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The selection of the suitable renewable hybrid pairs: A case study

Uygun yenilenebilir hibrit çiftlerinin seçilmesi: Bir vaka çalışması

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The Selection of the Suitable Renewable Hybrid Pairs: A Case Study

Highlights

- *Comparison of the renewable hybrid pairs*
- *Analysis hybrid energy effect on the energy management*
- *Hydro and solar energy are the optimum hybrid energy couples*

Graphical Abstract

In this study, an algorithm is meant for outlining the installed power of an integrated hybrid energy system. As a result of algorithm, hydro and solar energy are the optimum hybrid energy couples.

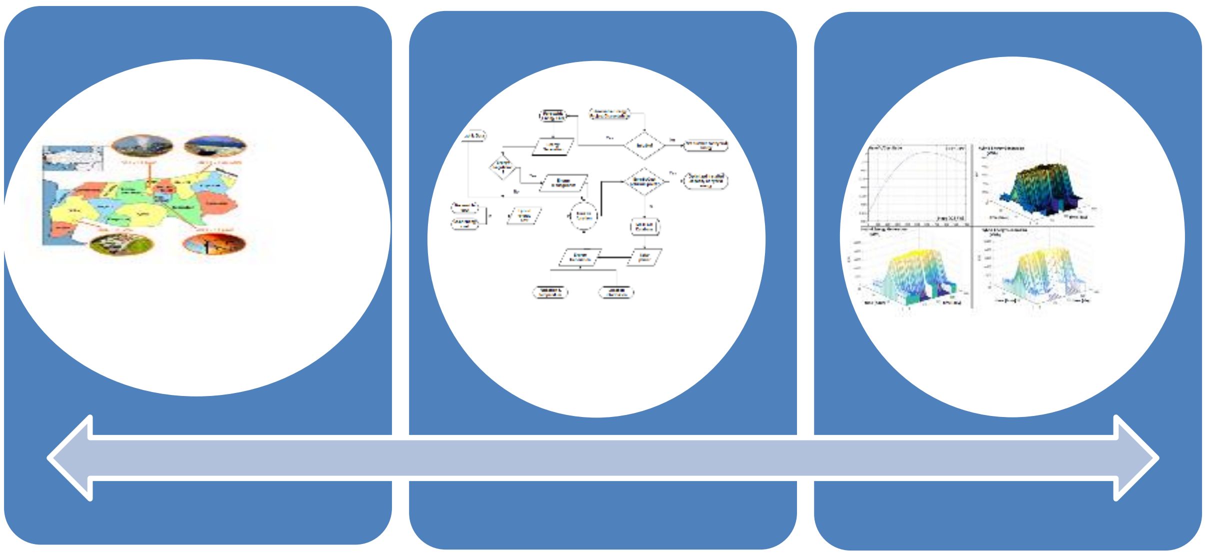

Figure. Graphical Abstract

Aim

Explaining the optimum renewable energy source selection for the hybrid energy system.

Design & Methodology

An algorithm has been designed to figure out the which renewable energy source is so suitable to be integrated into the hybrid energy.

Originality

Widely used renewable energy source located in the same area reviewed for the selection of hybrid energy.

Findings

Hydro and geothermal energy is suitable renewable energies to be integrated with solar energy.

Conclusion

Hydro and solar energy integration is the best solution for renewable hybrid couple and energy management.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

The Selection of the Suitable Renewable Hybrid Pairs: A Case Study

Araştırma Makalesi / Research Article

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ABSTRACT

The renewable hybrid energy system may be quite an energy that uses the same energy infrastructure. Although hybrid energy structures are fed from different types of renewable energy sources, they are systems that give energy to the grid over the same busbar and energy transmission line. The amount of energy that hybrid energy systems can deliver to the grid is limited by the installed capacity of the main source. A well-designed hybrid system can produce more stable electricity throughout the year. The advanced technology networks of various energy sources guarantee the very best efficiency in energy production. Hybrid energy systems combine centralized and non-local storage with intelligent and low-loss control and energy consumption. Also, energy management is provided owing to this integrated renewable hybrid system. During this study, a brand-new algorithm was designed for renewable hybrid selection. Algorithm and integrated renewable hybrid systems are clarified by a case study. A solar power system is used as one of the hybrid pairs for all renewable energy sources.

Keywords: Hybrid energy, energy management, solar energy.

