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Determination of Hybrid Renewable Energy Systems for Project Type Public Library Building

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Abstract- In this context, the most convenient hybrid renewable energy system (HRES) option for the public libraries, which give services in the project type service buildings within the General Directorate of Culture and Tourism Ministry, will be chosen by evaluating the potentiality of renewable energy sources of region. In this way, both the usage of the most convenient energy source and the efficient usage of energy will be supplied. The public Library in Kirklareli City has been chosen as the example for the project type service building in this study. The most convenient option among HRES options is determined by evaluating the all energy sources potentiality of Kirklareli for the service building of Kirklareli City Public Library. It is calculated that the most appropriate HRES is PV/wind/battery for the library. The predicted total project cost of HRES is estimated to be 119,492$ and unit energy cost is determined as 2.01$/kWh for the library.

Keywords Keyword1, Public library; Renewable energy; Hybrid renewable energy systems; Kırklareli City Public Library.

1. Introduction

The energy is one of the significant parameters playing role in increasing the life standards and determining the socio-economic development level of countries. A great amount of the current account deficit of Turkey, which imports 70% of its energy demand, stems from the energy import. Thus, Turkey is dependent on foreign countries in terms of energy. In addition to this, fossil fuels cause some environmental problems, therefore, the use of alternative and renewable energy sources is necessary. The renewable energy sources are environmentally friendly, clean, abundant in nature, based on the type of source, technologically developed and potentially local. The renewable energy technologies have the strategic importance in protecting environment, decreasing the CO_2 emissions and reaching the sustainable economic developments. It is possible to generate the electricity from the renewable energy sources. These sources have environmental benefits compared to the traditional energy sources [1,2]. In 2023, 530TWh electricity demand is envisioned and the Turkish government plan to supply 30% of demand with renewable energy resources [3].

The renewable energy sources are basically wind, hydro, biomass, solar and geothermal energies. In order to generate electricity from these energy types, there must be sufficient resource potential. For example, in order to benefit from the geothermal energy source, there must be hot water sources and the heat level of the water must be adequate for the energy production [1]. Otherwise, it is not possible to talk about the use of this energy or the useful energy production. Similarly, in order to benefit from the biomass energy sources, forest, animal and organic wastes can be used. Nowadays, the solar and wind energy are popular renewable energy sources. The solar and wind energy types are local power producing sources. The solar and wind energy sources cannot independently carry out the sustainability of energy because of the seasonal and periodical changes. In order to overcome these constraints, the hybrid power systems based on the wind producing elements must be combined with battery storage systems [4-7]. There are many studies related to the use of renewable energy sources and to the production of energy from these sources, and to HRES which is the most convenient option in the literature. There are a lot of papers about HRES in the literature. Some of them are summarized below. Khan and Martin have evaluated techno-economic aspects of hybrid renewable energy system integrated with membrane distillation as a sustainable means of providing cooking gas, electricity, and arsenic-free water applied to rural and remote areas of Bangladesh. They have conducted

