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# COST EVALUATION OF TECHNOLOGIES FOR SPACE HEATING, COOLING AND DOMESTIC HOT WATER FOR MULTIFAMILY APARTMENTS IN R. N. MACEDONIA

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Abstract: In the residential sector in R. Macedonia, most of the existing buildings are energy inefficient with high heating energy consumption, fossil fuels and direct use of electrical energy as a heating source. A lack of information and high Capital Expenditures (CAPEX) are identified as main reasons for the low attractiveness of district heating (wherever available) and heat pumps respectively. Therefore, the aim of this paper is through techno–economic assessment of different heat sources and technologies to provide well–founded answers that would create a good basis for future decisions in this sector. As the key performance is used Levelized Cost of Energy (LCOE) considering climate and economic conditions in R. Macedonia. The analysis is conducted for a reference heating area of 70m$^2$ with specific heating energy consumption of 70 kWh/m$^2$a, cooling energy 20 kWh/m$^2$a and 30 kWh/m$^2$a for domestic hot water (DHW). The considered technologies are heat pump air–water and air–air, electric boiler, natural gas boiler, wood pellet boiler and district heating. Sensitivity analysis is performed to assess the extend to which the change in investment, electricity and fuel prices affect the LCOE and economic viability. Results indicate that district heating has lowest LCOE, followed by system with air conditioners.
Keywords: cost optimal, heating energy, LCOE

## 1. INTRODUCTION

Heating and cooling energy are dominant in the total energy consumption in buildings. Therefore, the main accent is posed on the energy savings through renovating existing buildings and implementing renewable energy sources as a heating and cooling energy sources. Building sector has significant share in the country total energy consumption, making it a significant factor which can contribute toward fulfilling climate protection targets. According to the Eurostat analysis of the energy consumed by end users in the EU in 2019, there were revealed three dominant categories: transport (30.9 %), households (26.3 %), and industry (25.6 %). The building sector holds the key potential to fulfill climate protection targets. Dominant share in the use of energy in households in the EU in 2019 was for heating (64% of final energy consumption in the residential sector), with renewables accounting for more than a quarter (28%) of EU households space heating consumption [1]. Decarbonization in building sector is focused on the heating and cooling systems as a main primary energy consumer. The pathway for decarbonization of the heating sector is by integration of renewable energy sources and increasing the share of the 4$^{th}$ and 5$^{th}$ generation of district heating systems.

In the World Bank research study, A Roadmap for Sustainable Development [2] it is found that almost two–thirds of annual heat demand in the Western Balkans is met using firewood (42%) and electricity (21%). Total annual heat demand in the Western Balkans is estimated to be 8 Mtoe, or 93 thermal terawatt–hours (TWhth). The residential sector accounts for more than 70% of heat demand. The commercial and industrial sectors account for 18% of annual heat demand, and the public sector 10%. In the residential sector, firewood is the most common fuel for heating in all the Western Balkan countries, except in Albania where electricity is the primary heating method. Since N. Macedonia is part of the Western Balkan countries these statistical findings are also valid for the current situation in N. Macedonia.

The renovation wave strategy which is part of the European Green Deal contains an action plan with concrete regulatory, financing and enabling measures to boost building renovation. Objective is to at least double annual energy renovation rate of buildings by 2030 and to foster deep renovation [3]. Considering that 85–95% of existing buildings still will be in use in 2050, from roughly 75% are not energy efficient. The building sector is pointed out as having the largest potential for cost–efficient reduction of emissions [4]. Therefore, the renovation of both public and private buildings is an essential action and has been singled out in the European Green Deal as a key initiative to drive energy efficiency in the sector and deliver on objectives.

