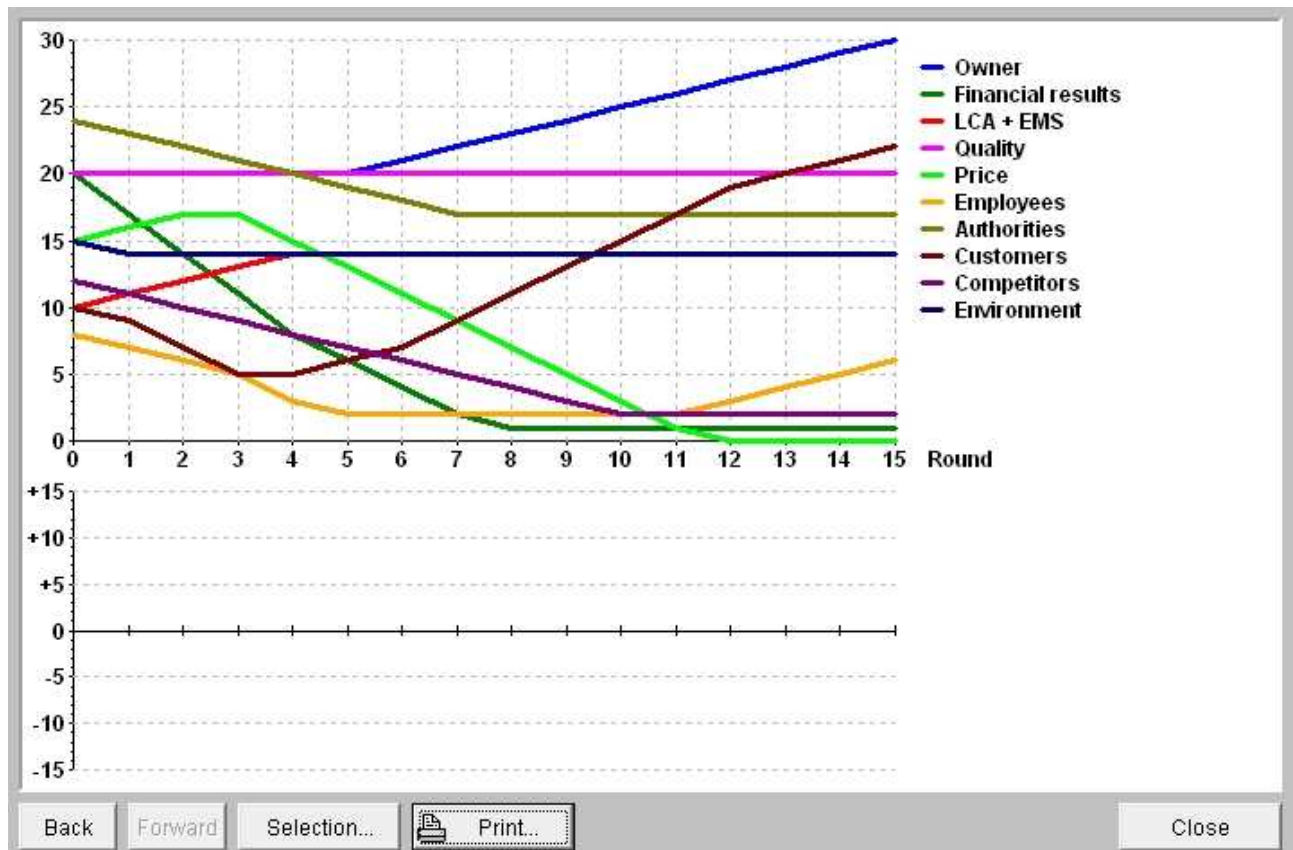


Figure 5.18 Simulation results, critical variables without self-controlling feedback, stable policy test, surroundings-focused interactions.

In the critical variable policy test, despite the use of low magnitude effect strengths, after initial period of stability, strong changes or fluctuations of the variables occur. To stabilize the fluctuations, the internal self-controlling feedback mechanisms were introduced. As fig. 5.19 and 5.20 show, that controlling feedbacks did not allow to stabilize the fluctuations significantly. As already mentioned, the SMPV does not support the introduction of corrective action after certain number of simulation runs. As the result, after 15 runs of simulation, many variables are freezing (Competitors, Authorities, Environment) or exploding (LCA+EMS, Quality, Customers). The solution to that problem could be the possibility of merging two existing policy test (i.e. baseline policy and policy implemented after freezing of some variable), which option is currently unavailable in the SMPV.

As for the policy tests taking into consideration core variables of the system (fig. 5.21 and Appendix XII), the results resembled those for the critical variables scenarios. For example for stable policy tests without self-regulatory feedback loops, increased level of the LCA and the EMS implementation was coupled with increased product quality. Price level – after initial lowering – was going up. Worsening of the financial results is due to the investments necessary to implement the LCA and EMS, as well as improved state of the environment.