to technical assessments and optimization using with HOMER. Results show that electricity demand can be met with such a system while simultaneously providing 0.4 m^3/day cooking fuel and 2-3 L/day pure drinking water per person [8]. Elhadidy and Shaahid put forth a system suggestion such as PV/wind/diesel HRES and various combinations of these systems components. The most convenient of these systems is PV/wind HRES, which is supported by the diesel generator, and it has been planned to supply the electricity demand of Zahran city in Saudi Arabia via the HRES [9]. In this study, which consists of a similar combination, Al- Badi has investigated the techno-economic feasibility of the hybrid PV/wind/diesel power generating system in order to supply the electricity demand of Al Hallaniyat Island [10]. Moharil and Kulkarni have realized the performance analysis of PV system installed in Sagadeep Island in West Bengal region of India [4]. Alvarez and his colleagues have proposed an optimization technique, branch and cut algorithm, to design hybrid isolated microgrid in Unguia. The proposed hybrid power generating system is considered with two different storage system to supply the current load demand of the region [11]. Celik has investigated the annual system performance of autonomous PV- wind hybrid energy systems with battery storage [12]. Ma has techno-economically realized the feasibility of PV/wind/battery hybrid power system. Finally, the performance of system has been investigated in detail [13]. Maklad has investigated the potential and the convenience of electricity production from the wind-solar hybrid power system for the buildings in Australia. Consequently, he has realized that the efficient and economical usage of wind-solar HRES is possible [14]. Ramoji and Kumar have put forth a new approach for the optimum economic sizing of wind-solar hybrid system in terms of economy and ecology. They have used various optimization techniques for the design of hybrid solar and wind system [15]. This study aims to focus on the options of HRES which will be used in supplying the energy demand of the service buildings of public libraries used commonly as a project model nowadays, and built in many cities and counties, by Culture and Tourism Ministry, especially in 1990s in Turkey [16]. In this context, the most convenient HRES option for the public libraries, which serve in the project type service buildings within the General Directorate of Culture and Tourism Ministry, will be chosen by evaluating the potential of energy sources of region. In this way, both the usage of the most convenient energy source and the efficient usage of energy will be supplied. The public Library in Kirklareli City has been chosen as the example for the project type service building in this study. The most convenient option among HRES will be determined by evaluating the potential of renewable energy sources of Kirklareli for the service building of Kirklareli City Public Library.

2. The public libraries as a place

There are many definitions about the public libraries which are the social institutions giving service based on education, culture, information and leisure time activities related to the democratic and social development without making any kind of discrimination among the community members [17,18]. In the book of IFLA, which is considered as one of the main sources about the public libraries, called " Public Library Service: IFLA/UNESCO Principles for Development", the public libraries are defined as "the institutions that are built, supported and funded by local, regional or national managements or other social foundations; enable access to many studies which are the products of imagination and information via various sources or services; give equal services to every fraction of the society without making discrimination in terms of race, nationality, age, gender, religion, language, economy, insufficiency, profession and education difference" [19]. In other words, the public libraries are the democratic institutions that help to supply a peaceful world, affect to realize the economic, social, educational, cultural and technical development of society, enable to form a healthy public opinion by integrating into society, supplying lifelong education and leisure time activities to the service of humanity by presenting the cultural products and information to humanity via all kinds of library materials and various communication ways without making discrimination in terms of gender, age, race, nation, religion, language, education, culture, social-economic status and political difference of opinion [20]. The main aims of the public libraries are to develop education and give services such as cultural, technological activities and entertainment, to every user from any age group [21]. In other words, it can be said that the public libraries can be efficiently used by every fraction of the society and is one of the main aims of society [18]. Like other organizations, the public libraries are organizationally based on the existence of definite inner elements and the combination fit for the purpose. The libraries need five main factors to carry out their aims and functions. These are; user, collection, budget, staff and building [22]. The building is the place where the public library service is given. The construction of the public library buildings, which are posited in a center place, physically attractive, modern, and supply the need via computer, technical tools, lighting, heating and ventilation facilities, and have table, chair and shelves designed according to the comfort of the users and have the necessary facilities for the disabled users, is among the important conditions for giving the best service to the users [23].

The building is one of the most important elements in the public library service. The public library buildings must be designed to reflect the functions of the library service and be flexible enough to changing and to new services and accessible to everyone [19]. Especially, technology is an affecting factor in the spatial design of the public libraries as it is in many areas. Technology, among the modern library designs, is considered as a structural element of the library and become an element integrating the library and forming a new face of it [24]. The development in the construction technologies, which started in 20th century and gained raise in 21st century, allowed the usage of different materials and designs and affected the public library buildings in the newly constructed library buildings.

