RESIDENTIAL HEATING WITH WOOD AND WOOD PELLETS: LIFE CYCLE COST ANALYSIS AND AIR QUALITY IMPACTS

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ABSTRACT

In the recent years air pollution is a huge global problem. It seriously affects the human health and consequently the economies of countries. The residential heating with firewood is one of the major sources of ambient air pollution particularly when the wood-fired appliances are poorly optimized which results in considerable emission of harmful products obtained from the incomplete wood combustion. Wood pellets, due to their composition and the usage of modern stoves with optimized and controlled combustion, score better with respect to air pollution.

The aim of this work is to evaluate the residential heating with firewood and wood pellets by performing a cost-benefit analysis for both.

A household that utilized both types of heating was used as a case study. The cost analysis was carried out by calculating the life cycle costs in the usage phase of the firewood and wood pellets. A cost projection for a future period of ten years was also done. For the needs of the benefit analysis an estimation of air pollutant emissions when firewood or wood pellets is combusted, was performed.

The results show that for a period of 10 years, in the case of wood pellets, the life cycle costs would increase about 40% compared to the life cycle costs for firewood. From an environmental point of view, wood pellets show much better results. Namely, the emission of harmful PM10 particles and carbon monoxide is reduced much more than twice.

Summarizing, heating with pellet fuel is more expensive, but the benefits achieved are significantly greater in terms of noticeably reduced air pollution, less harmful health consequences, and respectively more savings in the health system and the overall economic system as well.

KEYWORDS: Air pollution, firewood, wood pellets, cost-benefit analysis, life cycle costs.

JEL CLASSIFICATION: Q51, Q53, Q57

INTRODUCTION

In the last few decades, the planet Earth is facing with a noticeable climate changes. The climate changes are generally caused by the increased concentrations of carbon dioxide in the atmosphere from the usage of fossil fuels, which in turn causes a greenhouse effect and global warming. As a consequence, sea levels are rising, the ice on the poles and glaciers is melting, sudden temperature differences and weather disasters (storms, floods, earthquakes, fires) happen. All these changes lead to large-scale environmental problems, such as the greenhouse gas emissions, acid rains, extinction of some animal species etc.

There are numerous measures for mitigating the climate changes, most of them including energy efficiency in all aspects of life, use and/or increase of the share of renewable energy sources in the energy mix, optimization of waste management procedures and reduction of emissions from waste treatment, use of public transport and bicycles, introduction of transport taxes, reduction of greenhouse gas emissions in agriculture, forest protection, etc.

According to the World Bank report on Macedonia's green growth (World Bank Group, 2014), R. of North Macedonia has the most polluted air in Europe and was ranked on the fifth place with respect to the number of deaths per year caused by polluted air i.e. by the presence of PM10 particles in the air. At the same time, thousands of lost working days were recorded, which resulted in an economic cost of 253 million euro per year or 3.2% of the Gross Domestic Product (GDP) in the Republic of North Macedonia. Globally, according to the Global Burden of Disease (GBD) study (Institute for Health Metrics and evaluation, 2020), the air pollution, indoors and outdoors, in addition to the harmful effects on human health, also affects crop yields and the environment, with effects on biodiversity and ecosystems. These impacts have significant economic consequences, which might affect the economic growth as well as welfare.

One of the major air pollutants in R. of North Macedonia, especially in the larger cities, is the burning of firewood as a mode for heating of many households. Having in mind that the city of Skopje is the most polluted city in the country, but also one of the most polluted cities in Europe, especially during winter, the aim of this paper is to study the air pollution in the city of Skopje caused by the two modes of residential

heating, firewood and wood pellets. The evaluation of the economic and environmental implications of both types of heating should contribute towards choosing less polluting sources for residential heating and thus mitigating the climate changes on a long term.

RESEARCH METHODOLOGY

A household that utilized both types of heating was used as a case study. The cost analysis was performed by calculating the life cycle costs in the usage phase of both, the firewood and wood pellets. A cost projection for a future period of ten years was also done. For the needs of the benefit analysis, based on data from several relevant databases, an estimation of air pollutant emissions when firewood or wood pellets is combusted, was done.

