HYBRID RENEWABLE ENERGY SYSTEM APPLICATION FOR ELECTRICITY AND HEAT SUPPLY OF A RESIDENTIAL BUILDING

by

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Renewable and distributed energy systems could provide a solution to the burning issue of reliable and clean supply of energy, having in mind current state and future predictions for population growth and fossil fuel scarcity. Hybrid renewable energy systems are novelty in Serbia and warrant further detailed research. The aim of this paper, is to analyze the application of renewable energy sources for electricity and heat supply of a typical household in Serbia, as well as the cost-effectiveness of the proposed system. The influence of feed-in tariff change on the value of the investment is analyzed. Small, grid-connected hybrid system (for energy supply of a standard household), consisting of geothermal heat pump for heating/cooling, solar photovoltaic panels and small wind turbine for power supply is analyzed as a case study. System analysis was conducted with the help of RETscreen software. Results of techno-economics analysis have shown that investing in geothermal heat pump and photovoltaic panels is cost-effective, while that is not the case with small wind turbine.

Key words: *hybrid renewable energy system, photovoltaic, residential building, wind, ground-source heat pump*

Introduction

Serbia is still in the beginner stage of exploitation of renewable energy sources (RES), with the exception of hydro energy and woody biomass, which have already been successfully used [1]. Integration of two or more renewable sources into a hybrid system in Serbia is not yet practiced and this area needs to be further researched, in order to determine the sources which are most promising for household application. Recently biggest advances have been made in the field of solar, wind and biogas sector, where investors/power producers exploit feed-in tariffs, whereas production of thermal energy from renewables is regulated at municipal level [2, 3]. Residential buildings have high share in total energy consumption. Therefore, finding new ways of supplying households with enough energy is an important factor in the process of energy reform [4]. The biggest and hence most important energy consumer in the household is heating system. Costs of heating are additionally increased due to the poor thermal insulation of houses and apartments. The solution to this problem is a combination of energy efficiency measures, RES, and *green* building using natural materials.

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Many studies have described, modelled and analyzed hybrid power systems. Paska *et al.* [5] present results from design, build and exploitation of hybrid power systems – using solar photovoltaic (PV), wind energy, fuel cells, and a battery storage unit. Small hybrid systems which use wind turbines and PV modules have been studied extensively in many papers [5-10], mostly focusing on design and optimization of stand-alone power systems. Dagdougui *et al.* [6] discusses modeling and optimization of a hybrid renewable energy system by presenting a dynamic model that is able to integrate different RES and one storage device to feed a *green* building for its thermal and electrical energy needs in a sustainable way. Panapakidis *et al.* [7] state that optimized combination of two technologies limits the inefficiencies of the sole operation of each one. Published literature on hybrid renewable energy systems indicates that wind/PV hybrid systems are becoming increasingly popular in the last decade [8]. Studies have reached similar conclusions that these types of hybrid systems represent excellent solution for remote area power application where grid expansion is costly. However, in order to introduce hybrid systems in existing power distribution network, in-depth study is to be carried out to check feasibility and technical competitiveness [8]. A study from Greece [9] using older version of RETScreen software discussed installation of building-integrated grid-connected PV system. Results have shown that without special financial support mechanisms, such as feed-in tariffs and subsidies installation of PV panels cannot be cost-effective. Although, this study was conducted more than ten years ago (in 2002), results have also shown that in Serbia nowadays similar conclusions can be drawn. Although, the cost of PV panels has significantly decreased over the past decade, similar problems are still present. Bakić *et al.* [10] perform technical analysis of a hybrid wind-PV energy system with hydrogen gas storage using TRNSYS16 software. The purpose of the study was to design a realistic energy system that maximizes the use of renewable energy and minimizes the use of fossil fuels. The reduction in the CO_2 emissions is also analyzed in [10].

