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Hybrid Renewable Energy Systems for Public Buildings: Optimization and Sustainability

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Abstract: This study develops an optimization model for hybrid renewable energy systems (HRES) to improve energy efficiency and sustainability in public buildings. A case study at the Faculty of Mechanical Engineering in Mostar integrates a water-to-water heat pump, photovoltaic panels, solar collectors, and a small wind turbine. A two-step optimization process was used: the Simplex method optimized the thermotechnical system, minimizing the Net Present Cost (NPC), while Homer Pro determined the optimal electricity generation configuration. The VIKOR method ranked six scenarios based on energy, environmental, and economic criteria. Results show that Scenario S5, featuring a 120 kW water-to-water heat pump and solar collectors covering 60% of domestic hot water demand, achieved the lowest primary energy consumption (58,438.6 kWh), lowest CO_2 emissions (19,284.7 kg/year), and the most favourable Levelized Cost of Heating/Cooling (LCoH/C). Scenario S2, with pellet and air-to-water heat pumps, exhibited the highest autonomy (100%) but at a higher cost. The study confirms that HRES, particularly heat pump-based solutions, can cut emissions and reduce reliance on fossil fuels while maintaining economic feasibility. These findings support the transition towards prosumer-based energy models, aligning with Bosnia and Herzegovina's decarbonization goals.

Keywords: decarbonization; energy autonomy; multi-criteria analysis; prosumer

1 INTRODUCTION

Numerous studies in recent years have focused on developing optimization models for energy systems particularly on the integration of renewable energy sources (RES). The motivation for these projects stemmed from global challenges related to climate change rising greenhouse gas emissions and energy insecurity. The European Union through its Green Deal aimed to achieve climate neutrality by 2050 offering countries like Bosnia and Herzegovina (B&H) the opportunity to adapt their energy strategies accordingly [1, 2]. The building sector both globally and in B&H remains a significant energy consumer accounting for around 40% of total energy use.

In B&H more than 90% of this energy is derived from fossil fuels such as coal, firewood, and natural gas, while the share of renewables remains negligible [3, 4]. This reliance on fossil fuels leads to substantial CO_2 emissions exacerbating climate change. Researchers have developed numerous models for optimizing hybrid systems that integrate various RES technologies such as solar collectors, photovoltaic panels, heat pumps, and small wind turbines.

These systems have demonstrated significant potential in reducing energy costs and emissions while improving energy security. For instance, Hamdy et al. (2016) employed multi-objective optimization methods for residential buildings using Matlab, while Ghaem (2018) developed optimization models for rural polygeneration systems using TRNSYS and Homer Pro [5, 6].

Similarly, Zečević (2018) applied the VIKOR method to analyze energy efficiency in educational institutions contributing to the advancement of multi-criteria decision-making methods [7]. This study utilized a hybrid energy system at the Faculty of Mechanical Engineering in Mostar as a case study. The system includes a water-to-water heat pump, solar collectors, photovoltaic panel, and a small wind turbine. Experimental measurements conducted on this system provided the data necessary for developing an optimization model. Statistical data indicates that in 2021. renewable energy accounted for 29% of global electricity generation while in B&H the share was less than 2% [8].

The International Renewable Energy Agency (IRENA) estimated that increasing the share of renewables in the energy mix could reduce CO_2 emissions by up to 70% by 2050 [9].

This research builds on previous works such as those by Wright and Farmani (2001) who used genetic algorithms to optimize building energy systems, and Elkadeem et al. (2021) who combined GIS tools and multi-criteria methods to analyse energy solutions for rural areas [10, 11]. It contributes to the field by integrating a two-step optimization approach that combines the Simplex method for thermotechnical system optimization, Homer Pro for grid-connected electricity system configuration, and the VIKOR method for multi-criteria ranking of scenarios.

The novelty lies in applying this combined method to a real-world case study of a public building in Herzegovina with experimentally validated data. The research uniquely considers both operational and installation constraints, providing insights into system behavior under realistic climatic and energy demand conditions. Unlike most studies focusing solely on cost or energy indicators, this work addresses the energy-environment-economy (3E) dimensions simultaneously, supporting the prosumer transition model in public sector buildings.

The goal of this research was to create a two-step optimization model that simultaneously considers energy, economic, and environmental aspects while enabling the transformation of traditional consumers into prosumers that both produce and consume energy.

2 METHODOLOGY

The optimal hybrid energy system for consumer energy supply is determined through a multi-step optimization process. Single-criteria optimization approaches often fail to meet all investor requirements, while some optimization tools may not provide sufficient accuracy [12].