It is seen that the concepts and approaches such as the applications of smart buildings in newly constructed public libraries, green building concept, the usage of renewable energy sources, which are peculiar to information society

buildings, are used nowadays [25-27]. In the words of Muscogiuri, [28] "In the design of public libraries of the information society, the quality of goods and architecture, the flexibility, economic sustainability and environmental sustainability are the key words". Briefly, the public libraries which give information and culture services to every fraction of the society must be organized with a modern understanding and a perspective fit for a developing technology. The inner and outer designs of the public libraries are interdisciplinary process and related to many various disciplines. The cooperation that the librarians will constitute with the energy systems engineers, architects and other experts in the usage of renewable energy sources in the public libraries will provide the spatial design in the public libraries with health and functionality as part of our project [29].

3. Hybrid renewable energy systems (HRES)

The types of HRES are named in accordance with the type of source from which the energy will be produced. Energy is generated efficiently with the usage of wind, solar, ater, animal and plant wastes. More than one of these sources come together and form the hybrid power generating system via the hybrid method. In order to evaluate the above-mentioned energy sources efficiently and effectively, the source type, which will be used in the energy production, must have sufficient potential in the place where they will be used. The potential of source may not be enough in the place where the energy production process will take place. In this situation, the aimed and planned energy production level out of HRES will not be realized. Thus, the duration of compensation of depreciation cost of the realized energy investment will be increased. Otherwise, dead investment will take place.

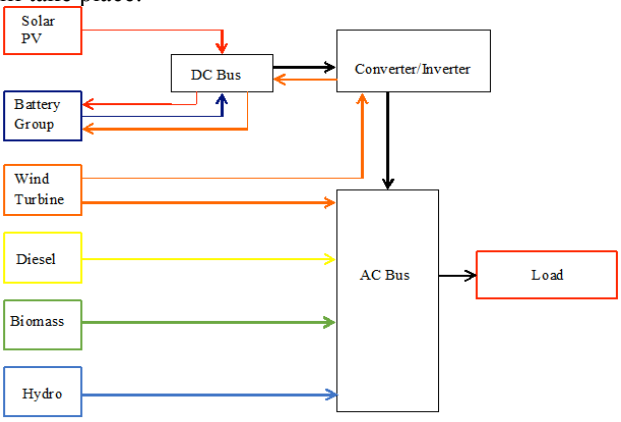

Fig. 1. The general schematic demonstration of HRES

HRES are classified in two categories. Grid connected and Stand-alone HRES. In the formation processes of these HRES, in the region where this system will be established, the load of the place that will be used, the access to grid and the current situation of the energy sources in the region play important roles. The most convenient HRES configuration is created by solving the optimization problem and taking into consideration all these parameters. In this solved HRES, the fractions of energy sources in the HRES (wind and solar) are determined, by considering the general situation of the energy sources of region, so as to compensate the load demand of the place used. Some of the grid connected HRES are PV/Wind/Battery, PV/Battery, Wind/Battery HRES. The main components in these HRESs are wind and/or solar energy, battery, converter. The main energy source in wind/PV/Battery HRES are wind and solar energy. It is possible to produce energy via wind turbine and solar panels. The energy produced from the wind turbine is directly used by the consumer. If it is insufficient, then in this situation, DC power converters in the battery groups will be converted to AC power and the necessary energy is obtained. The solar panels play an efficient role in charging the battery groups since they are connected to DC bus. If the battery groups are full, then the solar panels directly support the load via converters. Although the unit cost of the electricity produced from the grid connected hybrid system is more expensive than the electricity bought from the grid, it will be possible to produce clean electricity in parallel to the percentage being of the renewable energy in the HRES. The stand-alone HRES are rather used in the places where the city electricity cannot be reached, or the transportation cost is high. The electricity gained via these systems are produced from the renewable energy sources at the rate of one hundred percentage. The fact related to these systems must not be ignored. The renewable energy sources are originally discontinuous energy sources, therefore, a supportive energy provider such as diesel is needed in this kind of hybrid energy system. In this way, when there is no wind or solar energy, this supportive energy unit provides continuous electricity [1-3]. The items for the selection of the most convenient hybrid system for the public library example are below:

