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An integrated analysis for sustainable supply of remote winter tourist centers – a future concept case study

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Abstract: In every power system there are consumer areas away from traditional power networks. Existing grid expansion can always be treated as one of the ways of powering them over long transmission and distribution lines. This is often characterized by significant transmission losses, as well as significant investments, depending on the distance and the infrastructure development. On the other hand, there are cases when these consumers are not connected to the power system and use alternative methods of supply. For that matter, possible solutions may use locally available energy sources. In this paper, comparative analyses between independent power supply through particular hybrid power system (HPS) configurations and the distribution network expansion option are performed. Storage, which represents a major problem in such HPS concepts today due to cost and capacity, is proposed to be in the accumulators of electric vehicles. In addition, an analytical methodology for selecting a sustainable solution for powering remote consumers was implemented. This analysis was verified with reference to a specific type of consumer, a winter tourist center, using real indicators and measured data on wind and solar energy potential at the site. It was shown that such an approach improves the selection of the most favorable sustainable supply solution and is suitable for consumers away from developed distribution networks, e.g., tourist centers, livestock pastures, and small factories. Proposed HPS concepts with storage in the electric vehicles of guests and employees could be a viable solution when this transportation mode becomes dominant in the future.

Key words: Hybrid power system, remote powering, renewable energy, sustainable power system planning

1. Introduction

Today, when the majority of electricity is produced from fossil fuels, measures against environmental pollution are intensifying, promotion and integration of renewable energy sources (RESs) are growing [1], and more and more countries and power systems are turning towards sustainable development [2,3]. In such a concept, hybrid power systems (HPSs) are increasingly attracting attention and are seen as part of the solution [4–6] that can contribute to sustainable development. HPSs based on locally available RESs can offer a cost-effective and pollution-free alternative to expensive grid extensions and can decrease fuel transport costs and transmission and distribution losses in remote areas of the world. They can also give opportunities for expanding generating capacities in order to cope with increasing demand in the future.

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In the recent available literature there is much discussion about the high percentage of RESs in energy systems as a contribution to sustainable development, e.g., [7]. A lot of work has been done on optimal HPS sizing, as in [8–14]. In [8] simulation and optimization techniques were revised, as well as existing tools needed to simulate and design stand-alone HPSs. In [9] an analysis of HPS optimum sizing approaches in the available literature was provided, showing that they can make significant contributions to wider renewable energy penetration by enhancing the system applicability in terms of economy. Optimal sizing of an autonomous hybrid photovoltaic (PV)/wind system was presented in [10], focusing on system reliability and the lowest value of leveled energy cost, whereas in [11] the HPS was complemented with a diesel generator as well. In [12] the methodology for autonomous HPS optimization using genetic algorithms was provided. Further, in [13], an approach for optimal operation control of a hybrid multisource system with the aim of meeting the load energy requirement with reliability and minimized life cycle costs was proposed.

A HPS consisting of a PV, a diesel generator, and a battery was also looked at in [15]. Here a case study was performed on a village, where part of the diesel-generated electricity could be displaced by the PV plant combined with a battery for backup purposes. Other comparative analyses between various HPS applications and HPS configurations were also performed for different case studies, e.g., for Jordan in [16]; for a small community in Bangladesh, resulting in a prefeasibility study of introducing the HPS as an alternative to grid extension in [17]; and for a village in Saudi Arabia, as presented in [18], in the form of a feasibility study for a wind-PV-diesel HPS. In addition, diverse ways of storing excess electricity in HPSs configurations based on RES were also discussed, as in [19].

This paper, however, addresses the issue of supply to remote consumer areas, at sites with exploitable RES potential. Depending on the consumer type, they are characterized by specific load profiles. A lack of connection to the classical power system is very common, particularly in developing countries. The objective is to process this specific type of consumer and propose a sustainable concept for their power. For these purposes, a winter tourist center has been chosen, resulting in a case study based on real indicators, with measured data on wind and solar energy potential and other prevailing conditions at the site. Proceeding in this sense, several remote supply solutions are observed and discussed. Comparative analysis between independent power supply options through various HPS configurations and the distribution network expansion option is performed. Also considered are HPSs utilizing available solar and wind energy potential, with the aim of satisfying local consumer needs. As a future concept, a storage option in the electric vehicles of guests and staff of the tourist center is introduced.

Different analyses of the integration of electric vehicles and their role in sustainable systems exist in the available literature. For example, in [20] a unit commitment model that can simulate the interactions among plug-in hybrid electric vehicles, wind power, and demand response was demonstrated. In [21] the possibility of using a fleet of plug-in hybrid electric vehicles to regularize possible energy imbalances caused by variable RESs in the northeastern Brazilian power system was evaluated. In [22] the consequences of integrating plug-in hybrid electric vehicles in a wind-thermal power system supplied by one-quarter wind power and three-quarters thermal generation was investigated. However, this paper considers a system that uses available RESs on the site and at the same time balances output power variations and the missing power from electric vehicles. In this paper an integrated analysis has also been performed, consisting of a mathematical model formulation, optimization of HPS configurations for different cases, and implementation of an appropriate analytical approach for obtaining the most favorable sustainable solution, taking into account appropriate sustainability factors. For HPS configuration analyses, simulations, and capacity optimization purposes, the National Renewable Energy

Laboratory's micropower optimization model, the software tool HOMER (http://www.homerenergy.com), is used.

The proposed approach can find considerable applications in examples of systems in developing countries on the path to sustainable development.

