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Katarzyna Grzesik*, Kinga Guca**

Screening Study of Life Cycle Assessment (LCA) of the Electric Kettle with SimaPro Software***

1. Introduction

The increasing awareness of the possible impacts associated with products, has increased interest in the development of methods to better understand and address these impacts. One of the techniques for this purpose is life cycle assessment (LCA).

LCA addresses the environmental aspects and potential environmental impacts throughout a product's life cycle from raw material acquisition through production, use, end of life treatment, recycling and final disposal [1]. Life cycle assessment is a "cradle-to-grave" approach. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth.

LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.).

By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process [2, 3].

The goal of this paper is conducting the screening LCA of a popular electric kettle Zelmer model 17013, manufactured, used and disposed in Poland.

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* AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Management and Protection of Environment, Krakow, Poland

** AGH University of Science and Technology, Graduate of Faculty of Mining Surveying and Environmental Engineering, Krakow, Poland

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2. Methodology

2.1. Life Cycle Assessement Framework

According to ISO standards the life cycle assessment framework has four phases [1, 3, 4]:

1. Goal and scope definition, the product(s) or service(s) to be assessed are defined, a functional unit for comparison is chosen and the required level of detail is defined.
2. Inventory analysis of extractions and emissions, the energy and raw materials used, and emissions to the atmosphere, water and land, are quantified for each process, then combined in the process flow chart and related to the functional unit.
3. Impact assessment, the effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance.
4. Interpretation, the results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

2.2. SimaPro – the Software Tool for LCA

SimaPro is a professional tool to collect, analyze and monitor the environmental performance of products and services. Life cycles could be modeled and analyzed in a systematic and transparent way, following the ISO 14040 standards.

Goal and Scope Definition

The scope of the study describes the most important methodological choices, assumptions and limitations. LCA is an iterative procedure, the study starts with initial choices and initial requirements that can be adapted later when more information becomes available.

A particularly important is the functional unit. Functional unit defines what is being studied.

Inventory Analysis

SimaPro, can handle advanced inventory techniques. The result of the inventory phase is referred to as the LCI results. It is a list of emissions and raw materials with an amount. In many cases, the list covers a few hundreds of substances, which make the LCI result very difficult to interpret.

The core of the LCI phase is building a process tree that describes all relevant processes in a life cycle. The data structure in SimaPro contains two different building blocks [6]:

1) processes are the building blocks of the process tree that contain environmental data,
2) product stages do not contain environmental information, but they describe the product and the life cycle.

A process in SimaPro contains data on environmental flows, such as: emissions to air, water and soil, solid waste (final waste), non material emissions, such as radiation and noise, use of raw materials (in order to model depletion). Processes can be linked to each other to create networks.

Product stages are used to describe the composition of the product, the use phase and the disposal route of the product. Each product stage refers to processes. If a product contains steel, there is a link to the process that describes steel production.

There are some different product stages [6]:

- Assemblies contain a list of materials and subassemblies and a list of production or transport or energy processes. The assembly can be understood as the definition of a product.
- Life cycles are the central product stages. They contain links to:
  - one assembly, representing the product (this assembly can have subassemblies),
  - a number of use processes, such as energy use, transport etc,
  - a disposal or waste scenario,
  - an additional life cycle.
- Life cycles can also link to other life cycles, allowing the creation of models in which products use other products like batteries, filters, tyres, and packaging.
- Disposal scenarios describe the end of life route of entire products that may still be reused or disassembled. They contain a number of processes, representing the environmental load connected to the scenario, a number of links to disassemblies, disposal scenarios, waste scenarios or reuse records that specify to which destinations the product flow [6].

Impact Assessment

Life cycle impact assessment is defined as the phase in the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. The SimaPro does not develop impact assessment methodologies, it enables to select one that has been published [6].

The impact assessment results can be displayed as a graph. SimaPro can generate a process network, in which each process has a small bar chart showing the contribution of this process to the total environmental load [5].

An important step is the selection of the appropriate impact categories. In the Eco-indicator 99 methodology eleven impact categories have been chosen [7]: carcinogens, respiratory organics, respiratory inorganics, climate change, radiations, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, fossil fuels.