According to the literature review [5], most of the occurring strategies for renovation of residential buildings consider energy efficiency. The large share of methodologies involving energy and economic factors is partially caused by the well–established cost–optimal approach, incorporating Life Cycle Cost (LCC) calculations. The cost–optimal method is proposed by the EU Commission for the minimum energy requirements on the national level and further developed through Annex 56 on the building level [6] and IEA, methodology for Cost Effective Energy and Carbon Emission Optimization in Building Renovation; Annex 56; International Energy Agency: Paris, France, 2017.

## 2. BACKGROUND ANALYSIS

More than 500 000 dwellings in N. Macedonia have high specific energy consumption i.e. with average energy intensity approximately of 200 kWh/m$^2$ per year [7]. Most of the existing buildings are constructed during the period of 1980–1990 (especially public buildings) when there were not defined energy requirements. Also, most dominant fuel in the heating sector is solid fuel mainly wood and wood pellets with individual stoves and hot water boilers. The electricity is second most utilized heating fuel source mainly represented by individual electrical heaters and electrical hot water boilers according to Makstat and UNDP study. In the past few years, it can be noted an increased installation of individual air–conditioners and heat pumps for central heating which is due the decrease in the market prices. Therefore, to meet the EU requirements for carbon neutral building sector until 2050 in N. Macedonia the accent should be on the existing buildings i.e. on the renovation phase decreasing the buildings energy consumption and integration of renewable energy sources.

In recent years, there has been an increasing trend for electricity generation from renewables, and better utilization of waste energy. This promotes the opportunity for the electrification of the heating sector and a shift away from fossil fuels. Electric heat pumps could play a central role in the Macedonia's future approach to heating, together with the decarbonized electricity grid. Additionally, heat pumps can be integrated into district heating networks, which may provide additional carbon emissions reduction potential.

The applied procedure in this paper considers economic and energy indicators, analyzing the optimal investment in heat source and technology for the climate and economic conditions in R. Macedonia, which are deterministic factors in defining optimal heating/cooling system. Life cycle cost analysis has been largely applied to demonstrate the economic viability of nearly zero energy buildings (and high energy performance buildings) with integrated renewable energy sources, where usually investment costs are higher compared to the traditional constructions to reach higher energy and environmental targets and the business plan needs a wider perspective [8].

## 3. METHODOLOGY

Understanding how much and when heat is consumed is fundamental to evaluate heat supplying technologies and designing cost–effective strategies to meet heat demand. In this paper are used analyses from a study for empirical residential heat consumption, including space heating and domestic hot water demand, for the five main types of dwellings through smart meter data [9], and investigates hourly heat load profiles over a year to estimate variations in total heat demand as well as peak demand.

Life cycle cost assessment (LCC) is an economic evaluation technique that is used to determine the total cost of owning and operating a facility over period of time. Life cycle cost is associated with an energy delivery system over its lifetime or over a selected period of analysis and considers the time value of money.

Beside the life cycle cost method, another method to benchmark and select optimal system with renewable energy sources is the Levelized Cost of Energy (LCOE). This method is described by the International Energy Agency (IEA) as the "average price that would have to be paid by consumers to repay exactly the investor/operator for the capital, operation and maintenance and fuel expenses, with a rate of return equal to the discount rate". The levelized cost of energy (LCOE) allows alternative technologies to be compared when different scales of operation, different investment and operating time periods, or both exist. For example, the LCOE could be used to compare the cost of energy generated by a renewable resource with that of a standard fossil fueled generating unit. This method is a widespread in comparing different energy generation technologies. It considers comparison of the total costs (fixed + variable) in reference to an energy supply system with the energy supplied by this system over its lifetime.

Levelized Cost of Energy (Heat) is used as technical and economical Key Performance Indicator (KPI) used in this paper to define the optimal system configuration.