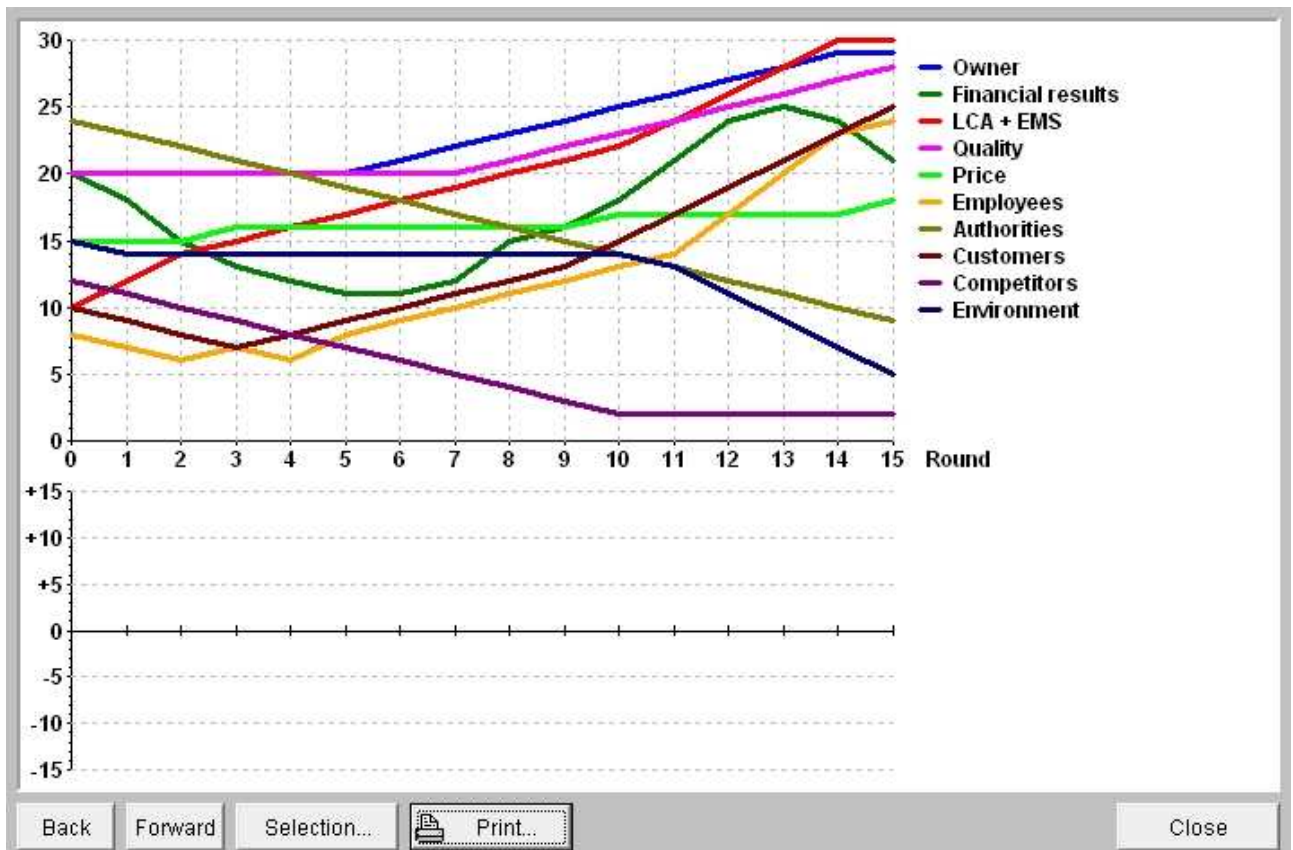


Figure 5.19 Simulation results, critical variables with self-controlling feedback, stable policy test, simultaneous interactions, years 0 to 15.