Once the impact categories are defined and the LCI results are assigned to these impact categories, it is necessary to define characterisation factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result. Normalisation is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem. This is done by dividing the impact category indicators by a "normal" value. The most common procedure is to determine the impact category indicators for a region during a year and, if desired, divide this result by the number of inhabitants in that area [6]. Weighting is the most controversial and most difficult step in life cycle impact assessment. It is a normative step, in which the weighting factors are assigned to normalised results. These weights should represent the views of society or a group of stakeholders [7].

Databases

Data in SimaPro are organised as a set of libraries with data that can be used in all projects. SimaPro main database contains library with eleven impact assessment methods.

SimaPro has also additional databases such as [5].:

- BUWAL250: 248 Processes, focus on packaging materials.
- Danish Food data: 500 Processes covering a wide range of food products.
- Dutch input output data: 195 processes; 105 Dutch sectors, and 3 times 30 sectors for OECD and Non OECD sectors covering the entire import and export.
- Ecoinvent data: 2700 Unit processes with full documentation and uncertainty data. Plus 2700 system processes.
- ESU ETH data: 1100 unit processes plus 1100 systems, dating from mid nineties, covering energy, transport and most frequently used materials; mainly for Europe.
- Franklin USA data: 78 Proceses covering the most important energy, transport and material production processes in the USA.
- IDEMAT: 508 processes covering many materials.
- Industry data: 74 processes from well known industrial associations.
- USA input output data: 481 processing covering the entire USA economic output; data are stored per dollar output, using the input output dataset.

Interpretation

The interpretation in SimaPro is designed as a checklist that covers the relevant issues mentioned in the ISO standard [1]. All data in life cycle models have some uncertainty. It could be distinguished three main types:

1) data uncertainties,
2) uncertainties on the correctness (representatively) of the model,
3) uncertainties caused by incompleteness of the model.

The ecoinvent dataset comes out in two versions, one version with Unit processes, and one with systems. In the unit process version, almost all data points come with a specification of uncertainty. Uncertainty on the correctness of the model refers to the fact that there is not one way to make a model of reality. Uncertainty caused by incompleteness refers to the unavoidable data gaps.

2.3. Data on the Electric Kettle Zelmer Model 17013

Data on the kettle structure and its component elements was obtained from service manual of Zelmer electric kettle model 17013 and from the technical data on this model published by the manufacturer on the Zelmer website. [8–10]. The kettle components were weighed on a verified technical balance. The materials were assigned to the components based on data provided by kitchen appliances manufacturers and on SimaPro databases.

3. Results

The goal is conducting the screening study of life cycle assessment of the plastic electric kettle. Functional unit for this study is the Zelmer electric kettle model 17013, weighing 918 g, with power 1900 W, capacity 1.7 l. The kettle was manufactured in 2005, it is used in Poland for 5 years, three times a day for boiling 1 liter of water.

The electric kettle has 30 components [8], however for the purpose of this LCA study, those components were grouped into: housing (with lid), heater, base, main cable and small parts. System boundaries of this analysis include: assembly stage, with links to production pro-cesses, raw material acquisition etc, the use stage – electricity consumption and waste scenario. The use of water for boiling, the packaging of the kettle and also transport were excluded from system boundaries.

Assembly Stage

The process tree for the assembly stage for electric kettle is shown in figure 1.