Geothermal heat pump has substantially higher initial costs than conventional heating systems, mainly because of the capital costs of the heat pump unit and the ground connection (including drilling or trenching). On the other hand, geothermal heat pumps can have low operating costs due to their high efficiencies [11]. However, Self *et al.* [11] state that for majority of European countries heat pumps are economically advantageous compared to conventional heating methods because the overall cost of installing and operating the geothermal heat pump is considerably lower over a 20-year lifespan. Demirbas [12] estimates expected annual growth rates for geothermal energy by 2040. For the period of 2010-2020 growth rate is estimated at 8% annually. Moreover, implementation of heat pump in locations with low heating requirements may not be economical due to high initial costs. Naturally for every project specific in-depth analysis must be conducted in order to accurately identify cost-effectiveness and efficiency. Another advantage of installing heat pump system is that it has dual purpose – heating in the winter and cooling in the summer.

When assessing CO_2 emissions from geothermal heat pump, dominant factor is CO_2 emission factor for power plants which produce input energy for heat pump – electricity. Thus, in countries where large portion of electricity is produces using renewable power sources (such as Sweden, Austria, Finland, Norway, *etc.*) emission factor is less than 0.5 $kgCO_2/kWh$ significant reductions of CO_2 emission can be achieved. Hanova and Dowlatabadi [13] have established a threshold value of 0.76 kg/kW, so majority of EU countries would achieve considerable reductions of emissions by using geothermal heat pump.

The aim of this paper, is to assess the potential and cost-effectiveness of hybrid renewable energy system for heating/cooling purposes and power supply of the residential building in Serbia. As a case study small hybrid system (for a standard household) is analyzed, consisting of geothermal heat pump for heating/cooling, solar PV panels, and small wind turbine for power supply.

Hybrid renewable energy system application

Renewable resources

In 2011 Intergovernmental Panel on Climate Change published a study reporting that close to 80% of the world's energy supply could be met by RES by 2050. Theoretically, the best case scenario is that the RES could power the world [14]. However, the goal of achieving cost effectiveness and sustainable development demands that green energy ought to be profitable and competitive with other, cheaper and more mature technologies (although some renewable technologies themselves are already mature and well known).

Some technologies, such as heat pump, can be exploited everywhere, as they can use ground as the heat source, if there are is no shallow ground water source of surface water source available. Shallow layers of ground (until the depth of a few hundred meters) as a heat source is exploited with ground source heat pump. According to Lund *et al.* [15] in a paper that reviews direct utilization of geothermal energy from 1995-2010, geothermal (ground-source) heat pump has the largest installed capacity and largest energy use, accounting for 68.3% of capacity and 47.2% of use in total geothermal utilization worldwide (direct utilization). Geothermal energy in Serbia is mostly used for industrial heating and in balneology. However, the use of heat pump for low-temperature space and water heating is not included in the Energy balance of Serbia. In projection for 2013 Energy balance for Republic of Serbia, use of biogas, wind, solar, and geothermal make less than 1% in renewable energy balance [1].

Solar PV technology is dependent on solar resources at the location, weather conditions, time of year, *etc.* Solar radiation index is usually determined experimentally on site or it can be calculated based on meteorological data using free online calculators. Average solar radiation in Serbia is from 1.1 kWh/m^2 per day in the north to 1.7 kWh/m^2 per day in the south in January; and 5.9-6.6 kWh/m^2 per day in July. In the Vojvodina province, average value of solar radiance ranges from 1300-1700 kWh/m^2. The intensity of radiation is among the highest in Europe – average solar radiation for Serbia is 1400 kWh/m^2; it is about 30% higher than in central Europe. Solar radiation potential is estimated at 0.6 million ten (solar energy potential is estimated to be about 14% of total RES potential in Serbia) [16, 17].