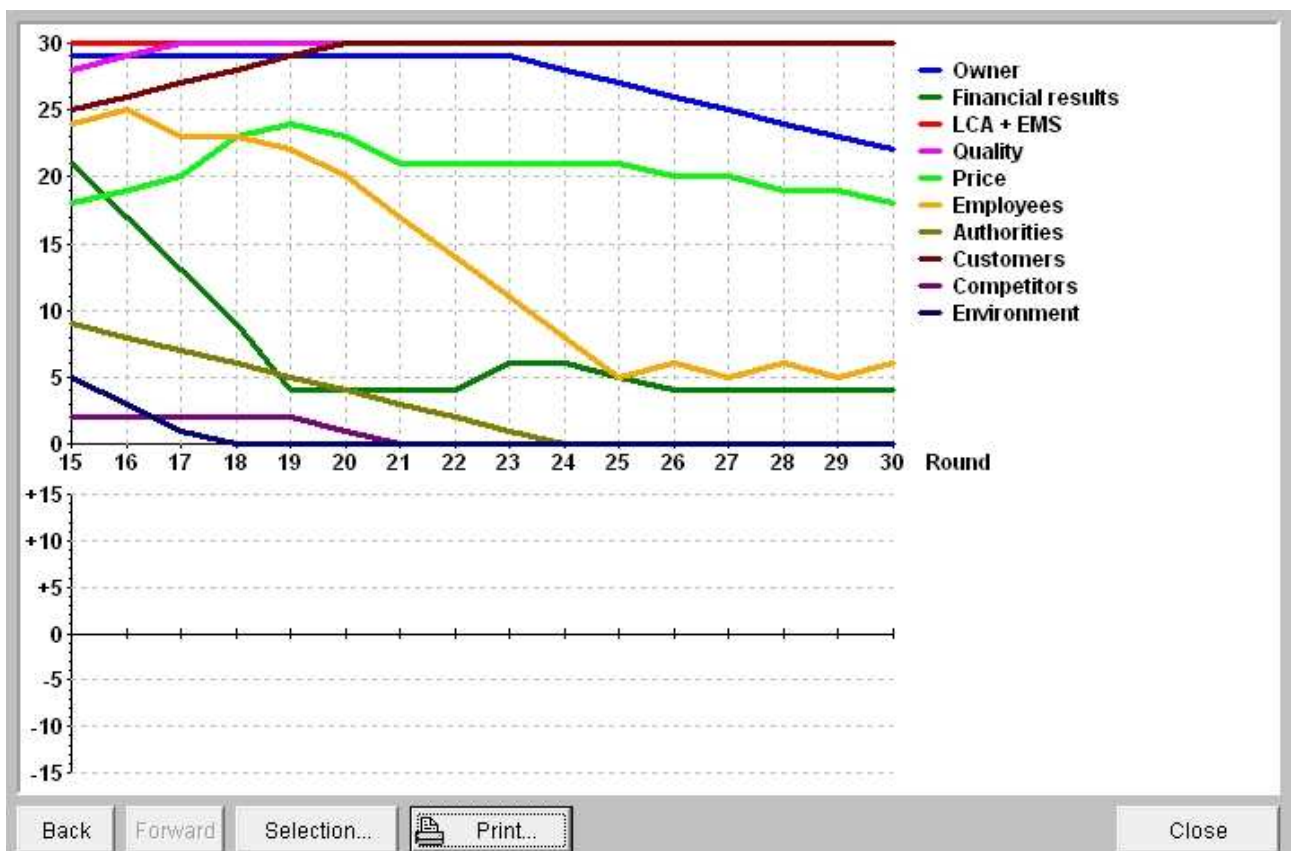


Figure 5.20 Simulation results, critical variables with self-controlling feedback, stable policy test, simultaneous interactions, years 15 to 30.