2. Methodological approach and case study formulation

Without explicitly focusing on the optimal sizing of a HPS, the objective of this paper is to address the issue of sustainable powering of special consumer types away from developed distribution networks, e.g., tourist centers, livestock pastures, or small factories. For these purposes, comparative analyses between an independent power supply through particular HPS configurations and the distribution network expansion option are performed. Storage, which represents a major problem in autonomous HPS concepts today due to cost and capacity, is proposed in the accumulators of electric vehicles. Further on, an integrated analysis is conducted by:

- providing a mathematical formulation of the problem,
- applying an appropriate software tool for establishing convenient HPS configurations,
- improving the selection of the most favorable, sustainable solution through the implementation of an analytical methodology developed and adjusted to the specific problem treated in the paper.

For these purposes, a case study has been conducted.

2.1. Case study formulation

A tourist center located in Rostovo, in the central part of Bosnia and Herzegovina (B&H), consisting of a hotel with 45 rooms, a ski lift, and 6 dependent houses forming an eco-village, was considered. The center is mainly focused on working during winter months. It is connected to the power system, but its features have been used as an example of a consumer whose autonomous power supply is to be conceptualized. The electricity is delivered over long transmission lines from centralized power plants over a 20 kV distribution line to consumers. The annual load profile is taken from the appropriate measuring point and is presented in Figure 1. The considered time frame was 1st of January 2012 to 31st to December 2012. The registered maximal hourly load was, as expected, in December, and it amounted to 108 kW. Lowered consumption is registered during periods without snow, when the ski lift does not work at all. The average daily consumption was 789 kWh.

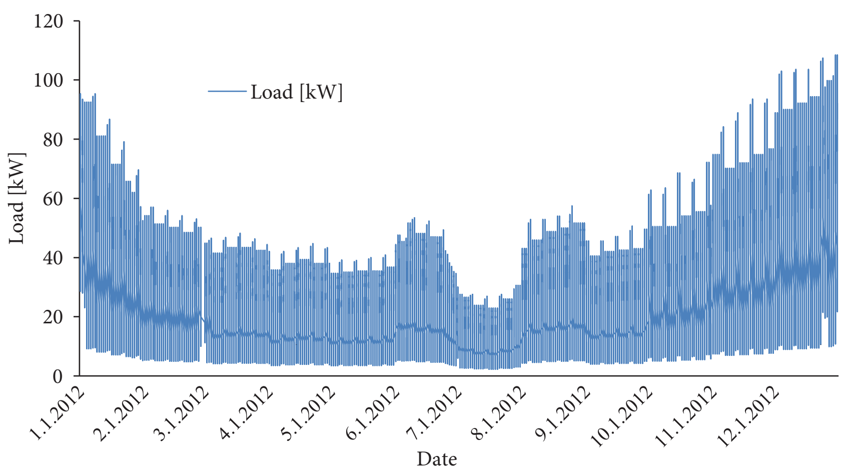

Figure 1. Annual load profile [kW] for the Rostovo winter tourist center.

Data used for the analyses, simulations, modeling, and optimization of various HPS configurations are taken from an active data acquisition and monitoring system in the local vicinity of the Rostovo tourist center. The system is equipped with 4 first-class anemometers, a wind vane, measuring sensors for air pressure, humidity and temperature and a pyranometer, all in accordance with IEC Standard 61400-12 on wind turbines (part 12-1) and MEASNET recommendations (Measuring Network of Wind Energy Institutes: Evaluation of Site-Specific Wind Conditions; Version 1, 2009). Measured data refer to 10 min averages, which entailed making 52,560 observations per measured value for the considered time frame. Raw, unfiltered data, in order to avoid subjectivity, have been used.

The average annual wind speed is 5.5 m/s. During spring and autumn the average monthly wind speed values are mostly higher than the annual average. During January, October, and December icing of anemometers occurred, due to low temperatures, and snow and ice deposits. Since unfiltered dates have been processed in the analyses, this resulted in wind speed values of 0 m/s or values lower than actual at the site. This further led to no energy production from wind turbines during these periods of time. The average annual daily radiation is 4.255 kWh/m^2 and the average clearness index equals 0.573, with highest values during the summer months.

The following 4 different HPS configurations for the autonomous supply of the proposed winter resort have been considered:

- Case I: HPS consisting of PV power plant (PVPP) and wind power plant (WPP), with storage possibility.
- Case II: HPS consisting of PVPP and WPP, without storage possibility.
- Case III: HPS consisting of PVPP, WPP, and a diesel generator (DG), without storage possibility.
- Case IV: HPS consisting of PVPP, WPP, and a DG, with storage possibility.

All these HPS cases have been compared to the case as it is now, connected to the centralized power system, as Case V, which represents the traditional approach. In order to obtain the most appropriate HPS configuration for each of the considered cases, the software tool HOMER has been applied. Thus, the HPS components have been dimensioned in accordance with real indicators at the site. For all 4 cases, a PVPP of installed capacity of 10 kW and a Fuhrländer wind turbine (WT) of 250 kW installed capacity were chosen as appropriate, taking into account available space and other prevailing conditions at the location. Converters of unit capacity of 10 kW were considered in each case. A generator running on diesel was analyzed in Cases III and IV. As storage possibilities, electric vehicles from guests and staff of the tourist center have been proposed in the framework of a future concept when electric vehicles become a dominant transportation mode. The maximum number of electric vehicles has been determined in compliance with the tourist center's capacity. Nominal capacity of the accumulator is 800 Ah. Further optimization of the configurations is done by the applied software tool, taking into account set constraints. These restrictions relate to the reliability of the considered HPS configurations, which is treated through capacity shortage in this paper, provided by the software tool as an option. Thus, in Case I and Case III a maximum annual capacity shortage of 10% has been allowed. Case II has been analyzed without any capacity shortage limitations. Case IV has been discussed as a HPS configuration ensuring supply to the consumer most of the time (maximum allowed annual capacity shortage of 1%). The resulting 4 HPS configurations are shown in Figure 2.