Uygun Yenilenebilir Hibrit Çiftlerinin Seçilmesi: Bir Vaka Çalışması

ÖZ

Yenilenebilir hibrit enerji sistemi, aynı enerji altyapısını kullanan sistemler olarak görülebilir. Hibrit enerji yapıları her ne kadar farklı enerji kaynaklarından beslenseler de, şebekeye aynı bara ve enerji nakil hattı üzerinden enerji veren sistemlerdir. Hibrit enerji sistemlerinin şebekeye verebileceği enerji miktarı, ana kaynağın kurulu kapasitesi ile sınırlıdır. İyi tasarlanmış bir hibrit sistemi, yıl boyunca daha istirarlı bir şekilde elektrik üretebilmektedir. Çeşitli enerji kaynaklarının ileri teknoloji ağları, enerji üretimindeki en yüksek enerji verimliliğini garanti etmektedir. Hibrit enerji sistemleri, akıllı ve düşük kayıp kontrollü merkezi ve yerel olmayan depolamayı, enerji tüketimi ile harmanlamaktadır. Ayrıca, entegre yenilenebilir hibrit enerji sayesinde enerji yönetimi sağlanabilmektedir. Bu çalışmada, yenilenebilir hibrit enerji seçimi için yeni bir algoritma tasarlanmıştır. Algoritma ve yenilenebilir hibrit enerji sistemleri vaka çalışması ile açıklanmıştır. Güneş enerji sistemi, tüm yenilenebilir enerji kaynakları için hibrit çiftinden biri olarak kullanılmıştır.

Anahtar Kelimeler: Hibrit enerji, enerji yönetimi, güneş enerjisi.

1. INTRODUCTION

Renewable Energy is the energy from this energy flow within the continued natural processes. Today, major global energy comes from fossil fuels. Renewable energy sources play role in reducing this dependency. In general, solar, wind, biomass, geothermal, and hydro energy are widely used renewable energy sources all over the world. System stability and quality are the foremost items of the grid system. The distribution of the electricity has to be provided to the end-users during this scope. It is a usual time-honored practice to limit the grid availability for renewable energy. Renewable energy capacity utilization rates are relatively below the fossil-based energy sources. This case gives rise to ineffectiveness in transformer capacity utilization. Furthermore, this instance is hindering the investment in renewable energy. High potentially renewable energy sources/plants are postponed because of this inadequate installed capacity of the transformers. A replacement transformer building/equipment and its infrastructure expenditures are very costly. For this reason, higher capacity utilization usage of a transformer is easier than a novel one.

Distributed energy systems are the new trend around the globe. This method aims for more efficient utilization by decreasing the losses of the grid system. Mutual usage may well be the simplest way of efficient utilization. Renewable energy can be a clean and sustainable energy source. Hybrid energy can include renewable sources. Hybrid energy systems are experiencing a robust increase in an age supported by rethinking lifestyles and fast technological progress in the name of conservation of resources. The advanced technology networks of varied energy sources guarantee the best efficiency in energy production. Hybrid energy systems combine centralized and non-local storage with intelligent and low-loss

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control and energy consumption. Such an energy supply network aims to require the care of a balance between production and consumption. To understand this, seamless integration of various technologies associated with the assembly, storage, and consumption of energy is vital, providing new areas for innovative solutions.

Saharia et al. [1] developed a solution for the optimization point of integrated hybrid facilities. Jung and Villaran [2] reviewed the design of hybrid renewable facilities for microgrid systems. Suresh et al. [3] used a HOMER model for simulation of the standalone hybrid energy. Asrari et al. [4] performed a case study for a countryside of Iran. Eltamaly et al. [5] stated the optimal size in their stufy for hybridization. Nehrir et al. [6] reviewed configurations of alternative energy systems for a generation. Ma et al. [7] assessed hybridization from a techno-economic point of view. Diemuodeke et al. [8] designed a decision-making structure for the hybrid energy systems. Palej et al. [9] analyzed the optimal point of hybrid facilities. Sharafi and ELMekkawy [10] emphasized a PSO methodology for hybrid renewable energy systems. Bhandari et al. [11] modeled hybrid system, which consists of hydro, wind, and, solar energy. Amer et al. [12] emphasized a PSO effect on cost reduction of hybrid facilities. Esmaeilion [13] emphasized climate changes in his study. Jaszczur et al. [14] reviewed hybrid systems for the residential load. Ismail et al. [15] used an artificially intelligent model such as a genetic algorithm for designing a multilayer system.

Mayer et al. [16] reviewed a household-level hybrid energy system. Bahramara et al. [17] reviewed hybrid energy optimization by using the HOMER program. Marchenko and Solomin [18] researched the cost vulnerability of the integrated energy systems in Russia. Maleki et al. [19] determined the best hybrid model for remote areas in Iran. Al-falahi et al. [20] reviewed the optimal size of the standalone hybrid system. Bourennani et al. [21] clarified the most widely adopted hybrid energy systems like PV, wind, fuel cells. Erdinc and Uzunoglu [22] stated the optimum point of hybrid energy by using different methodologies. Fulzele ve Dutt [23] used the HOMER program for designing hybrid energy. Sawle et al. [24] reviewed the feasibility of an integrated energy system. Negi and Mathew [25] clarified why hybrid energy is so applicable for off-grid systems.