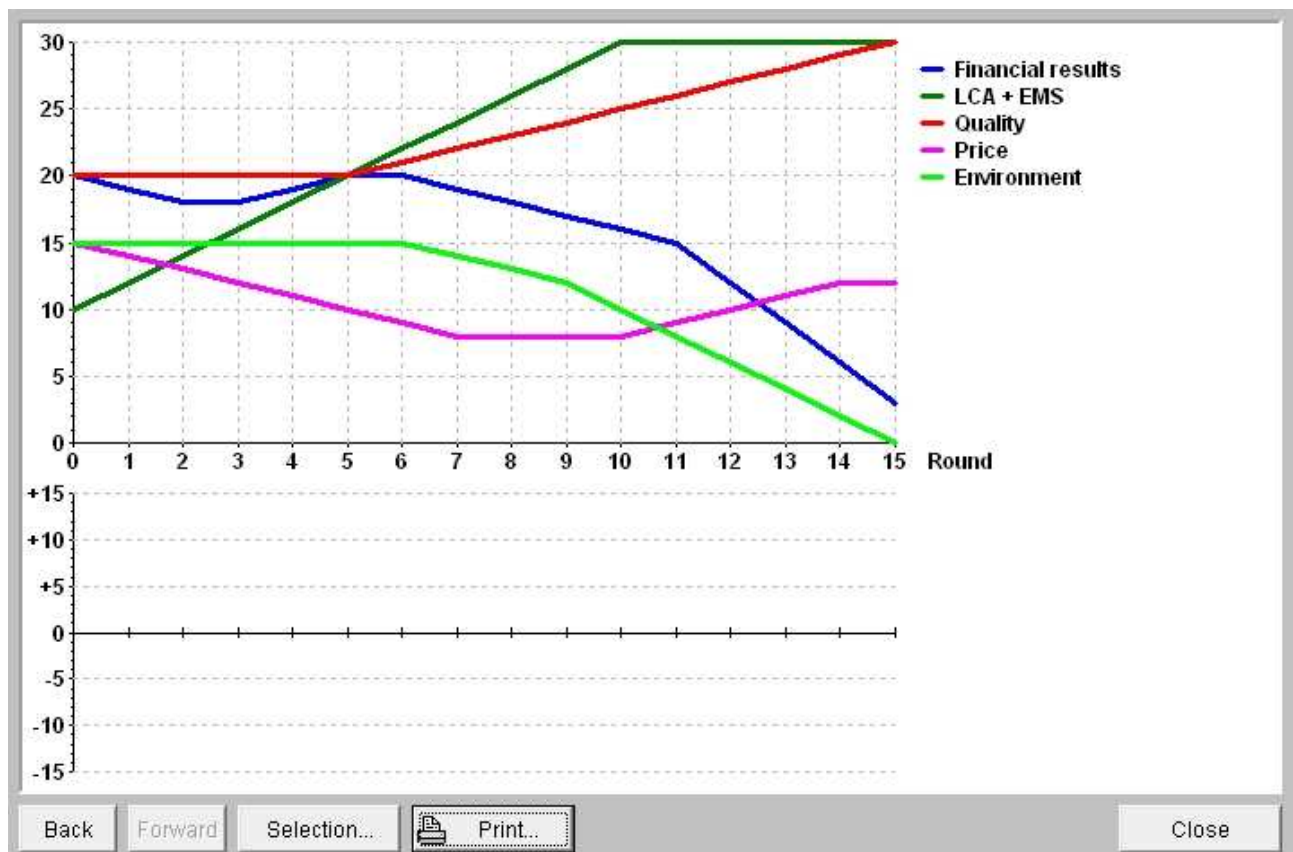


Figure 5.21 Simulation results, core variables without self-controlling feedback, stable policy test, simultaneous interactions.

As for the policy test with greater amplitude of interrelation strengths (“fluctuating” policy tests, fig. 5.22 and in the Appendix XII), the initial behaviour of variables is similar to that observed in stable policy tests: implementation of the EMS and the LCA increases product quality, the state of the environment is improved, but at the same time financial results are lowered. The difference of these fluctuating scenarios is the strength of the system instability. It may be observed easily, that most of the variables either freeze or explode after short number of simulation runs. Subsequently, they start fluctuating with great amplitudes (i.e. Financial results, or Employees).

One has to remember, that these graphs should not serve as the sole basis for the prediction of the system behaviour. The Sensitivity Model allows user to understand the system in a better way, thus facilitating future predictions. The question about the time span of the modelling runs also appears. Usually, such a long-term predictions are valid only for the first few years. After 5 to 10 years, the uncertainty of predictions is so high, that one can see the results only as a kind of hint, not the sound base for the decision makers. Nevertheless, as already mentioned, the aim of the SMPV is to facilitate the understanding of the system and its functioning, not to model it.