- The place where the public library is located (Center/out of town)
- The energy demand of the library
- The situation of the regional energy sources (wind/solar)
- The realization of the cost analysis of the possible HRESs (PV/Wind/Battery, PV/Battery, Wind/Battery etc.)
- The best selection of HRES

In order to answer the question "which hybrid system is the most convenient one?" we must consider the potential of regional renewable energy sources, the energy demand and the unit cost of produced electricity. For example, if the regional wind energy characteristic is under average, the establishment of a hybrid system based on the wind energy will not be economic. All the possible HRES must be considered and the most convenient one must be preferred. On considering the renewable energy potentials of 7 regions in Turkey, it is seen that Marmara, Aegean and South East Anatolia are pioneer lands in terms of wind energy potentiality [30].

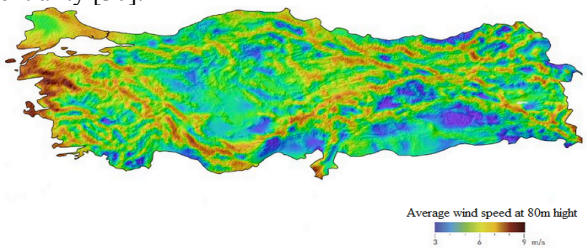

Fig. 2. The wind energy map of Turkey

The South Anatolian, Aegean and Mediterranean regions are pioneer regions in terms of insolation rates. In Figure 3, the wind energy map of Turkey is seen [31,32]. For example, the wind and solar energy of the region for a public library in Aegean region can be evaluated via the maximum measurements. The most convenient hybrid system is determined by carrying out the processes given above.

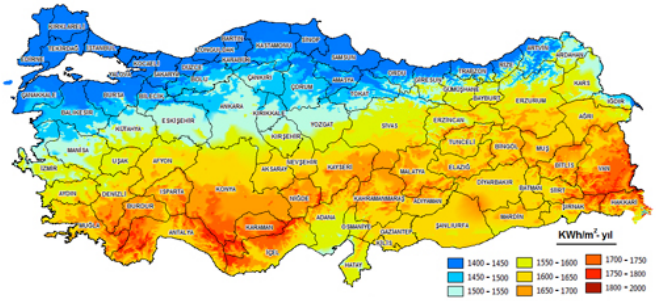

Fig. 3. The solar energy map of Turkey

4. The Design and Evaluation of HRES for the Buildings of Project Type Public Libraries in Turkey

As a result of the public administration based on mainly central government, a large number of the public libraries carry out their services depending on the General Directorate of Libraries and Publishing which is the main service unit of Culture and Tourism Ministry. The services of these libraries are planned by the General Directorate of Libraries and Publishing. The necessary funding, staff, collection and building are supplied by the same unit. The activities such as creating strategy, standards, legal structure, controlling and new service areas are carried out by the central government [22, 33-35]. The design, construction and planning of the service buildings of public libraries are done by the General Directorate of Libraries and Publishing of The Culture and Tourism Ministry.

Table 1. Type project details of Library Building

Sections/Parts	Descriptions
Child Section	This section is about the written and visual materials for children
Exhibition Hall	The hall in which sundry works of art are displayed
Conference Hall	The hall in which the conferences and panels are periodically carried out
Internet Hall	This section has been formed in order that the users can make researches via internet
Adult Hall	This section is about the written and visual materials for adults
Kırklareli archive section	This section has books, periodical publishes and sources about the history and culture of Kırklareli
The works written in Ottoman language	This section has the published works written in Arabic alphabet before the adoption of the Latin Letter
The women studies hall	This section is about the written and visual materials for women.