In this study, the first step involved the Simplex method applied to optimize the thermomechanical segment of the hybrid system. Through cost-optimal analysis this method identifies the optimal combinations of technologies that constitute the hybrid system. The global objective function was defined as the Net present cost (NPC) of the system.

The electrical energy component of the hybrid system was optimized using Homer Pro software which evaluates system configurations based on cost-effectiveness criteria.

The second step involved ranking and selecting the optimal hybrid system using the VIKOR method, a multi-criteria decision-making technique. For this purpose, criteria functions representing influential parameters in the optimization process were defined, and weight factors were assigned to each criterion to reflect investor preferences.

These weight factors guided the optimization toward solutions that balance energy, environmental, and economic considerations.

2.1 Simplex Method Optimization Process

The Simplex method developed by Dantzig in 1947. [13] is a linear programming technique that solves optimization problems through iterative steps starting from an initial solution and progressing to an optimal solution, if one exists.

It is finite, providing solutions in a limited number of iterations, and general, capable of addressing any linear programming problem or identifying when no solution exists.

In this study the Simplex method was applied to optimize the thermotechnical segment of the hybrid system which supplies energy for heating, cooling, and domestic hot water.

The NPC representing total system costs over its lifetime (investment, operational, and maintenance costs) was used as the objective function. Nonlinear cost functions describing individual technologies were linearized and optimized to minimize the NPC with the solution representing the minimum value of the objective function. The linearized optimization objective function is given by Eq. (1).

$$\begin{aligned} NPC_{\text{sys}} &= \sum_{i=1}^{n} C_n \cdot (X_n + dx_n) + \\ &+ \sum_{i=0}^{20} \frac{[C_m \cdot (X_n \cdot X_m + dx_n \cdot X_m + dx_m \cdot X_n)]}{(r+1)^i} + \\ &+ \sum_{i=0}^{20} \frac{\left[C_f \cdot (X_n \cdot X_m + dx_n \cdot X_m + dx_m \cdot X_n)\right]}{(r+1)^i} \end{aligned} \tag{1}$$

where X_n and X_m indicate the installed power and operating time of certain technology in (kW) and (kWh) respectively, C_m and C_f are operating and fuel costs in (BAM/kWh), and C_n is the investment cost in (BAM/kW), dx_n and dx_m represent changes in the values of variables during iterations in the optimization process.

Investment costs were a function of installed capacity, operating and fuel costs were a function of energy produced. In the optimization process using the Simplex method, several constraints were defined to ensure the hybrid system meets energy demands and operational requirements.

These constraints included limits on the installed power of each technology, ensuring it aligns with the calculated heating and cooling demands. Operating time constraints were also set based on seasonal requirements reflecting the building's usage patterns.

Additionally, total energy demand for heating, cooling, and domestic hot water was incorporated, alongside conditions ensuring the system's total installed power satisfies the building's thermal losses and gains. Non-negativity constraints ensured all variables remained realistic, and initial values were set within these boundaries to enable accurate and efficient optimization [14].

2.2 Optimization Process Using Homer Pro

As part of the first step of hybrid system optimization in this study, the segment of HRES responsible for meeting the consumer's electricity demands was also optimized to determine the best system configuration. Unlike the thermotechnical segment, which is designed to fully meet consumer needs autonomously, the electricity generation system allows for the purchase and sale of electricity to the grid. This approach considers a grid-connected hybrid electricity generation system based on RES, in contrast to standalone systems. In alignment with the optimization function used for the thermotechnical segment, the electricity generation system was optimized based on the (NPC), calculated using Homer Pro software.

Homer Pro derives total annual costs which are then used to determine the (LCoE).

The LCoE serves as a key metric in the second optimization step using the VIKOR method. Homer Pro calculates the total annual system costs based on a predefined relationship Eq. (2).

$$C_{\text{ann.tot}} = CRF\left(i \cdot R_{\text{proj}}\right) \cdot C_{\text{NPCel.}} \tag{2}$$

where $C_{\text{ann.tot}}$ is the total annual system costs (BAM), i is the discount rate set at 5%, R_{proj} is the project lifespan set at 25 years, $C_{\text{NPC.el}}$ is the present cost of the system (BAM), CRF is the Capital recovery factor which depends on the system's lifespan and the discount rate [15].

2.3 Optimization Process Using VIKOR Method

In the second step of system optimization the previously mentioned multi-criteria optimization and ranking method VIKOR was used. To perform optimization and ranking of hybrid system scenarios with this method influential criteria were defined to select the optimal configuration of the hybrid system consisting of both the thermotechnical segment and the electricity generation segment. Each criterion influencing the selection of the optimal combination of technologies was calculated as an independent function with its values optimized for decision-making purposes.