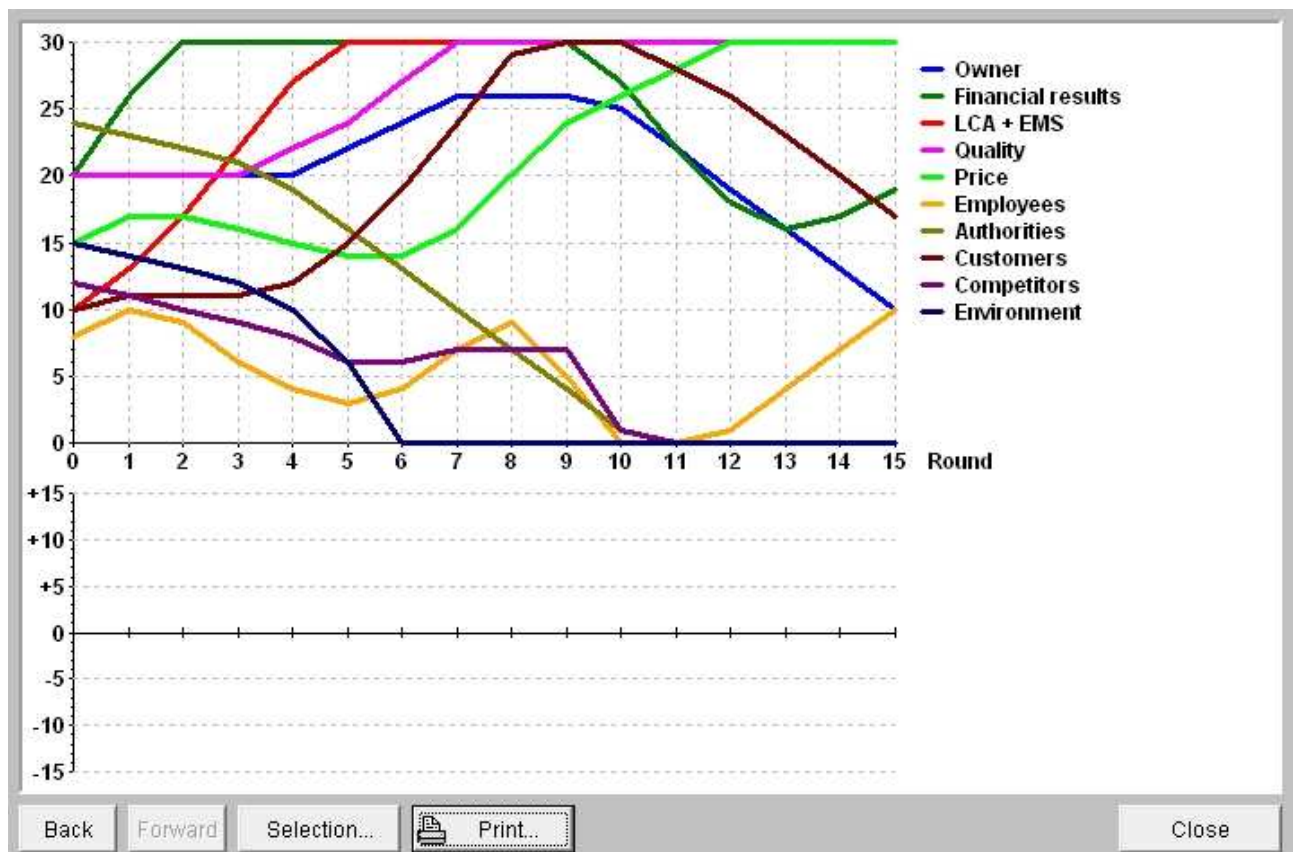


Figure 5.22 Simulation results, critical variables without self-controlling feedback, fluctuating policy test, simultaneous interactions.

5.10 Cybernetic evaluation

The last module of the SMPV can be seen as the summary of the system model description. Here, the user can specify, whether the system he described fulfils the eight cybernetic rules of a sustainable system. The Sensitivity Model developers identified the following rules: self-regulation by negative feedback, independence from growth, orientation on functions, Jiu-Jitsu principle, multiple use, recycling, symbiosis, and finally a biological design (table 5.5).

Table 5.5 Biocybernetic principles governing the functioning of self-sustainable system. Source: SMPV, modified.

No.	Rule	Description
1.	Self-regulation by negative feedback	A feedback control system stabilizes itself via negative feedback. Positive feedback is necessary in order to get things started. However, a subsystem in which positive feedback loops prevail will enter into a process of amplification in one direction or the other, e.g. it will either explode or freeze. In either case, it destroys itself, thus eliminating a disturbing element in the overall system. Hence, any positive feedback cycle needs to be dominated by negative feedback, bringing it back to a self-regulating equilibrium.

No.	Rule	Description
2.	Independence from growth	The settling down of a system to a stable equilibrium is not compatible with continuous growth. This is why in the biological process it is either growth (unstable, temporary) or function (stable, permanent) that is optimal, but hardly ever both. Systems ought to be examined as to whether they are oriented primarily toward functioning rather than toward growth. Of course it is not growth as such but dependence on growth which is dangerous for a system, as shown by the breakdowns of enterprises or entire national economies.
3.	Independence of a system function from specific product	The independence of a system of its products gives it even greater flexibility in reacting to external fluctuations. Dependency on resources is minimized, cementation due to technical fixation avoided. Products come and go, function is permanent. Only function-oriented systems will survive in the long run.
4.	Use of the Jiu-Jitsu principle	This principle aims at using already existent forces and energies by softly guiding them in the desired direction, rather than fighting and reducing them to zero. Disturbing forces are to be turned around by small inputs of steering energy so that they become supporting instead.
5.	The principle of multiple use	This principle is a variation of the Jiu-Jitsu theme. What one creates or does should serve more than one purpose at a time. Multiple use also means solving problems with several partial solutions and not with one 100% solution. In case one solution fails, the rest still works: the system shows multistability.
6.	The principle of recycling	This principle requires the reintegration of waste products into the living circulatory process among the involved systems. Recycling should also be extended to energy and heat recovery and even communication and information. This requires a departure from the linear, mono-dimensional mode of thinking that knows only beginning and end, definite causes and effects.
7.	The principle of symbiosis	Symbiosis (coexistence of different species to their mutual benefit) leads to considerable savings in raw material, energy, and transport and thus to multiple benefits. The more diversity there is in a system, the more possibilities exist for symbiosis. Large uniform structures do not profit of the advantages of symbiotic relationships (lack of stabilizing effects). They need more long-range transport for supply and waste and thus are much more expensive and eventually bound to collapse than small scale mixed structures.
8.	Basic biological design	This rule deals with creative bionic design. Every product, every function and organization should be compatible with the biology of man and nature. Design and planning should be controlled by feedback from the environment, including the social environment.

