Life Cycle Assessment of Individual Wood Biomass Heating Systems in Households

Boban Pavlović, Dejan Ivezić, Marija Živković

COMETa 2020
5th INTERNATIONAL SCIENTIFIC CONFERENCE
26th - 28th November 2020
Jahorina, Republic of Srpska, B&H
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

LIFE CYCLE ASSESSMENT OF INDIVIDUAL WOOD BIOMASS HEATING SYSTEMS IN HOUSEHOLDS

Boban Pavlović[1], Dejan Ivezić[2], Marija Živković[3]

Abstract: The use of solid fuels (wood biomass and coal) for heating of households continues to be common practice within European countries. Solid fuel combustion in households contributes more than 46% to total emissions of fine particulate matter. In this study, a life-cycle assessment (LCA) of firewood-based and pellet-based heating systems is performed. These two systems represent two different types of individual wood biomass heating systems. In the case of the firewood-based heating systems, it is analyzed a typical stove in Serbian households, and in the case of pellet-based, a modern wood pellet-based furnace is analyzed. The objective of the LCA study is to assess the environmental performance of heating systems using GWP index, expressed through CO2-eq emissions. According to the results, wood pellet furnace could reduce emissions by 38% compared with the firewood stove. The results showed that wood pellet furnace has a lower negative impact on the environment and climate change, and at the same time, it ensures the financial benefits through savings and conservation of natural resources. This research showed that the implementation of LCA for assessing heating systems is an efficient and relatively simple method for obtaining new information regarding the household heating sector.

Key words: Heating, Life-cycle assessment, Wood biomass, Individual heating systems

1 INTRODUCTION

Heating in households has a significant share of final energy consumption in most of the European countries. In EU households, heating and hot water alone account for around 79% of total final energy use [1], [2]. The use of solid fuels for heating of households continues to be common practice within European countries [3]. Solid fuel combustion in households contributes more than 46% to total emissions of fine particulate matter, i.e., three times more than road transport in the European Union (EU) [4].

[1] Junior Research Assistant, M.Sc., Boban Pavlović, University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia, boban.pavlovic@rgf.bg.ac.rs
[2] Full Time Professor, Ph.D., Dejan Ivezić, University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia, dejan.ivezic@rgf.bg.ac.rs
[3] Associate Professor, Ph.D., Marija Živković, University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia, marija.zivkovic@rgf.bg.ac.rs

Solid heating fuels consist primarily of wood and coal but can also include forestry and agricultural residues and even municipal solid waste. Most solid fuels are burned in small-scale combustion devices, such as household heating stoves or small boilers for single houses, apartment buildings, etc. [3].

In Household Budget Survey 2018, published by the Statistical Office of the Republic of Serbia [5], solid fuels (wood and coal) are used in 56.6% of households for heating in Serbia.

The usage of wood biomass for heating in Serbia is characterized by excessive use of firewood for heating without adequate replanting, minimal use of wood residues, and low wood combustion efficiency [6]. In the last decade, wood pellets have seen high growth rates in consumption, and also in production, in Serbia [7]. From the complete production of wood fuels in Serbia, the expansion of production capacities was largest in the wood pellet segment. Until 2016, over 54 pellet production facilities were actively operating [7].

To obtain a comprehensive analysis of the environmental impact of heating systems (HSs) based on wood biomass, a complete lifecycle process that involves a holistic cradle-to-grave assessment approach is recommended [8].

The life cycle assessment (LCA) is useful for decomposing and analyzing the environmental impacts and effects of products and services because the assessment is extended across the entire life cycle of products and services. Therefore, LCA is the common practice for estimating the environmental impact of different issues in the field of heating sector development towards cleaner technologies [9].

In this study, the LCA of firewood-based and wood pellet-based HSs is performed, as two different types of individual wood biomass-based HSs. A typical stove used in the Serbian household for decades and a modern wood pellet-based furnace, very popular in the recent period, are analyzed.

The main objective of this LCA study is to assess the environmental performance of two HSs based on wood biomass installed in Serbia using the global warming potential (GWP) index. The study also aims to identify the LC phases that contribute the most to the GWP of each HS.