The following criteria functions were defined for optimization using the VIKOR method:

- **f1: Primary energy consumption**

Primary energy consumption is calculated as the ratio of energy used for heating, cooling, and domestic hot water preparation divided by the average efficiency of the technology such as the COP for heat pumps and split system air conditioners as presented in Eq. (3).

For technologies that use electricity as the driving energy source the consumed energy is multiplied by the primary energy factor for the grid in Bosnia and Herzegovina ($k_{\mathrm{prim.}}$ B&H = 2.2) [16].

$$E_{(\mathrm{C,H,DHW}).\mathrm{prim}} = \frac{Q_{(\mathrm{C.H.DHW}).\mathrm{nd}}}{COP \text{ or } \eta} \cdot k_{\mathrm{prim}} \tag{3}$$

where $Q_{(\mathrm{C.H.DWH}).\mathrm{nd}}$ is the annual energy required for heating/cooling and domestic hot water (kWh/year), COP is the coefficient of performance for the heating/cooling system, η is the efficiency of the technology used for heating and DHW such as boilers, k_{prim} is the primary energy factor for the grid in B&H. The total primary energy consumption $E_{\mathrm{prim.tot.}}$ was calculated as the sum of primary energy consumed for heating, cooling, and domestic hot water (DHW) needs.

- **f2: Share of RES in total primary energy**

The share of renewable energy sources (RES) is calculated as the total energy produced from RES divided by the total primary energy consumption of the scenario given in Eq. (4).

$$U_{\mathrm{RES}} = \frac{E_{\mathrm{RES}}}{E_{\mathrm{prim.tot}}} \tag{4}$$

where U_{RES} is the share of renewable energy sources in total primary energy (%), E_{RES} is the energy produced from renewable energy sources (kWh), $E_{\mathrm{prim.tot}}$ is the total primary energy consumption of the scenario (kWh).

- **f3: Degree of autonomy**

The degree of autonomy of the hybrid system represents the ratio of the total electricity produced by the hybrid system installed at the consumer's site to the electricity consumed. This function is calculated exclusively for electricity, as all heating and cooling energy needs of the consumer are fully met by the system's own production given in Eq. (5).

$$\varepsilon_{\mathrm{AUTON.}} = \frac{E_{\mathrm{El.Prod.}}}{E_{\mathrm{El.Cons.}}} \tag{5}$$

where $E_{\mathrm{El.Prod.}}$ is the electricity produced by the hybrid system (kWh), $E_{\mathrm{ELCons.}}$ is the electricity consumed by the consumer (kWh). The degree is in % calculated.

- **f4: Carbon footprint (CO_2 emissions)**

Carbon dioxide emissions were calculated based on the energy consumed from fuel for direct emissions and the electricity consumed from the grid for indirect emissions and then summed accordingly to Eq. (6).

$$E_{\mathrm{CO_2}} = k \cdot M + k_{\mathrm{grid}} \cdot N \tag{6}$$

where E_{CO2} are the direct and indirect emissions of CO_2 in (kg/a), k is the emission factor of fuel (kg CO_2/kWh), k_{grid} is the emission factor of electricity grid of B&H which is 0.7746 (kgCO_2/kWh$_{\mathrm{el}}$) [16], M is the total fuel consumption in kWh and N is the total electricity consumed from grid in kWh.

- **f5: Levelized cost of heating/cooling (LCoH/C)**

The levelized cost of thermal energy LCoH/C represents a measure of the net present cost of energy production calculated as the ratio of the net present cost of the system to the total energy produced [17]. The LCoH/C is calculated according to Eq. (7).

$$LCoH/C = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{7}$$

where I_t are the investment cost (Capex) (BAM/kW), M_t are the operational and maintenance costs (Opex) in (BAM/kW or BAM/kWh), F_t are the fuel cost (BAM/kWh), r is the discount rate (5%), n is the lifespan (set to be 20 years), E_t is the thermal energy produced for heating, cooling and DHW (kWh).

- **f6: Levelized cost of electricity (LCoE)**

The levelized cost of electricity uses the same formula as the levelized cost of heating/cooling and was automatically calculated in the Homer Pro software.