Even more location dependent energy source is wind. Therefore, it is essential to carefully and thoroughly analyze local weather conditions, wind patterns and speeds in the last couple of decades in order to make the right decision whether to invest in wind turbines [6]. On-field or nearby measurements and a reliable model are needed to estimate the wind rose or the duration curve for local, exploitable wind potential, it's diurnal and seasonal profile [7]. It is estimated that there is a technologically justified wind potential of around 0.2 million tons of oil equivalent in Serbia, which could replace 10% of total electric energy consumption of the country. With current technology levels in Serbia total capacities of wind generators, which could be implemented in electro-energy system in Serbia, is about 1300 MW of installed power, which is approximately 15% of total energy capacity of Serbia. Especially interesting for foreign investors is Vojvodina province as a part of Republic of Serbia with almost two thirds of it has wind speed that exceeds 4 m/s, and the needed constant level of 5 m/s could be found in several locations [18]. The RES that are studied in this paper are:

– geothermal energy – groundwater heat pump for space heating/cooling,
– solar PV panels for power production, and
– small domestic wind turbine for power production.

The RES chosen to be included in the case study are selected based on resource potential at the location. Based on experience from Serbia and review of literature [19] on wind/PV hybrid systems, two main problems are evident:

– errors and over-sizing of small wind turbine systems due to lack of accurate data on wind speeds, frequency, *etc.* and
– high initial capital and long payback periods.

The use of hybrid wind/PV and other hybrid power systems are increasingly popular, and so are heat pump systems. Currently, in Vojvodina province, which is a northern part of the Republic of Serbia, the geothermal energy exploitation is dominant in the non-energy sector, even though the primary objective of the exploitation should be to use in energy field for fuels substitution, which would result in fossil fuel preservation and pollution minimization [20]. House from the case study is situated in the suburbia of the city of Novi Sad (Vojvodina province), with tolerant social attitude towards visual pollution (in the case of wind turbine). There is no Sun blockage or shadowing.

Residential building case study

For the case study new residential building in the municipality of Novi Sad is selected. The most important information are:

– newly built family home, Novi Sad, Serbia, $^{\circ}$N 45.3 $^{\circ}$E 19.9,
– net heating surface: 200 m^2,
– number of house residents: 4,
– standard hot water needs, and
– standard electrical power needs.

Average – standard energy needs in a modern household are: heating 62%, hot water heating 11%, cooking 12%, and lighting, household appliances, cooling 15% [21]. Most dominant energy consumer is the heating system. In a modern building energy distribution (heat losses) is expected to be: outside windows 51%, outside walls 21%, roof 10%, floor/basement 6%, and heating system 12% [21]. Thermal efficiency for each element is based on its heat transfer coefficient. Serbian regulation on energy efficiency in buildings [22, 23] specifies maximum heat transfer coefficient for each structural element, one for newly built and one existing buildings. The classification of the building cannot be carried out until a detailed calculation of the heat loses for each specific building [23]. Energy class of the building is indicator of building's energy characteristics. Residential building from this case study is regarded as class C building based on the following data:

– heat load for space heating is 50 W/m^2, and
– cooling load for space cooling is 30 W/m^2.

Energy efficiency

A building classified as a low-energy building does not, by default, satisfy certain comfort requirements. Low comfort can be the result of inadequate heat distribution, and also if heat is at an inadequate temperature level for this specific building. Inadequate heat distribution can cause, for example, higher consumption (lower efficiency) than optimal (thermal bridge). Both of these problems can nowadays be solved using low-temperature surface heating systems and high-temperature cooling systems. Basic characteristics of surface heating and cooling systems are low energy consumption, and high efficiency. This is true for residential as well as for commercial and industrial buildings: in comparison with classical systems operating costs are lower by 6-12% [22], comfort level is high; and what is especially important in this paper is the possibility of using RES. The most important fact concerning low-temperature heating systems is that this heat can be generated without fuel combustion. The following chapter discusses the use of RES for heating and cooling purposes. It is assumed that the comfort needs are previously met, as well as demands for energy efficiency of the building.