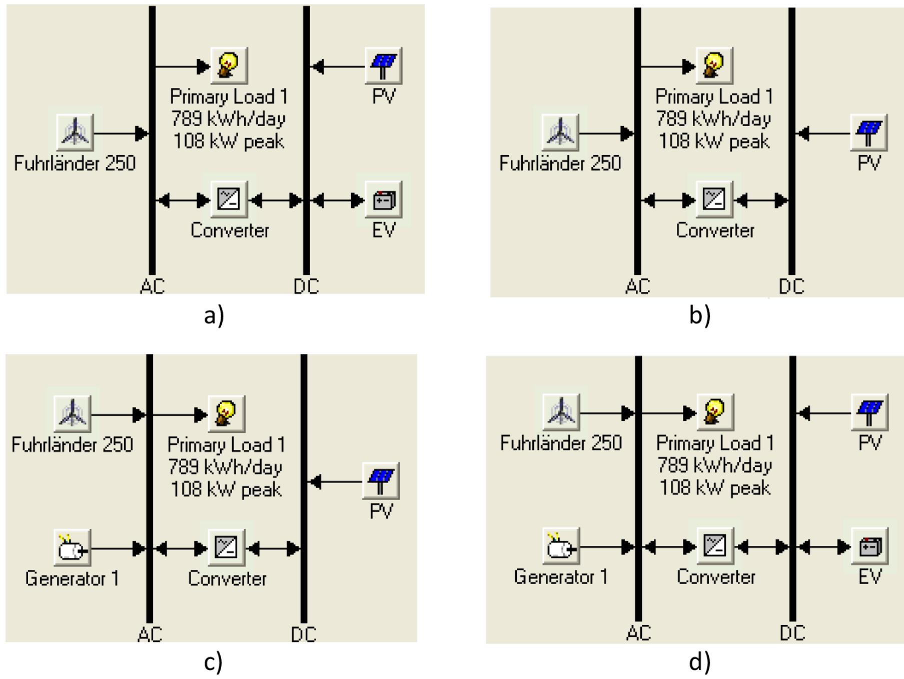

Figure 2. Hybrid power system configurations for a) Case I, b) Case II, c) Case III, and d) Case IV.

The project considers a time period of 30 years with an annual interest rate of 8%. The lifetime of the generating units and the convertors is estimated at 20 years, after which replacement of the dilapidated equipment is foreseen. The DG lifetime is estimated at 25,000 working hours.

2.2. Mathematical model

The proposed HPS consists of a WPP, PVPP, electric vehicles, and a DG. The scheme of the HPS for the power supply of the winter resort is shown in Figure 3.

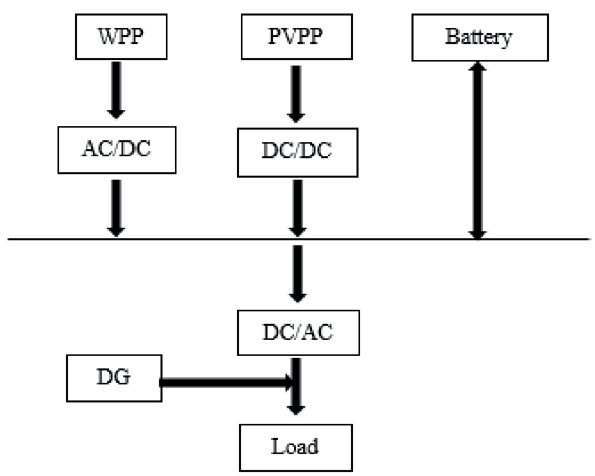

Figure 3. Diagram of the proposed hybrid power system.

The dominant source of electricity is the WPP. For electricity storage purposes, batteries in electric vehicles from guests and staff of the tourist center have been proposed. In this sense, this component of the system does not affect the overall investment.

The prevalent consumer is the ski-lift that runs during the winter day for approximately 8 h and can be considered as a fixed, deterministic load. All other loads in the system can be considered as random.

For system supply analysis and HPS configuration sizing, the parameter of loss of power supply probability (LPSP) has been used, adjusted to this particular case as compared to [10,23]. Loss of power supply (LPS) of the system can be represented by the following relation:

$$LPS\,(t_i) = L\,(t_i) - \{[W_{WPP}\,(t_i) + W_{PVPP}\,(t_i) + SOC\,(t_i) - SOC_{min}]\,\eta_{inv} + W_{DG}(t_i)\} \tag{1}$$

where $L(t_i)$ is the load profile; $W_{WPP}(t_i)$,$W_{PVPP}(t_i)$, and $W_{DG}(t_i)$ are the output power from the WPP, PVPP, and the DG, respectively; and $SOC(t_i)$ is the state of charge of the battery, all in the ith 10-min time interval. η_{inv} is the efficiency of the DC/AC inverter and t_i is the considered time period (in this case 10-min time intervals) for which the aforementioned values are calculated, based on real, measured data: load, wind speed, air density, humidity, temperature, pressure, and global solar radiation.

The output power of the WPP is given by the following equation, as used in [24]:

$$W_{WPP}(t_i) = \frac{\rho_i}{2} A_w v_i^3 c_{pi}(\lambda\theta) \tag{2}$$

where v_i is the mean 10-min wind speed at the location at hub height, ρ_i the average 10-min value of air density, A_w the surface of the WT blades, and $c_p(\lambda,\theta)$ the WT characteristics representing the degree of aerodynamic conversion. This coefficient depends on the speed ratio λ between the blade speed and the wind speed at hub height v_i and θ, representing the pitch angle.

The output power of the PVPP, as in [10], is given by:

$$W_{PVPP}(t_i) = \eta_{PVPP} A_{PVPP} N I_i \tag{3}$$

where η_{PVPP} is the current efficiency coefficient of the panel (depending on the temperature and the working point-power point tracker), A_{PVPP} is the surface of the panel, N denotes the number of panels, and I_i is the global irradiation [W/m^2] at the location in the ith 10-min time interval.