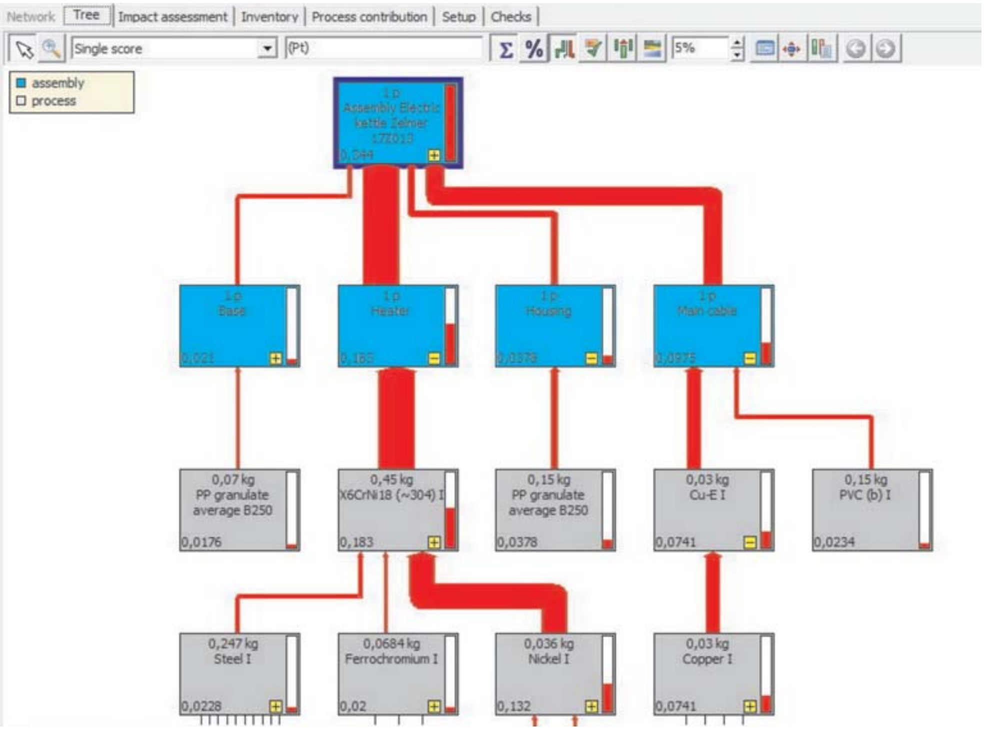
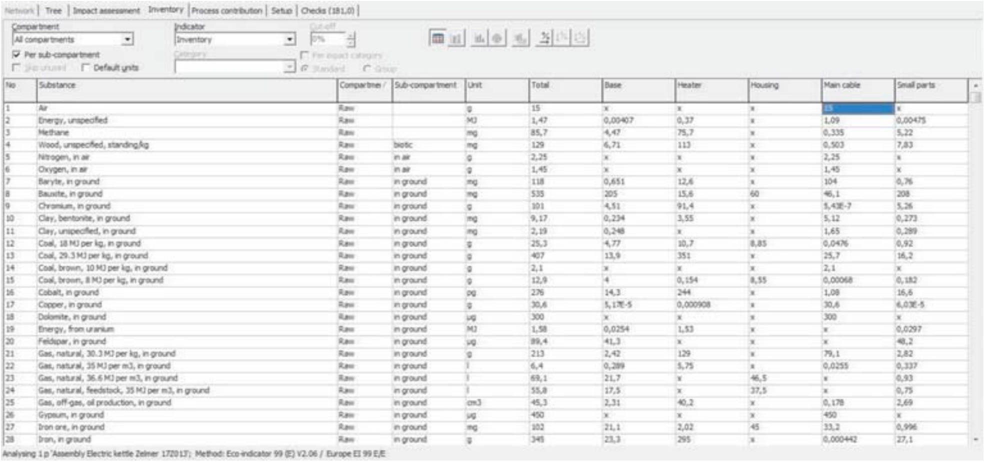


Fig. 1. The process tree for the assembly stage of the electric kettle

Assembly stage describes the composition of the product. The kettle components link to processes. Processes are identified in the database indexes according to their output. Those processes contain environmental information. All the data on environmental flows (emissions, raw materials) are gathered in the inventory results. The fragment of the inventory table is shown in figure 2. In the tree each process has a small bar chart showing the contribution of this process to the total environmental load. It is clear from the tree that the biggest contribution to the environmental impact has heater, i.e. the processes in which materials of the heater are produced. With the cut-off criteria of 5% only 20 nodes of 606 are visible; the small parts of the kettle are not visible in the presented tree.

For the assembly stage of the electric kettle impact assessment has been done, and as the assessment method the eco-indicator 99 with eleven impact categories has been chosen. Impact assessment after weighting for assembly stage is shown in figure 3, single score is shown in figure 4.

The impact categories which have dominating role in total environmental load for the assembly stage of the kettle are: fossil fuels, respiratory inorganic and minerals.