LITERATURE REVIEW

The environmental impact of heating systems (individual home heating systems, larger institutional heating systems and small and medium central heating systems) that use firewood, natural gas, heating oil or propane, along with the respective life cycle analysis were investigated by Jim Bowyer (Bowyer, 2012). For some of the investigated systems a complete life cycle analysis was made, whereas for some of them the life cycle analysis referred only to the extraction of energy resources, transport, combustion and removal (if any) of ash and other combustion residues. Conclusions on combustion emissions and air quality, energy efficiency, life cycle costs as well as general environmental impacts have been drawn.

In the paper of Buchholz and collaborators (Buchholz et al., 2017) the greenhouse gas emission starting from the phase of production till the end use of the biomass pellets was studied. Product life cycle analysis was used as a tool to calculate the greenhouse gas emission during the process of collection, processing and usage of wood pellets for residential heating versus the same process when other heating fuels are used. The results showed that pellets consisting of 50% sawmill residues and 50% pulpwood generate approximately the same heat as that of fossil fuels.

In 2015, Kjellson and Svensson (Kjellson & Svensson, 2015) conducted a survey of low-income households in South Africa which use paraffin¹ stoves for cooking and

¹A fossil fuel, relatively cheap

in the recent years some of them have started to use wood pellets instead the paraffin. The focus of the study was to assess the environmental, economic and sociological aspects of using fossil versus renewable fuels. The environmental and economic aspects, appearing during the utilization phase of the respective fuel, were assessed through life cycle assessment (LCA) and life cycle cost analysis (LCCA), respectively. The results have showed that majority of the households are ready to change the current fossil fuel with another fuel for cooking if the four important criteria (safety, non-harmful health consequences fuel availability and quality) are met. The economic analysis has shown that during the utilization phase the wood pellets are more economical than the paraffin system over a period of 16 years. It has been concluded that wood pellets can be used as cooking fuel instead of paraffin, and that it is likely to improve the standard of living of low-income households.

The Report for evaluation of the greenhouse gasses emission from biofuel and fossil fuels in North-western Canada (SRC, 2011), has shown that use of biofuels is rapidly expanding due to the increase of oil prices and the introduction of climate change policies. The research prior to this report has shown that using biomass as a fuel reduces greenhouse gas emissions and has a number of other environmental and socio-economic benefits, especially when wood biomass residues are used as raw materials in the energy efficient conversion technologies, such as burning the wood biomass residues or using them in combination with other fuels to generate heat and electricity. Three scenarios, use of firewood for residential heating, use of pellets for residential heating and use of for residential heating, were analyzed. It was shown that the wood chips produced from local sources showed the lowest greenhouse gas emissions during the entire life cycle. Imported wood pellets and local firewood when burned in traditional stoves showed the highest greenhouse gas emissions after heating, after oil. Based on the life cycle analysis the utilization of locally produced wood chips and pellets is recommended as one of the strategies to reduce fossil greenhouse gas emissions.

The environmental impact and the evaluation of costs for producing wood pellets were assessed also by Pergola (Pergola et al, 2017). Two types of pellets were analyzed by doing life cycle assessment (LCA) and analysis of the life cycle cost (LCC) for both systems. The results showed that by-products of wood processing can be an effective

solution to reduce both, the production costs and environmental impact when wood pellets are concerned.

An analysis done at the University of Michigan (Knudson, 2018) compared the life cycle costs of three different heating technologies: wood pellets, propane gas and heating oil. Two buildings with different area and under two scenarios (subsidized and unsubsidized wood pellet heating units) were investigated. It was shown that in all cases the wood pellet heating units are less expensive than propane and heating oil. The utilization of propane is 26.2% more expensive than the subsidized wood pellets and 35.7% more expensive than the subsidized wood pellet heating unit. Oil heating is 12.2% more expensive than the unsubsidized wood pellet heating units and 20.7% more expensive than the subsidized wood pellet heating unit. Wood pellet boilers also have the advantage of having a longer life span than oil and propane units. The authors have also emphasized that despite the observed costs savings wood pellets are not widely used for central heating.