Fig. 5.23 presents the summarizing evaluation of the system model “Polish Enterprise” examined in previous sections. The cybernetic evaluation allows user to examine the eight rules with respect to every sphere of life, presented in the criteria matrix. Simultaneously, the SMPV user is able to make comparisons between initial state of the system and state of the system after application of some changes. This module of the Sensitivity Model was used, however, in different way. Since the description of the spheres of life is very general, only the entire model, without distinction of the specific criteria matrix categories and subcategories, was evaluated.

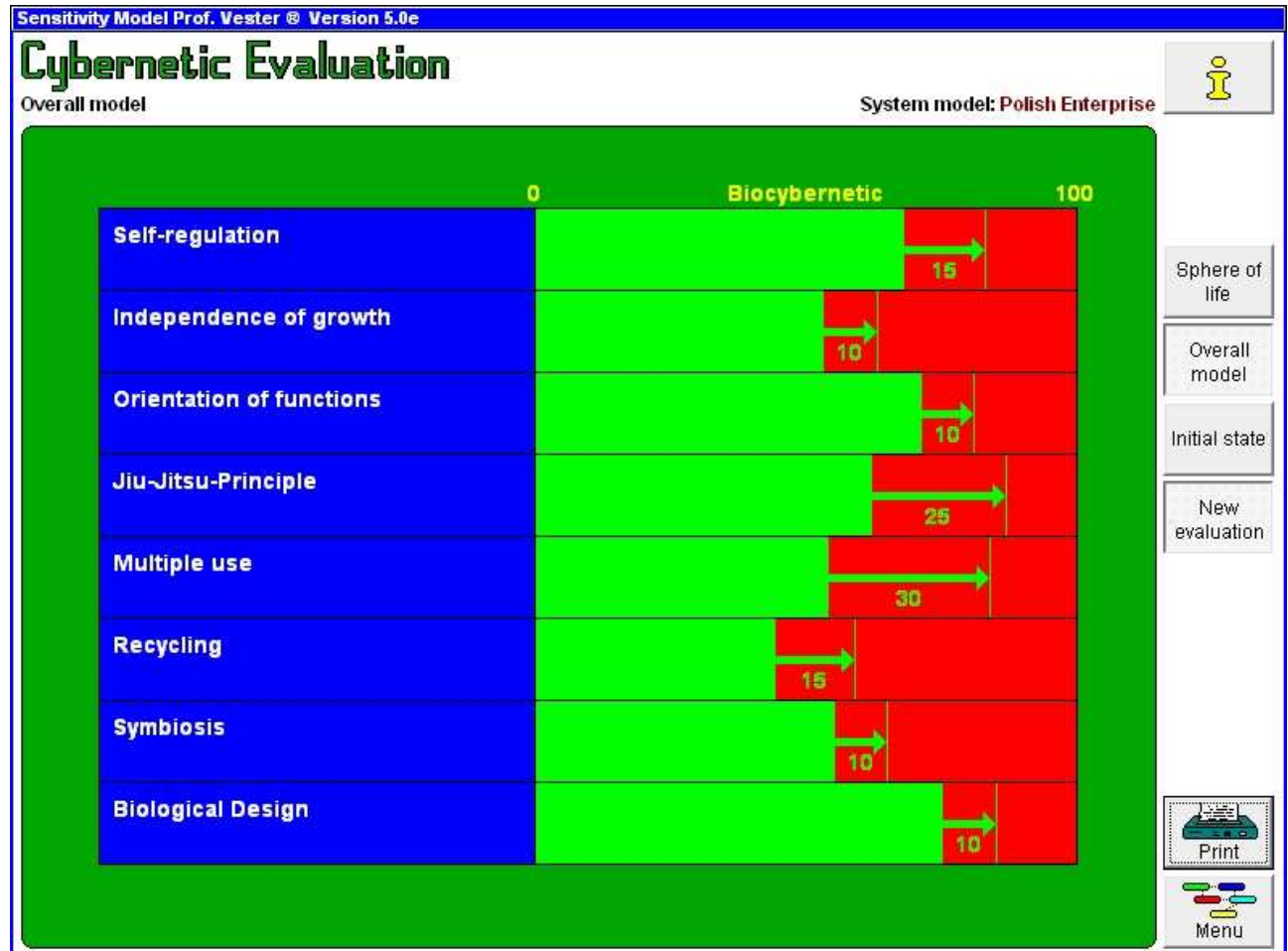


Figure 5.23 Cybernetic evaluation of the system model “Polish Enterprise”. Green bars denote the evaluation of the current overall system, green arrows – the theoretical potential for improvement of the system description.