Bernal-Agustin and Dufo-Lopez [26] simulated a standalone hybrid energy system. Rahman et al. [27] predicted the energy generation amount of hybrid energy by using artificial intelligent methodologies. El Khashab and Al Ghamedi [28] compared hybrid energy projects composed of PV, fuel cell, wind energy by using the HOMER program. Sabishchenko et al. [29] stated the flexibility possibility of Ukraine’s energy sector by using renewable hybrid energies. Bocklisch [30] stated a storage system of hybrid energies. Camargo et al. [31] stated the importance of hybrid renewable energy for residential buildings. Kougias et al. [32] developed sustainable energy models for island mode locations. Xu et al. [33] stated hybrid energy models for buildings. Calik and Firat [34] analyzed performance of saturated photovoltaic cell by using Fresnel lens. Swese and Hançerlioğulları [35] reviewed photovoltaic/thermal structures consisting of magnetized fluid. Ozturk et al. [36] investigated ZnO based nano thin film’s profile which can be used as solar energy material. In the studies conducted within the literature, researches are about the performance of various renewable energy sources with different characteristics. During this study, the aim is to see the foremost compatible renewable hybrid energy pair. For this purpose, an algorithm is designed that repeats itself cyclically and continues to figure until it gives the optimum result. Additionally, a case study was conducted to clarify the algorithm. Within the designed algorithm, solar power is directly selected as the renewable hybrid energy pair. The most reason for this choice is that solar energy has an available energy generation profile regardless of the location difference. To get electricity from other renewable energy sources, special conditions and locations must be found. Hybrid pair selections were also effective when choosing solar energy. As of the top of February 2022 in Türkiye, solar energy was preferred the foremost within the hybrid system requests made to official institutions (EMRA-Energy Market Regulatory Authority). Within the application made for existing 30 energy plants, the most energy sources of which are wind, hydro, geothermal, fossil fuel, and coal, 1 wind energy was preferred as a hybrid pair, while 29 solar energy plant requests were made [37]. Within the case study, existing energy facilities located within the borders of the same province and with similar installed capacities were taken into consideration. It's been revealed that solar and hydropower plants, whose generation profiles are complimentary and compensatory, are the foremost suitable hybrid renewable energy pair. While wind and biomass energy facilities couldn't establish a meaningful integrated system with solar power, more suitable results were obtained in geothermal and hydro energy. Consistent with the cost/benefit methodology, while it's possible to determine an auxiliary hybrid solar energy plant with an installed power of 14.9 MW for hydro energy, a solar energy system with an installed power of 4.9 MW for geothermal energy.

2. MATERIAL and METHOD

As mentioned solar, hydro, wind, geothermal, and biomass widely used renewable energy sources all over the world. The PV array power may be calculated by Equation 1. The hydropower may be calculated by Equation 2. The wind generation may be calculated by Equation 3. The geothermal power will be calculated by Equation 4. The biomass power is calculated by Equation 5

$$Ps = I \, . \, V \tag{1}$$

$$N = \varrho \, . \, g \, . \, \mu \, . \, Q \, . \, H \tag{2}$$

$$P = \frac{1}{2}.\rho.V^3.C_p.A \quad (3)$$
$$ATP = m.c_p.(T_{geo,\ in} - T_{geo,\ out} \quad (4)$$

Where is the solar power, I is current, V is the voltage, N is the hydro-energy power (MW), ϱ represents the water density (1,000 kg/m3), g represents the gravity value (9.81 m/s2), μ is the efficiency coefficient of the power facility (efficiency of turbine/generator/transformer), Q is the flow rate (m^3/s), H represents the elevation of the hydro facility (m). P is the wind power (MW), ρ is the intensity of air (kg/m3), V is the velocity of wind (m/s), C_p is the power factor, A is the stroke area (m2). ATP is the available thermal power of geothermal, m is the mass flow (kg/s), $.c_p$ is the specific heat capacity of water (kJ/kg), $T_{geo,\ in}$ is the incoming temperature (K), $T_{geo,\ out}$ is outlet temperature (K), BP is the biomass power plant size, M is the mass flow (tons/year), Hu is the net heating valuer (MJ/kg), To is the yearly operation time, e is the efficiency of the plant;

dynamics. So, capacity utilization rates are different. It is a vital issue for an investment decision. The third step is renewable energy implementation costs. The iterative function is the last section. MATLAB is used as data storage. Any calculations are used for the loop. The output is calculated per the restriction of potential, capacity utilization rate, and costs. The optimization function is the sum of potential level, capacity utilization rate, and cost. The sum of this function is calculated for renewable sources. Results are changed with each new loop. The output function is defined for all-new iterations. The optimization point is identified as a result of the iterative loop.