Charging and discharging of the battery is given by Eqs, (4) and (5), respectively, as used in [10] and adjusted to this particular model:

$$SOC\,(t_i) = SOC\,(t_{i-1}) + \frac{\eta_{cb} I_b(t_{i-1})}{C_b} t_i \tag{4}$$

$$SOC\,(t_i) = SOC\,(t_{i-1}) - \frac{I_b(t_{i-1})}{C_b} t_i \tag{5}$$

η_{cb} is the coefficient of the battery charging efficiency, $I_b(t_i)$ the discharge current in the ith 10-min time interval, and C_b the battery capacity, where $SOC(t_i)$ cannot be less than the minimal state of charge of the battery, SOC_{min}. The nominal capacity of the battery can be taken, but it is kept in mind that the battery's capacity changes with aging.

The output power of the DG is calculated by:

$$W_{DG}(t_i) = P_{DG}(t_i)\eta_{DG} \tag{6}$$

where $P_{DG}(t_i)$ is the capacity of the DG in the ith 10-min time interval and η_{DG} the efficiency coefficient of the DG.

In the considered case study, discharging of the battery has been considered. It is assumed that the batteries are charged during nighttime. If there are conditions that allow the batteries to be charged during the day, then, at that time, the DG is turned off.

By definition and as presented in [10,23], the LPSP for the considered time period is:

$$LPSP = \frac{\sum_{i=1}^{n} LPS(t_i)}{\sum_{i=1}^{n} L(t_i)} \tag{7}$$

where $t_i = 10$ min and n is the number of 10-min time intervals in the considered time period. From Eq. (7) the total output power of the DG for the considered time period can be obtained. The working time at nominal capacity W_{DGN} of the DG can be calculated from:

$$t_{in} = \frac{\sum_{i=1}^{n} W_{DG}(t_i)}{W_{DGN}} \tag{8}$$

From this, the fuel consumption can further be calculated and used for HPS optimization purposes and cost evaluations.

From the standpoint of supply, the critical period of the day is the time when the ski-lift is operating, i.e. from 8 AM until 6 PM, so that the number of 10-min time intervals is 60. Since winter months are critical, due to the dominant consumption of the ski lift, LPSP can be calculated for 4 months: December, January, February, and March. In case the desired LPSP value corresponds to 1 day in these 4 months, using available optimization methods for the optimization of the investment, it is possible to optimize the number of PV panels and the number of working hours of the DG. The cost of the PV panels predominantly affects the investment and the costs for the DG fuel affect the operating costs of the system. WPP is the fixed part of the system and the batteries are the accumulators of the electric vehicles. In this particular case, the software tool HOMER has been applied for HPS optimization purposes.

2.3. Analytical approach for the selection of the most favorable solution

In order to obtain the most suitable solution for remote tourist center supply out of the considered options, an analytical approach has been proposed and implemented in this paper. Sustainable development has been the focus of the elaboration.

The proposed model consists of 7 steps, where each of these steps has its own substeps and/or requirements and/or calculations. Essential steps include the following and they can be implemented as a universal approach for solving similar problems:

1. Problem identification
2. Specification of initial facts and assumptions
3. Obtaining input parameters
4. Obtaining/calculating results

5. Performing the analyzing process

6. Rejection, modification, or acceptation of problem formulation/input parameters/the process

7. Solution implementation

The algorithm of the implemented methodology is presented in Figure 4, where its application to the selected case study has also been demonstrated.