The VIKOR method is a multi-criteria decision-making approach used to rank and optimize hybrid energy systems based on conflicting criteria. It identifies a compromise solution by minimizing the distance from an ideal solution while considering trade-offs [18, 19]. The method begins with constructing a decision matrix (DM) of criteria functions for all alternatives. The best (f*) and worst (f–) values for each criterion are identified, and the normalized distances are calculated as in Eq. (8).

$$d_{ij} = \frac{f_i^* - f_{ij}}{f_i^* - f_i^-} \text{for all } i = 1..n. j = 1..m. \tag{8}$$

where d_{ij} are the distances, i is the number of scenarios or alternatives and j is the number of criteria functions. For this study the matrix is set to be 6 by 6 for six scenarios and six criteria functions. Weighted sums (S_i) and maximum distances (R_i) are calculated as in Eq. (9).

$$S_i = \sum_{i=1}^{n} w_i d_{ij}; R_i = \max_i \left[w_i d_{ij} \right] \tag{9}$$

The compromise ranking measure (Q_i) is determined by Eq. (10).

$$Q_i = \upsilon \cdot \frac{\left(S_i - S^*\right)}{\left(S^- - S^*\right)} + (1-\upsilon) \cdot \frac{\left(R_i - R^*\right)}{\left(R^- - R^*\right)} \tag{10}$$

where υ represents the weight of decision-makers' preference for group utility versus individual regret. The alternative with the lowest Q_i is the optimal solution provided it satisfies stability and dominance conditions.

In this study the Simplex method was used to optimize the thermotechnical segment of the hybrid system, after which the electricity consumption for the same system was calculated and input into Homer Pro software to identify the optimal configuration for meeting the consumer's electricity demands. This combination represented the first scenario for the VIKOR method. The other five scenarios were randomly selected to provide insight into a broader range of technology combinations for covering different consumer energy needs, including some based on renewable energy sources (RES) and others on fossil fuels. Since both the Simplex method and Homer Pro optimize systems solely from a cost perspective, the VIKOR method offered a multi-criteria perspective, enabling optimization beyond costs to include energy and environmental aspects. This was facilitated by previously defined criteria functions allowing optimization across the 3E framework: energy. environment. and economy. The overall two step optimization model is presented in Fig. 1.

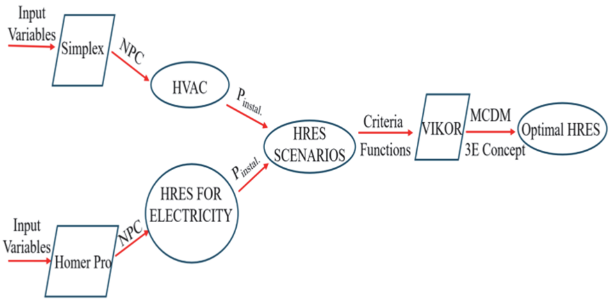

Figure 1 Two-step optimization model

3 EXPERIMENTAL RESEARCH

The study was conducted at the Faculties of Mechanical Engineering in Sarajevo and Mostar, focusing on system performance and climate data analysis. Key parameters included temperature, solar irradiance, wind speed, heat output, and electricity use. Solar data for Sarajevo were measured and validated against PV GIS, while Mostar used PV GIS data reduced by 10% due to the absence of local measurements. All climate data were validated using records from the Hydrometeorological Institute of Bosnia and Herzegovina.

Comparison of measured and 15-year average PV GIS solar radiation for Sarajevo is presented in Fig. 2.

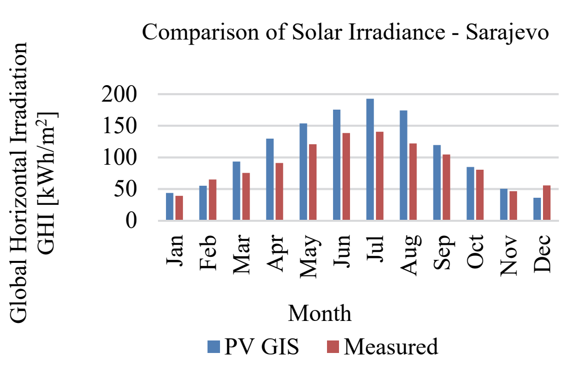

Figure 2 Comparison of solar Irradiance for Sarajevo

The solar irradiance was measured for the year 2021. and compared with a 15-year reference period available from the PV GIS database. It is noteworthy that in certain months measured values exceeded those obtained from the PV GIS database, as observed in December the least favorable month, and February. The highest solar irradiance was recorded in July. On an annual average, the irradiance obtained from PV GIS was 109 kWh/m^2, while the measured value was 89.9 kWh/m^2 reflecting a difference of approximately 17%. As mentioned in earlier chapters the solar irradiance for the Mostar area used in optimization calculations was reduced by 10% to simulate more challenging conditions for solar-based technologies and assess their competitiveness under such circumstances.

Although a review of scientific studies indicates a good match between measured and retrieved solar energy values, a 10% reduction in the retrieved values was adopted in this study. To assess the solar energy potential for the specific micro-location (climatic region South - Mostar) where the analyzed consumer model is located, a comparison was conducted with Sarajevo which represents a typical example of the North climatic region in the Federation of Bosnia and Herzegovina and presented in Fig. 3.