2 METHODOLOGY

Even though wood is considered a cleaner energy source than fossil fuels, it is important to evaluate the interactions with the environment over the whole lifecycle of each HS (materials, manufacturing, transportation, use, and final disposal) [10]. Life cycle assessment (LCA) systematically analyzes pollution and resource connected to delivering a specific product or service. As such, the LCA identifies environmental hot spots and enables a comparison of different energy sources and HSs for households [11].

A systemized framework for conducting LCAs was released by the International Organization for Standardization during the period 1997–2000, resulting in the standards ISO 14040, 14041, 14042, and 14043 [12]. In 2006, standard ISO 14040 was revised, and a new standard ISO 14044 was presented. Formal changes include the reduced number of standards, the reduced number of annexes, and the reduced number of pages that contain requirements. All these changes are intended to increase the readability and accessibility of the standards [13].

The ISO 14000 family is concerned with “environmental management” which is primarily focused on [11]:

- Minimizing harmful effects on the environment caused by its activities,
- Achieving continual improvement of its environmental performance.

However, since LCA considers the environmental aspects and the potential impacts of a product or a service system throughout its life, it becomes a very useful method for researching studies related to the problem of sustainable development, cleaner production, energy savings, and environmental protection.

This study follows an approach that is based on the international standards series ISO 14040. It is made up of four steps (four main phases): Goal definition and scoping, Inventory analysis, Impact assessment, and Interpretation [13] (Figure 1).

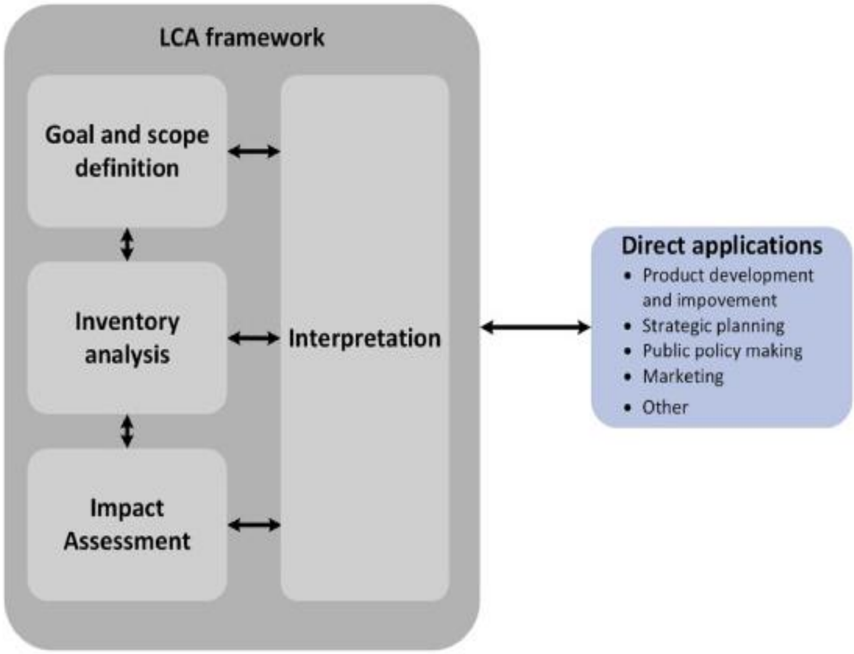

Figure 1. LCA phases according to ISO 14040:2006 [14]

These four steps are covered in four ISO standards on Life Cycle Assessment: ISO 14040 (General principles), ISO 14041 (Inventory and Goal and Scope), ISO 14042 (Impact assessment), ISO 14043 (Interpretation) [15].

Life-cycle assessment (LCA) is considered as an effective method to evaluate the greenhouse gas (GHG) emissions of a particular HS throughout its lifetime [9]. In this paper, it is implemented the Global Warming Potential (GWP) as an impact assessment method. All aggregated GHG emissions are converted to CO_2-equivalents based on GWP with a 100-year time horizon (GWP100). The calculation of GWP100 is defined in the IPCC Assessment Report [16].

3 THE SCOPE AND INVENTORY DATA

The scope of this study is under ISO 14000 and it deals with the comparative LCA of HSs throughout all stages of HSs' lifetime.

The exact data on the structure of energy use for space heating by the fuel and type of HS are not available in Serbia. For that reason, the inventory data of each phase of the LC process is collected through literature review and technical specifications from the manufacturer of the analyzed HSs.