Levelized Cost of (Heat) Energy:

$$C_R = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{1}$$

$$LCOE = \frac{C_R C_O + C_j}{E} \tag{2}$$

where: $S_j$ – Annual benefits (energy savings compared to base scenario), [euro/year], $C_j$ – Total annual costs, [euro/year], $C_o$ – Investment costs, [euro/year], $C_R$ – Capital recovery factor, [euro], n – project lifetime, [years], i – discount rate, $E$ – Produced energy (heat and electricity), [kWh/year]

According to the data from the State statistical office the existing average living space in Skopje (urban part) is 69 m2 [10]. Therefore, it is decided that referent building for further techno–economic analysis is considered as apartment with conditioned area of 70 m$^2$. Though the energy consumption is calculated in regard of predefined specific heat energy consumption kWh/m$^2$a. Considering that buildings have different energy performance and according the data from the district heating company in Skopje – Balkan Energy Group, average specific heat energy consumption is 100 kWh/$m^2$a. Considering that in the future actions are directed toward increasing energy efficiency, in the analysis is considered renovated (energy efficient) building/apartment with specific heat energy consumption of 70 kWh/$m^2$a for Scenario 1 and in Scenario 2 additionally is considered specific cooling energy of 20 kWh/$m^2$a and specific heating energy of 30 kWh/$m^2$a for DHW.

Investment cost i.e., capital expenditures (CAPEX), operation and maintenance costs and fuel prices are obtained as average from the Macedonian market. Prices for the variable and fixed part for the district heating system operated by Balkan Energy Group, are defined by the Energy and water services regulatory commission of the Republic of N. Macedonia. To enable comparison between different energy sources and technologies, the DH system fixed, and variable part are merged into equivalent price per kWh. In the following Table 1, are presented values for the input parameters for the energy model.

Table 1. Input parameters for the energy model

| | | |
|---|---|---|
| Conditioned (heating/cooling) area | 70 | $m^2$ |
| Specific heat energy consumption | 70/120 | kWh/$m^2$a |
| Specific heat load | 80/100 | W/$m^2$ |
| Variable energy price- DH | 0,033 | EUR/kWh |
| Fixed price - DH | 17,12 | EUR/KW |
| Specific DH price | 0,05 | EUR/kWh |
| Electricity price - high | 0,126 | EUR/kWh |
| Electricity price - low | 0,064 | EUR/kWh |
| Wood pellet (Hd = 4,5 kWh) | 0,25 | EUR/kg |
| Wood pellet (Hd = 4,5 kWh) | 0,056 | EUR/kWh |
| *Natural gas price | 0,05 | EUR/kWh |
| Natural gas price | 0,13 | EUR/kWh |
| Heat pump air-water COP (seasonal) | 3 | |
| Heat pump air-water COP (seasonal) | 2,7 | |
| CAPEX | | |
| District heating | 650 | EUR |
| Electric boiler | 650 | EUR |
| Heat pump air to air | 2500 | EUR |
| Heat pump air to water | 4200 | EUR |
| Wood pellet boiler | 1050 | EUR |
| Natural gas boiler | 700 | EUR |
| Operation and maintenance | 2% from investment | |

* Natural gas price before the rapid price escalation (energy crisis)

In the CAPEX for Scenario 1 (heating only application) are considered expenditure only for the heat source technology since heat emitters are same for each of the technologies (hot water radiators). In the Scenario 2 for the systems which can provide only heating, like district heating, natural gas boiler and wood pellet boiler, are considered additional air–conditioners with CAPEX of 1000 euro.

Further it is conducted sensitivity analysis, to identify and evaluate parameters and boundary conditions with the largest impact on the life cycle cost of the analyzed systems, namely, the investment costs (heat source equipment), fuel price and thermal efficiency. This analysis provides possibility for assessment on the potential life cycle costs range regarding the input uncertainties with a high degree of confidence.

In the sensitivity analysis, the CAPEX, energy/fuel price and thermal efficiency, are varied in the range of +/–20%.

## 4. RESULTS AND DISCUSSION

The results obtained from the sensitivity analysis of the parameters are presented in the form of a tornado diagram, which facilitate the comparison of the effects of one variable (or uncertainty) on the output (value) of an independent variable.

