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Comparing the environmental impact of using various energy sources in family house heating systems

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Abstract: Environmental impacts of using various sources of energy in heating a family house with 180 m² of floor surface were compared by means of the SimaPro computer programme and attached to its databases, describing the environmental impacts of using typical materials and technologies. The set of compared heat energy sources comprised a ground loop, a heat pump, a liquid gas combustion furnace, an earth gas combustion furnace, a coal combustion furnace, a straw combustion furnace, a wood combustion furnace and an electric stove. After normalisation (which meant recalculating the impacts into their shares in the average impact of the kind, experienced by an average European in a year), weighting (which meant attaching arbitrary weights to three aggregate impact categories according to a methodology Eco-indicator 99 E/E) and aggregating the results into so called eco-points the wood combustion furnace turned out to have the greatest impact. It was followed by a coal burning furnace, an electric stove and an oil burning furnace. The heat pump had the smallest impact. A big impact of the wood and other biomass burning furnaces was due to a high emission of CO presumed in the used database, which can be disputed.

Keywords: *family house heating, environmental impact, SimaPro application, Eco-indicator 99.*

1. Introduction

Production, usage, and post-usage waste disposal have their impact on the environment. For an evaluation of such impacts during individual phases of products' life and then over its whole life or an evaluation of the influence of various processes, a method called the Life Cycle Assessment (LCA) method is being applied. This method aims at an identification and

hierarchization of environmental impacts of a product or a process and gives ground for determining ways of minimization of the most adverse impacts. The procedure adopted in the LCA is an analysis of environmental aspects over the whole lifetime of a product or a process, starting from the extraction of raw materials, through production of materials, sub-assemblies and final product, management of by-products, transportation, distribution, usage, until the final utilization of the post-usage waste. Due to such a comprehensive approach it is possible to compare different technologies and select the one with the lowest impact on the environment (Wach, 2002).

The present study compares, using the LCA methodology, nine sources of energy for heating a family house. The following technologies of energy production were compared: a heat pump of water-water type, a wood gasification boiler, a compressed straw heated boiler, a wooden pellets heated boiler fed by a screw conveyor, a condensation boiler for liquid gas, a low-temperature oil boiler, a coal boiler with upper combustion system, an electric boiler and a boiler heated with natural gas distributed by a municipal network. Analyses, carried out by using the SimaPro version 7 software, were limited to the environmental impact assessment of using different energy carriers for thermal energy production. Processes related to the production and the post-usage waste utilization of a boiler and other equipment used for energy production were not included, assuming that those impacts were similar for different energy sources. The influence of infrastructure needed for the supply of individual energy carriers was accounted for as far as it had been included in the databases attached to the software.

2. Methodology

The present requirements related to the protection of natural environment impose a need of carrying out a complete life cycle assessment of a product, including production, usage and waste utilisation phases (PN-EN 14040..., 2009). Because of the increasing complexity of such analysis computer-aided tools, in particular specially designed software enabling a comprehensive assessment of a process' or product's impact on the environment, play a key role here. One of the most popular applications of this type is SimaPro, created by a Dutch company

Pre Consultants (Introduction..., 2008). The application evaluates damages to environment basing on the estimation of loads attributed to individual categories of influence.

An analysis carried out by using the SimaPro software may be divided into three phases (Introduction..., 2008):

- defining the goal and scope of analysis,
- setting up a data inventory including definitions of individual production processes, definitions of materials used, of types of waste and ways of their disposal; in this phase the characteristics of new processes may be created and inserted into the database or characteristics already described for other projects, stored in software archives, used,
- assessment of the environmental impact consisting in selection of an assessment method, carrying out the calculations and presenting the results in a form of charts and/or tables; impact assessment may be carried out with different methods the software provides for; the selection of method depends mainly on whether it accounts for all types of impact present in a particular case.

SimaPro software in its version 7 provides a few pre-set environmental impact assessment methods, including CML (Centre of Environmental Science at the University of Leiden) versions 2000 and 2001, Ecopoints 97 (Swiss made), Eco-indicator 95 and Eco-indicator 99 versions E, H, I (Dutch made), EPS 2003 (Environmental Priority Strategies in Project Design, mainly by Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology), IMPACT 2000 (combination of other databases by Pre Consultants), Ecological Scarcity 2006 (an extension to Ecopoints 97), EDIP 2003 (Institute for Product Development, Technical University of Denmark), EDP 2007 (Environmental Product Declarations, composed by Swedish Environmental Management Council) (Introduction..., 2008). For the present study the recommended by the programme producer Eco-indicator 99 method was applied.

