FEASIBILITY OF CLOSED LOOP GROUND SOURCE HEAT PUMP FOR RESIDENTIAL HEATING AND COOLING APPLICATIONS IN SERBIA

Aleksandar I. Jokić, Nevenka Nikolić, Nataša Lj. Lukić*

University of Novi Sad, Faculty of Technology, Bul. cara Lazara 1, 21000 Novi Sad, Serbia

Corresponding author; E-mail: nlukic@tf.uns.ac.rs

Households sector in Serbia presents a great chance for energy savings and introduction of renewable energy sources in the future. The public policies in Serbia are currently limited, but this kind of study can influence public measures that would undeniably generate long-term social and economic benefits to the country. The aim of the present work is to assess economic feasibility of closed loop heat pump systems for heating and cooling purposes in Serbia's residential sector. The heat pump system was compared to the most commonly used heating fuels in households. Results indicate that the implementation of ground closed loop heat pump systems for heating and cooling purposes in Serbia's residential sector as a substitute for electric heating is economically feasible. Inadequate prices of natural gas and electricity in public supply are the main problems associated with the project's financial benefits. The best results were obtained in the scenario with combined debt ratio (40%) and grants (~30%) for the project realization, for which equity payback period is approximately three years, while benefit to cost ratio is 2.52. Investigated financial metrics (equity payback, internal rate of return assets and net present value) indicate the same positive results considering financial viability of the project.

Key words: Thermal-economic modelling, Ground-coupled heat pump, Vertical ground loop

Nomenclature

Abbreviations

CDD	cooling degree-days [°C day]
GSHP	ground source heat pump
GWHP	groundwater heat pump
HDD	heating degree-days [°C day]
HGSHP	horizontal ground heat exchanger coupled heat pump
IRR	internal rate of return

NPV	net present value
VGSHP	vertical ground heat exchanger coupled heat pump

1. Introduction

Through import Serbia fulfils a significant portion of its energy needs (especially in the area of oil and natural gas), hence, as other so-called energy importer countries, it must work on the energy independence. In doing so it must rely on its own sources of energy. Serbia is a part of Energy Community that includes Western Balkan Countries which do not fulfil the necessary administrative and economic levels required for European Union membership due to various reasons. Within the process of EU accession, Serbia is planning to reach a 25.6% renewables target in the country's final consumption by 2020 [1]. Renewable energy sources in Serbia are mainly based on the production of electricity from large river flows and the utilization of biomass for households heating and to a smaller extent for industrial purposes. The analysis of Serbia's energy consumption by sectors suggests that households use 35.48% of final energy consumption. On the other hand, household's consumption of heat energy comprises more than half, around 56%, of total heat energy used [2]. It is obvious that any savings in this sector can lead to substantial implications on the national level.

According to Atlas of Family Housing in Serbia [3], family houses accounted for 87.35% of all residential units in Serbia (based on postal house number). Due to the numerous historical socio-political events, the most intensive construction time was during the post-war renewal period, 1946-1970, accounting for almost 40% of the total building stock while at the same time around 16% was built prior to this period [3]. The main characteristics of family houses of this period (after mid-20th century) are almost identical manifestation of residential architecture in nearly all parts of Serbia, while local particulars of the traditional construction systems, materials and techniques have been abandoned. Unfortunately, energy consumption of vast majority of these buildings does not meet present-day standards regarding energy consumption [3].

Although at first glance the situation with family housing sector in Serbia is rather dim, private initiative has shown people's awareness of energy efficiency. Though in small steps, in this manner current trends in energy savings are followed but still at insufficient scale. As for other countries fuel source prices influence the end users' preference [4].The most common improvements include placement of adequate thermal insulation, usage of different fuels for heating (such as wood pellet), whereas introducing new heating technologies such as usage of condensing boilers and heat pumps is rather sporadically implemented.

Heat pumps are based on simple and well-known technical principles, so the use of shallow geothermal energy by heat pumps is considered an environmentally friendly alternative to traditional heating techniques [5-8]. There are two major variations of these kinds of systems: ground source heat pump (GSHP) and groundwater heat pump (GWHP). Synonyms for GSHP systems are closed loop systems and ground coupled heat pump systems [9]. The number of shallow geothermal installations has been increasing over the past decades especially in Europe and North America, while in Asia; China is the leading country [10]. About 55.2% of direct geothermal energy usage all over the world is associated to ground source heat pumps [11]. GSHP technology is present and growing in application worldwide [12]. According to World Geothermal Congress data [12] countries like Germany, Greece, Sweden, and Switzerland show constant growth in GSHP installed capacity since 1995, while, in case of France, Turkey and especially Norway growth is even higher although it is registered after 2005.

However, in Serbia heat pump technology is still in its initial stage primarily in respect to hydro-geothermal potential [13, 14]. Nowadays, among Serbia's neighbouring EU member countries heat pump technology is attracting more attention. Serbia is located in the region of Southeast Europe occupying southern Pannonian Plain and the central Balkan. Its climatic conditions make it suitable for heat pump technology application as well as favourable geothermal properties. Serbia has reasonably complex geology. Terrestrial heat flow map of Serbia indicates that under most of Serbia values of heat flow are higher (100 – 120 mW/m^2) than the average of 60 mW/m^2 for the rest of Europe [15]. High values indicate the presence of a geothermal anomaly that is an extension of the geothermal anomaly of the Pannonian Basin [15, 16]. There are 775 installed geothermal heat pump units of which closed loop vertical systems make up 2% and water-source units 98% [17].