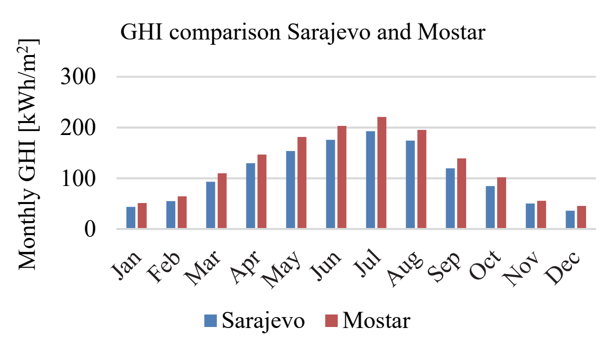

Figure 3 Comparison of GHI for Sarajevo and Mostar

Measuring outdoor air temperature and wind speed were among the most critical parameters during the research. The measurements were conducted over a one-year period (2021) which was used as the baseline year for calculating the energy needs of the consumer model. Both parameters were measured at a one-minute time step at the meteorological station of the Faculty of Mechanical Engineering in Mostar. To verify and validate the data the measured values for temperature and wind speed were compared with data provided by the Federal Hydrometeorological Institute of Bosnia and Herzegovina. The results of temperatures are presented in Tab.1.

Table 1 Comparison of average monthly outdoor air temperatures (Mostar)

Month	MS-MF UNMO	MS Mostar
Jan	5.4	5.6
Feb	8.5	8.9
Mar	10.1	10.0
Apr	12.4	12.3
May	18.6	18.4
Jun	25.6	25.3
Jul	27.8	28.5
Aug	26.9	26.6
Sep	22.3	22.1
Oct	14.7	14.6
Nov	12.3	12.2
Dec	7.7	7.8
Average	16.0	16.0

The measured average wind speed at the meteorological station of the Faculty of Mechanical

Engineering in Mostar was 1.082 m/s. Compared to 1.969 m/s at the MS Mostar station indicating a 40% lower wind potential at the consumer's location. This reduction is attributed to the urban setting of the faculty surrounded by obstacles like buildings and trees, as well as measurement uncertainties and the positioning of the station. The wind rose from MS Mostar is presented in Fig. 4, while the average measured wind speeds are presented in Tab. 2.

Table 2 Measured monthly wind speeds - Faculty of Mechanical Engineering

Month	Speed / m/s
1	0.616
2	0.746
3	1.091
4	1.037
5	0.923
6	0.923
7	1.271
8	1.140
9	1.083
10	1.580
11	1.395
12	1.183
Average	1.082

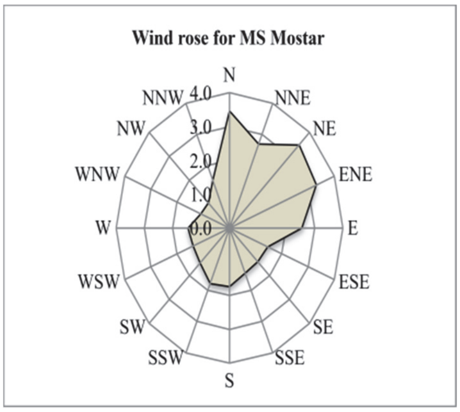

Figure 4 Wind rose with average wind speeds for MS Mostar

As presented in the Fig. 4, and Tab. 2 the avearge wind speed at 15 meter height of the mast is 1.082 m/s and the dominant wind direction is north-east. The meteorogical station of Faculty of Mechanical Engineering from Mostar is presented in Fig. 5.

Figure 5 Meteorogical station MF UNMO

Based on the measurements of outdoor air temperature the energy consumption for heating and cooling the prosumer building was calculated using heating and cooling curves. For the Simplex method, calculations were performed on a daily average basis, while hourly averages were used to determine the system's partial load coefficient. This approach enabled accurate definition of technology capacities for both the electricity optimization in Homer Pro and the multi-criteria analysis using the VIKOR method. The building's heating and cooling loads were set at 143 kW and 165 kW, respectively, based on DIN 4701 and VDI 2078 standards. The Eq. (11) presents the energy needed for heating and cooling.

$$E_{\mathrm{H.(C)}} = \frac{t_{\mathrm{ID}} - t_{\mathrm{O}}}{t_{\mathrm{ID}} - t_{\mathrm{OD}}} \cdot Q_{\mathrm{D(H.C)}} \cdot \tau_{\mathrm{(H.C)}} \tag{11}$$

where t_{ID} is the Indoor design temperature (20 °C), t_{O} is the Outdoor air measured temperature, t_{OD} is the Outdoor air design temperature which for Mostar for heating mode is -6 °C and for cooling mode is 38 °C, $Q_{\mathrm{D(H.C)}}$ is the calculated heating and cooling load of the building and $\tau_{\mathrm{(H.C)}}$ is the time in hours. The time when the system is working is set to be 10 h/day cause of the buildings working hours. The calculated needed heating and cooling energies are 114.070 MWh and 21 MWh respectvly. The heating curve is presented in Fig. 6.