In this assessment methodology, its authors defined the environment by a set of biological, physical and chemical parameters influenced by human activity and reciprocally influencing the functioning of nature and human beings (Czaplinka et al., 2001). Based on this definition three basic aggregate categories were selected for the assessment of environmental damages:

- human health (HH),
- ecosystem quality (EQ),

- resources (R).

Within each aggregate category a number of detailed categories is included which, when summed up, decide about the degree of the aggregated impact. Indicators such as emissions of carcinogens and impairing the respiratory system organic and inorganic substances, depletion of the ozone layer, additional radiation and influence on climate change are accounted for within the category "human health".¹ The categories ecotoxicity, eutrophication/acidification and land use are included in the "ecosystem quality" aggregate category.² The "resources" category is defined by an additional amount of energy needed in the future for extracting less accessible minerals and fossil fuels and as well as decreasing quality.³

In order to determine the total impact of a product or a process on the environment the so called normalization⁴ and weighting⁵ shall be carried out, producing in this way a combined final result expressed in eco-indicator points (Pt). The value of 1 Pt corresponds to a one thousandth of annual environmental load attributable to one European citizen.

An environmental impact assessment of using the nine different sources of energy for heating a family house with 180 m² of floor surface was carried out using the databases attached to the SimaPro software. The assessment was limited only to the process of thermal energy production.

¹ The unit of human health hazard is DALY (Disability Adjusted Life Years), an indicator used for determining the deterioration of human health status. It is measured by the total number of years of human life lost as the consequence of premature deaths or lived in disability as a result of injury or disease.

² In case of ecosystem quality, PDF (Potentially Disappeared Fraction) or PAF (Potentially Affected Fraction) is used as an indicator. It refers to a disappearance of organisms, which deemed strategic for ecosystem functioning shall be present in ecosystems in a defined amount, and the presence of which is decreased as a result of changes in acidity or amount of nutrients. PDF is also used for expressing an unnatural land occupation and toxic emissions. The multidimensional unit expressing a damage to ecosystem is the PDF related to land area and time (PDF • m² • year).

³ The assessment of raw materials consumption is carried out accounting for both the energy needed for extracting minerals and their concentration. The negative impact is expressed by an expected increase of energy consumption (in MJ) in relation to 1 kg of raw material, caused by the deterioration of extraction conditions and the poorer concentration of raw material which will be used as a substitute for presently used raw material after its depletion.

⁴ Normalization consists in dividing an impact by an impact load of a given type experienced annually by one European.

⁵ Weighting is carried out using weights defined by a panel of selected experts, resulting in a hierarchisation of the results with respect to their importance for the total environmental impact. For example, when using the Eco-indicator 99 E/E method, the software-suggested weights are 500 for the "human health" category, 300 for "ecosystem quality" and 200 for the "resources" category. Those values may be changed by the software user.

Table 1. Annual energy consumption dependent on heating technology

Energy consumption	Energy source								
	heat pump	wood	straw	pellets	liquid gas	fuel oil	coal	electric boiler	natural gas
unit	kWh	m ³	kg	ton	l	l	ton	kWh	m ³
consumption, units per year	2700	22	9087	4.5	2340	1603	4.14	11077	2500