Estimated heating/cooling load

Estimated heating and cooling loads for the family house (class C with standard thermal insulation) are: for space heating 10 kW, for hot water heating (heating load for hot water is around 16% of the space heating needs) 1.6 kW, and for space cooling 6 kW. The duration of heating and cooling season at the location is 2685/1581 °C per day (based on meteorological data for this location). Total energy needs annually are: for space heating 26.85 MWh, for hot water heating (for the whole year) 4.296 MWh, and for space cooling 9.486 MWh.

Estimated electrical power needs

Electrical power is needed for lighting and household appliances $0.17 \times 11.6 = 1.98$ kW. Estimated electrical power needs are about 17% of thermal needs, not including cooling requirements (heat pump is used for cooling of the building) [22]. Electricity is needed for lighting and household appliances. Average monthly consumption is estimated at 600 kWh per month and annual energy consumption is 7200 kWh/a. Furthermore, geothermal system uses electrical energy for the operation of compression heat pump and auxiliary equipment in both heating and cooling regimes. Electrical power needs in peak period are 2.9 kW, while total annual energy amounts to 8000 kWh/a. Total annual energy needs therefore are:

– maximum power in peak period: $1.98 + 2.9 = 4.88$ kW and
– total annual energy: 7200 kWh/a + 8000 kWh/a = 15200 kWh/a.

Results and discussion

When designing distributed power and heat sources it is essential to analyze weather conditions and annual temperature distribution, as well as other indicators in order to choose the optimal energy source for this location. Results have shown that one renewable source at this specific location is not sufficient to produce useful final energy. Therefore, preliminary feasibility studies and modeling are crucial in the project design. Nowadays there are several useful and easy-to-use software, which greatly simplify and shorten the process of designing the system and finding the right renewable energy source. The software used is RETScreen version 4. Moreover, a comparison between investments for wind and PV systems, for different values of feed-in tariff is performed (feed-in tariff from 2012 and 2013), followed by short discussion and commentary.

Heating and cooling – geothermal heat pump

In the Vojvodina province (where city of Novi Sad is located) so far 75 hydrothermal wells have been established, their average yield is 9.5 l/s and average temperature 48.8 °C. Total heating potential (capacity) of all systems with built infrastructure and that can be readily exploited is around 54 MW [24].

Results have shown that the installation of heat pump for the purpose of space and water heating and space cooling is acceptable from environmental viewpoint, as well as cost-effective. One heat pump with capacity 10.8 kW is chosen for both heating and cooling purposes (heating requirements are of primary interest). Heat pump characteristics are: model 50RVS/RHS0485, producer carrier, capacity 10.8 kW, delivered heat 22 MWh, and the coefficient of performance for the entire season is 3.7.

Financial indicators used for the assessment of cost-effectiveness are simple payback period and internal rate of return (IRR). Results for heat pump heating system investment are given in the tab. 1. Installation of heat pump allows different design solutions of pipeline network structure, this way one heat pump unit can operate in different conditions and/or be used for various purposes. If heat pump unit were to be installed with automatic tracking system that registers changing conditions at the location, optimal operating regime would be achieved and subsequently, significant savings. This is already customary in most systems, since energy efficiency is top priority.

Table 1. Results for geothermal heat pump system, obtained using RETScreen [25, 26]

Financial parameters		Annual costs and debt payback	
Inflation rate	2.5%	Operation and maintenance	100 €
Lifetime of the project	25 years	Fuel costs – heat pump system	582 €
Value of the debt	60%	Debt payback ten years	492 €
Interest rate of the debt	8%	Total annual costs	1174 €
Duration of the debt	10 years	Financial sustainability	
Initial cost	5500 €	Simple payback period	8 years
Annual savings and revenue		Return on capital	8 years
Fuel costs – natural gas scenario	1367 €	IRR before taxation – capital	17.9%
Total annual savings/revenue	1367 €	IRR before taxation – assets	8.7%

Electrical power

Small wind turbine and roof-mounted PV array are tested for power generation. Results are given in the paper.