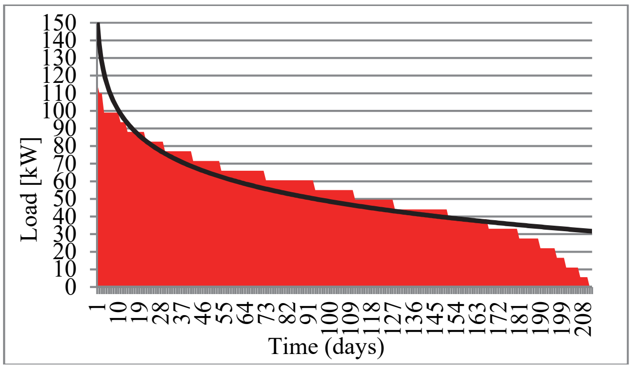

Figure 6 Heating curve of the model building

4 OPTIMIZATION MODEL APPLICATION

The first step involved optimization using the Simplex method which provided the first scenario for the thermotechnical segment of the HRES. For the remaining five scenarios required for VIKOR the thermotechnical segment was randomly selected. For each thermotechnical segment of the HRES the electricity requirements were calculated to determine the optimal system for covering electricity needs using the Homer Pro software. The base electricity consumption was measured using a digital meter when the heat pump was out of service. Technologies with respective costs which were used in Simplex method are presnted in Tab. 3.

Capex was determined based on the average prices of technologies available on the Bosnian market for capacities ranging from 50 to 200 kW (BAM/kW), Opex was calculated per kWh of produced thermal energy including estimated operational and maintenance costs (BAM/kWh).

For some technologies, such as heat pumps and CNG boilers marked * in Tab. 3, Opex was set as a fixed 2% of

Capex annually. The fuel cost was calculated per kWh of produced thermal energy, taking into account the efficiency of each technology. For CNG boilers, efficiency was based on the higher heating value, while the COP of the water-to-water heat pump installed at the Faculty of Mechanical Engineering was measured and reported in Špago et al. [20], with an average value of 3.8. For other types of heat pumps and split air conditioning systems, a lower COP was assumed (3 and 2.5 respectivly).

Table 3 Technologies used in Simplex method

Technology	Capex	Opex	C_{fuel}	η / COP
CNG Boiler	120	2.4*	0.072	0.98
HP W-W	550	11*	0.0395	3.8
Coal Boiler	150	0.02299	0.043	0.7
Wood pellet Boiler	170	0.008335	0.082	0.85
Wood Chip Boiler	260	0.0133	0.051	0.78
HP A-W	450	9*	0.05	3
El. radiator	110	0	0.1531	0.98
AC - split sys.	350	7*	0.06	2.5

When using the Simplex method, some technologies, such as heat pumps and split air conditioning systems, were allowed to operate in both modes (heating and cooling) due to the milder climatic conditions in the Mostar area, which enable heating with these devices. The convergence of the global optimization objective function is shown in Fig. 7.

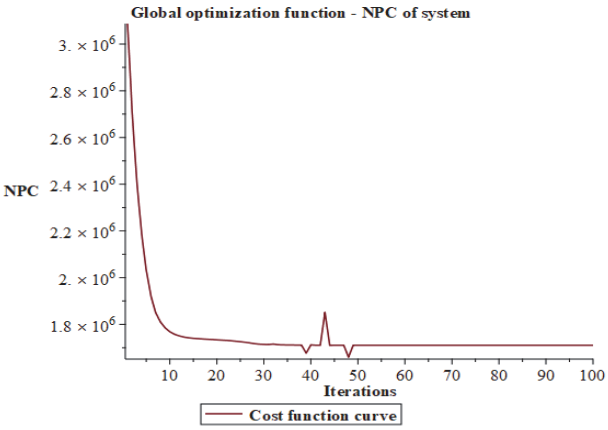

Figure 7 Convergence of NPC objective function in Simplex method

Fig. 7, shows a minor deviation in convergence between iterations 35 and 50, likely caused by the activation of predefined constraints related to operating times and maximum installable capacities of selected technologies. For instance, some systems, such as pellet boilers, are restricted to operate in a single mode (heating), with their capacities and runtimes limited to the building's calculated peak demand.