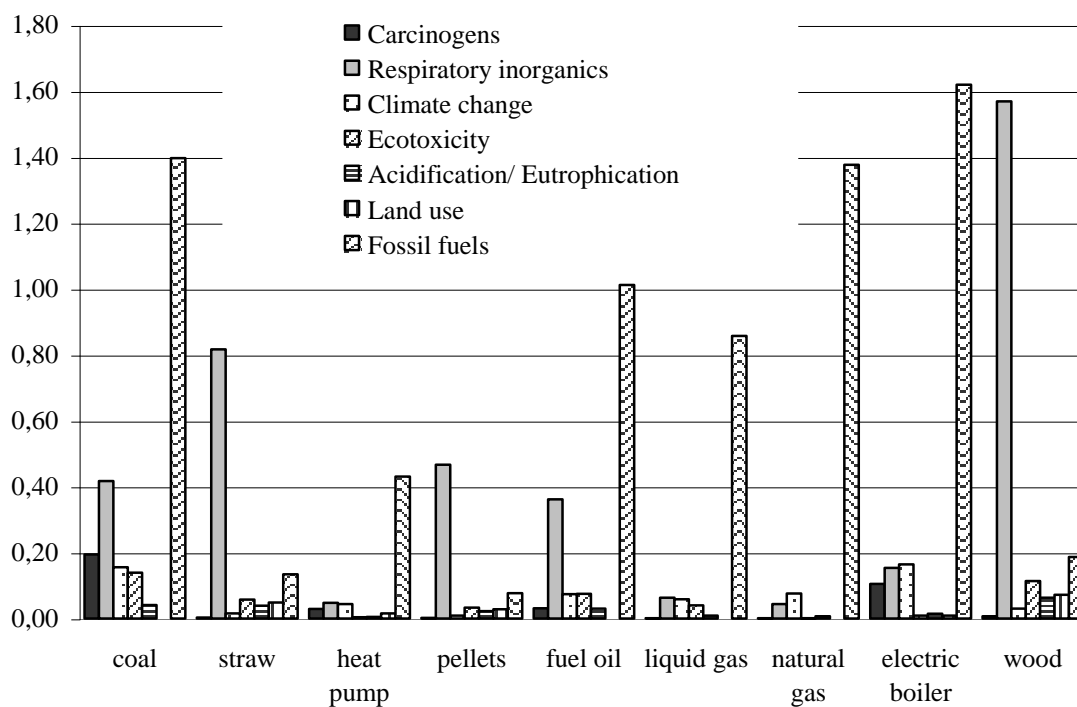
Source: Manteuffel Szoeg and Olesik, 2008.

The necessary amount of energy or fuel needed for an all year round heating of the house was determined on the basis of heater instruction brochures or branch publications (Laskowski 2006, 2007, 2008; Małkowska 2006) and through interviews with distributors of heating installations (Manteuffel Szoeg and Olesik 2008) (Tab. 1). With regard to the requirement that the energy consumption entered into the application must be expressed in MJ/year (or TJ/year), the consumption expressed in natural units was converted for particular energy carriers into MJ using typical calorific values. In the estimation of waste amount produced during the combustion of different energy materials it was assumed that the ash content in coal is 5%, in wood 1.5%, in pellets 1% and in straw 3.5%. The remaining technologies of heat production assessed were deemed waste-free.

3. Findings

The results of comparisons of impacts of energy resources are presented in Figures 1 through 4.

Figure 1. Comparison of energy sources per environmental impact category after normalisation of individual impacts, Ecoindicator 99 Europe E/E methodology⁶



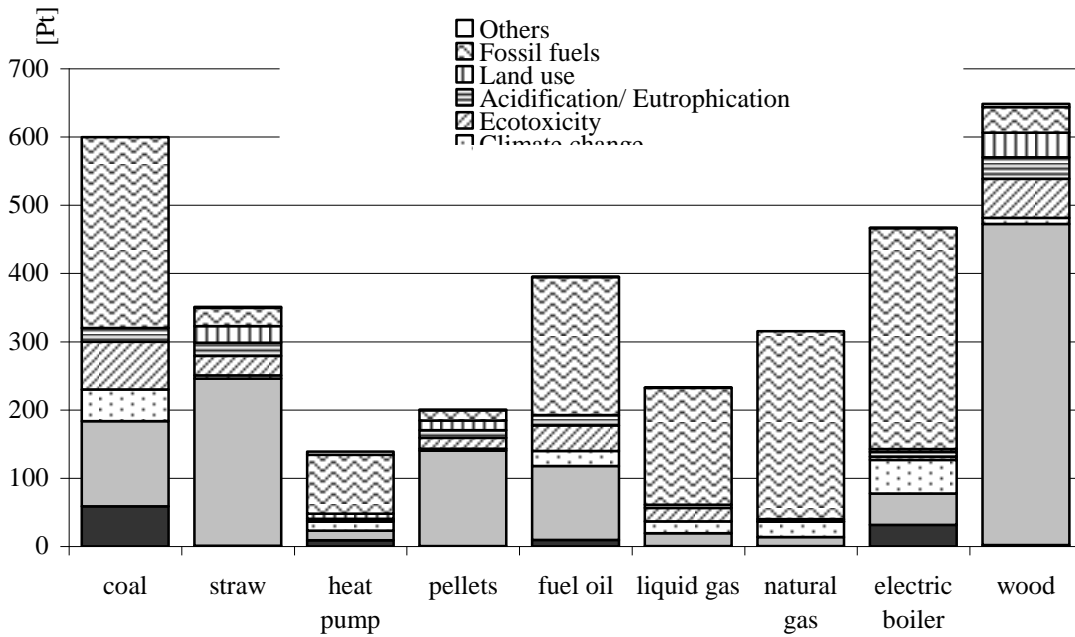
Source: authors' own elaboration.