Small wind turbine

Meteorological data for wind speed at Novi Sad meteorological station were available only for the height of 10 m. Wind speed at the heights of 25 m and 50 m were estimated fig. 1(a). Wind speed measured at 10 m is lower than 5 m/s, which is the lowest value for the efficient operation of most wind turbines. Estimates for 25 m and even 50 m height also suggest wind speed lower than 5 m/s. These values imply small generated power values. Calculations have shown that only about 31% (0.31 = 0.193/0.625) of theoretical wind power is converted to electricity, as shown in fig. 2(a). For the acceptable height of 25 m and 5 m rotor diameter (turbine is situated in suburbia) basic characteristics of the wind turbine are: rotor diameter 5 m, surface area 19.6337 m^2, and working hours per year 8760. For the height of 25 m is estimated: 0.01057 kW/m^2 and 0.2074 kW of wind power, 96.8593 kWh/m^2 and 1817.7 kWh of energy [25, 26]. Wind speeds at heights of 25 m and 50 m are calculated using empirical equations from [27]:

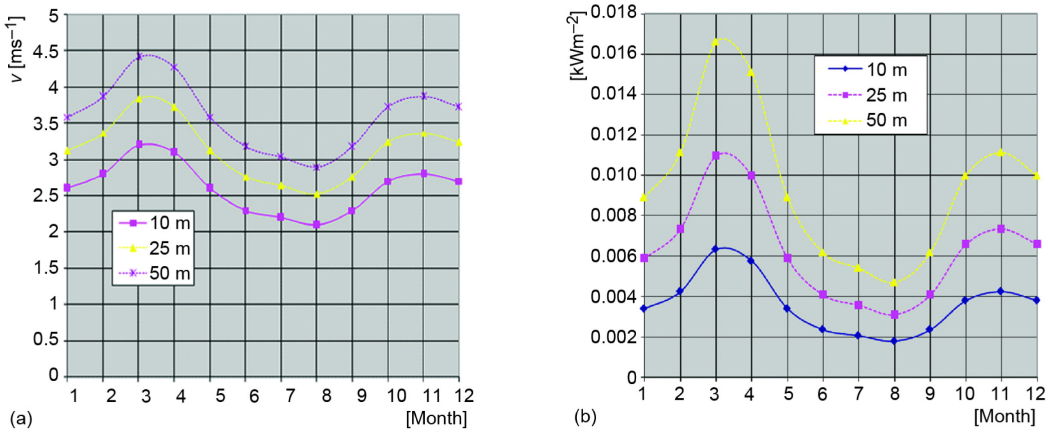

Figure 1. (a) – measured wind speed (10 m) and estimated wind speeds (for 25 m and 50 m); (b) – estimated wind power monthly (for 10, 25, and 50 m) [26-28]. Measured wind speed values are average values up to 2012

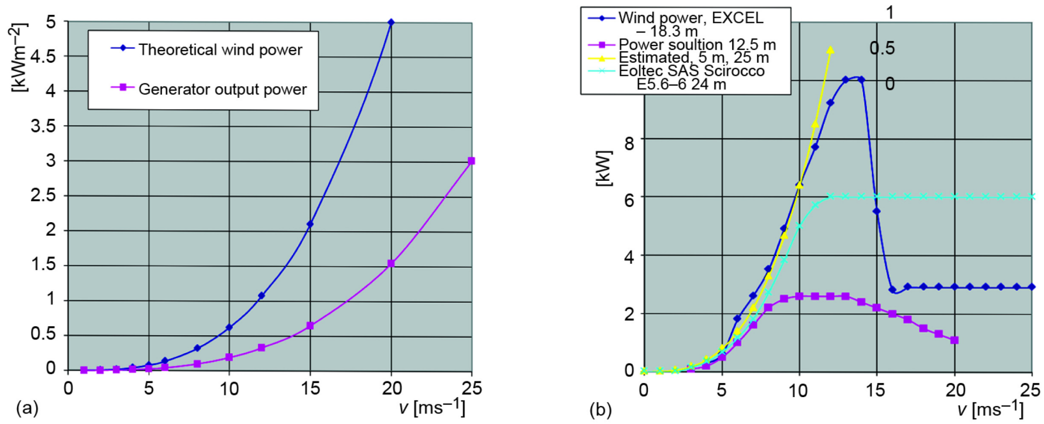

Figure 2. (a) – theoretical wind power and output generator power with 31% conversion to electricity. (b) – generated power as a function of wind speed for three different turbines in comparison with estimated wind power at the location [26, 28]