3.1 Case study details

For a detailed LCA study, it is obligatory to consider the operational period of HSs for a specific living space. The operating energy consumption of HSs is calculated by using data from the available Energy Agency of the Republic of Serbia's (AERS) report on the comparative costs of housing heating in the annual report [17]. The AERS's methodology is based on the analysis of a typical flat of 60 m^2 that is heated to 20°C for 16 hours a day, 180 days a year. The required specific heat for heating of 150 kWh/m^2 has been adopted, so according to this methodology, it is necessary to provide 9000 kWh of heat for the heating season.

Most of the residential stoves that are in use in Serbia today are low-to-mid-price and low-to-mid efficiency, compared to the best available models in the European market. To estimate the amount of fuel needed for one heating season, it is used AERS's data on the average efficiency of HSs and the lower heating value (LHV) (net calorific value) of each fuel. It is assumed that the period of use of the appliances is 20 years.

Table 1 shows the estimated annual amount of fuels needed for space heating [18] in the case of firewood and wood pellet HSs for a typical flat [17]. The adopted efficiency data are based on [17] because manufacturers overestimate the efficiency in their specifications that are mostly based on researches in laboratory conditions.

Table 1. The estimation of the annual amount of fuel consumption [17], [18]

Fuel	Efficiency (%)	LHV (MJ/kg)	Annual amount (kg)
Firewood	55	14.7	4,007
Pellet (wood)	80	17	2,383

The efficiency of HSs and LHV are assumed to remain unchanged for the entire life span of the systems [9]. To avoid unequal treatment of HSs, it is assumed the same transportation distances from the manufacturing location to the house, and the same type of lorry for the analyzed HSs. As for the waste treatment scenario, it is assumed that 80% of the materials by mass will be recycled and the remaining 20% will be disposed of in a landfill.

3.2 Heating systems specification

For the LCA of the individual HSs, two wood biomass-based HSs manufactured in Serbia, are chosen: firewood-based and wood pellet-based.

Firewood stoves are widely used in all Western Balkans countries, while wood-pellet appliances are less common [19]. However, the characteristic of the market of wood fuels in Serbia in the last decade has been the fast rate of growth in wood pellet consumption. The wood pellets produced by wood residue are favorable feedstock energy because of their high calorific value, low ash content, and slagging rate [20]. The basic information and material composition of HSs are given in Table 2 [21], [22]. The materials mentioned in Table 2 form the bulk of the furnace's weight (90%). Other materials that constitute a smaller fraction of the appliance weight were not considered for the analysis.

Table 2.Specifications of HSs [22], [23]

SMEDEREVAC 7 NEW LINE MBS		**MBS PELLET 6 - 10 KW**	
			
Capacity	6.5 kW	Capacity	8.5 kW
Dimensions (HxWxL)	740x720x570 mm	Dimensions (HxWxL)	980x560x490 mm
Weight	71 kg	Weight	108 kg
Steel	63 kg	Steel	97 kg
Aluminum	3.5 kg	Aluminum	6 kg

4 LIFE CYCLE ASSESSMENT

All stages in a product's life cycle can result in the generation of emissions. The related emission factors were obtained from [21], [22], [23] and [24]. Table 3 and Table 4 summarize the inventory data with the results of the GWP100 for two types of HS. In the presented tables, the most significant LC phases of HSs are estimated – production, transport, use[4], and recycling and/or final disposal.

Emission factors (emissions per unit of the physical weight of materials) are obtained from the Ecoinvent 3.0 database (expressed by GWP100 per kg) [24] and the EPA stationary combustion emission factors inventory [23] (expressed by GWP100 per kg).

Table 3. LCA of firewood-based HS - SMEDEREVAC 7 NEW LINE MBS [21], [23], [24]

LC phase	**Contribution**	**Amount [kg]**	**GWP100 per kg [kg CO2-Eq/kg]**	**GWP100 total [kgCO$_2$-eq]**
Production	Steel production	63	2.445	154
	Aluminum production	3.5	26.57	93
Transport	Transport, freight, lorry 16-32 metric ton, EURO5	8	0.1648	1.32
Use	Heating (20 years)	80140	0.026	2084
Waste treatment	Recycling of steel	50	-2.445	-122.25
	Recycling of aluminum	2.8	-26.57	-74.4
	Treatment of scrap steel, inert material landfill	13	4.311e-3	0.06
	Treatment of waste aluminum, sanitary landfill	0.7	0.04198	0.3
TOTAL				**2136**

[4] It is assumed that use of firewood and wood pellet is not carbon neutral, i.e. it is assumed that the used wood has not been replaced by the newly planted one.