In this study, an iterative loop is developed to pick the acceptable renewable hybrid pair. The developed algorithm is given in Fig. 1

With hybrid structures coming to the fore, algorithms developed to determine which renewable energy sources are more compatible in themselves. In these studies, the aim is to determine the point of optimal sizing where the

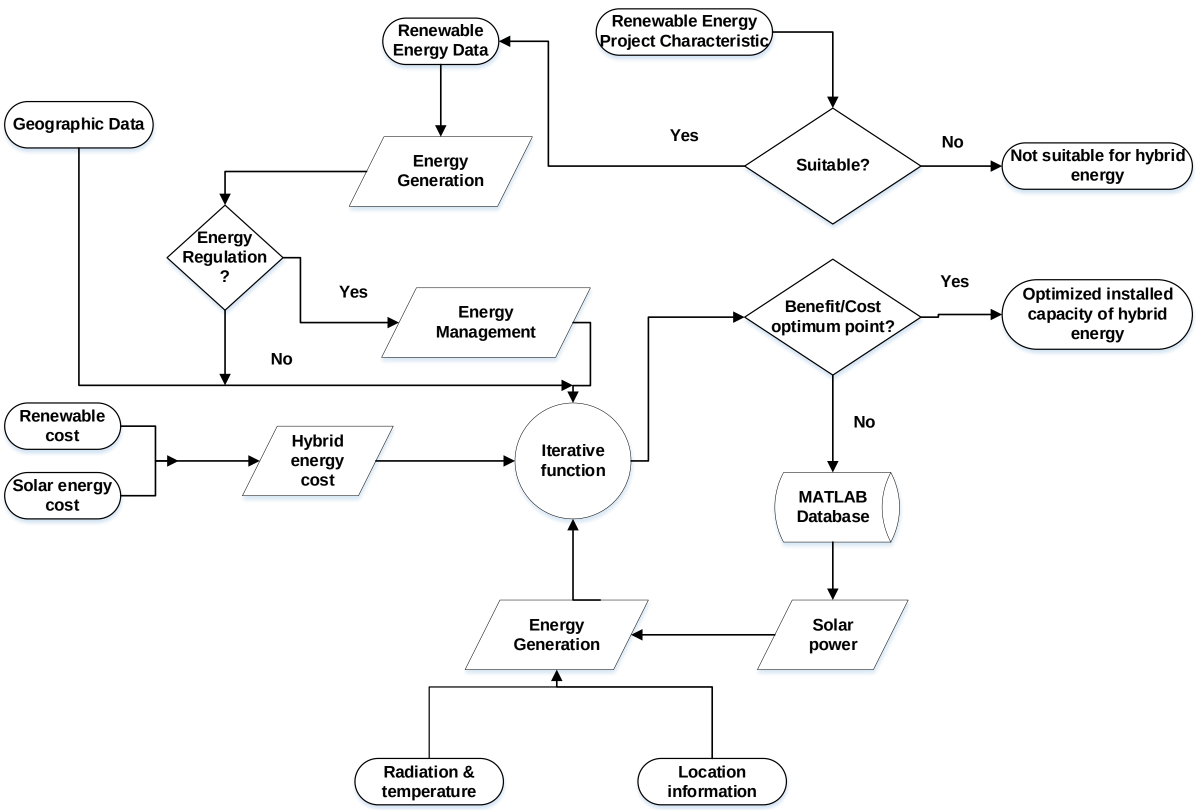

Fig. 1. The designed algorithm

Solar energy is chosen as hybrid pair for all kinds of renewable energy. Owing to its high availability potential, solar energy can be applied easily to other renewable energies. Renewable Selection Algorithm within the beginning of the algorithm, the position, and potential of renewables data are given. Potential is often shown on several levels. The second step is about the capacity utilization rate. Each renewable source has its hybrid structure in question is the most applicable. Renewable energy sources have different characteristics from each other. Renewable energy is generally, its endless, non-fossil source (coal, petroleum, and carbon derivative), which may be obtained on earth and in nature mostly without the necessity for any production process, with an occasional level of CO2 emission when generating power, and with much lower environmental damage and impact than conventional energy sources. It refers to energy resources like hydro, wind, solar, geothermal, biomass, biogas, wave, current energy, and tide, hydrogen, which are renewed with motion and exist in nature can be used.

Each renewable energy has a different electricity generation profile. While river-type hydropower plants are highly dependent on precipitation, solar power is dependent on radiation and temperature. While the reservoir, pressure, and temperature are the most required parameters for geothermal energy, establishing a sustainable raw material supply chain in biomass power, directly affects the electricity generation of the facility. Currently, it is possible to benefit from solar energy only during daylight, rapid fluctuations can be observed in wind energy, and the energy generated may differ depending on the period observed. The performance of each renewable energy project can operate at different capacity factors, regardless of its type, and geothermal and biomass energy plants are generally in operation with a higher capacity factor.

In this algorithm, three main sections are;

- Renewable Energy
- Expenditure
- Iterative loop

In the renewable energy section, the information and parameters required for the electricity generation of the sources that will form the hybrid energy couple are entered. Also, if there will be any limitations in the calculations, it is reflected in the algorithm. Since solar energy is designed as a hybrid partner in all renewable energy sources, data for solar energy generation is entered separately. These data mainly consist of information such as coordinates, radiation, temperature, equipment, which affect electricity generation. The reason why solar energy is considered a direct hybrid energy partner is that it is accessible in most places regardless of location. Regarding the integrated hybrid structures, the solar energy potential is considered to be more available for all renewable energy sources.