ECONOMIC ANALYSIS OF THE RESIDENTIAL HEATING WITH WOOD VS. WOOD PELLETS

The goal of the economic analysis was to determine the life cycle costs during the utilization phase of both, residential heating with firewood and residential heating with wood pellets and to evaluate which one is economically more beneficial. The obtained results should assist in assessing if the transition from firewood to wood pellets is financially affordable for the households. The other life cycle stages (design, development, natural resource extraction and the manufacturing of the stoves) are not evaluated.

Life cycle costs (LCC)

The two alternatives of residential heating, with firewood and with wood pellets, differ in the type of stoves and amount of fuel needed during the utilization phase. LCC for both cases can be presented as a sum of the investment costs, C_I , operational costs, C_O , replacement costs, C_{Repl} , and residual costs, C_{Res} . as given with expression (1)

$$LCC = C_I + C_O + C_{Repl} - C_{Res} \quad (1)$$

The *investment costs* are the one-time costs related to the purchase of the stove whereas all costs related to the utilization phase of the stove are *operational costs*. The *replacement costs* refer to costs related to the replacement of the whole stove, or parts of it, during the utilization period. The *residual value* is the net worth of the stove at the end of duration time. Generally, both types of stoves, for wood pellet and firewood stove don't have any residual costs during their lifetimes.

The costs described above can be also divided into *initial costs*, *recurring costs* and *non-recurring costs*. The difference between recurring and non-recurring costs is that the first ones occur frequently during the lifetime, while the non-recurring cost is a one-time cost. The division in initial, recurring and non-recurring cost types is needed because in some cases a parameter, e.g. replacement costs, can include both recurring and non-recurring costs.

The future costs (calculated as present values) of the initial, non-recurring and recurring costs are determined using the expressions (2), (3) and (4).

$$\text{Initial costs:} \quad C_{PV} = C_T \quad (2)$$

$$\text{Non-recurring costs:} \quad C_{PV} = C_T \frac{(1+e)^t}{(1+d)^t} \quad (3)$$

$$\text{Recurring costs (annually fixed):} \quad C_{PV} = C_T \frac{(1+d)^t - 1}{d(1+d)^t} \quad (4)$$

where C_{PV} is the present value of the future cost, C_T refers to the current value of cost, d is discounting rate, e refers to escalation rate and t is period of time (in years).

The initial, non-recurring and recurring costs for both types of heating, considered in this paper, are given in Table 1.

Table 1. Residential heating costs in the usage phase of the fuel

Cost*	C_i (MKD)		C_o (MKD)		C_{repl} (MKD)	
	Firewood	Wood pellets	Firewood	Wood pellets	Firewood	Wood pellets
Initial	Purchase of stove $C_T = 18.000$	Purchase of stove $C_T = 46.000$				
Recurring			Purchase of firewood (annually) $C_T = 29.325$	Purchase of pellets (annually) $C_T = 36.509$ Single tariff electricity for	Maintenance (annually) $C_T = 1.000$	Maintenance (annually) $C_T = 2.000$

				starting the stove $C_T = 4.381$		
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Source: Sandra Spirova, 2020. Analiza na troshocite i pridobivkite na merkite za namaluvanje na zagaduvanje na vozduhot so poseben osvrt kon nachinite na zagrevanje na domakinstvata. Master thesis. Integrated Business Institute. Skopje

The present values of the initial and recurring costs for both types of heating are calculated according to expressions 2, 3 and 4, for a period of 10 years, discount rate of 1,8% (SKIBOR, 2020) and zero escalation rate (Fuller & Petersen, 1996). The obtained results are presented in Table 2.

It can be observed that the LCC are higher by about 48% when wood pellets are used compared to the costs when firewood is used.