Especially in 1990s, unique type service buildings which are also called the project type public libraries in many cities and counties of Turkey were built. Nowadays, these buildings are commonly used by the public libraries. Although the energy consumption of these library buildings varies, the structure of these buildings is the same. The example building in this study "Kirklareli City Library" is a project type building. The details of the library segments are shown in Table 1.

The consumed electrical energy in the departments shown in Table-1 constitutes the basic electricity demand of library building. The number of active computers in the internet hall is 28 and the large amount of the energy demand is done by the computer and lighting loads. The load demand of Kirklareli City Public Library is shown in Fig. 4.

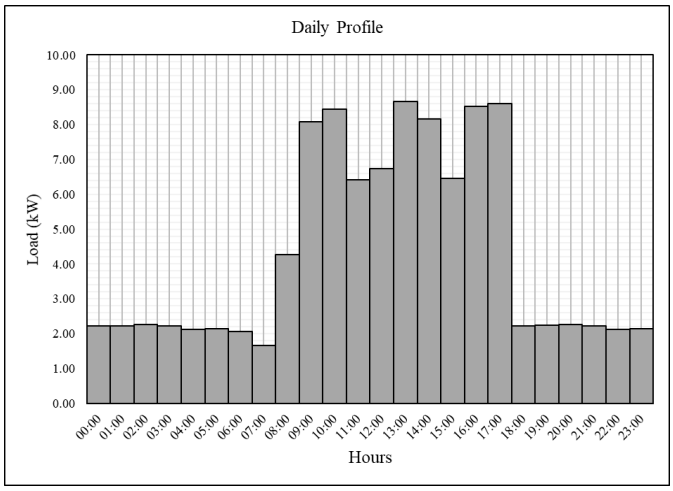

Fig. 4. The load demand of Kırklareli City Public Library

When the load demand is investigated, the minimum and maximum load consumption rates are 1.659kW, 8.672kW in Fig. 4. The load demand in hourly basis is planned to be supplied by the most convenient HRES. According to the load data, the minimum load demand occurs between 00:00 and 06:00 o'clock. Load profile of the public library is demonstrated in Fig. 4. In summer, load demand is bigger, because air conditioning systems in offices are used more. For summer, maximum value of the hourly load demand is 11.5 kW which occurs between 12:00 and 15:00.

When the wind speed data of Kirklareli city is investigated, it is seen that the minimum and maximum wind speed rates are respectively 4.30m/s, 5.5m/s.

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^{k}} \quad (1)$$

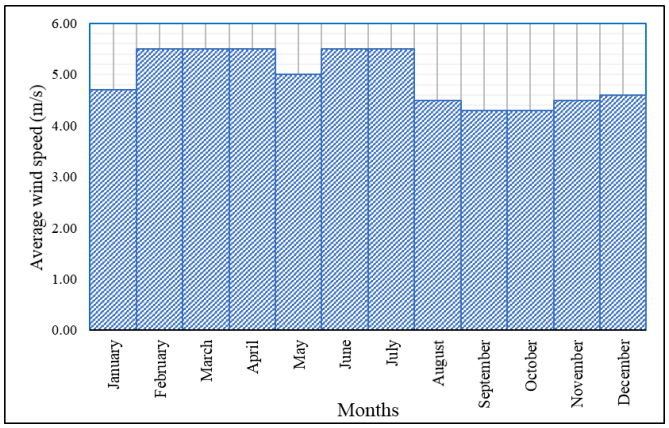

Fig. 5. The average wind speed rates in monthly basis

As it is seen in Equation (1), the wind speed data of last three years is evaluated by using the probability density distribution function of wind energy. There are many methods for finding the k and c parameters. The most common one in the literature is the graphic method. As a response to the speed evaluation spaces, cumulative frequency data is gained. The transformation process has phases as they are shown below.

$$x_i = \ln(v_i) \tag{2}$$

$$y_i = \ln\left[-\ln(1-p_i)\right] \tag{3}$$

k and c parameters $y = ax + b$ are shown with the fixed linear equation. k and c parameters are gained with equation (4) and equation (5).