The aim of the present work is to assess economic feasibility of closed loop heat pump systems for heating and cooling purposes in Serbia's residential sector, as well as to promote the use of this kind of systems. To conduct the viability study RETScreen4 software was used.

2. Methodology

The huge number of software tools for economic analyses of renewable-energy systems is in usage today [18]. RETScreen software is used for both electrical and thermal systems design, and it is a proper tool for pre-feasibility and feasibility studies [19, 20]. This software is developed by Natural Resource Canada [21] and is open for public use for feasibility analyses of clean energy projects. Applications of RETScreen software is reported in many research articles [10, 20]. Procedure for techno-economic assessment of the project is done through main steps that include: site selection; energy, emission and financial analysis; followed by sensitivity and risk assessment [10].

Feasibility study of implemented vertical closed loop heat pump system for cooling and heating purposes was done in RETScreen4 software. For this study, a building with 120 m^2 floor area is considered. Taking into account climatic characteristics of the country this house requires both cooling and heating. A medium insulation with energy demand of 58 and 42 W/m^2, for heating and cooling, respectively is assumed. The current energy demand is met by the air conditioner for cooling, while for heating purposes various kinds of fuel are used (solid fuel, natural gas and electricity).

The house is located in Novi Sad, Vojvodina (northern Serbia's province) and the available land area around the house is reasonably large taking into account the typology of single family accommodation in Serbia. As for the specific climatic conditions, heating load of the house is used for the heat exchanger design. For this specific location, the annual value of heating degree-days (HDD) is 2685 °C d, while annual cooling degree-days (CDD) value is 1581 °C d. Influence of location selection will be examined by varying site location in Serbia for cities available in RETScreen Climate Database.

As any project depends on the financial viability, financial analysis was also conducted. Parameters used to perform financial analysis are fuel cost escalation rate, inflation rate, discount rate, debt ratio and interest rate, etc. Their values are summarized in Table 1. Incentives and grants can play a decisive role in renewable energy project viability because of higher initial costs [18, 22]. To complete comparison between cases with and without administrative grant or debt, four scenarios have been considered. The first scenario (scenario A) is the case without any grant or debt for the proposed heat pump project. In scenario B, debt was not taken into consideration whereas grant amount was one third of the project value. On the other hand, in scenario C grant was not considered. While the fourth considered situation (scenario D) is the case where grant amount is around the one third of project value, i.e. 3000 € (total initial costs 8480 €) and the debt ratio is set at 40%. Calculated financial viability output results, such as benefit-cost ratio, equity payback and internal rate of return assets (IRR-assets), were used to assess project feasibility.

Table 1. Parameters used for the financial analysis

Parameter				
Fuel cost escalation rate (%)			4	
Inflation rate (%)			3	
Discount rate (%)			10	
Project life (years)			25	
	scenario A	scenario B	scenario C	scenario D
Debt term (years)	-	-	20	20
Debt ratio (%)	-	-	40	40
Debt interest rate (%)	-	-	5	5
Incentives and grants (€)	-	3000	-	3000

3. 3. Results and discussion

Households in Serbia mostly use solid fuels (40.9%) such as coal, wood, etc.; whilst around 25% use electricity and 10.6% natural gas for heating purposes [23]. Therefore, the heat pump system investigated in this paper was compared to these types of fuels. Using RETScreen4 software a model has been developed to study heating and cooling loads of the building in question i.e. free standing single-family house.

The base case heating system represents current conventional system using coal, natural gas or electricity as fuel. Annual energy consumption to meet heating demand of building is 13 MWh, while for cooling it is 10 MWh. Fuel costs for heating season 2015/2016 were used to calculate fuel prices for the base case heating system [24]. Annual fuel consumption of coal in the base case heating system is around 6 tonnes, while the annual cost of fuel is 732 € (coal price 122 €/t). Natural gas has the price of 0.38 € per cubic meter and the price of electricity is 0.11 € per kWh. Annual consumption of gas is 1756 cubic meters, which gives the amount of 667 € for annual fuel cost. Heating load of building in the case of electricity is satisfied at the price of 1459 €, annually. In the case of cooling, in all three cases air conditioner is assumed and the total price for consumed energy is 254 €.

The performance and financial viability of ground source heat pump (GSHP) depend on the type of ground heat exchanger. For GSHP applications the most common are vertical ground exchangers (system VGSHP) and horizontal ground exchangers (system HGSHP) [10]. In this study, VGSHP system was proposed to avoid potential problems with land availability although they have higher initial costs due to drilling. Heating and cooling capacities are 7 and 5.1 kW, respectively. Standard values for coefficients of performance were selected [21]: 2.8 for heating and 3.5 for cooling mode. Project life in the study is 25 years. The total cost of VGSHP system to meet both heating and cooling demand of the house is 8480 €.