The results of this overall evaluation are shown on the graph with the green bars. In most of the cases, the description of the system fulfils more than 50% of the biocybernetic rules. The only exception is the recycling. Here, the description of the functioning of the non-material variables was given. Thus, estimation of the recycling rule (applicable for the production or product/material flows) seems not to be appropriate in the context of this research. The fulfilment of other criteria is located in the range between 60 and 70%.

The green arrows present the evaluation on the potential of the improvement of the system description. Theoretically, this potential should simply reach the values of the 100% in case of every rule. Nonetheless, that would be very hard to achieve such level, taking into consideration the complexity of the system presented. The considerable improvement is possible to achieve only after investing a substantial amount of time and money resources on the system research. Due to the time and money constraints, this investment lies definitely outside the possibilities of research presented in this dissertation.

5.11 Summary

Examination of the system model “Polish Enterprise” with the SMPV gave an insight into the nature and complexity of the environment, in which enterprises have to develop and sell their products. The completion of the subsequent program modules led to the following conclusions:

- The system comprises of 27 major variables; 10 of them consist the crucial part of the system;
- The scope of the variables covers the all major spheres of life present in the biological and industrial systems;
- The active, passive, critical and buffering elements of the system were identified;
- The amount of the interrelationships between all 27 variables is so large, that without simplification, system modelling could not be completed;
- The positive feedback loops slightly prevailed over the negative feedback loops; however, the nature of majority of interactions could not be unequivocally determined; the results of stable policy tests have showed, however, that the systems represents satisfying stability;
- For the company being examined, the future predictions on increasing quality and level of the LCA implementation are very promising; however, the danger of the extensive financial costs and lowering of the financial gains has to be considered and balanced;
- The implementation of the LCA can be performed simultaneously with enforcing the EMS; both variables have the same effects on other variables playing significant role in the system;
- Implemented LCA and EMS may strengthen the position of the company on the internal and external market;
- The success of the company does not depend solely on the implementation of the EMS and the LCA; many variables and factors determine the possibility of achieving desired goal;

- Energy-using-Products directive does not play at this moment in time an extremely significant role; however, together with the effects of other laws and standards, as well as activities of authorities, its impact on the future functioning of the company must not be underestimated;
- The system description from the point of view of fulfilling the biocybernetic rules is satisfying with the values of fulfilment between 45 to 75%;
- The potential for improvement lies between 10 and 30%; nonetheless, a large investment of time, money and human resources would have to be done in order to achieve this improvement.

PART D

SUMMARY AND CONCLUSIONS

6. Summary and conclusions

6.1 Summary and discussion of findings

Sections A, B and C presented the results of the detailed analysis of the LCA with respect to literature research, modelling and application in the framework of the Environmental Management System and the EuP directive.

In Part A, primary sources of standards were identified with respect to the Life Cycle Assessment and Environmental Management system based on the ISO 14000 family standards. Furthermore, comparison to the developed Energy using Products directive has been made. On the basis of the literature research, the modelling of the LCA could be performed. All applications of the LCA are industry-oriented. Therefore, the project of the LCA was started in cooperation with the FagorMastercook company.

Within the company, very detailed input data for the LCA modelling were collected. The product example used in the LCA research was the gas-electro cooker KGE 3490X. The LCA analysis was done in compliance with the ISO standards and referring to the EuP directive. To get a full picture of the environmental performance of the product, the gas and electricity consumption of the average user was estimated, based on the questionnaire analysis. The questionnaires were distributed and collected in the author's hometown, Lubawka, in Poland.

During the next step of the research, the SimaPro modelling software has been used. The data from the Life Cycle Inventory were used as the input data for the SimaPro package, and the analysis of environmental impacts was done with the help of the seven different Life Cycle Impact Assessment methodologies. In the first stage, only the KGE 3490X and its production stage was modelled, including some production-recycling processes and transportation module. In the second stage, more than seventy use processes were created, reflecting the gas and electricity consumption necessary for preparation of meals in average Polish household. The time perspective used in the second modelling stage was set up to one year. Thus, the modelling of use phase was done, and results could be compared to those of the first modelling stage. Additionally, the three different End-of-Life scenarios were created. Realistic one represented the actual waste management model present in the municipality of Lubawka, namely recycling of the metal parts and landfilling of all other materials. Optimistic scenario represented the best possible option of the waste management, namely recycling. The pessimistic option included mainly incineration of the cooker after its end-of-life.