First it is considered Scenario 1, where technologies are compared for only heating application. On Figure 1 are presented results for the LCOH for each of the heat source (technology), considering reference case with input parameters defined in Table 1, for apartment with area 70$m^2$ and specific energy consumption of 70 kWh/$m^2$. Because DH has the lowest LCOH, an additional comparison was made to determine the relative difference with LCOH for each of the analyzed technologies. Results from the comparative analysis are presented on Figure 2.

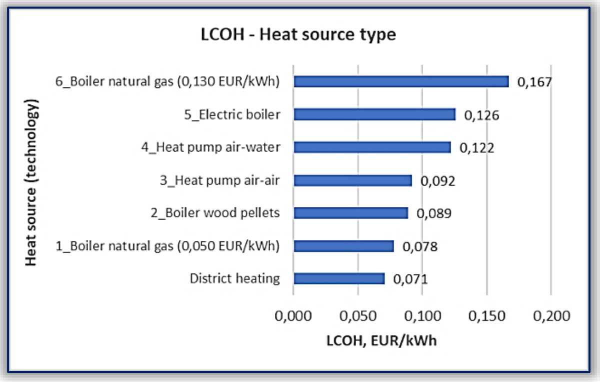


Figure 1. Summary LCOH for heating area 70$m^2$ and specific heating energy 70 kWh/$m^2$a

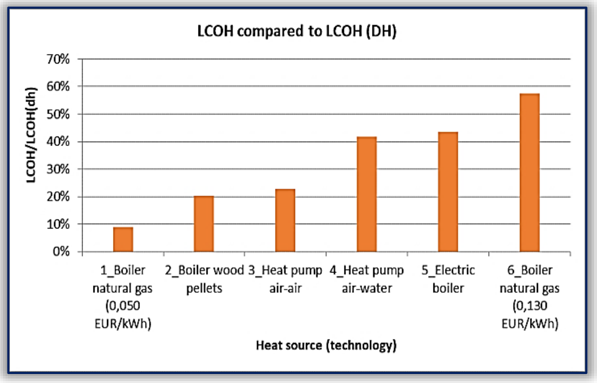


Figure 2. Comparison between DH LCOH and LCOH for each of the considered technologies

Further arise the need to assess the influence that have change in CAPEX, fuel/electricity, and efficiency on the LCOH. Therefore, sensitivity analysis is performed with change on the input parameters in the range of +20% to –20% from the reference case. The results are presented in form of tornado diagram, where it can be easily noticed change in LCOH as function from the changes in input variables i.e., CAPEX, fuel/electricity price and thermal efficiency. In the analysis for the district heating and electrical boiler the thermal efficiency is not considered in the sensitivity analysis since district heating delivers directly net heat to the consumer and electrical boiler efficiency does not significantly change at part load conditions.