In VGSHP financial viability analysis four scenarios were surveyed (Table 2.). In the first scenario (A) no grants and no debt for the project are foreseen. As it can be seen from the results in the case of coal and natural gas heating, equity payback is longer than project life. For this scenario, only viable equity payback is in the case of electricity used for the base case heating system, 7.7 years. On the other hand, IRR-assets have negative values for coal and natural gas while in the case of electric heating IRR-assets is 14.3%.

Table 2. Financial viability of VGSHP (comparison with different base case heating systems)

Fuel type	scenario A	scenario B	scenario C	scenario D
Base case heating coal				
IRR assets (%)	-0.3	2.7	-4.9	-3.0
Equity payback (years)	>project	19.3	>project	23.9
Benefit-cost ratio (-)	0.29	0.64	0.02	0.61
Base case heating natural gas				
IRR assets (%)	-2.2	0.6	-7.5	-6.0
Equity payback (years)	>project	23.6	>project	>project
Benefit-cost ratio (-)	0.21	0.57	-0.10	0.49
Base case heating with electricity				
IRR assets (%)	14.3	21.3	11.6	17.1
Equity payback (years)	7.7	5.2	6.3	2.9
Benefit-cost ratio (-)	1.43	1.79	1.93	2.52

As one more parameter of project viability, the benefit-cost (B-C) ratio is considered. It is the ratio of the net benefits to costs of the project. The value of this parameter greater than 1 indicates project profitability [21]. According to this parameter for the scenario A, the only financially viable project is the replacement of usage of electricity for heating and cooling purposes by VGSHP for which the B-C ratio is 1.43.

In the scenario B, financial viability of the project is improved for all three fuel types considered. As expected, government grants can improve renewable energy projects viability, as they are likely to have higher initial costs [18, 22]. Although the equity payback period is shorter than project life for the coal and natural gas it's near the end of project life of 25 years (19.3 and 23.6, respectively). Positive IRR-assets values for this scenario regardless of fuel type used in the base case heating system also suggest better viability of the project. Nevertheless, in the case of coal and natural gas they are significantly smaller than benefit rate of Serbian banks (14%). According to the results of financial investigation for the scenario B, the only financially viable project is the replacement of electricity for heating and cooling purposes by VGSHP, as for the previous scenario.

For scenario C (no grant, debt 40%) and scenario D (grant 3000 € and debt 40%) similar results are obtained. In both scenarios, replacement of electricity as heating and cooling fuel is the most feasible project. The most promising results are achieved by applying scenario D with equity payback period of just 2.9 years and benefit-cost ratio 2.52. At the same time results for IRR-assets (17.1%) suggest that investors would be willing to invest in this kind of project development.

Possible explanation for these results can be found in energy price policy in Serbia. The priority of Serbia's energy sector development is energy market creation and establishment of market energy prices. Change in final consumption of energy can be achieved through appropriate price policy as the price is the simplest and the straightest manner of leading energy consumption into the desired direction [25].

For example, the price of natural gas (0.38 €/m^3 or 0.040 €/kWh) is almost two times lesser compared to EU average (0.071 €/kWh), while in the case of electricity the disproportion is even higher [26]. In Serbia, electricity price has a range of price lists (tariffs) according to sectors, period and amount of consumption. Hence, the price of 0.11 €/kWh was estimated from the available data about usage of electricity for residential building heating [24]. This price is significantly higher compared to the price of 0.06 €/kWh for the so called green zone i.e. households that consume less than 350 kWh per month. On the other side, EU average price for electricity is 0.211 €/kWh [26].

The repeated calculation for scenario D in the case of natural gas used for heating purposes, with EU average prices included yielded quite different results. In this example, financially viable project is the replacement of usage of natural gas for heating and cooling purposes by VGSHP system. Equity payback is 1.9 years, while the B-C ratio is close to 1 (0.97). In the case of electric heating, with repeated calculations taking into account EU average price for electricity of 0.211 €/kWh, feasibility of suggested project is improved so the equity payback is just 1.2 years while the B-C ratio is 5.18. With this significant improvement, it was reasonable to also recalculate scenario A, the case without any initiatives and debts. In this case, equity payback period is 3.9 years with significant increase in values for IRR-assets (28.0%) and B-C ratio (3.03).

Another way of improving financial viability (besides applying the market price of heating fuels) of these types of projects would be through introduction of income for reduction of greenhouse gas emissions. The biggest reduction, around 16.1 tonnes of carbon dioxide emissions, is achieved in substituting coal heating while in the case of the natural gas the carbon dioxide reduction was only 0.8 tonnes. In the case of electric heating reduction is 5.7 tonnes. These reductions could be explained by electricity production in Serbia that is mainly based on lignite powered old thermal power plants with average energy efficiency less than 30% with high losses in distribution around 14% [24].

3.1. Site selection and vertical ground heat exchanger

The most financially feasible project in this study is the replacement of electric heating and cooling by ground source heat pump coupled with vertical heat exchanger, scenario D. This model was further evaluated for site location selection and type of the ground.

Serbia covers a relatively small surface area and its climate is moderate-continental with more or less pronounced local characteristics [27]. Nevertheless, in this study similar results were obtained for the majority of selected locations from RETScreen Climate Database. The locations were selected according to the population density, so three locations for mountain resorts were not selected even if they are available in the software database. The B-C ratio was in the range between 2.39 to 2.78, while equity payback period is around 2.8 years (Fig. 1.).