The results of the first phase of the LCA modelling revealed, which materials and subassemblies used in the production of the gas-electro cooker caused the highest environmental burden. For materials, one should mention mainly steel low and high alloy and austenitic steel, as well as float glass. As for the subassemblies, the heaviest and most complicated parts (equipment, oven, side walls, glass plate) caused the highest impact on the environment. The results of the different LCIA methodologies varied due to the high level of details of the input data. However, general pattern showed, that production of steels is the main responsible process for the environmental burden. This was expressed in various manners in the LCIA methodologies. Such impact could be i.e. classified as abiotic resource depletion, or expressed as SO_x emissions.

Results of the second modelling stage revealed relatively small importance of production and transportation part of the cooker. Most of the environmental burden created during the life cycle of the cooker is stemming from the gas and electricity consumption. This statement is valid especially for often used applications of the cooker (boiling of water for hot beverages) or meals (cooking of potatoes), or energy-consuming applications (baking of cakes).

The application of recycling processes helps to minimize the overall environmental burden of the cooker. The waste management scenario applied in the municipality of Lubawka (recycling of metal parts, landfilling of other parts) has a relatively positive impact on the environment, especially in comparison to (theoretical) incineration option. However, one has to remember about existing potential for improvement, as presented by the optimistic scenario. Secondly, the cooker consists mainly of metal. For other household appliances disposed off in Lubawka, the results could be much worse.

The last part of research, namely sensitivity analysis in the SMPV modelling software, helped to analyze the role of the LCA in the EMS and with respect to the application of the European directives. A comprehensive analysis of the entire system was made. This analysis focused on the way, in which Polish companies may function, including such variables as employees, price, quality, customers, etc. In this modelling stage, the EuP directive become a part of larger system, namely EU and Authorities variable. Generally speaking, the boundary of the analysis was much broader in comparison to the LCA modelling. The collection of the input data for such large system requires investment of considerable time and financial resources. The SMPV software, based on the fuzzy logic principles, facilitated understanding of such complex system without these costly investments. The results of the sensitivity analysis have shown, that the LCA helps to achieve the company's goals and targets, namely better financial results and minimized impact on the environment. One has, however, to be very careful: over-investment in time and money consuming

LCA studies may cause lower competitiveness of the products on the market, resulting in lower demand on the products, and finally in severe financial problems. Furthermore, the achievement of the company's environmental goal is dependent not only on the implementation and on maintenance of the environmental tools, such as the LCA or the EMS. Many elements of the system have to function properly. In order to improve the total environmental performance, decision makers have to take into a consideration also proper functioning of i.e. authorities, trade unions, etc.

6.2 Achievements of the study

This doctoral thesis was dealing with a wide scope of environmental analysis basing on the LCA technique. Its unique character and achievements may be summarized in the following points:

- The study performed was the first LCA made in Poland for the scientific purposes, and one of the first LCA studies performed in Poland at all; thus, the results of the LCA and sensitivity modelling may be regarded as unique;
- Very detailed input data were collected; more than 600 processes and materials were included in the production and transportation phase of the LCA; further 80 processes were created for the use phase of the modelling;
- Life Cycle Analysis evaluated product's environmental impacts with the help of different methodologies, not only one single LCIA; therefore, the assessment of the environmental impacts could be done from many perspectives;
- Results of the analysis are applicable not only for internal purposes, but also for the public disclosure and compliance process with the Polish and European law;
- Unique data on the use phase of the cooker were collected, with the help of the questionnaires; Since the cooking habits are specific for each country, such data are not available in the ("Western") databases; the specificity of Polish market and people's cuisine habits could be represented with fidelity;
- The sensitivity analysis of the entire system in which Polish enterprise is functioning was performed, including social, economical, legal, and political aspects taken into consideration;
- The sensitivity analysis has shown the performance and interdependence of the LCA and EMS in the system, as well as its positive impact on the competitiveness of the company and potential obstacles and risks.

6.3 Suggestions for further research and improvements

The following studies and improvements of the results can be carried out in the future:

- LCA of other products of the FagorMastercook, especially comparative studies with other cookers;
- Continuous monitoring of the FagorMastercook environmental performance using the LCA technique;
- Comparison of the LCA results obtained for other products with the results of this research;
- Implementation of the LCA techniques in the Environmental Management System of the FagorMastercook;
- Collection of the detailed data on the use phase processes in the Polish society, as well as comparison with the cooking habits of the other European and non-European nations;
- Publishing of the LCA results and hints for the end users of the household appliances, aiming at minimization of the environmental impacts of the product in the life-time perspective;
- Incorporation of the system-wide thinking, similar to that presented in the sensitivity analysis, in the decision-making process of the companies.

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Declaration

Declaration in lieu of an oath

Herewith I declare in lieu of an oath that I prepared this work on my own and without using any other as the quoted aids. The thoughts taken directly or indirectly from foreign sources are marked as such. Till now this work was not presented neither in the same nor in similar form to any other examining authority and has also not been published.

Cottbus, the 18.01.2010

Marek Gawor