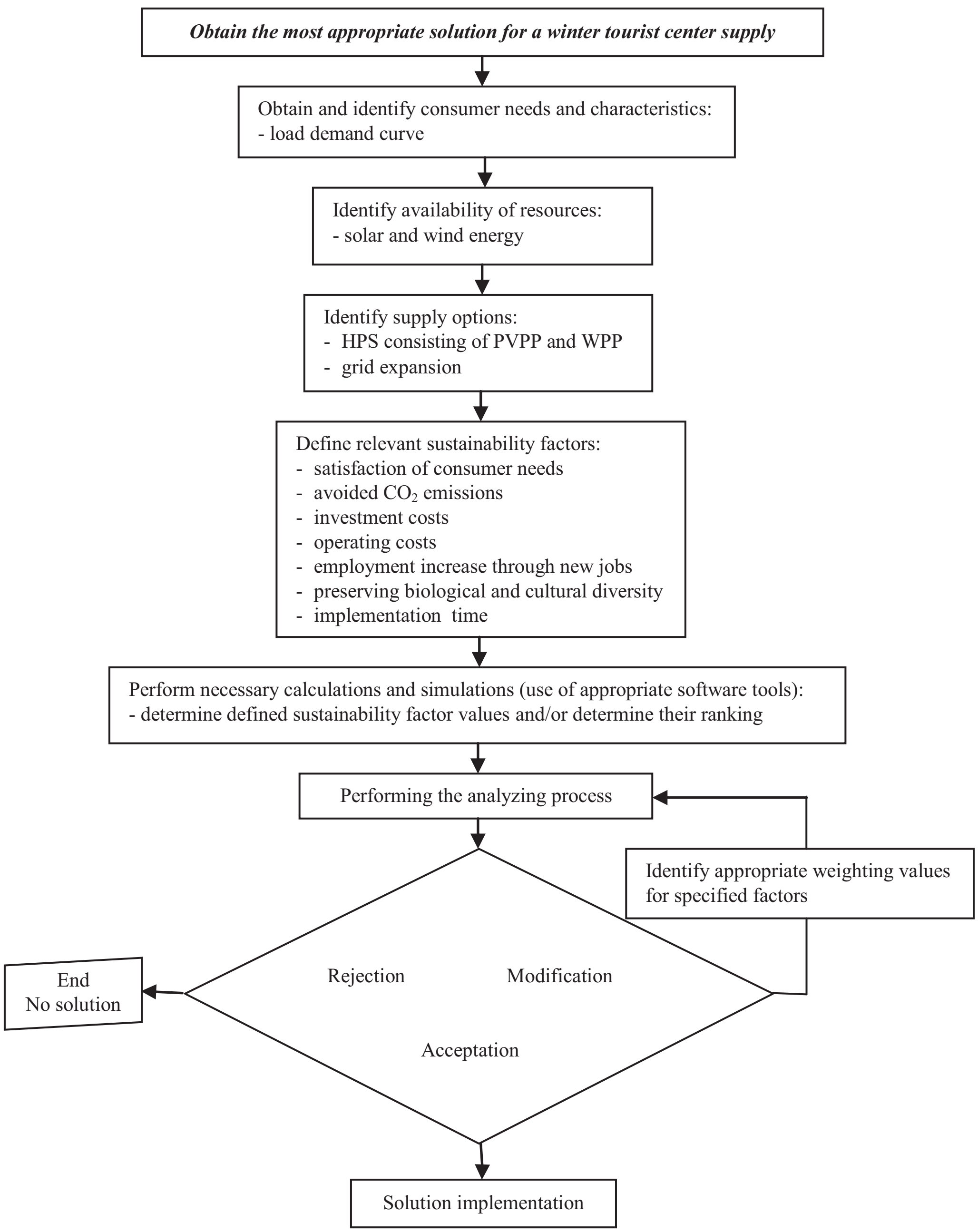

Figure 4. Algorithm of the methodology approach used.

In the process of finding the most appropriate solution, 5 different supply cases have been considered, i.e. the extension of the existing electricity network and 4 HPS configurations for independent power supply. The conception of autonomous supply has been addressed by taking into account the complementary nature of solar and wind energy, as elaborated in [25], and benefits of combined operation of PVPP and WPP at one site.

After identifying consumer needs, available RESs, and supply options, relevant sustainability factors, by which the evaluation of the proposed solutions is performed, are defined. Since in the performed case study analysis the desired objective is a sustainable solution, the following sustainability factors are used:

- Systemic factor: satisfaction of consumer needs
- Environmental factor: avoiding CO_2 emissions
- Economic factor: investment costs
- Economic factor: operating costs
- Social factor: employment increase through new jobs
- Environmental factor: preserving biological and cultural diversity
- Systemic factor: implementation time

Given that the proposed approach can be applied for solving other similar problems, the list of selected sustainability factors can then be adapted to any specific situation.

After that, the corresponding matrix of considered supply options and defined sustainability factors is set. Assessment (ranking) of individual supply options based on defined sustainability factors is performed. The assessment is done in the range of *0* to *n – 1*, where n indicates the number of considered cases. The advantage of this approach is that it is not necessary to know precise values of individual sustainability factors in corresponding cases, but rather to determine their mutual order. If the ranking of considered cases by specified sustainability factors is not obvious, it is necessary to determine their value by performing adequate calculations (e.g., using appropriate software tools) and then to execute the rankings. In the considered case study, the software tool HOMER has been applied for determining values for some of the sustainability factors in certain HPS configurations. Another advantage of this approach is that for the final ranking of the considered cases, the discussed sustainability factors do not necessarily need to be expressed in the same units.

Upon obtaining the ranking of considered supply options in the first run, an appropriate analysis process is conducted. Depending on the output results, one can accept, reject, or modify the problem formulation and/or sustainability factors and/or the process, by assigning weighting values to sustainability factors. In this sense, it is possible to go back to the previous step and carry out the analysis process again. In the proposed algorithm shown in Figure 4, this is represented by a corresponding loop. Obtained results can then be accepted and the solution implemented. In an extreme case it is also possible to stop the whole process without obtaining adequate solutions.

3. Results

In order to promote the concept of an autonomous and sustainable way of powering the proposed consumer types, appropriate HPS configurations with storage in electric vehicles has been discussed. In this research, it has been assumed that electric vehicles already possess adequate components that enable them to buy and sell energy to the grid. Accordingly, in the simulations, investment, operation, and maintenance costs for storage are taken as zero. Payments for the service of using electric vehicles are intended to be reimbursed through particular benefits for the car owners, e.g., reduced hotel prices, free tours, or free ski passes.

Four HPS configurations for autonomous supply were established using the HOMER software. Comparative analyses between these HPS configurations and the distribution network expansion option were performed. For these elaborations, an analytical approach was introduced. Calculations and analyses were verified using a real example and actual measurements, with the appreciation of available tourist center capacity, space requirements, available resources, etc.

3.1. Case I simulation results

The optimal HPS configuration for the Rostovo winter tourist center for Case I was 60 kW in PVPP, 1 Fuhrländer WT, 40 accumulators in electric vehicles, and 70 kW in converters. This HPS configuration also serves as the initial base for all other cases discussed in this paper. For comparison purposes, the considered HPS configurations are presented in Table 1, together with their main resulting characteristics.

Table 1. Results for considered hybrid power system configurations.

Item	Case I	Case II	Case III	Case IV
HPS configuration – generating facility type: installed capacity [kW]	PVPP: 60 WPP: 250 Converter: 70 DG: -	PVPP: 60 WPP: 250 Converter: 60 DG: -	PVPP: 60 WPP: 250 Converter: 40 DG: 35	PVPP: 60 WPP: 250 Converter: 70 DG: 45
Number of electric vehicles	40	-	-	40
Production [kWh/year]	771,966	771,966	854,520	804,590
Share of HPS components in the total electricity generated [%]	PVPP: 10 WPP: 90 DG: -	PVPP: 10 WPP: 90 DG: -	PVPP: 10 WPP: 80 DG: 10	PVPP: 11 WPP: 85 DG: 4
Renewable fraction [%]	100	100	70	89
Capacity shortage [%/year]	9.9	37.3	8.5	0.8

The net present cost (NPC), consisting of capital investment, replacement, operation, and maintenance and salvage costs, obtained by simulation equals 51,1615 €. The highest costs are for the WT, and the lowest costs, i.e. zero, are for the storage (electric vehicles).