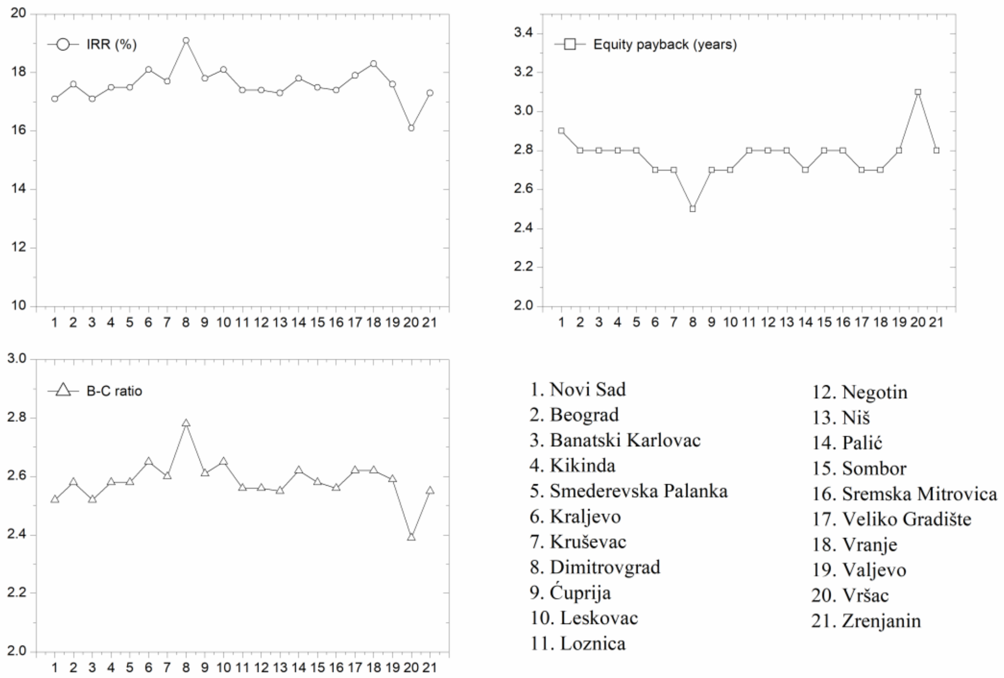

Figure 1. Financial viability output results for different site locations, scenario D

At the same time results for IRR-assets (around 17.5%) suggest that investors could be interested to invest in this kind of projects throughout the country. The similarities of results obtained for various locations can be explained by a similar number of heating days for different selected locations [28]. The carbon dioxide reduction has similar results as financial parameters and is in the range from 5.5 to 6.0 tonnes of yearly removed CO_2.

The length of vertical loop of ground heat exchanger is governed by building load and type of ground formation [10]. In this study, standard borehole layout of 6.1 m was selected. It determines the minimum separation between boreholes in a vertical system if more than one borehole is needed [21]. For dry light soil (loose sand, silt) the longest borehole loop length is needed, 299 m, while for moist soil of this type loop length is around twofold shorter, 144 m. In the case of heavy soil (clay, compacted sand, loam) the lengths of the borehole are 107 m and 144 m, for moist and dry soil, respectively. The shortest loops, 73 m and 60 m, were calculated for light and heavy rock formations, respectively. Taking into account geological and hydrogeological maps [29] of the selected locations the most likely soil type that can be expected is damp heavy soil. The most of selected locations are situated in river basins so it is justified to assume moist soils with good thermal regimes due to the presence of ground water. In the case of practical realization of the project, more detailed analysis of soil must be conducted.

3.2. 3.2. Sensitivity analysis

For this combined heating and cooling project (scenario D) sensitivity analysis was done. The first step was applying one at a time method of sensitivity analysis [22]. The chosen parameters were: initial costs, debt ratio, debt interest rate and fuel costs-proposed case. The sensitivity range was ±30%. Fuel cost-base case was not taken into consideration. Although, it should be mentioned that an increase in fuel cost-base case (+30%) shortened the equity payback period to 1.7 years, whilst a decrease in cost of 30% led to prolonged period, 8.9 years, as could be expected. Major influence of base case fuel cost is evident in decreasing electricity prices (-15% and -30%, which is unlikely scenario of electricity price movement) whilst the increase in price resulted in smaller differences. Similar results were observed for IRR-assets. According to strategies of energy market development in Serbia, it is implausible that electricity price will be lower [25].

The change of initial costs in defined range resulted in equity payback period change to 5.2 and 0.7 years for +30% and -30%, respectively. Fuel cost price had the second highest influence to the equity payback period with the range of values between 4.2 and 2.2 years for +30% and -30%, respectively. Debt ratio and debt interest rate had smaller influence on mentioned financial parameter. When debt ratio is increased for +30%, equity payback period decreased to 1.7 years, while on the other hand increase of debt interest rate from 5.0% to 6.5% (i.e. +30%) resulted in slightly extended payback period to 3.0 years.