Table 2. Costs in the user phase of the firewood and wood pellets

	Firewood	Wood pellets
C_i (MKD)	18.000	46.000
C_o (MKD)	275.287	389.325
LCC (MKD)	293.288	435.326

Source: Authors calculation

ENVIRONMENTAL ANALYSIS OF THE RESIDENTIAL HEATING WITH WOOD VS. WOOD PELLETS

The emission of harmful gaseous components and solid particles from burning wood and wood-based products is monitored by following the emission factor, expressed as amount of pollutant emitted during the combustion of a unit mass of fuel, (mg m^{-3}).

Table 3 shows the concentrations of CO, NO_x, C_xH_y and PM₁₀ particles during the combustion of firewood and wood pellets.

Table 3. Average concentration of harmful gaseous and solid particles emission from combustion of firewood and wood pellets

	Stove efficiency (%)	CO (mg m^{-3})	NO _x (mg m^{-3})	C _x H _y (mg m^{-3})	PM ₁₀ (mg m^{-3})
Firewood	88	1423	362	35,7	93,2
Wood pellets	95	980	374	45,5	29,7

Source: Schmidl, C. et al., Particulate and gaseous emissions from manually and automatically fired small scale combustion systems, *Atmospheric Environment*, 45 (2011) 7443-7454

It can be noticed that the total emission of carbon monoxide (CO) and solid PM₁₀ particles in the ambient air is 45% and 213%, respectively, higher when 1 m³ of firewood is burned compared to the emission of these components wood pellets are used. A similar result is obtained from the latest data of Balkan Energy Group (BEG) according to which for each received kWh of energy the total emission of PM₁₀ and PM_{2.5} particles when burning firewood is 152% more than their emission when pellets are used (BEG, n.d.).

When it comes to the emission of nitrogen oxides and hydrocarbons, the difference in the emission factor for both types of residential heating is insignificant (2-4%).

DISCUSSION OF THE RESULTS

The results obtained from the economic analysis show that if the way of residential heating is changed from stoves with firewood to stoves with wood pellets, for a period of 10 years it would cause increase in the LCC by 48% (Table 2).

On the other hand, by burning 1 m³ of firewood the emission of harmful PM₁₀ particles in the air is 213% higher compared to the emission of PM₁₀ from wood pellets. With respect to the emission of CO, it is 45% higher when firewood is used for residential heating. Considering the fact that on average a household uses 7 to 10 m³ of firewood during the heating season, and that in the Skopje region about 33% of the total number of households use firewood (according to the State Statistical Office the consumption of firewood in Skopje is the largest in the country and amounts to 190,000.00 m³ out of a totally 230,000.00-280.00.00 m³), the results indicate that the change of the heating mode of households from firewood to heating with wood pellets, although is more expensive in the long run, the increase in costs is many times less than the air pollution caused by firewood heating.

The overall benefit arising from the change of the heating mode primarily refers to a reduction of the health consequences and premature mortality, which on the other hand leads to savings in the health system and total savings from 34,000,000 € to almost 161,900,000.00 € per year if the concentration of solid PM₁₀ and PM_{2.5} particles in the air would decrease to 1 µg / m³ and 15 µg / m³, respectively (WHO & OECD, 2015).

CONCLUSION

Air pollution, in addition to the caused negative climate changes, also causes deterioration in human health, which in turn significantly affects the economies of countries, through the emergence of direct and indirect costs.

Firewood burning is one of the major air pollutants and the largest source of finely suspended solid particles with harmful effects on human health. Given that the city of Skopje is on the top of the list of most polluted cities in Europe, especially in winter, the purpose of this research was to analyse the cost-effectiveness of environmental measures taken in the city to reduce air pollution, with a focus on the ways of residential heating, as one of the major reasons for the large air pollution in the city.

The results showed that the environmental effect (*significantly decreased air pollution*) is much more expressed than the economic one (*moderate increase of the costs*) if wood pellets are used instead of firewood for residential heating.

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