Compartment: All compartments

☑ Per sub-compartment

☐ Skip unused ☐ Default units

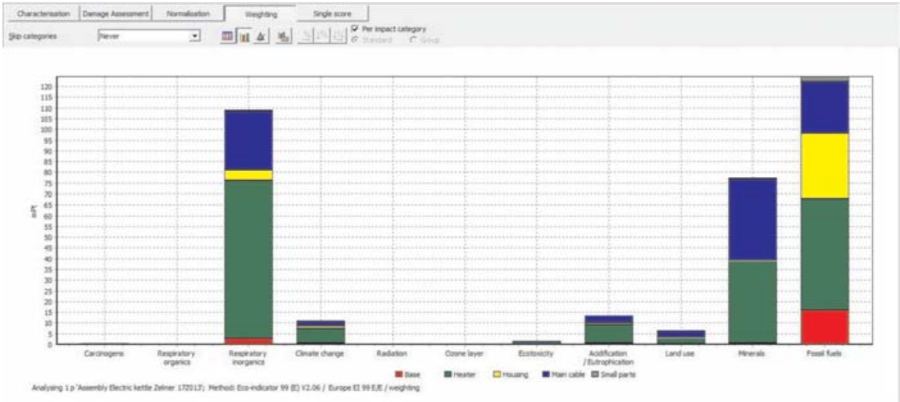
Indicator: Inventory

Cut-off: 0%

No	Substance	Compartment	Sub-compartment	Unit	Total	Base	Heater	Housing	Main cable	Small parts
1	Air	Raw		g	15	x	x	x	15	x
2	Energy, unspecified	Raw		MJ	1,47	0,00407	0,37	x	1,09	0,00475
3	Methane	Raw		mg	85,7	4,47	75,7	x	0,335	5,22
4	Wood, unspecified, standing/kg	Raw	biotic	mg	129	6,71	113	x	0,503	7,83
5	Nitrogen, in air	Raw	in air	g	2,25	x	x	x	2,25	x
6	Oxygen, in air	Raw	in air	g	1,45	x	x	x	1,45	x
7	Baryte, in ground	Raw	in ground	mg	118	0,651	12,6	x	104	0,76
8	Bauxite, in ground	Raw	in ground	mg	535	205	15,6	60	46,1	208
9	Chromium, in ground	Raw	in ground	g	101	4,51	91,4	x	5,43E-7	5,26
10	Clay, bentonite, in ground	Raw	in ground	mg	9,17	0,234	3,55	x	5,12	0,273
11	Clay, unspecified, in ground	Raw	in ground	mg	2,19	0,248	x	x	1,65	0,289
12	Coal, 18 MJ per kg, in ground	Raw	in ground	g	25,3	4,77	10,7	8,85	0,0476	0,92
13	Coal, 29.3 MJ per kg, in ground	Raw	in ground	g	407	13,9	351	x	25,7	16,2
14	Coal, brown, 10 MJ per kg, in ground	Raw	in ground	g	2,1	x	x	x	2,1	x
15	Coal, brown, 8 MJ per kg, in ground	Raw	in ground	g	12,9	4	0,154	8,55	0,00068	0,182
16	Cobalt, in ground	Raw	in ground	pg	276	14,3	244	x	1,08	16,6
17	Copper, in ground	Raw	in ground	g	30,6	5,17E-5	0,000908	x	30,6	6,03E-5
18	Dolomite, in ground	Raw	in ground	µg	300	x	x	x	300	x
19	Energy, from uranium	Raw	in ground	MJ	1,58	0,0254	1,53	x	x	0,0297
20	Feldspar, in ground	Raw	in ground	µg	89,4	41,3	x	x	x	48,2
21	Gas, natural, 30.3 MJ per kg, in ground	Raw	in ground	g	213	2,42	129	x	79,1	2,82
22	Gas, natural, 35 MJ per m3, in ground	Raw	in ground	l	6,4	0,289	5,75	x	0,0255	0,337
23	Gas, natural, 36.6 MJ per m3, in ground	Raw	in ground	l	69,1	21,7	x	46,5	x	0,93
24	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	in ground	l	55,8	17,5	x	37,5	x	0,75
25	Gas, off-gas, oil production, in ground	Raw	in ground	cm3	45,3	2,31	40,2	x	0,178	2,69
26	Gypsum, in ground	Raw	in ground	µg	450	x	x	x	450	x
27	Iron ore, in ground	Raw	in ground	mg	102	21,1	2,02	45	33,2	0,996
28	Iron, in ground	Raw	in ground	g	345	23,3	295	x	0,000442	27,1