Thus, for further analysis two combinations of parameters, initial costs and fuel costs-proposed case, as well as initial costs and debt ratio, were selected as key parameters that are simultaneously varied by the indicated percentages. The estimation of sensitivities of the chosen key financial parameters is based on Monte Carlo simulation methods. The results of these calculations are presented in Fig. 2.

Increase in initial costs resulted in prolonged equity payback period and has a synergetic effect with proposed case fuel costs; the highest values (7.6 years) are obtained at initial costs increase for 30% with the same increase in fuel cost. The shortest period of equity payback are achieved in the situations when initial costs are decreased by 30%, in all cases it was shorter than a year. Variations of debt ratio have antagonistic effect when combined with variations in initial costs. The shortest periods are obtained at maximal values of debt ratio and minimal values of initial costs.

These kinds of results could be supported by development strategy for energy sector in Serbia. Market price of electricity in Serbia is inadequate and its escalation can be almost certainly expected in the future. According to the strategy of energy sector development, electricity price will be increased to such a level and in such relation towards prices of other energy products, that on one hand it will be demotivation tool for its irrational use, especially for heating, and that on the other hand it will promote the use of other energy products or procedures such as heating pumps for heating purpose [25].

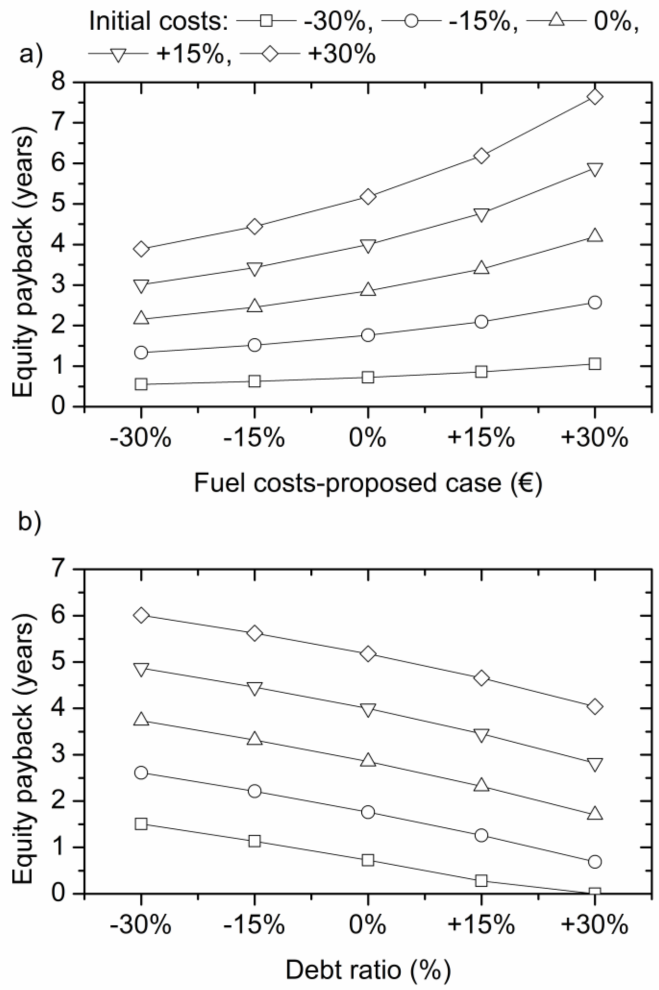

Figure 2. Sensitivity analysis on equity payback period (scenario D); influence of a) initial and proposed case fuel costs and b) proposed case fuel costs and debt ratio

One at a time method of sensitivity analysis for IRR-assets revealed similar deductions as for equity payback. The highest influence on the IRR-assets have initial and fuel costs followed by debt ratio and debt interest rate. The escalation in initial costs by 30% led to the decrease in IRR value to 11.3% and for the fuel costs, the same increase yielded the value of 12.2%. Both values are lower than current banking benefit rate in Serbia, around 14%. These situations can be discouraging for the potential investors, although in all other cases the IRR had values above 14%. At the same time, trend of declining of banking benefit rate can be expected so all cases should be eligible for funding.

. Initial costs and fuel proposed case costs as well as initial costs and debt ratio were selected as key parameters that are simultaneously varied by the indicated percentages. The obtained results are shown in Fig. 3.

For initial costs increase in almost all situations are resulting in IRR below current banking benefit rate in Serbia, around 14%. In the case of lowering initial costs from the base case resulted IRR values are well above the threshold of 14%. At the same time, synergetic effect is present between increase of initial costs and other two selected parameters. Increase in initial costs, as well as debt ratio and fuel costs, resulted in declining values of IRR-assets. With 30% increase of initial costs all IRR values are beneath 14% IRR threshold, while for the increase of 15% only reduction in proposed fuel cost of 30% is sufficient to yield values of IRR higher than the threshold (Fig. 3a). In the case of debt ratio simultaneous variations with initial costs it can be observed that for the higher initial costs, lower values of debt ratio are needed (40% or lower) to yield IRR above the threshold.