Results presented in the Figure 1 point out that in case of thermal energy production from non-renewable sources, the highest relative (to the average load) impact is noted in the fossil fuels category. It is obvious that using fossil fuels contributes to the reduction of their stock. The respiratory problems are due to emissions of CO. Moreover, the combustion of hard coal has the highest impact on the cancer incidence.

The influence within the categories and this synthesized to single indicator is presented in Figure 2, where the results after normalization and weighing are presented. Weighing was carried out using a system of weights from the Eco-indicator 99 E/E methodology.

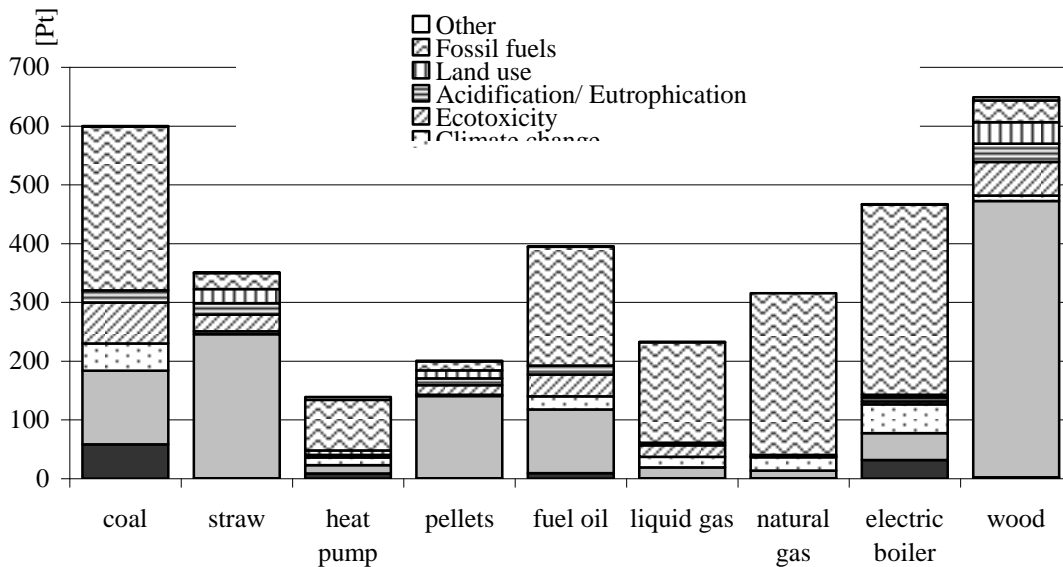
⁶ Because of an insignificant impact in such categories as ozone layer, radiation, respiratory organic and minerals, they were not included in the presentation of results. In Figure 2 they are presented jointly in the "others" category. The unit is the average annual impact of a given type experienced by (and caused by) a European.

Figure 2. Comparison of energy sources per impact category and a synthesized single score after weighing, Ecoindicator 99 Europe E/E methodology



Source: authors' own elaboration.

Figure 3. Comparison of energy sources after weighing per aggregate impact category and the endpoint (single score) indicator, Ecoindicator 99 Europe E/E methodology



Source: authors' own elaboration.

The highest environmental impact is noticed in the thermal energy production as a result of combustion of wood (649 Pt), hard coal (600 Pt) or using an electric boiler (467 Pt). The technology with the lowest environmental impact is a heat pump. Heat production using a heat pump influences the environment in an insignificant degree. When compared to traditional electric heaters, heat pumps provide substantial savings of electricity. The Coefficient of Performance (COP) for a typical heat pump is 3 to 5 (for electric heaters ~1) which means that more than 70% of heat delivered by a heat pump is produced from the ground-loop source, and the rest from the electric power supply. It must be remembered, however, that in case of a heat pump the most significant environmental impact occurs after ending the operation (which was not accounted for in the present analysis). The cooling agent used in the pump, classified among controlled substances, is treated as a hazardous waste and must not be stored in a landfill. Similarly, a proper disposal of brine, acting as a frost resistant agent, also poses a problem after ending the operation.