The Simplex method demonstrated that the optimal solution is the installation of a water-to-water heat pump and an AC system with power capacities of 60 kW and 105 kW, respectively. The remaining scenarios for the VIKOR method are listed in Tab. 4, and Fig. 8 illustrates the calculated electricity consumption for Homer Pro.

This was determined based on measured baseline electricity consumption of the building, with the hourly electricity consumption of technologies using electricity, such as heat pumps, added to it. The total DHW energy is calculated based on the maximum number of ocupants which is set to be 375, and the yearly DHW need is 17,424 kWh.

Fig. 8 shows the monthly electricity consumption by scenario. The highest consumption is observed in Scenario 4, which relies entirely on electricity-based technologies. Scenarios using heat pumps and solar collectors demonstrate lower and more balanced consumption throughout the year.

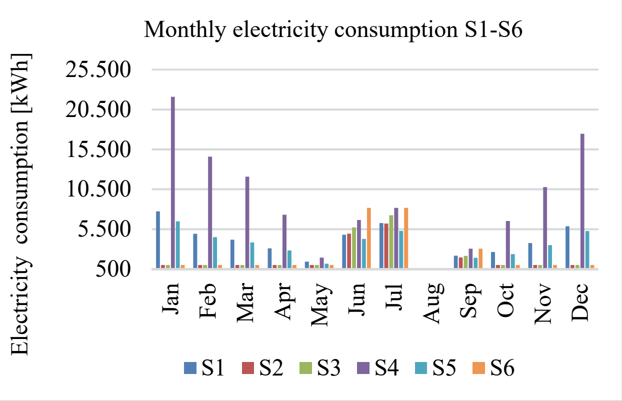

Figure 8 Monthly electricity consumption by scenario

Table 4 VIKOR scenarios

S1	HP W-W as primary resource (60 kW) and AC split system (105 kW) as a backup system for peak loads.
S2	Pellet boiler 63 kW as primary resource for heating and DHW, additional 80 kW of coal boiler for heatng back up. HP A-W (100 kW) for cooling and add. AC 65 kW as back-up.
S3	Coal boiler (63 kW) as prim. resource for heating and DHW with additional 80 kW CNG boiler. AC split system (165 kW) for cooling.
S4	Electric radiators for heating (143 kW) and 165 kW of AC split system. Additional 19 electric 2 kW water heaters for DHW.
S5	HP W-W (120 kW) for heating, cooling and DHW. Addtional 45 kW of AC for peak load. 10 of total area 25.3 m^2 solar collectors which can cover 60 % of DHW needs.
S6	Coal boiler 143 kW and AC split system of 165 kW.

Fig. 8, shows that Scenario 4 has the highest energy consumption, as it uses only electricity. In Homer Pro, the system optimization limited wind turbines to 5 and solar panels to 30 kW. The analysis also included a diesel generator and batteries to evaluate the need for backup and storage. The electricity purchase price was set at 0.15 BAM/kWh, while the selling price was set at the reference rate of 0.12 BAM/kWh. The schematic of the HRES for electricity demand is presented in Fig. 9.

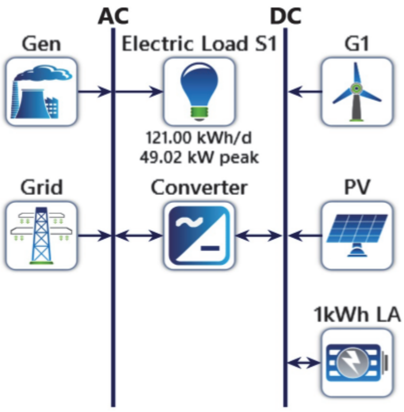

Figure 9 Scheme of technologies analyzed in Homer Pro

The prices used for Homer Pro are presented in Tab. 5.

Table 5 Costs of technologies for Homer Pro

#	$C_{\text{inv.}}$	$C_{\text{repl.}}$	$C_{\text{oper.}}$	C_{fuel}
PV	1,200	1,100	10	•
DC-AC Inverter	380	370	5	•
Batery	450	450	5	•
WT	1,000	1,000	5	•
Grid	•		•	0.15
Diesel gen.	330	320	0.045/h work	2.65

In all scenarios, the optimal setup included the full 30 kW of PV panels and inverter sizes averaging 22 kW. Wind turbines, batteries, and a diesel generator were not needed, and all scenarios remained grid-connected, off-grid systems were excluded. A hybrid electricity system was added to support the thermotechnical part, after which VIKOR criteria were calculated and scenarios ranked by the 3E method.