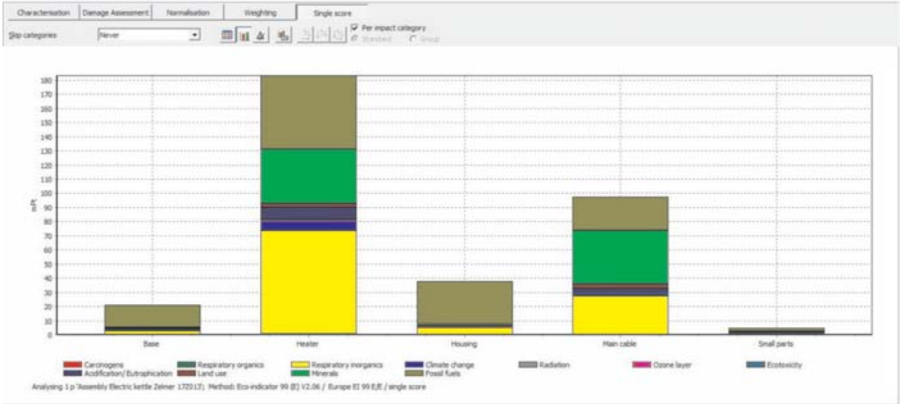
Analysing 1 p 'Assembly Electric kettle Zelmer 17201J'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E

Fig. 2. Fragment of inventory results for assembly stage of the electric kettle



Analysing 1 p 'Assembly Electric kettle Zelmer 17201J'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E / weighting

Fig. 3. Impact assessment – weighting for assembly stage of the electric kettle



Analysing 1 p 'Assembly Electric kettle Zelmer 17201J'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E / single score

Fig. 4. Impact assessment – single score for assembly stage of the electric kettle

At the assembly stage all components of the electric kettle contribute to the environmental load, however their share distribution is not equal. The biggest share to the total environmental impact has heater and then main cable.

The Use Stage of the Electric Kettle

The electric kettle at the use stage needs electricity. The power of the kettle is 1900 W. The kettle is used three times a day for boiling one liter of water, which takes 4 minutes. Daily kettle is used for 12 minutes. During five years of usage the kettle needs 693,5 kWh of electricity. The kettle is used in Poland, so the electricity supply must be related to Polish situation of electricity production. Based on the data of the structure of electricity produced in Poland in years 2008–2009 [11], the process "Electricity Poland" was input to SimaPro database. Then this process was linked to the life cycle of the electric kettle.

The Waste Scenario for the Electric Kettle

At the last stage of electric kettle life the waste scenario is proposed. It is assumed that 30% of the kettle would be recycled and 70% of the kettle component would be landfilled. Although SimaPro has waste scenarios for both: municipal waste and household waste, they cannot be linked to the life cycle of the kettle disposed in Poland. In those waste scenarios, relevant for the Netherlands, 23% of municipal waste is landfilled and 77% is incinerated. In Poland, at the moment, 0.4% of municipal waste is incinerated. So the individual waste scenario, with 30% recycling rate and 70% landfilling rate, is proposed for the electric kettle.

The Life Cycle of the Electric Kettle

The life cycle of the electric kettle Zelmer contains following stages of the product life:

- assembly stage with links to processes,
- use stage which is the consumption of electric energy produced in Poland,
- waste scenario.

The life cycle of the plastic electric kettle Zelmer model 17013 is shown in figure 5.

In the process tree of the kettle life cycle only 20 nodes of 657 are visible with the 0.06% cut-off criteria. With this cut-off criteria, four components at the assembly stage and the waste scenario are visible. When the cut-off criteria is set for 0.5%, only one component in the assembly stage is visible and none of the waste scenario. For the life cycle of the electric kettle the most significant stage concerning the environment impact is use of electricity produced in Poland. It is 99% of all environmental impact, caused during the entire life cycle of the electric kettle.