Results of calculations, aggregated into a synthetic indicator denoted in the software as "single score" are presented in Figures 2 and 3. In case of biomass combustion (wood, pellets, straw) the share in the total impact has the "human health" category. In case of wood and straw combustion the impact on human health is even more significant than in case of coal combustion (by 250 Pt in case of wood). The big impact of these technologies is determined by a significant emission of CO accompanying wood combustion. This gas, even in insignificant amounts, blocks the oxygen binding in haemoglobin. Hypoxia, which in an extreme case leads even to death, may occur as a consequence. Technologies based on biomass, defined as emitting substantial amounts of CO, were considered significantly detrimental for human health, in particular because of respiratory problems caused by the emission of non-organic compounds. In case of wood combustion the impairing respiration inorganics count for 73% of the negative impact on human health (for straw and pellets the share is 70%). Such significant impact in this category decided that wood combustion, in view of the model calculations, appeared the most hazardous technology of thermal energy production.

When comparing the heating by combustion of hard coal with the heating using electric boiler, supplied with electricity also produced by coal combustion, the coal boiler proves to have a higher impact on environment and human health. This is caused by different technologies of energy production. Huge power plants thanks to protective devices installed (e.g., filters and

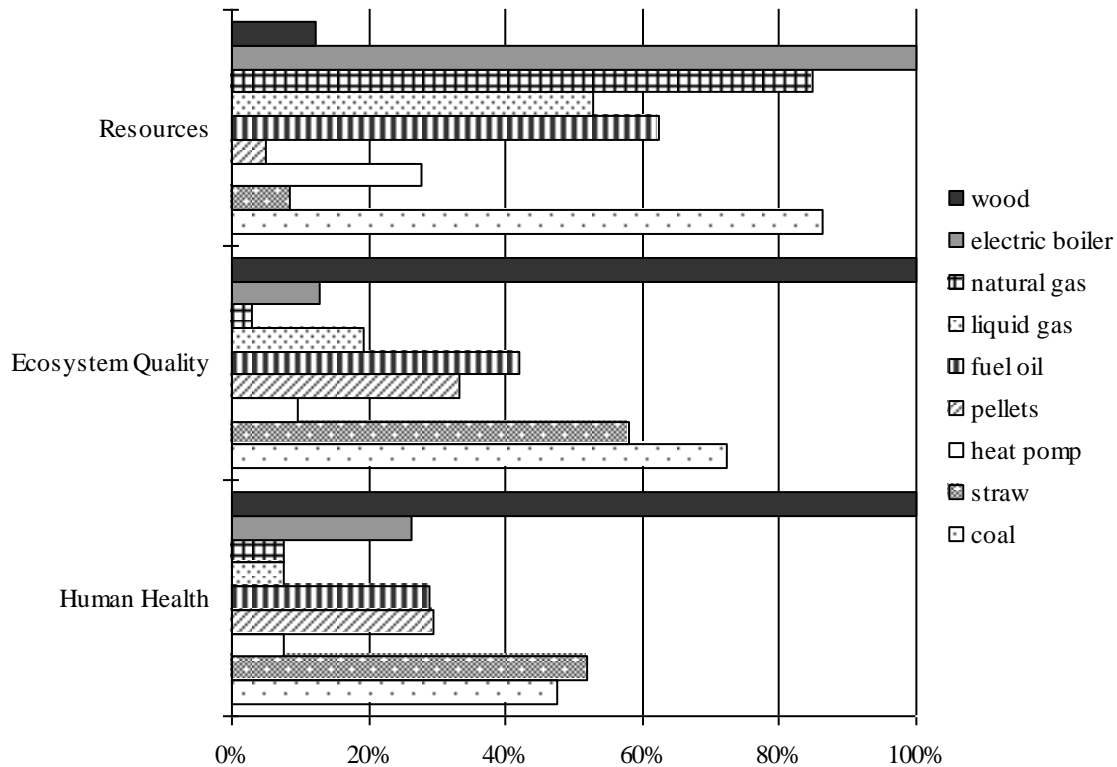
absorbers) and higher energy efficiency have a lower impact on the environment, calculated per unit of produced energy, than the household boiler installations.

In case of fossil fuels, the factor deciding on the total value of the eco-indicator is the influence on resources depletion. For natural gas the contribution of this category to the total assessment is 87%, for liquid gas 74%, and for heating oil 51%.