According to obtained results in HOMER, most of the consumer's requirements are met by the WPP, as can be seen from Figure 5. The PVPP, with 4 times lower installed capacity compared to that in the WPP, gives its highest output power during summer months. The load profile and the unmet load are shown in Figure 6. Unmet load occurs during winter months. However, anemometer icing has been registered during some days of these periods; thus, the unmet load is actually expected to be lower than that obtained.

3.2. Case II simulation results

For defining the HPS configuration in Case II, the installed capacities of generating units obtained in Case I have been considered, but without the possibility of storing any excess electricity. This resulted in the HPS configuration given in Table 1. This variant has been investigated in order to determine the characteristics of supplying consumers in certain standalone HPS configurations with the lowest value of the NPC and to obtain the capacity shortage in cases when intermittent RESs generate electricity without storage possibilities.

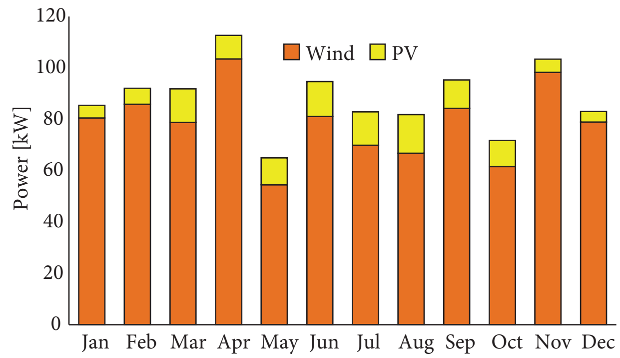

Figure 5. Output power [kW] of the hybrid power system components on a monthly basis for the system configuration in Case I.

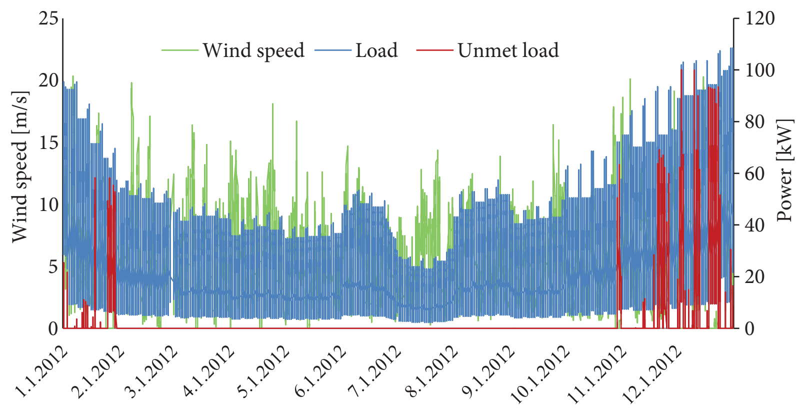

Figure 6. Load profile [kW] and unmet load [kW] vs. wind speed [m/s] during the year for hybrid power system configuration in Case I.

The NPC is 50,4748 € and differs from the one obtained for Case I by only slightly lower values for converters, as seen from Table 2. The average monthly output power from the PVPP and the WPP are the same as obtained for Case I, as presented in Figure 5. The load profile and the unmet load are shown in Figure 7. Unmet load occurs during the whole year and a very large capacity shortage value is obtained, as shown in Table 1.

Table 2. Resulting economic indicators for considered hybrid power system configurations.

Item	Case I	Case II	Case III	Case IV
Capital cost [€]	425,000	420,000	418,750	436,250
Net present cost [€]	511,615	504,748	1,033,269	716,041
Operating cost [€/year]	7694	7528	54,586	24,853
Consumed energy costs for 20 years [€]	633,567	633,567	633,567	633,567
Consumed energy costs for 30 years [€]	950,350	950,350	950,350	950,350

3.3. Case III simulation results

The standalone HPS configuration discussed throughout Case III has been analyzed to determine the effects of introducing generating units whose output is not as variable as that from the WPP and/or PVPP, but without any storage possibility. This resulted in 60 kW in PVPP, 1 Fuhrländer WT, 40 kW in converters, and 35 kW in a DG, as shown in Table 1.

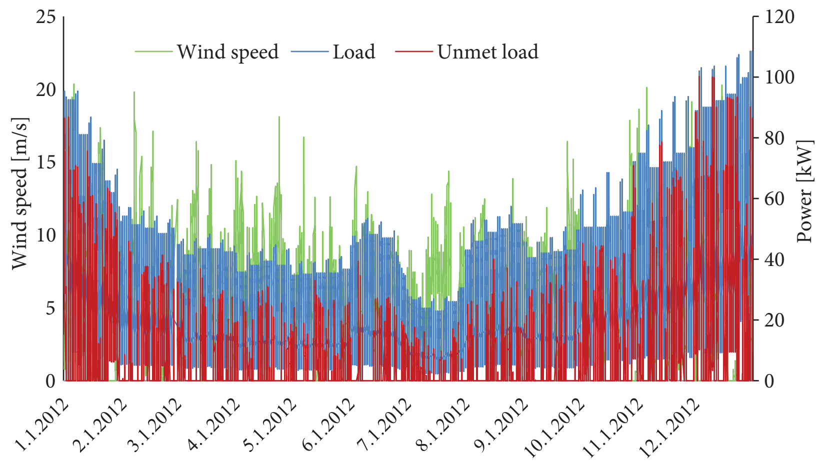

Figure 7. Load profile [kW] and unmet load [kW] vs. wind speed [m/s] during the year for hybrid power system configuration in Case II.