$$c = \exp\left(\frac{-a}{b}\right) \tag{4}$$

$$k = b \tag{5}$$

The relation between xi and yi is obtained by using a and b coefficients in the right equation of the ax+b form. K and c parameters are measured by considering these coefficients. In this way, k=2.25 and c=4.52m/s are measured by using the graphic method [31, 36,37]. The latitude and longitude of Kirklareli is 41° 44' N ve 27° 13' E. When the solar radiation data in 2018 is evaluated via HOMER software, it is seen that the average annual solar radiation is 3.912kWh/m^2/d and the average annual clearness index is 0.470. The HOMER software analyzes the solar radiation data via Graham algorithm [38]. When the solar and wind data of Kirklareli city is evaluated, it is seen that the wind and solar energies of this city have enough potential for the installation of a little strong HRES.

Cost of energy (COE) and Net present cost (NPC) elements of this system have been taken into consideration by focusing on the economic parameters when the modelling process is carried out. COE defines the NPC as the average cost/kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production. The equation for the COE is as follows [39]:

$$CoE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC}} \tag{6}$$

In this equation: $C_{ann,tot}$ is total annualized cost [$/year], $E_{prim,AC}$ is AC primary load served [kWh/year], $E_{prim,DC}$ is DC primary load served [kWh/year]. The lifetime of the project is considered as 20 years. All systems are ranked according to net present cost, and all other economic outputs are calculated by using the NPC. The NPC is calculated according to the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \tag{7}$$

In this equation $C_{ann,tot}$ is total annualized cost [$/year], CRF is capital recovery factor, i, real interest rate [%], R_{proj} is project lifetime [year] [39].

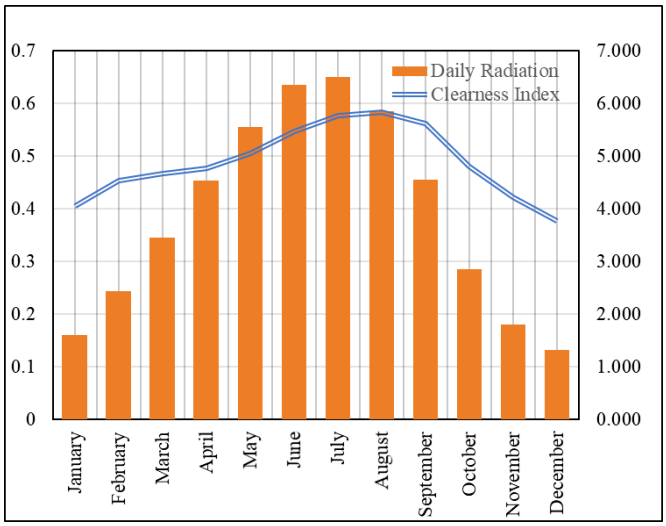

Fig. 6. The solar radiation data in Kırklareli

In this context, the 1 kW unit price of the selected PV panel is 7200 dollars. The panel changing cost is 6000 dollars and maintenance and reparation cost is 20 dollars. There is no controlling via solar pursuit system [40]. The output of panel is DC and the lifetime of it is 20 years. The DC output of BWC Excel R is 7.5kW and cut in speed of BWC Excel R is 3m/s, rated speed is 12m/s and cut-out speed is 23m/s. The unit price of wind turbine is 25570 $. The cost of panel replacement is 15000 $ and maintenance cost is 3000 $/year [41]. Surrette 6CS25P has been selected for the energy storage in the hybrid system. Nominal capacity and voltage are 1156Ah in 6V. The energy amount stored in a battery is 6.94kWh. The performance is %80 and the beginning, change and operation &maintenance costs are respectively 1100$, 1000$ and 10$/year [2]. The power converters function as converting into DC-AC system in the hybrid system, the costs and change of installation of a system of 1kW are respectively 800$ and 750$ [42]. The simulation of system can be carried out after all the components of the HRES which will be developed for Kirklareli City Public Library, have been identified.