$$u(z_2) = u(z_1)\left(\frac{z_2}{z_1}\right)^{\alpha} \tag{1}$$

where α = 1/5, z_1 is usually taken as the height of measurement, approximately 10 m, and z_2 – the height at which a wind speed estimate is desired. The parameter α (wind profile exponent) is determined empirically. The equation can be made to fit observed wind data reasonably well over the range of 10 to perhaps 100 or 150 m if there are no sharp boundaries in the flow. Wind power at heights of 10 m, 25 m, and 50 m in fig. 1(b) are calculated using equations from [28]. Maximal theoretical wind energy is calculated:

$$W = \frac{1}{2}mv^2 = \frac{1}{2}\rho V v^2 = \frac{1}{2}\rho A V v^3 = 0.625 A v^3 \tag{2}$$

where ρ is the air density (approximately 1.25 kg/m^3), A – the rotor surface (volume $V = Av$), and v – the wind speed. Maximum power that can be achieved through a wind turbine due to design restraints is 16/27, *i. e.* 0.59259 from the theoretical power (Betz law). Taking into account the efficiency of wind turbine, which is 0.65 and the generator efficiency of 0.8, final power equation for wind power station is:

$$W = \frac{16}{27} \cdot 0.65 \cdot 0.8 \cdot 0.625\, Av^3 \tag{3}$$

$$W = 0.193\, Av^3 \tag{4}$$

Therefore, only 31% (0.193/0.625) of theoretical wind energy can be transformed into electricity using wind turbines [28].

The selection of small wind turbine model and techno-economic analysis was conducted using RETSreen 4 software, which enables the user to optimally choose and test several alternative scenarios. Small wind turbine model Scirocco E5 6-6 – 24 m (manufacturer Eoltec SAS) was chosen. With installed capacity of 6 kW, wind tower 24 m high, rotor diameter 6 m, and swept area of 25 m^2 at the given location it produces about 2 MWh per year which is about 17% of power needs of the building. Total investment costs (including auxiliary devices for grid connection) were estimated and are 18000 €. Having in mind usual financing and credit opportunities and conditions, and according to cumulative cash flow, investing in small wind turbine at the given location is not cost-effective and economically justifiable. Most important financial indicators are given in tab. 2.

Table 2. Results for wind system, obtained using RETScreen [25, 26]

Financial parameters		Annual savings and revenue	
Inflation rate	2.5%	Revenue from produced electricity	195 €
Lifetime of the project	25 years	Total annual savings/revenues	195 €
Value of the debt	60%	Financial sustainability	
Interest rate of the debt	8.00%	Simple payback period with donation	61.5 years
Duration of the debt	10 years	Return on capital with donation	> duration of project
Initial cost	18 000 €	IRR before taxation – capital	–8,3%
Grant	6 000 €	IRR before taxation – assets	–10.4%
Annual costs and debt payback			
Operation and maintenance	0	Debt payback – ten years	1610 €
Fuel costs – PV system	0	Total annual costs	1610 €

Results presented in the table are calculated using current feed-in tariff, which changed in 2013. It was reduced from 95 €/MWh to 92 €/MWh. In accordance with new data, a comparison of the two investments can be performed. As expected, due to the reduction of income from 202 € per year to 195 € per year, financial indicators worsened. Simple payback period increased from 59.5 years to 61.5 years. In addition, pre-tax IRR for capital was further deceased from –8% to –8.3%. Similarly, pre-tax IRR for assets decreased from –10.2% to –10.4%.