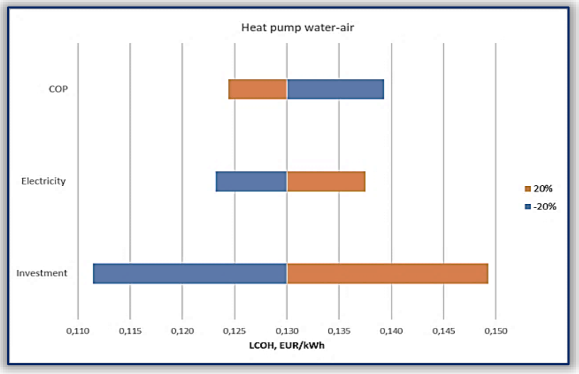


Figure 3. Sensitivity analysis for heat pump water–air LCOH – Scenario 1

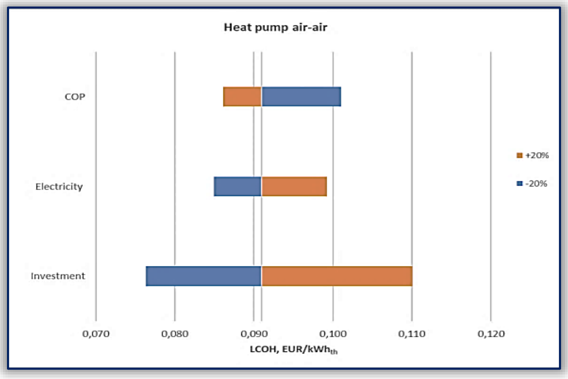


Figure 4. Sensitivity analysis for heat pump air–air LCOH – Scenario 1

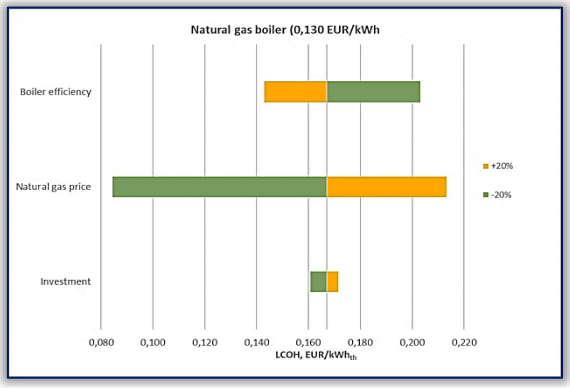


Figure 5. Sensitivity analysis for LCOH natural gas boiler – Scenario 1

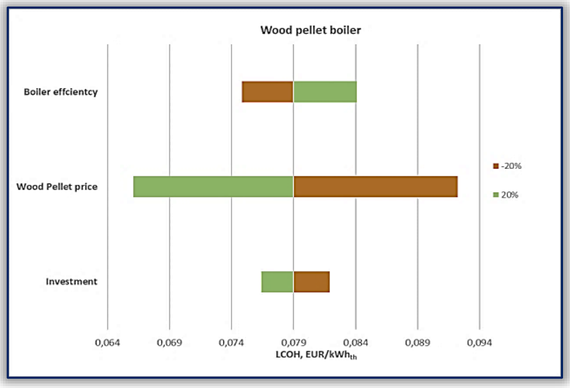


Figure 6. Sensitivity analysis for LCOH wood pellet boiler – Scenario 1

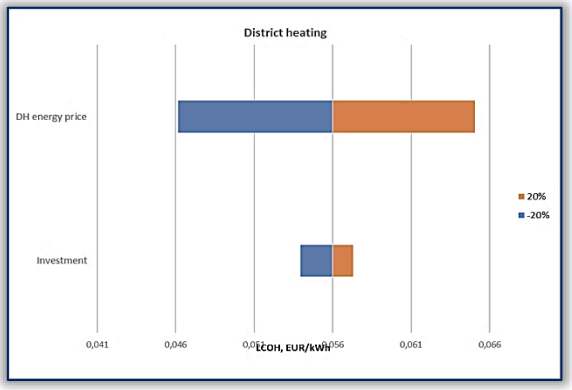


Figure 7. Sensitivity analysis for LCOH District Heating – Scenario 1

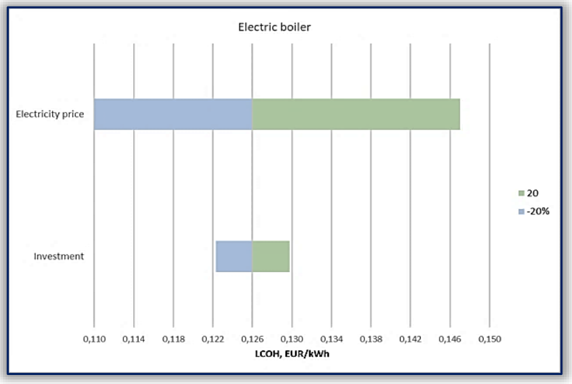


Figure 8. Comparison between DH LCOH and LCOH for each of the considered technologies