The IRENA 2019 renewable energy cost report was used for cost reference [38]. Since the last published report belongs to 2019, the trend is sustained in renewable energy sources, which are in decreasing trend, and therefore the current cost values are determined by taking the common in renewable energy sources that don't have any trend. The present cost for solar power has been determined as 820 thousand USD/MW. This cost for wind energy has been accepted as 1.4 million USD/MW. Wind energy plant costs, which were 1.473 million USD/MW on a worldwide scale in 2019, are updated with the prediction that the downward trend will continue. For geothermal energy facilities, the installed capacity cots between 2010-2019 on a world basis are given within the report. No investments were made in 2011, and extreme cost realizations were experienced in 2010 and 2012 compared to other years. Therefore, the value of the geothermal investment has been taken because the average of the remaining 7 years and a price of roughly 3.75 million USD/MW has been accepted. The worldwide costs for biomass energy plants between 2010 and 2019 are given within the report. Since there's no link and trend between the value incurred between years, approximately 2.3 million USD/MW is estimated because the cost of biomass energy by averaging the prices incurred between 2010-2019. Equations are given in below for iterative optimization. The optimization function is the most point of the total. It is a function of potential, capacity utilization rate, and costs.

$$Cost\ (x) = \ Renewable\ (x) + iter.solar\ cost \tag{6}$$

$$\text{Loop(x)} = Ps/Cost\ (x) \tag{7}$$

$$foptimum(x) = \max\left(\text{Loop(x)}\right) \tag{8}$$

Where, $\boldsymbol{Cost}$ is the cost of renewable and solar energy, $\boldsymbol{x}$ is the hybrid couple, $\boldsymbol{Loop}$ is the iterative loop of the algorithm, $\boldsymbol{foptimum}$ is the optimal point of the algorithm. It is too simple and effective method for making a hybrid availability and installed capacity decision. A case study is performed for clarification of this algorithm.

3. RESULTS AND DISCUSSION

A case study is carried out for explaining the algorithm. The installed capacity of the integrated hybrid energy decision is obtained from the algorithm. For the case study, one of the hybrid partners was chosen as solar energy and its parameters were applied in the algorithm. Geothermal, wind, hydro, and biomass energy were chosen as other renewable energy partners. The reason for choosing these sources is that they are the most widely used sources. The facilities located in the Aydın province of Türkiye were selected for the selected renewable energy sources. In Fig. 2 below, location information about the relevant facilities is given

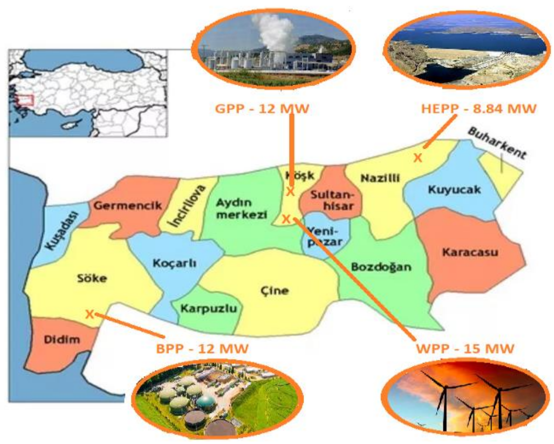

Fig. 2. The location of existing renewable energy projects

Project characteristics is given in the Table 1 below.

Table 1. The hydropower plant project's characteristics

	HEPP	GPP	WPP	BPP
Installed Capacity (MW)	8.84	12.00	15.00	12.00
Electricity Generation (MWh)	8,385	66,295	43,897	81,865
Capacity Factor (%)	10.83	63.07	33.40	77.88

Türkiye has rich potential in terms of clean and sustainable energy sources. Under normal conditions, it is too hard to see renewable facilities, which have very different characteristics from each other, located at short distances. The facilities given in Aydın province are both close to each other, and facilities were selected to observe the results of the algorithm. The data of the facilities were obtained from the Energy Exchange İstanbul (EXIST) transparency platform. This platform provides an opportunity to share generation data for energy market companies. The main acceptances of this study, are given in below;

- GPP is the geothermal energy power plant
- SPP is the solar energy power plant
- HEPP is the hydroenergy power plant
- WPP is the wind energy power plant
- BPP is the biomass energy power plant
- SHE is the hybrid solar hydro energy
- The GPP's economic lifetime is accepted as 20 years
- GTC Solar GG1H-72-430-450 450 Watt PV panel's technical specification is used as solar energy parameters
- The meteorological data is addressed to the Turkish State Meteorological Service
- The daily-based radiation is addressed on the NASA website.
- The hourly based irradiance of the location is performed by the empirical method
- The integrated hybrid power results from the algorithm
- The IRENA 2019 report parameters are used for calculating the existing renewable energy facilities' cost and expenditure
- The real electricity generation of renewable facilities is obtained from EXIST (Energy Exchange İstanbul) platform
- The iterative loop is formed by 1,000 steps
- Per step is stated as 25 kW