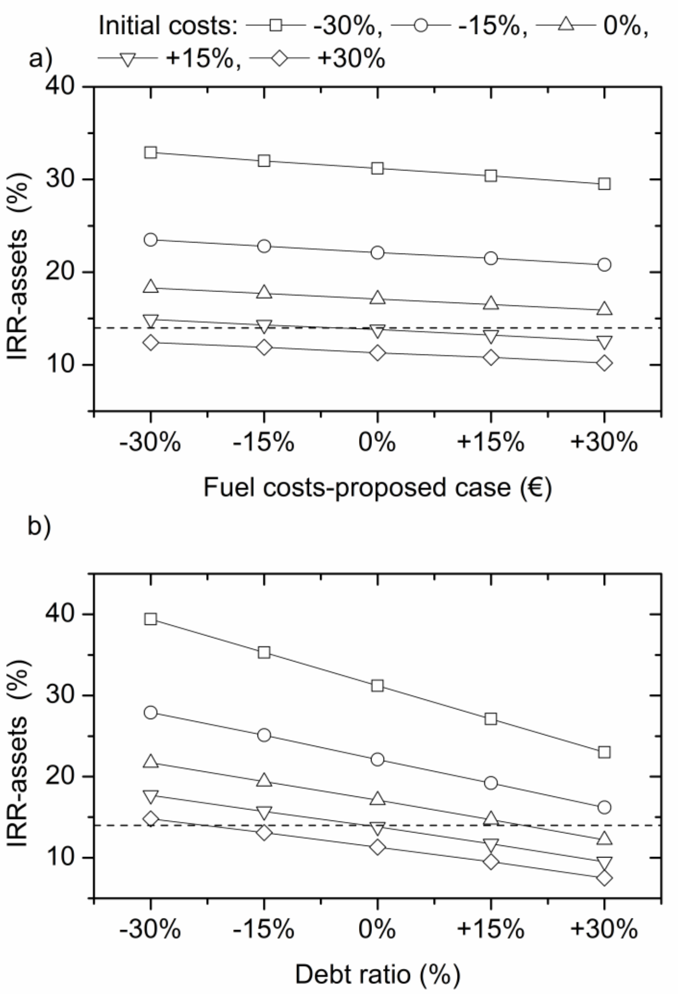

Figure 3. Sensitivity analysis on IRR-assets (scenario D); influence of a) initial costs and proposed case fuel cost and b) initial costs and debt ratio, dash line IRR-assets, 14%

3.3. Risk analysis

After the sensitivity analysis, a risk analysis was performed on scenario D as it showed the best financial results. The project presents an important financial risk for the home owners and for this reason risk analysis is a useful tool to investigate variables of the project that can positively or negatively affect it [22].

A risk analysis is done by specifying the uncertainty (range ±10%) associated with selected parameters to evaluate their impact on IRR-assets and equity payback period. Parameters were: initial costs, fuel costs-proposed case and debt related data (ratio, term and interest rate). Under these assumptions, RETScreen is used to perform a Monte Carlo simulation (repeating financial analysis 500 times) permitting every of selected financial parameters variations under a normal distribution simultaneously and independently in a specified range, ±10% [21]. The results of the analysis, relative contribution of the uncertainty of selected parameters to the variability of the financial indicator along with probability distribution of the indicator, are presented in Figs. 4 and 5.

The direction of the horizontal bar (positive or negative) is a sign of the relationship amongst the financial parameter and indicator. Initial costs have the biggest relative impact on both equity payback period and IRR-assets, around 0.85. For equity payback period, positive relationship increases its value, whilst for IRR-assets negative value means the reduction of the rate of return. Debt ratio has the second relative impact on the equity payback and it is negative, but in the case of IRR-assets it has positive effect and it is the third factor by influence. For equity payback, fuel cost – proposed case is the third most important parameter (has positive influence) while for the IRR-assets it is the second one and has negative influence. Debt term and interest rate have the lowest influences, and in their case the influences are opposite for the two selected financial parameters.

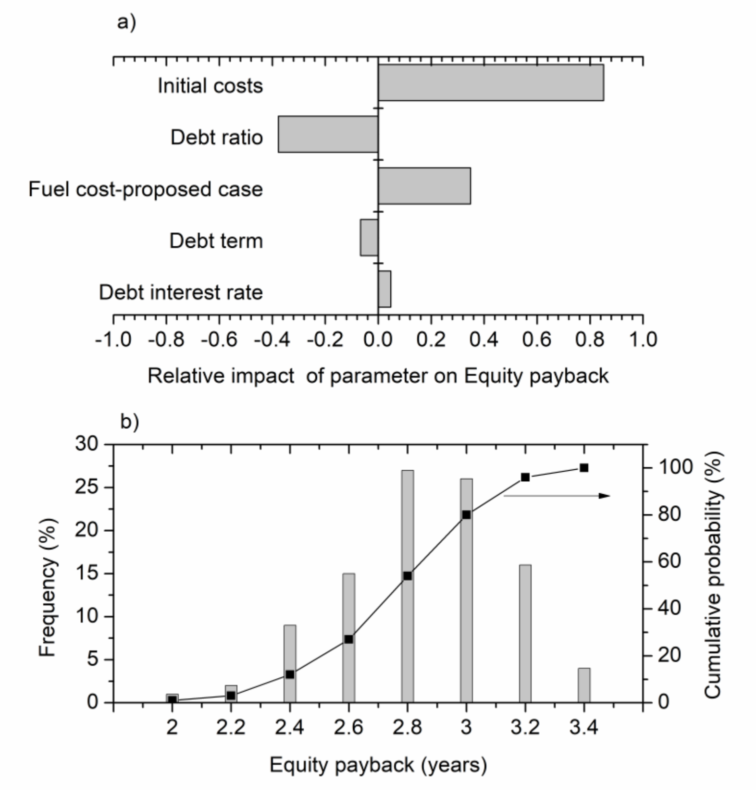

Figure 4. Risk analysis on equity payback (scenario D); influence of a) relative impact of financial parameters and b) frequency and cumulative probability of equity payback