Table 4. LCA of wood pellet-based HS - MBS PELLET [22], [23], [24]

LC phase	Contribution	Amount [kg]	GWP100 per kg [kg CO2-Eq/kg]	GWP100 total [kgCO_2-eq]
Production	Steel production	97	2.445	237.2
	Aluminum production	6	26.57	159.4
Transport	Transport, freight, lorry 16-32 metric ton, EURO5	8	0.1648	1.32
Use	Heating (20 years)	47660	0.026	1239
Waste treatment	Recycling of steel	77	-2.445	-188.3
	Recycling of aluminum	4.8	-26.57	-127.5
	Treatment of scrap steel, inert material landfill	20	4.311e-3	0.08
	Treatment of waste aluminum, sanitary landfill	1.2	0.04198	0.5
TOTAL				**1322**

Once the LCA results of two HSs are obtained, it can be made a comparison of two HSs. Also, it can be analyzed and determined the most significant phases of HS's life cycle. To simplify results, only dominant materials of HSs which represent 90% of complete HSs were analyzed.

According to the total GWP 100, wood pellet HS could reduce CO2-eq emissions by 38% (814 kg CO_2-eq) compared with firewood-based HS if the whole life cycle is analyzed. In the production phase of the LC, firewood-based HS has a lower impact on the environment and climate changes. This is directly related to the quantity of materials of which HS was made. Over the use phase, wood pellet-based HS has a lower impact. This is due to the quantity of fuels and higher efficiency of the wood pellet-based HS which would have been used for heating according to the case scenario. In the waste treatment phase, wood pellet-based HS achieves more benefits than firewood-based HS due to the quantity of materials that could be recycled.

5 CONCLUSIONS

The way of using wood biomass for heating is a very important issue that reflects on energy consumption and environmental performance. Deployment of more efficient technologies in the combustion of biomass results in significant benefits for the environment, climate change mitigation, and sustainable development.

The obtained results show that wood pellet-based HS has a lower negative impact on the environment and climate change, and at the same time, it ensures the financial benefits through savings in wood biomass consumption and conservation of natural resources.

This research showed that the implementation of LCA for assessing the HS alternatives is an efficient and relatively simple method for obtaining new information that is helpful in the decision-making process. However, the obtained result is not final, and it should be further developed to reduce initial assumptions:

- The same lifetime of HSs;

- The same material structure of HSs;
- The same waste treatment scenario;
- The same emission factors for fuels.

Therefore, further research should consider the wider scope of LC indicators and environment variables that have a significant influence on choosing the best alternative for heating.