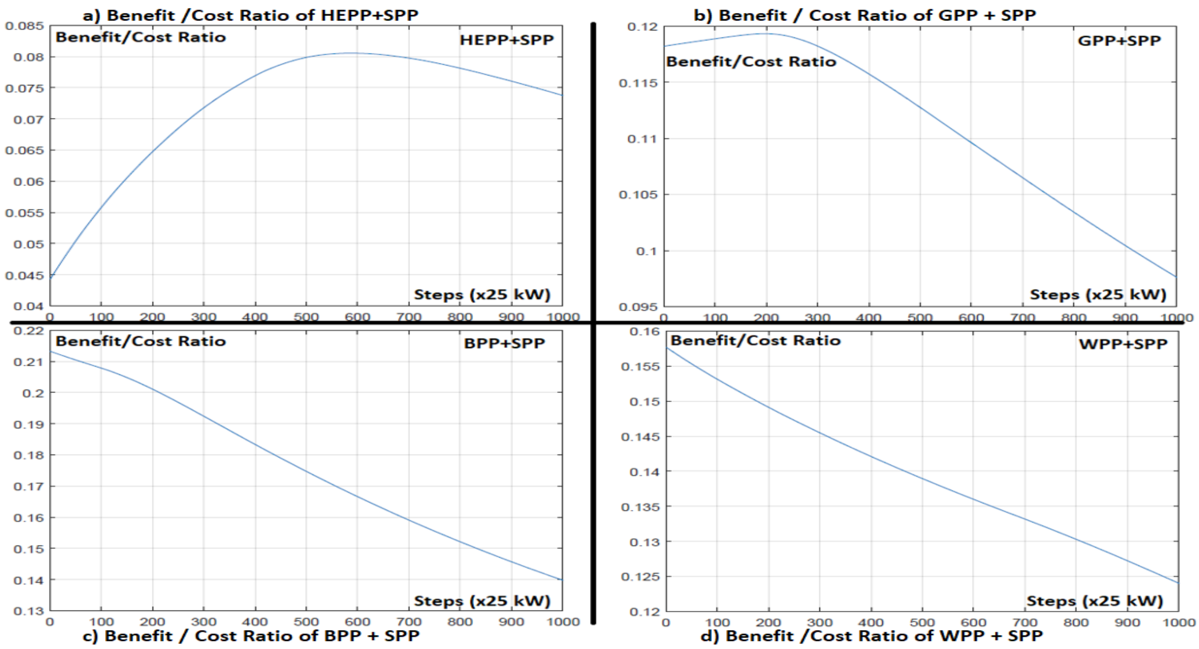

Fig. 3. The benefit / cost ratio of a) HEPP+SPP, b) GPP+SPP, c) BPP+SPP, d) WPP+SPP

- The GPP facility is a binary type plant
- The SPP's and WPP's economic lifetime are accepted as 25 years
- The HEPP's economic lifetime is accepted as 50 years

The algorithm gives the optimum point of integrated hybrid renewable energy systems. The algorithm was applied to all renewable energy sources one by one. The results obtained as a result of the application are given in Fig 3.

When the algorithm results are examined, it has been revealed that using hybrid energy in wind and biomass energy is not meaningful. The main reason for this conclusion can be shown as the irregular energy generation of wind energy and its generation profile that often intersects with the solar energy system. In biomass energy, it is thought that a negative result is obtained as the energy benefit that can be obtained as a result of its high capacity utilization rate is far below its cost. Since the capacity utilization rate of hydro energy is very low, a hybrid energy proposal compatible with solar energy has emerged. In geothermal energy, unlike solar energy, the decrease in generation in summer and increase in winter months made hybrid energy meaningful. As a result of the algorithm, the electricity production of hydro and geothermal energy facilities, which can be installed as possible with solar energy, is given in Fig. 4. and Fig. 5.

As a result of the algorithm, step 596 for hydro energy yielded the most suitable hybrid energy result. The solar installed power corresponding to this step is 14.9 MW. This result shows that hybrid energy can be applied with a larger capacity than the existing hydropower plant. With the implementation of the designed hybrid energy, the capacity utilization rate of hydro energy rises from 10.83% to 36.86%. Likewise, step 196 for geothermal energy showed the viable hybrid energy point. In response to this step, a hybrid energy facility with an installed capacity of 4.9 MW, working in harmony with geothermal energy, can be established. In this design, the capacity utilization rate of geothermal energy rises from 63.07% to 70%.