5. Result and Discussions

Optimum size of the components (wind turbine, PV panel, battery bank, power converter) in the hybrid system is determined by the HOMER simulation tool, taking the technical characteristics into consideration and minimizing total net present cost of the system. Moreover, the optimum HRES type (wind/battery, PV/battery and Wind/PV/battery) is determined by taking a number of components into account. When the simulation of HRES that will be developed for Kirklareli City Public Library is carried out, the parameters of the sensitivity analysis of system must be known. In this study, the parameters of wind speed and solar radiation have been considered for the sensitivity analysis. The wind speed ranges between (4m/s – 8m/s) and the solar radiation ranges between (3.2kWh/m^2/d-4.8 kWh/m^2/d). In Figure 7, the simulation result of the HRESs is shown.

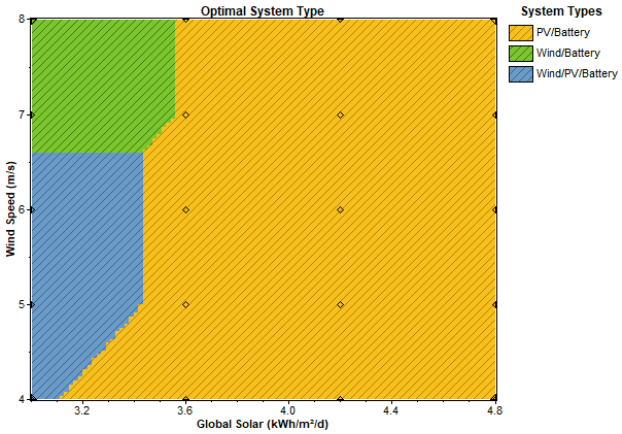

Figure 7 Simulation Result of the HRES

When the simulation result is investigated, it is seen that the place marked in blue in the simulation with the wind speed from 4m/s to 6.5m/s and the solar radiation between 0-3 kWh/m^2/d is the most suitable place the wind/solar/battery HRES. Similar to this, the place marked in green with wind speed value from 6.5m/s to 8m/s and 0-3.4 kWh/m^2/d is the most suitable place for the wind/battery HRES. The place marked in yellow with wind speed value from 4m/s to 8m/s and 2.8 - 4.8 kWh/m^2/d is the most suitable place for the solar/battery HRES.

Project type Public Library Buildings have been built in the same structural properties everywhere in Turkey. Therefore, the electrical load demand of all public libraries is the same with Kırklareli Public Library. This demand can be met by using different HRES configurations. The HRES configurations are determined by analyzing potential of renewable energy sources. For instance, Small hydropower plant can alternatively be evaluated in the optimum HRES configuration in Black Sea region due to the fact that hydropower potential of these region is high. Besides, since in eastern Anatolia farming and animal husbandry are more popular, biomass energy can also be included in the analysis for this region.

6. Conclusions

While determining the most suitable HRES for Kirklareli City Public Library, an evaluation based on the wind speed value and solar radiation data is carried out. HRES configurations for Kirklareli City Public Library are wind/solar/battery, solar/battery and wind/battery. The most suitable system among HRESs has determined as wind/solar/battery after the result of sensitivity analysis. Kirklareli City Public Library is named as a project type building for the Public Libraries of Culture and Tourism Ministry in Turkey. Since the energy amounts consumed related to this type of project will be close to each other, similar studies for the other cities in Turkey can be carried out by applying only a change in the source type. The predicted total project cost of HRES for Kirklareli City Public Library is calculated as 119,492$ and unit energy cost has been determined as 2.01$/kWh.

This configuration consisting of solar and wind energy sources is applied for Kırklareli city because of the high potential of the sources, while in other regions, other alternative renewable energy sources such as Biomass, hydro etc. can be preferred according to their potential.

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