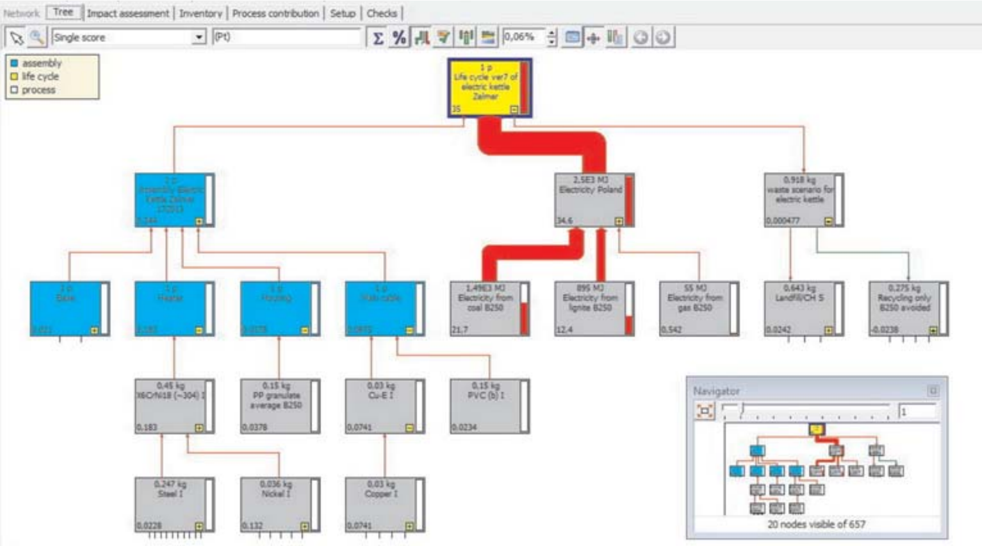
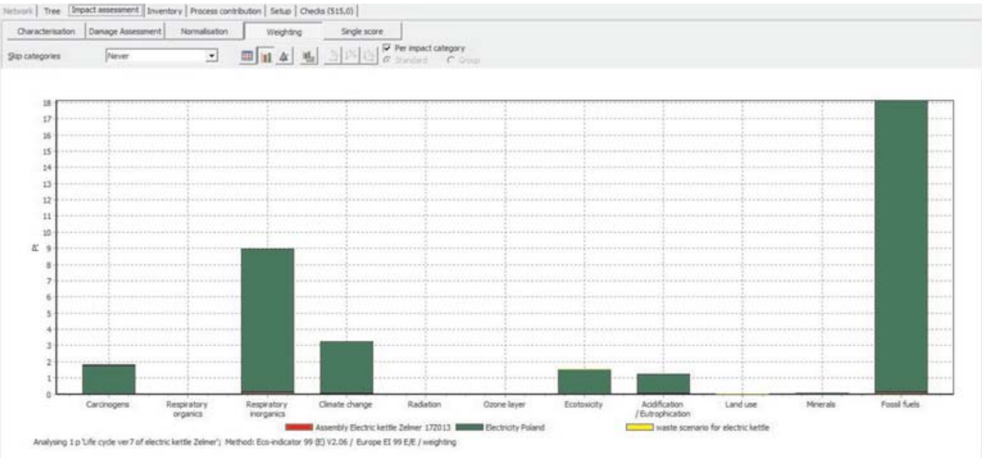