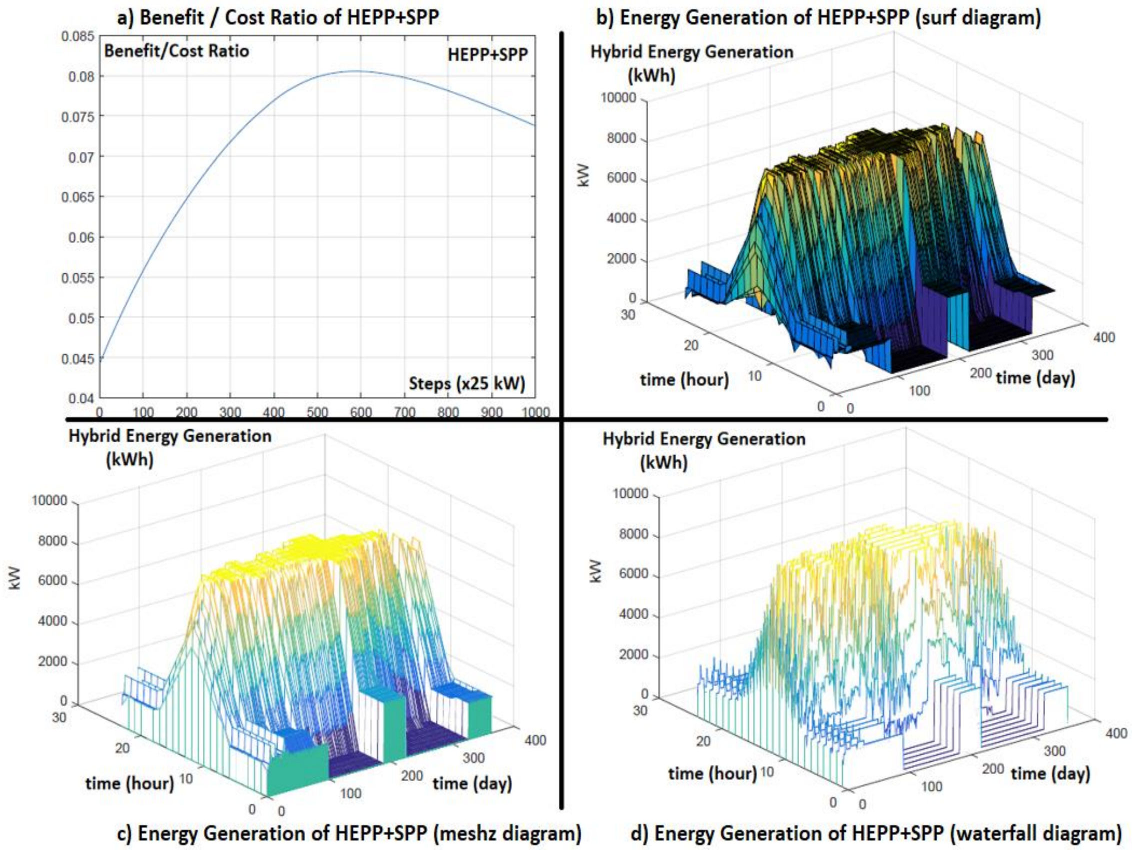

Fig. 4. The optimization of the SHE system (HEPP+SPP), a) Benefit / cost ratio of SHE system, b) Energy generation of SHE (surf diagram), c) Energy generation of SHE (meshz diagram), d) Energy generation of SHE (waterfall diagram)

The comparison of the renewable hybrid energies is given in Table 2.

Table 2. The summary of the renewable hybrid energies

	SHE	GPP+SPP	WPP+SPP	BPP+SPP
Hybrid Installed Capacity (MW)	14.9	4.9	-	-
Hybrid Elec. Generation (MWh)	28,543	73,645	-	-
Renewable Capacity Factor (%)	10.83	63.07	33.40	77.88
Hybrid Capacity Factor (%)	36.86	70.00	-	-