Frequency and cumulative probability of equity payback and IRR-assets are shown in Fig. 4b and Fig. 5b, respectively. Around 80% of the cases studied have equity payback period up to three years making it very profitable project under scenario D. The longest period of 3.4 years has frequency

4%. In the case of IRR-assets, all of the considered cases have values higher than current banking benefit rate in Serbia, 14%.

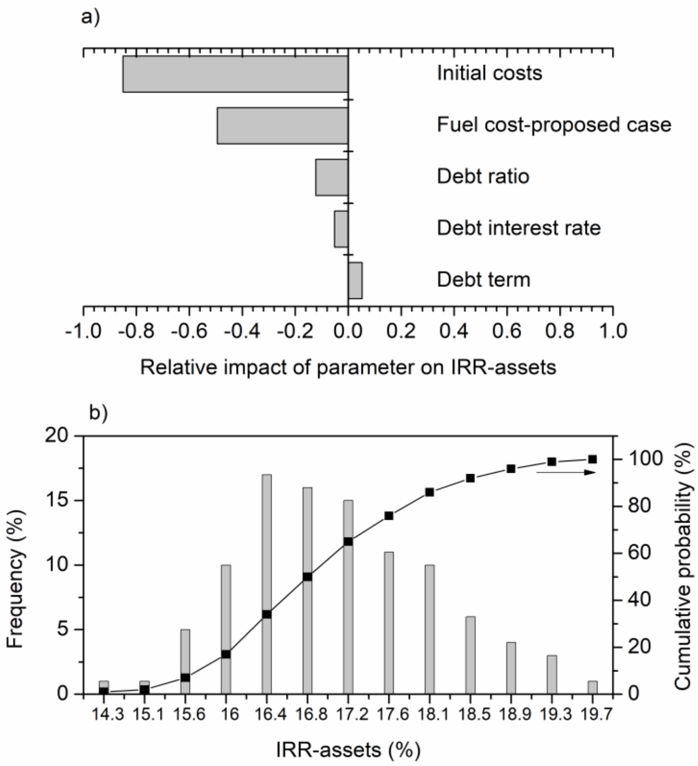

Figure 5. Risk analysis on IRR-assets (scenario D); influence of a) relative impact of financial parameters and b) frequency and cumulative probability of IRR-assets

The payback period ignores the time value of money, contrasting to other methods such as net present value (NPV) and internal rate of return (IRR-assets). Positive NPV values are an indicator of a potentially feasible project [21]. So, for further confirmation of this project viability risk analysis on NPV was conducted. All values for NPV were positive with a median value of 7738 €, while the minimum and maximum within level of confidence were 7124 € and 8501 €, respectively.

4. Conclusions

Four scenarios with different financing structures have been considered. Heating and cooling capacities are 7 and 5.1 kW, respectively. For the most investigated site locations in this study, borehole loop length around 107 m is calculated as number of locations are positioned in river basins, so it is justified to assume moist soils with good thermal regimes due to the presence of ground water. Financially feasible project is the replacement of electric heating and cooling by heat pumps combining state grants and loans. Investigated financial metrics (equity payback, IRR-assets and NPV) indicate that project is financially viable. Benefit-cost ratio for electric heating and cooling replacement is in range 1.43 to 2.52 for scenarios A and D, respectively. Scenario D, which includes grants (30%) and debt ratio (40%) was the most feasible project, with equity payback period of just 2.9 years and IRR-assets of 17.1%. The main problem that arises from this study was found to be in energy price policy in Serbia. In contrast to managing low and inadequate energy prices, the government could play an important role in promoting this type of technology via adopting subsidies to promote heating and cooling by heat pumps [30].

References

[1] http://www.mre.gov.rs/ministarstvo.php.

[2] http://www.stat.gov.rs/WebSite/repository/documents/00/02/41/70/Energetski_bilansi_2015._-_konacni_podaci.pdf.

[3] Jovanović Popović, M., et al., *Atlas of Family Housing in Serbia*. Faculty of Architecture, University of Belgrade, GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit, 2013.

[4] Li, G., Environmental impact assessments of heat pump–gas fired water heater hybrid system for space heating application, *International Journal of Environmental Science and Technology*. (2018), DOI No. 10.1007/s13762-018-2090-3

[5] Blum, P., et al., CO2 savings of ground source heat pump systems – A regional analysis, *Renewable Energy*, *35*. (2010), 1, pp. 122-127, DOI No. http://dx.doi.org/10.1016/j.renene.2009.03.034

[6] Fridleifsson, I.B., et al., *The possible role and contribution of geothermal energy to the mitigation of climate change*, *IPCC Scoping Meeting on Renewable Energy Sources*, O. Hohmeyer,T. Trittin, Editors. 2008. p. 59–80.