According to the presented results, can be concluded that the district heating has lowest LCOH, which makes it optimal heating sources and system for considered economic and climate conditions in R. Macedonia. The LCOH for the heat pump water–air and air–air is most sensitive in the CAPEX change while the rest of the technologies are most sensitive in the heat source/fuel price change. On Figure 9 are presented results as summary for the heat source/fuel energy price influence on the LCOH for analyzed heat technologies. It is noticeable that LCOH for most of the heat technologies/source is affected by the fuel price change except the heat pump air–water and air–air are most sensitive to investment change.

Further sensitivity analysis is conducted to determine the optimal technology in regard of Levelized Cost of Energy, where the main difference with LCOH is the additional cost for the cooling equipment, cooling energy and heat energy for DHW, values as defined in Table 1. In Scenario 2, there are several additional modifications so that systems to be able to provide heating, cooling and DHW. In the system with heat pump air–air the DHW is heated directly by electric heater while in the heating systems: district heating, natural gas boiler, wood pellet boiler and electric boiler the cooling is provided by air conditioners (heat pump air–air) for which the additional CAPEX are 1000 euro and in the system with heat pump air–water additional CAPEX of 1300 is added for fan coils. On Figure 10 are presented results for LCOE for each of the technologies. According to the presented results, again in Scenario 2 the lowest LCOE has district heating system with air conditioners.

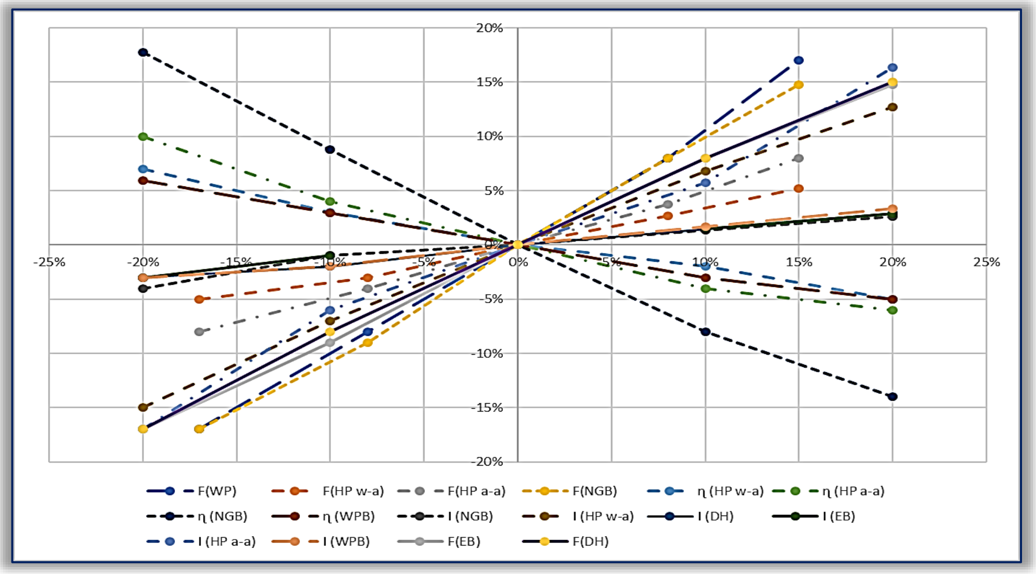


Figure 9. Change in LCOH relative to reference case as a function of I – CAPEX, F – fuel, η – thermal efficiency

To have better overview over the LCOE and the influence of the CAPEX market prices, it is performed sensitivity analysis. On Figure 11 are presented the results for LCOE change when CAPEX varied in the range of +/– 20% in regard of the reference case. According to the results, district heating has lowest LCOE, followed by the system with heat pump air–air and electrical heating for the DHW. It is interesting to notice that if the heat pump air–water CAPEX are increased for 20% regarding the reference case in Scenario 2, then LCOE is equal with the system with electric boiler air conditioners (heat pump air–air) and electric heater for DHW.