Fig. 5. The life cycle of the electric kettle

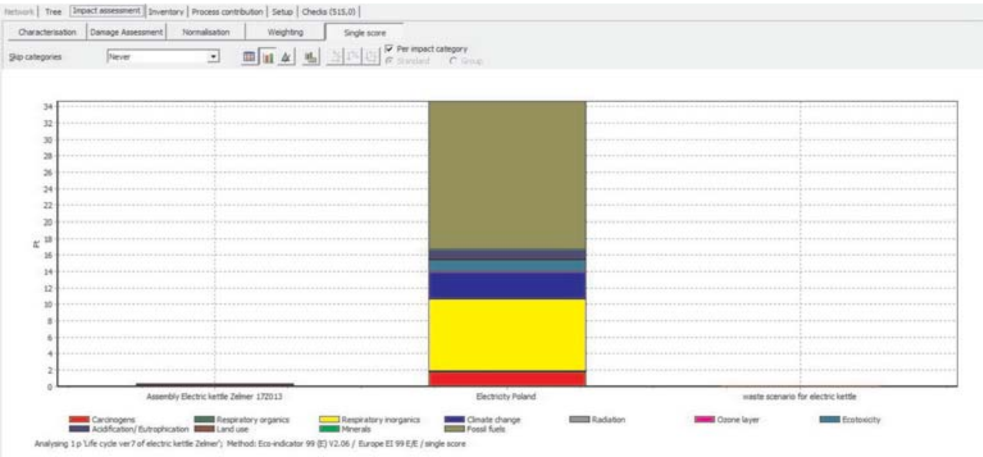
For the life cycle of the electric kettle the impact assessment has been done with eco-indicator 99 method. Impact assessment after weighting for life cycle is shown in figure 6, single score is shown in figure 7.



Analysing 1 p 'Life cycle ver7 of electric kettle Zelmer'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E / weighting

Fig. 6. Impact assessment – weighting for life cycle of the electric kettle

The impact categories which have dominating role in total environmental load for the entire life cycle of the electric kettle are: fossil fuels, respiratory inorganic and climate change.



Skip categories: Never

☑ Per impact category

Analysing 1 p 'Life cycle ver7 of electric kettle Zelmer'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E / single score

Fig. 7. Impact assessment – single score for life cycle of the electric kettle

The biggest contribution 99% to the total environmental impact during the whole life cycle of the electric kettle has use of electricity produced in Poland. Impact categories shown in figure 6: fossil fuels, respiratory inorganic and climate change are all resulting from electricity production that is combustion of coal and lignite.

4. Discussion of Results

The presented results have been obtained through screening study of LCA, that is a preliminary study, using technical data on the kettle model published by the manufacturer and already available data in SimaPro databases. Conducting the extensive study was not possible due to the lack of exact and detailed data. The extensive study could be done only by a manufacturer or designer of a product, who will have access and opportunity to gather the needed and precise data. Moreover in this study the infrastructure processes are not included. In many LCA studies capital goods are often not included, and for most LCAs this can give satisfactory results, although this may result in missing 30% of the environmental impacts.

Bearing in mind all the mentioned limitations of this study, some very clear conclusions could be defined:

- The dominant phase of life cycle is the use stage of the kettle. It means that in order to improve environmental performance of this product all efforts should be put in optimising the use phase that is to minimize the electricity consumption.

- Recycling or waste scenario does not seem to have a significant impact on the total environmental load, because the effect is nearly negligible in the whole life cycle of the kettle.
- the use stage of the kettle is recognized in Polish conditions of electricity production, in other geographical regions, where the structure of power supply is different (for example electric energy generated by nuclear power plants or hydropower plants etc), the results of LCA for the same kettle could be quite dissimilar.

5. Conclusions

Life cycle assessment is an important tool to evaluate possible impacts associated with products. LCA is a "cradle-to-grave" approach, it addresses the environmental aspects and potential impacts throughout a product's life cycle from raw material acquisition through production, use, end of life treatment, recycling and final disposal.

For the purpose of this study has been chosen a popular electric kettle Zelmer model 17013, manufactured, used and disposed in Poland. Data on the kettle structure and its components have been obtained from service manual and from technical data on this model published by the manufacturer. The screening LCA has been conducted with SimaPro software, a professional tool to collect, analyze and monitor the environmental performance of products, in which life cycles could be modeled in a systematic way, following the EN ISO 14040 standards.

The results of the LCA show that 99% of the total environmental impact during the entire life cycle of the electric kettle has the use stage of the product, that is consumption of electricity produced in Poland. All efforts to improve the environmental performance of this product should be put on optimising the use phase that is to minimize the electricity consumption.

The presented LCA is a screening study using already available data in SimaPro databases. Conducting the extensive study was not possible due to the lack of exact and detailed data. So the results have some limitations and definitely cannot be used to compare products.

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