As obtained from simulation results, out of the annually produced electricity, 10% is derived from both the PVPP and the generator, and 80% from the WPP. The DG is engaged for 3,617 h and thus Figure 8 provides the output power of the HPS components on a monthly basis. The unmet load is shown in Figure 9. Comparing them with results from Figure 6, a more frequent occurrence of the unmet load can be observed, but with amounts lower than that for Case I.

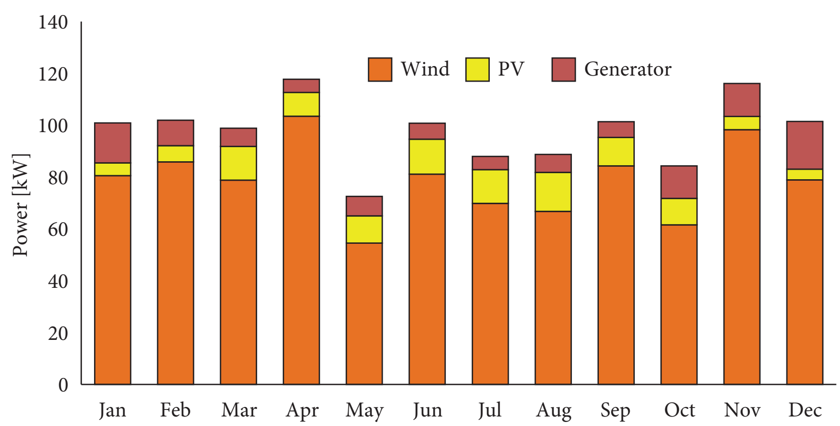

Figure 8. Output power [kW] of the hybrid power system components on a monthly basis for the system configuration in Case III.

The resulting NPC cost is 1,033,269 €, where more than 50% of this amount is for the DG. Such values are due to very high operation and maintenance costs for this unit compared to the PVPP and WPP, as well as fuel costs, which do not exist in cases when only RESs are present.

3.4. Case IV simulation results

The HPS configuration simulated throughout Case IV resulted in 60 kW in PVPP, 250 kW in 1 Fuhrländer WT, 70 kW in converters, 45 kW in a DG, and 40 accumulators in electric vehicles, providing storage possibilities, as can be seen from Table 1. An annual maximum capacity shortage of 1% has been allowed.

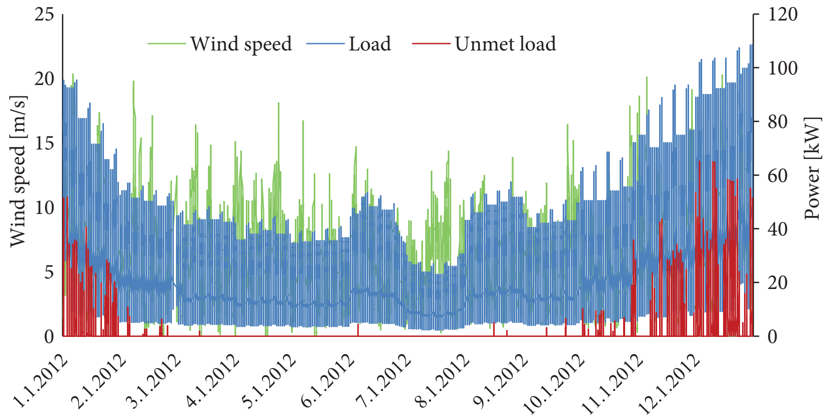

Figure 9. Load profile [kW] and unmet load [kW] vs. wind speed [m/s] during the year for hybrid power system configuration in Case III.

Simulation results show that from the total amount of electricity generated by the HPS, the WPP produces 85%, the PVPP produces 11%, and 4% derives from the generator. Accordingly, Figure 10 provides the output power of the HPS components on a monthly basis for this system configuration.

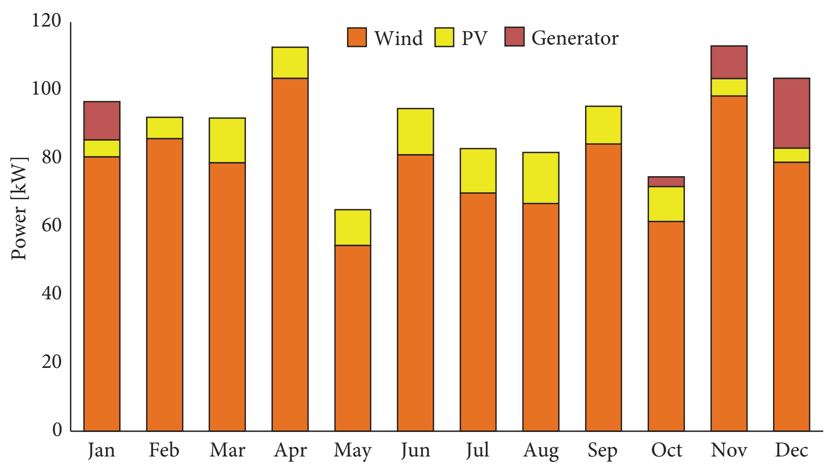

Figure 10. Output power [kW] of the hybrid power system components on a monthly basis for the system configuration in Case IV.

In this case, the NPC was 716,041 €. Due to the existence of a storage possibility, the DG is engaged only for 962 h. This resulted in lower operation, maintenance, and fuel costs for this facility compared to the DG costs in Case III, despite the higher power. The highest costs in this HPS configuration are for the WT. The unmet load occurs only in December, as can be seen from Figure 11.

3.5. Case V description of the current situation

The Rostovo tourist center is currently connected to the power system. The generating portfolio of this part of the power system of B&H is dominantly based on thermal power plants burning domestic coal. The rest is produced from large hydropower plants, where the ratio mostly depends on the hydrology, but does not exceed 40% annually. The CO_2 emission coefficient of the network is approximately 1000 kg CO_2/MWh. The total length of the overhead line at 20 kV, by which the electricity is delivered to the center, is 30 km. The network expansion for this length alone, without costs for substations or any other equipment, would require approximately 1,050,000 €.