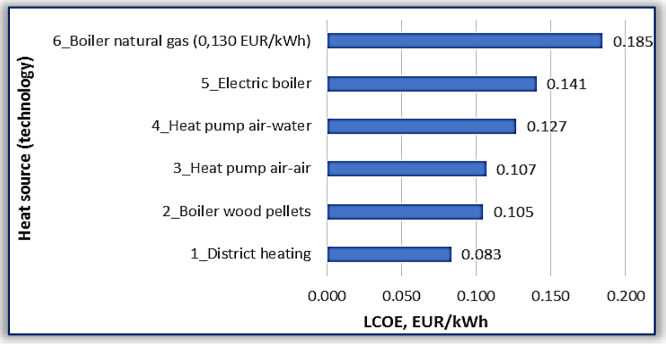


Figure 10. LCOE for heating, cooling and DHW

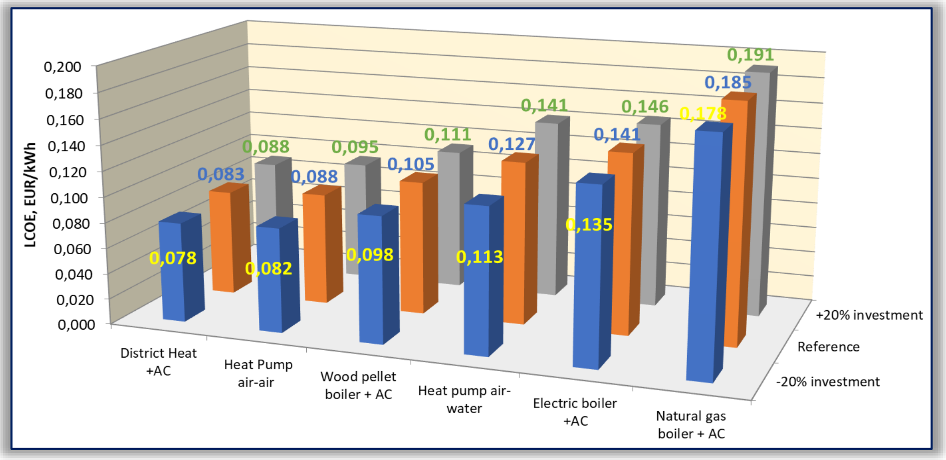


Figure 11. Sensitivity analysis for the LCOE with investment change, for systems providing heating, cooling and DHW

## 5. CONCLUSION

In this paper are compared LCOE for several technologies for apartment with conditioned area of 70 $m^2$ and specific heating energy 70 $kWh/m^2a$, specific cooling energy 20 $kWh/m^2a$ and 30 $kWh/m^2a$ for heating DHW. In the analysis are considered two scenarios: Scenario 1 only heating application and Scenario 2 providing energy for heating, cooling and DHW for apartment economic and climate conditions in R. Macedonia. From the presented results, the district heating system has lowest LCOE, in both Scenario 1 and Scenario 2 where additional air conditioners (heat pump air–air) are considered for providing cooling. Considering that in Macedonia only city of Skopje has functional district heating system, for the other residential buildings, is recommended the second system with lowest LCOE which is heat pumps air–air with electric heater for the DHW. It should be noticed, that also with the sensitivity analysis district heating system has lowest LCOE, followed by the system with heat pumps air–air (air conditioners) and electric heater. The LCOE for heat pump air–water and air–air are most sensitive to investment change, while for the rest of the technologies are most sensitive to the fuel price change.

It can be concluded that district heating system is a cost–effective and energy efficient solution, providing the possibility to achieve independence from fuel import and $CO_2$ targets, as well as take advantage of the free–market forces driving price changes on different types of fuel. Further analysis should be directed toward integration of solar energy into individual and district heating systems.

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