The PV solar cells

For the province of Vojvodina average annual insolation is about 2050 hours. The smallest amount of solar energy is received during December (about 760 W/m^2 per day), while the biggest amount of energy received is in July (about 6400 W/m^2 per day). Solar resources for the municipality of Novi Sad are given in fig. 3.

The average daily insulation on horizontal surface is 3.55 kWh/m^2, while under the optimal angle it is 4.03 kWh/m^2. For fixed (immobile) systems, where solar panels remain static throughout the year, optimal angle for Novi Sad area is 34° [29]. Average monthly insolation for the region of Novi Sad is given in fig. 4. The most energy is at disposal in July –180 kWh/m^2, least in December – 44 kWh/m^2. Annual average is 123 kWh/m^2. Solar PV panels with 35 m^2 surface area (the surface area was calculated using RETScreen 4 software), which are fitted on the roof of a 200 m^2 residential house can produce about 8 MWh electrical power per year.

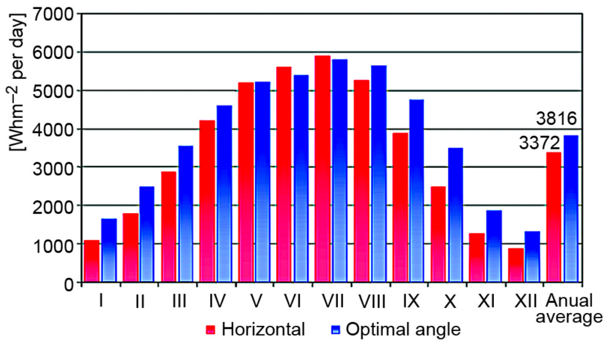

Figure 3. Daily insulation for the municipality of Novi Sad, average values up to 2012 [29]

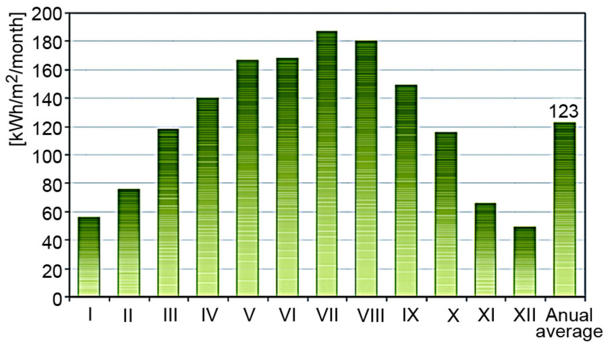

Figure 4. Monthly insolation in Novi Sad [29]

The PV system was selected by RETScreen software. Basic characteristics of the PV system are: manufacturer – Sunpower**,** model – mono-Si – SPR-320E-WHT, capacity per unit – 320 W, number of units – 20, solar collector area – 33 m^2, total capacity – 6.400 W, and efficiency – 19.6%.

From financial point of view, this solution is cost-effective only if power producer is registered for feed-in tariff system and if the project has received grant/subsidy for the investment in RES (for calculations grant of 5000 € is assumed). It is evident that with the current electricity price of 0.07 €/kWh (electricity from the grid), investing in PV panels is not cost-effective and electricity produced from PV cannot be competitive with the electricity from the grid. However, if investor were exploiting feed-in tariff system, mini power plant would have total capacity of 6.4 kW, produce 8.153 MWh of electricity per year, would reduce CO_2 emission by 4.5 t per year.

Financial indicators used for economic analysis of PV system are the same as for the other two systems, and are given in tab. 3. The PV system produced 8.153 MWh of energy, which would satisfy 68% of electrical energy needs annually. The shortage would be imported from the grid. Unless these financial benefits are secured, investment in PV panels for the residential building in this case study is not cost-effective and economically appealing.