5 RESULTS OF THE VIKOR OPTIMIZATION

The application of the VIKOR method enabled an in-depth analysis of the optimization process from the 3E perspective (energy, environment, and economy). The optimization results highlight the benefits of renewable energy sources (RES) compared to conventional systems, with scenarios featuring higher shares of RES being prioritized.

Key findings for the optimization results are presented in the table below. The optimal solutions for the energy aspect are scenarios S5 and S1. Scenario S5 uses a 120 kW water-to-water heat pump and solar collectors covering 60% of domestic hot water needs, resulting in lower CO_2 emissions and costs compared to conventional systems. Scenario S1, based on average daily temperatures, supplements peak loads using a split air conditioningsystem. The calculated VIKOR criteria functions are presented in Tab. 6.

Table 6 Calculated Vikor criteria functions

	f_1	f_2	f_3	f_4	f_5	f_6
S1	59,270.2	0.6	0.8	19,559.2	0.2	0.1
S2	142,511.6	0.9	1.0	13,912.2	0.3	0.1
S3	164,552.6	0.2	1.0	54,724.2	0.3	0.1
S4	202,862.0	0.2	0.3	66,944.5	0.3	0.1
S5	58,438.6	0.6	0.8	19,284.7	0.1	0.1
S6	168,980.4	0.2	1.0	58,361.2	0.2	0.1

The difference in primary energy consumption between S5 and S1 is marginal (1.5%), while S5 offers lower greenhouse gas emissions (284.43 kg CO_2/year less) and reduced costs. Scenario S2 ranks highest for the environmental aspect due to its combination of pellet boilers and heat pumps, achieving 100% energy autonomy and minimal direct CO_2 emissions from renewable energy sources. Scenarios S5 and S1 also perform well, emphasizing efficient energy use and significant CO_2 reductions compared to conventional systems. Scenario S5 demonstrates clear economic advantages with the lowest LCoH/C and LCoE values, followed by scenario S1. Although S2 achieves significant environmental benefits, its energy costs are higher, making it less favourable economically. The degree of autonomy was defined as the ratio of electricity generated by the hybrid system to total demand. In scenarios using conventional heating/cooling technologies like CNG, biomass, or coal boilers, electricity demand is lower, sometimes matching or exceeding production. However, optimization in Homer showed shortages in summer due to increased consumption, especially in scenarios 4 and 6, which use split air conditioning systems. The summary of 3E optimization is presented in Tab. 7.

Table 7 Summary of 3E optimization results and scenario rankings

Aspect	Weights	Criteria Functions	1st-Ranked Scenario	2nd-Ranked Scenario	3rd-Ranked Scenario
Energy	$f_1 = 0.3, f_2 = 0.2,$ $f_3 = 0.2, f_4 = 0.1,$ $f_5 = 0.1, f_6 = 0.1$	Primary Energy Consumption, RES Share, Autonomy, CO_2 Emissions, LCoH/C, LCoE	S5	S1	-
Environment	$f_1 = 0.1, f_2 = 0.2,$ $f_3 = 0.1, f_4 = 0.4,$ $f_5 = 0.1, f_6 = 0.1$	Primary Energy Consumption, RES Share, Autonomy, CO_2 Emissions, LCoH/C, LCoE	S2	S5	S1
Economy	$f_1 = 0.2, f_2 = 0.1,$ $f_3 = 0.1, f_4 = 0.1,$ $f_5 = 0.3, f_6 = 0.2$	Primary Energy Consumption, RES Share, Autonomy, CO_2 Emissions, LCoH/C, LCoE	S5	S6	S1

6 CONCLUSION

This paper focuses on optimizing hybrid energy systems for large-scale consumers like educational institutions, using the Faculty of Mehcanical Engineering in Mostar as a case study. This study analyzed six hybrid renewable energy system (HRES) configurations for a public building using a two-step optimization approach. The Simplex method minimized the NPC for thermal energy supply, while Homer Pro optimized electricity generation. Final ranking was performed using the VIKOR method based on energy, environmental, and economic indicators. Among all scenarios, S5, which includes a 120 kW water-to-water heat pump and solar collectors covering 60% of DHW demand, achieved: the lowest primary energy consumption (58,438.6 kWh/a), the lowest CO_2 emissions (19,284.7 kg/a), and the most favorable LcoHand LCoE (0.1 BAM/kWh). Scenario S2 reached the highest autonomy (100%) due to pellet and air-to-water heat pumps, but at a higher cost and with increased complexity. Scenario S5 offered the best overall balance across the 3E indicators. These findings demonstrate the potential for HRES implementation in public buildings in Bosnia and Herzegovina. They support policies promoting the prosumer model and the use of efficient heat pump systems combined with solar technologies. Future work should consider stochastic modeling, real-time pricing, and storage integration to further improve performance and flexibility.

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