In Figure 4 a comparison of environmental impact of different house heating energy sources is presented in three aggregate categories: resources, ecosystems quality and human health. Each time the highest impact was rated 100% and the influence of the other technologies proportionally lower.

In case of the "resources" category, the highest impact is observed for the electric boiler. Combustion of coal and natural gas influences the depletion of natural resources to a slightly lower degree (15 pp). A substantial contribution to the depletion of natural resources caused by an electric boiler and a heat pump is caused by their use of electric power. It was assumed in the model that the electricity comes mainly from coal combustion, which corresponds to the situation of Polish power production.

Figure 4. Comparison of energy sources per aggregate impact category, the highest impact set equal to 100%, Eco-indicator 99 Europe E/E methodology



Source: authors' own elaboration.

The highest impact on the "ecosystem quality" category is observed in case of wood (100%), coal (72%) and straw combustion (58%). High impact of biomass combustion on ecosystems results from the necessity of introducing into the landscape large mono-cultural areas. Moreover, using straw for heat production causes its deficiency in agriculture. In accordance with the methodology used for calculations, straw shall be first used for animal production (bedding, fodder) and for fertilizing purposes (straw ploughing), in order to keep a balanced content of organic substance in soil.

When analysing the "human health" category, it can be observed that also in this case the combustion of biomass and wood has the highest impact. Significant influence of wood, pellets and straw combustion on human health results from the emission of CO, discussed above, accompanying the combustion of these fuels.

4. Concluding remarks

The environmental impact assessment of different sources of thermal energy for heating a house, carried out using the SimaPro software and the Eco-indicator 99 method, has given proof that the most harmful for the natural environment method of providing the heating is wood combustion. Next to it is coal combustion, irrespectively whether it is a household boiler or in a power plant, where the electricity for powering an electric boiler comes from. The combustion of heating oil appeared to be more harmful for the environment than alternative energy sources like combustion of straw, wooden pellets or a heat pump. Among the technologies based on the combustion of fossil fuels, the technology of liquid gas combustion appeared to have the smallest impact (Fig. 3). In this case the final result is by 367 Pt (61%) lower than the result received for coal combustion.

A great deal of doubt arises in case of results related to biomass combustion. An analysis of literature does not confirm that biomass combustion is accompanied by such a great amount of CO emission as it is recorded in the database attached to the software. Presented results, however, indicate that in case of wood, straw and pellets combustion the total environmental hazard is for approximately 70% derived from the respiratory inorganics emission.

In the comparison limited to the thermal energy production process only, the lowest environmental impact is caused by a heat pump. Extending the analysis by an LCA assessment of equipment (boilers and pumps) might change the above presented order of technologies.

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Porównanie oddziaływania na środowisko wykorzystywania różnych źródeł energii w systemach grzewczych domów rodzinnych

Streszczenie

Oddziaływanie na środowisko wykorzystywania różnych źródeł energii w systemach grzewczych domów rodzinnych o powierzchni 180 m² porównano za pomocą programu komputerowego SimaPro i załączonej do niego bazy danych, opisującej wpływ środowiskowy typowych materiałów i technologii. W badaniach uwzględniono następujące źródła energii grzewczej: pompa ciepła z wymiennikiem gruntowym, piec olejowy, piec gazowy spalający gaz ciekły, piec gazowy spalający gaz ziemny, piec węglowy, piec na słomę, piec na drewno, piec elektryczny. Po normalizacji (tzn. przeliczeniu wpływu środowiskowego jako jego udziału w średnim wpływie danego rodzaju według średniorocznej dla Europy), przydzieleniu wag (tzn. określeniu arbitralnych wag dla trzech arbitralnych zagregowanych kategorii wpływu według metodologii ekowskaźnika 99 E/E) oraz zagregowaniu wyników w tzw. ekopunkty okazało się, że piec spalający drewno cechuje się najsilniejszym oddziaływaniem. W następnej kolejności znalazły się piec węglowy, piec elektryczny oraz piec olejowy. Najmniejszy wpływ na środowisko posiada natomiast pompa ciepła. Tak duże oddziaływanie pieca spalające drewno oraz inne rodzaje biomasy wynika z wysokiej emisji CO przyjętej w wykorzystywanej bazie danych, co może wydawać się dyskusyjne.

Słowa kluczowe: ogrzewanie domów rodzinnych, oddziaływanie na środowisko, oprogramowanie SimaPro, ekowskaźnik 99