Table 3. Results for PV system, obtained using RETScreen, [25, 26]

Financial parameters		Annual savings and revenue	
Inflation rate	2.5%	Revenue from produced electricity	1684 €
Lifetime of the project	25 years	Total annual savings/revenues	1684 €
Value of the debt	60%	Financial sustainability with donation 50 000 €	
Interest rate of the debt	8%	Simple payback period with donation	14.8 years
Duration of the debt	10 years	Return on capital with donation	16.1 years
Initial cost	30 000 €	IRR before taxation – capital	6.7%
Grant	5 000 €	IRR before taxation – assets	1.2%
Annual costs and debt payback		Without donation	
Operation and maintenance	0	Simple payback period without donation	17.8 years
Fuel costs – PV system	0	Return on capital without donation	18.1 years
Debt payback – ten years	2683 €	IRR before taxation – capital	4.4%
Total annual costs	2683 €	IRR before taxation – assets	0.3%

Results presented in the table are calculated using current feed-in tariff, which changed in 2013. It was reduced from 230 €/MWh to 206.6 €/MWh. In accordance with new data, a comparison of the two investments can be performed. As expected, due to the reduction of income from 1875 € per year to 1684 € per year, financial indicators worsened. Simple payback period increased from 13.3 years to 14.8 years. In addition, pre-tax IRR for capital was deceased from 8.3% to 6.7%. Similarly, pre-tax IRR for assets decreased from 2.2% to 1.2%.

Conclusions

The paper analyzed the possibility of using several RES – small hybrid system for the purpose of producing thermal and electrical energy for a single-family household. Residential building used as a case study is located in the vicinity of Novi Sad, in the region of Vojvodina, *i. e.* northern part of Serbia. Financial indicators used are simple payback period and pre-tax IRR on capital and assets.

In conclusion is should also be stated that for the calculation of CO_2 emission reduction RETScreen software was used. The RETScreen uses emission factor of 0.529 tCO_2/MWh for Serbia, which takes into account all fuels. On the other hand, other sources [30] indicate that the values of 0.943 tCO_2/MWh and 0.718 tCO_2/MWh are the correct emission factors for Serbia, used depending whether the project supplies new electricity to the grid or it reduces the consumption of electricity, respectively. Since we used RETScreen software for calculation, their data are referent for this analysis.

Heating, cooling and PV calculations were done using actual meteorological data for the specific location. Wind speed data were available only for the height of 10 m, so wind speed estimates for the heights of 25 m and 50 m were calculated. These estimates have shown that wind resources at the given location are modest and insufficient for wind power exploitation. As a result, investment in small wind turbine is neither energy-efficient nor cost-effective. It would produce only 17% (1817.7 kWh annually) of needed energy on a yearly basis. For the initial cost of 18000 € and with donation of 6000 €, simple payback period would be 61.5 years.

The PV panels can produce 68% of electrical energy needed on a yearly basis (8.153 MWh). However, they can be cost-effective only if producer sells electricity to the grid at higher prices (feed-in tariff system) and with the government donation of 5000 €, given the initial investment of 30000 €. With annual revenue of 1684 €, system would be paid off in 14.8 years. Note that today in Serbia only feed-in tariff system is active, but subventions and grants are not yet established. The results have shown that the introduction of subventions would significantly facilitate investment in renewables in Serbia.

In the case of geothermal heat pump, results calculated using actual meteorological data have shown that this scenario is energy-efficient and cost-effective. One heat pump unit with the capacity 10.8 kW was chosen. For the initial investment of 5500 € and revenue of 1367 € in fuel cost savings (natural gas replacement) simple payback period would be eight years. Therefore, it is the optimal solution for both heating and cooling of the building as well as for hot water heating. It can be concluded, according to the results, that geothermal heat pump and solar PV panels show the most potential for utilization in residential sector in Serbia.

It should be noted that feed-in tariff has an influence on financial indicators because it is the only source of income. However, the change in value of feed-in tariff is not substantial and therefore does not significantly affect financial indicators. This level of financial analysis has also shown that it is necessary to provide dynamic and sensitivity analysis that include time value of money.

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