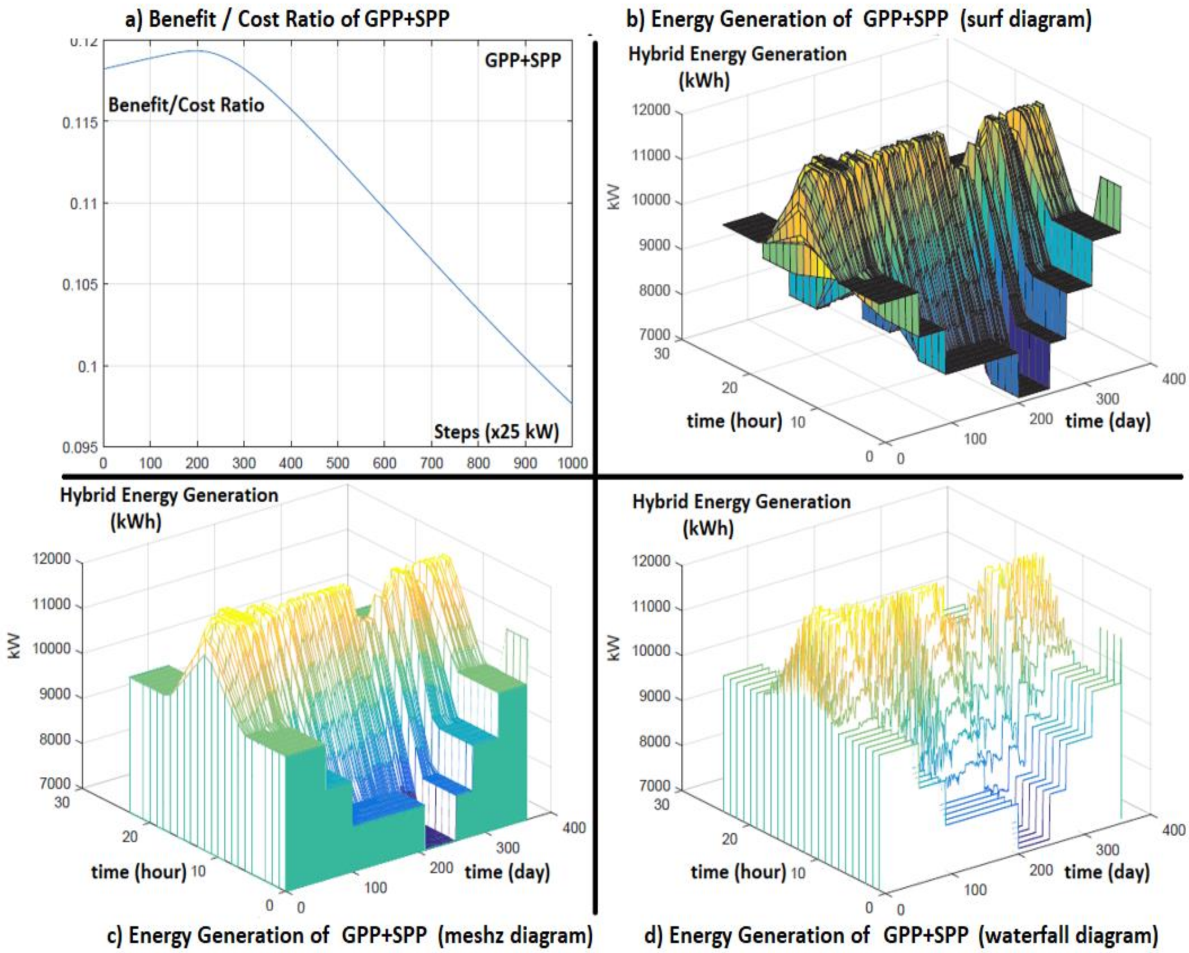

Fig. 5. The optimization of the GPP+SPP system a) Benefit / cost ratio of GPP+SPP system, b) Energy generation of GPP+SPP (surf diag.), c) Energy generation of GPP+SPP (meshz diag.), d) Energy generation of GPP+SPP (waterfall diagram)

4. CONCLUSION

The main result of this study is summarized below paragraph;

Energy management and appropriate energy acquisition have always remained important. Energy crises in recent years have led countries to find different solutions. In recent years, renewable energy is one of the sources that continue to rise globally. In the next stage, it is thought that renewable energy will continue to grow as hybrid energy. Hybrid energy both enables the management of existing energy and offers more cost-effective solutions. The issue of which renewable energy facilities can work in harmony with each other is on the agenda of many researchers. An algorithm has been developed to find the most suitable hybrid renewable energy pair. In this algorithm, solar energy is accepted as a natural partner of hybrid energy. The main reason for this can be shown as the high availability potential and affordable cost of solar energy. A case study was conducted to better explain the algorithm. Aydın province, which contains all renewable energy facilities, was chosen for the case study. The designed algorithm has been applied to existing renewable energy facilities with similar installed capacities and located within the same province. Wind, hydro, geothermal, and biomass energy facilities are considered the main renewable energy sources. The algorithm run in step with the benefit/cost methodology and also the total energy obtained from hybrid energy therefore the planned costs for this energy were compared. Within the existing wind and biomass power plants, a meaningful installed power optimization couldn't be made because of the overlap within the energy periods (day time generation) obtained from solar energy. In geothermal and hydro energy, solar energy has emerged as an acceptable hybrid couple because of the difference in generation profile. It's possible to ascertain an alternative energy plant with an installed power of 14.9 MW for hydro energy and 4.9 MW for geothermal energy. With this hybrid alternative energy plant which will support hydro energy, the capacity utilization rate will increase from 10.83% to 36.86%. In the geothermal, it's possible to extend the capacity utilization rate from 63.07% to 70%. With this designed algorithm, it will be determined which renewable energy pairs would be more suitable. The designed algorithm offers a straightforward and reliable decision mechanism. Regarding the outcomes, hydro and geothermal energy gave the best results for a hybrid application that can be made with solar energy. The main reason for this can be considered as the production characteristic of hydro and geothermal energy. Within the scope of hybrid structures, it will be possible to use the existing electricity infrastructures more efficiently without incurring additional costs.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mahir DURSUN: Conceptualization, Methodology, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing.

M. Fatih SALTUK: Conceptualization, Methodology, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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