REFERENCES

[1] EC, European Commission. Heating and cooling, Facts and Figures,https://ec.europa.eu/energy/topics/energy-efficiency/heating-and-cooling_en?redir=1#:~:text=In%20EU%20households%2C%20heating%20and,energy%20use%20(192.5%20Mtoe)*.&text=To%20fulfil%20the%20EU's%20climate,its%20use%20of%20fossil%20fuels(accessed 10 Sept. 2020).
[2] Martinopoulosa, G., Papakostas, K.T., Papadopoulos, A.M. (2018). A comparative review of heating systems in EU countries, based on efficiency and fuel cost, *Renewable and Sustainable Energy Reviews*, pp. 687-699.
[3] WHO, World Health Organization. (2015). Residential heating with wood and coal: health impacts and policy options in Europe and North America, WHO Regional Office for Europe, Copenhagen Ø, Denmark.
[4] Wolters, R. (2018). EU Policy regarding emission reduction from domestic combustion, European Commission, DG ENV / C3 Clean Air, https://www.unece.org/fileadmin/DAM/env/documents/2018/Air/WGSR/Roald_Wolters.pdf(accessed 10 Sept. 2020)
[5] SORS, Statistical Office of the Republic of Serbia (2018). Household Budget Survey, SORS, Belgrade.
[6] UNDP, United Nations Development Programme (2004). Energy, Environment and Poverty in Serbia and Montenegro, UNDP, Belgrade.
[7] Glavonjić, B. *(2017).* Position paper: Status of Using Wood Biomass for Energy Purposes in Serbia. UNDP Serbia, Belgrade. http://biomasa.undp.org.rs/wp-content/uploads/2018/11/POSITION-PAPER-Status-of-Using-Wood-Biomass-for-Energy-Purposes-in-Serbia-FINAL.pdf(accessed 15 Sept. 2020).
[8] Saba, S., Bachawati, M.E., Malek, M.(2020). Cradle to grave Life Cycle Assessment of Lebanese biomass briquettes, *Journal of Cleaner Production*, Vol. 253, pp. 119851.
[9] Zheng, M., Fang, R., Zitao, Y.(2016). Life cycle assessment of residential heating systems: a comparison of distributed and centralized systems, *Energy Procedia*, Vol. 104, pp. 287-292.
[10] Shah, V.P., Col Debella, D., Ries, R.J. (2008). Life cycle assessment of residential heating and cooling systems in four regions in the United States, *Energy and Buildings*, Vol. 40, pp. 503-513.
[11] Muralikrishna, I.V., Manickam, V.(2017). Chapter Five - Life Cycle Assessment, *Environmental Management - Science and Engineering for Industry,* Butterworth-Heinemann, Oxford, pp. 57-75.
[12] Pryshlakivsky, J., Searcy, C.(2013).Fifteen years of ISO 14040: a review, *Journal of Cleaner Production*, Vol. 57, pp. 115-123.
[13] Koroneos, C.J., Nanaki, E.A.(2012).Life cycle environmental impact assessment of a solar water heater, *Journal of Cleaner Production*, Vol. 37, pp. 154-161.
[14] Roumpedakis, T.C., Kallis, G., Magiri-Skouloudi, D., Grimekis, D., Karellas, S.(2020).Life cycle analysis of ZEOSOL solar cooling and heating system, *Renewable Energy*, Vol. 154, pp. 82-98.

[15] Goedkoop, M., Oele, M., Vieira, M., Leijting, J., Ponsioen, J., Meijer, E. (2016.), SimaPro Tutorial, PRé, San Francisco, California.https://www.pre-sustainability.com/legacy/download/SimaPro8Tutorial.pdf (accessed 20 Sept. 2020).
[16] IPCC, Intergovernmental Panel on Climate Change, Climate change (2014). Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the IPCC, IPCC, Geneva, Switzerland.https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf (accessed 30 Sep. 2020).
[17] AERS, Energy Agency of the Republic of Serbia (2018). Energy costs for heating residential space, AERS, Belgrade. (available only in Serbian)http://aers.rs/g/vesti/file/Dokumenti/grejanje.pdf (accessed 10 Sept. 2020).
[18] Forest Research (FR), Typical calorific values of fuels. https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels/.(accessed 20 Sept. 2020).
[19] IBRD/WB, International Bank for Reconstruction and Development / The World Bank (2017). Biomass-Based Heating in the Western Balkans A Roadmap for Sustainable Development, World Bank, Washington DC.
[20] Wang, C., Chang, Y., Zhang, L., Pang, M., Hao, Y. (2017).A life-cycle comparison of the energy, environmental and economic impacts of coal versus wood pellets for generating heat in China, *Energy*, Vol. 120, pp. 374-384.
[21] MBS (a), Milan Blagojevic Smederevo, Manual instruction for wood furnace http://www.etazgrejanje.com/cms_upload/catalog/product_files/1222_mbs7new_line_srpski.pdf (accessed 25 Sept. 2020).
[22] MBS (b), Milan Blagojević Smederevo, Manual instruction for pellet furnace. http://www.etazgrejanje.com/cms_upload/catalog/product_files/1150_mbs_pellet_-__uputstvo_za_rukovanje.pdf (accessed 25 Sept. 2020).
[23] EPA, Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf (accessed 25 Sept. 2020.)
[24] Ecoinvent, Ecoinvent 3.0. System Models in ecoinvent 3.https://www.ecoinvent.org/database/system-models-in-ecoinvent-3/system-models-in-ecoinvent-3.html (accessed 30 Sept. 2020).