[7] Li, G., Comprehensive investigations of life cycle climate performance of packaged air source heat pumps for residential application, *Renewable and Sustainable Energy Reviews*, *43*. (2015), pp. 702-710, DOI No. https://doi.org/10.1016/j.rser.2014.11.078

[8] Li, G., Investigations of life cycle climate performance and material life cycle assessment of packaged air conditioners for residential application, *Sustainable Energy Technologies and Assessments*, *11*. (2015), pp. 114-125, DOI No. https://doi.org/10.1016/j.seta.2015.07.002

[9] Haehnlein, S., et al., International legal status of the use of shallow geothermal energy, *Renewable and Sustainable Energy Reviews*, *14*. (2010), 9, pp. 2611-2625, DOI No. http://dx.doi.org/10.1016/j.rser.2010.07.069

[10] Sivasakthivel, T., et al., Study of technical, economical and environmental viability of ground source heat pump system for Himalayan cities of India, *Renewable and Sustainable Energy Reviews*, *48*. (2015), pp. 452-462, DOI No. http://dx.doi.org/10.1016/j.rser.2015.04.008

[11] Yousefi, H., et al., Feasibility study and economical evaluations of geothermal heat pumps in Iran, *Geothermics*, *72*. (2018), pp. 64-73, DOI No. https://doi.org/10.1016/j.geothermics.2017.10.017

[12] Rybach, L.,B. Sanner, *Geothermal Heat Pump Development: Trends and Achievements in Europe*, in: *Perspectives For Geothermal Energy In Europe*, (Ed., Editor^Editors), World Scientific Publishing Company. 2017.

[13] Antonijevic, D.,M. Komatina, Sustainable sub-geothermal heat pump heating in Serbia, *Renewable and Sustainable Energy Reviews*, *15*. 8, pp. 3534-3538, DOI No. http://dx.doi.org/10.1016/j.rser.2011.05.008

[14] Golusin, M., et al., Exploitation of geothermal energy as a priority of sustainable energetic development in Serbia, *Renewable and Sustainable Energy Reviews*, *14*. (2010), 2, pp. 868-871, DOI No. http://dx.doi.org/10.1016/j.rser.2009.06.026

[15] Milivojevic, M.,M. Martinovic, *Geothermal energy possibilities, exploration and future prospects in Serbia*, *World Geothermal Congress* 2000: Japan. p. 319-226.

[16] Bodri, L., Geothermal model of the earth's crust in the pannonian basin, *Tectonophysics*, *72*. 1-2, pp. 61-73, DOI No. http://dx.doi.org/10.1016/0040-1951(81)90087-1

[17] Lund, J.W.,T.L. Boyd, Direct utilization of geothermal energy 2015 worldwide review, *Geothermics*, *60*. (2016), pp. 66-93

[18] Zandi, M., et al., Evaluation and comparison of economic policies to increase distributed generation capacity in the Iranian household consumption sector using photovoltaic systems and RETScreen software, *Renewable Energy*, *107*. (2017), pp. 215-222, DOI No. http://dx.doi.org/10.1016/j.renene.2017.01.051

[19] Aksas, M., et al., *Thermo-economic Study of Hybrid Thermal Solar and Geothermal Heat Pumps System in Algeria*, in: *Renewable Energy in the Service of Mankind Vol I: Selected Topics from the World Renewable Energy Congress WREC 2014*, (Ed., Editor^Editors), Springer International Publishing. 2015.

[20] Lee, K.-H., et al., Preliminary determination of optimal size for renewable energy resources in buildings using RETScreen, *Energy*, *47*. (2012), 1, pp. 83-96, DOI No. http://dx.doi.org/10.1016/j.energy.2012.08.040

[21] RETScreen, http://www.retscreen.net/.

[22] Bustos, F., et al., Sensitivity analysis of a photovoltaic solar plant in Chile, *Renewable Energy*, *87*. (2016), pp. 145-153

[23] Glavonjic, B.D., Consumption of Wood Fuels in Households in Serbia – Present State and Possible Contribution to the Climate Change Mitigation, *Thermal Science*, *15*. (2011), 3, pp. 571-585

[24] https://www.aers.rs/g/vesti/file/Dokumenti/STRUJA/Grejanje%CENE.pdf.

[25] Serbian Ministry of Mining and Energy, *Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030. Republic of Serbia, Ministry of Mining and Energy*. 2016: Belgrade.

[26] Strandell, H.,P. Wolff, eds. *Key figures on Europe*. 2016, Publications Office of the European Union. 96, 184.

[27] http://www.hidmet.gov.rs/.

[28] *Pravilnik o energetskoj efikasnosti zgrada, (Regulations on energy efficiency of buildings)*. 2011, Official gazette Vol. 61, Republic of Serbia.

[29] http://geoliss.mre.gov.rs/.

[30] Cansino, J.M., et al., Promoting renewable energy sources for heating and cooling in EU-27 countries, *Energy Policy*, *39*. (2011), 6, pp. 3803-3812, DOI No. http://dx.doi.org/10.1016/j.enpol.2011.04.010

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