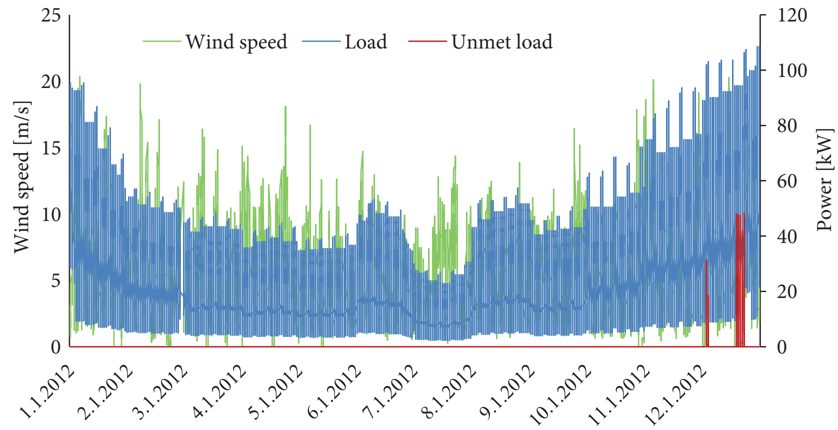

Figure 11. Load profile [kW] and unmet load [kW] vs. wind speed [m/s] during the year for hybrid power system configuration in Case IV.

4. Discussion

A presentation of the simulated HPS configurations and their main resulting characteristics are given in Table 1. Table 2 shows the main economic parameters of the HPS cases. It can be seen that capital costs for the 4 HPS configurations do not differ much, whereas NPC varies from –1.3% for Case II to 204% and 140% for Cases III and IV, respectively, compared to Case I. Only the investment in the grid expansion exceeds the obtained NPC values of the 4 considered HPS configurations.

Operating costs per year are much higher for HPS cases with a DG compared to cases without one. Also, frequent starting of the DG shortens its life time, while the frequent charging and discharging of accumulators in electric vehicle improves their performance.

For further indicative consideration on feasibility of the proposed HPS cases, an average purchase price for electricity of 0.11 €/kWh has been specified. Calculations show that for the consumed energy over the period of 20 years, it would be necessary to spend at least approximately 633,567 €. For the whole of the project's lifetime of 30 years, this amount would result in approximately at least 950,350 € for the consumed electricity at the aforementioned purchase price. These amounts exceed the initial costs for each simulated HPS case and do not even include investments in the network infrastructure, the connection, network maintenance costs, and network losses. The amount of money that the Rostovo tourist center would have to pay to the electricity distributor for the considered time period of 30 years is even higher than the NPC for each simulated HPS case, except Case III. However, even in Case III, when taking into account investments in the network infrastructure, connection to the distribution network, and losses that might arise in the long transmission and distribution lines, this HPS configuration is also expected to be viable.

The reliability of the considered HPS configurations is taken into account through capacity shortage values per year. Since anemometer icing does not necessarily mean WT blades icing and cessation of production, in each HPS case slightly lower capacity shortage values can be expected, due to somewhat higher electricity production from the WPP. The imposed restriction depends on the purpose of the consumer and its requirements, but the limit adopted in Case IV would be acceptable in most cases. However, establishing a smart management system within the consumer center [26] would enable a rational allocation of available energy and consumer needs satisfaction during peak loads and periods when the electricity is mostly needed. Also, a great share of RESs has been achieved in all 4 HPS cases.

Excess electricity exists in each of the simulated HPS configurations. Very high values, above even 70%, are registered in Cases II and III when part of the surplus energy cannot be stored anywhere.

Since the necessary results were obtained, the approach presented in Figure 4 has been further applied in the analysis. The matrix of considered supply options and specified sustainability factors was established, as shown in Table 3.

Table 3. Matrix of supply options and sustainability factors.

Sustainable factors	Case I	Case II	Case III	Case IV	Case V	Weighting value for the second run
Satisfaction of consumer needs	1	0	2	3	4	0.40
Avoided CO_2 emissions	4	4	2	3	0	0.20
Investment costs	2	3	4	1	0	0.15
Operating costs	3	4	0	2	1	0.10
Employment increase through new jobs	1	0	2	3	4	0.06
Preserving biological and cultural diversity	4	4	3	3	0	0.05
Implementation time	3	4	2	1	0	0.04

In the first run, when only the ranking of individual supply options based on defined sustainability factors is performed, Case II seems to be the best solution. However, when weighting values are assigned to sustainability factors, the most appropriate sustainable solution turns out to be the HPS configuration obtained for Case IV.

5. Conclusion

In the available literature, many articles treat the issue of consumer supply by HPSs based on wind, solar energy, and diesel generators, including storage. This work focuses on the comparative analysis between HPSs on a microgrid and the supply option over the transmission and distribution network. Here, autonomous HPSs are conceptualized by taking into account storage in the electric vehicles of guests and employees within the treated example of the winter tourist center. In this way, a possible future concept for a sustainable power supply is proposed, focusing on locally available RES utilization and capacity optimization, in accordance with real indicators at the site. The assessment is complemented by an analytical methodology, introducing appropriate sustainability factors for obtaining the most favorable supply option, suggesting a synthesis between economic development and environmental preservation, along with social welfare.

It is shown that an autonomous power supply by appropriate HPS concepts with storage in the accumulators of electric vehicles can be a viable solution in the future, when electric vehicles become the dominant transportation mode. Suitable consumer types are mountain resorts, tourist centers, livestock pastures, and small factories for the exploitation of resources in mountain areas such as medical herbs, mushrooms, etc. Such solutions with a high share of RESs in electricity generation, as well as an absence or significant reduction of emissions, would obtain strong approval from the community and special benefits through incentives.

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