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Research Article

Meeting of Energy Demand for Irrigation of Off-Grid Agricultural Land by Solar-Wind Energy System with Battery Storage

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Abstract

In this study, techno-economic and environmental feasibility analyzes of meeting the electrical energy required for irrigation need of agricultural land of 10,000 m^2, which is considered to be independent of the grid, in the rural area of Polatlı district of Ankara, with a solar-wind hybrid renewable energy system, were carried out using HOMER-Pro software. The electrical load required for irrigation was determined as 64 kWh/day. In addition, it is assumed that the electrical load of a house with an electrical load of 11.25 kWh/day close to the agricultural land will be met by the hybrid energy system to be installed. As a result of the examinations, it has been determined that the use of the hybrid energy system with solar-wind power to be created with a solar panel of 22.1 kW, a maximum power point tracking (MPPT) of 8 kW, a wind turbine of 10 kW, 138 pieces of 1 kW lead-acid batteries and a converter of 13.3 kW exhibited the most appropriate results. In this case, 41.8 % of the electrical energy to be obtained will be met from solar energy and 58.2% from wind energy, and electrical energy of 55,765 kWh will be produced annually. It has been determined that the initial investment cost of the system to be established is 405,536 ₺, the net current cost is 882,950 ₺, the cost of the electricity produced is 1.53 ₺/kW, and the investment will pay off in 9 years. In addition, it has been found that the amount of CO_2 to be released into the atmosphere will be 17,358 kg/year if the required electrical energy is met from the grid.

Keywords: Hybrid energy systems, Solar energy, Wind energy, Energy storage, Feasibility analysis.

Şebekeden Bağımsız Tarım Arazisinin Sulama Enerjisi İhtiyacının Batarya Depolamalı Güneş – Rüzgar Enerji Sistemi ile Karşılanması

Öz

Bu çalışmada, Ankara'nın Polatlı ilçesinin kırsal kesiminde şebekeden bağımsız olduğu kabul edilen 10,000 m^2'lik bir tarım arazisinin sulama ihtiyacı için gerekli olan elektrik enerjinin güneş-rüzgar hibrit yenilenebilir enerji sistemi ile karşılanmasının tekno-ekonomik ve çevresel fizibilite analizleri HOMER-Pro yazılımı kullanılarak yapılmıştır. Sulama için gerekli olan elektrik yükü 64 kWh/gün olarak tespit edilmiştir. Ayrıca tarım arazisinin yanında elektrik yükü 11,25 kWh/gün olan bir evin de elektrik yükünün kurulacak olan hibrit enerji sistemi ile karşılanacağı varsayılmıştır. Yapılan incelemeler sonucunda, 22,1 kW'lık güneş paneli, 8 kW'lık MPPT (Maksimum güç noktası takip), 10 kW'lık rüzgar türbini, 138 adet 1kW'lık kurşun-asit batarya ve 13,3 kW'lık konvertör ile oluşturulacak güneş-rüzgar hibrit enerji sisteminin kullanımının en uygun sonuçlar sergilediği belirlenmiştir. Bu durumda, elde edilecek elektrik enerjisinin %41,8'i güneş enerjisinden, %58,2'i ise rüzgar enerjisinden karşılanacak ve yılda 55.765 kWh elektrik enerjisi üretilecektir. Kurulacak sistemin ilk yatırım maliyetinin 405.536 ₺, net şimdiki maliyetinin 882.950 ₺, üretilen elektriğin maliyetinin 1,53 ₺/kW ve yatırımın 9 yılda amorti edeceği tespit edilmiştir. Ayrıca gerekli olan elektrik enerjisinin şebekeden karşılanması durumunda ise atmosfere salınacak CO_2 miktarının 17.358 kg/yıl olacağı tespit edilmiştir.

Anahtar Kelimeler: Hibrit enerji sistemleri, Güneş enerjisi, Rüzgar enerjisi, Enerji depolama, Fizibilite analizi.

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1. Introduction

Considering the gradual decrease of fossil fuels and their negative effects on the environment, the use of renewable and environmentally friendly energies has considerably gained attention in the last decades. Moreover, renewable energy resources will play an important role in agricultural development, particularly in constructing fertile agricultural lands with no grid. Today, agricultural lands close to the city centers are turning into settlements due to the rapidly increasing population. For this reason, needed agricultural lands are moved to rural areas without an electricity grid. In rural areas, on the other hand, since the energy required for farming activities is generally met from diesel generators, there are serious increases in greenhouse gas emissions released to the atmosphere together with production costs. It is possible to face many previous studies conducted with hybrid energy systems to meet the energy required for agricultural activities in rural areas away from the grid. Syuhada et al. carried out feasibility analyses of a wind-solar hybrid energy system that met the electricity need of a 558 W water pump used for 2520 liters/hour water requirement of a 15-hectare agricultural land selected independently from the grid in Indonesia. According to the results obtained from the analyses, it has been determined that the initial investment cost of the system designed will be $14,938 and the system will produce 3,210 kW/year of electrical energy (Syuhada, et al., 2016). Campan et al. aimed to dimension and simulate the systems providing the energy required for irrigation of agricultural lands independent of the grid in China from solar and wind energies in their studies. They found that systems pumping water with solar energy provided more suitable dynamic simulation results than systems pumping water with wind energy. They also reported that incompatibility between irrigation water requirement and the amount of water pumped reduced crop yield (Campana, et al., 2015). Xiang et al. investigated the meeting of the irrigation water demand of cassava grown in a region of Guangxi province in China by a wind-solar hybrid energy system experimentally and theoretically. They reported that the hybrid pumping system supported by a 22kW solar panel and 44 kW wind turbines exceedingly met the irrigation demand of an area of 26.66 ha. They also reported that photovoltaic irrigation systems would be more beneficial due to the inconsistency of wind energy potential and high costs (Xiang, et al., 2017).

In this study, techno-economic and environmental feasibility analyses were conducted to meet the irrigation energy needs of an off-grid agricultural land in Polatlı district of Ankara province using a solar-wind hybrid energy system. This study aims to increase the region's agricultural activities, encourage renewable energy sources in rural areas with no electricity grid, and provide guiding information to researchers and investors interested in this subject.

2. Material and Method

2.1. Investigated Region

The economy of Polatlı district (39°36.5' N, 32°5.0' E) is mainly based on agriculture. The district has 383,675 decares of irrigated and 1,789,500 decares of non-irrigated agricultural land. Wheat, barley, sugar beet, melon and onion are among the most produced products. According to the 2020 census, 126,623 people live in the district, and the entire population lives in the city center (Wikipedia, 2021).

2.2. Investigated Farmland and Electrical Load

It has been assumed that the agricultural land in need of irrigation is 10,000 m^2 (100x100 m) and the irrigation process is done with a drip irrigation system with a flow rate adjustment. It is assumed that each drip irrigation apparatus is adjusted to deliver 1.1 L of water per hour and is mounted to the evacuation pipeline at 50 cm intervals. The irrigation of 22,000 liters per hour from a total of 20,000 water drippers where evacuation pipes of 16mm diameter (Ø16), which are assumed to be 100 pieces, are present has been made. A schematic representation of the irrigation system is presented in Figure 1.

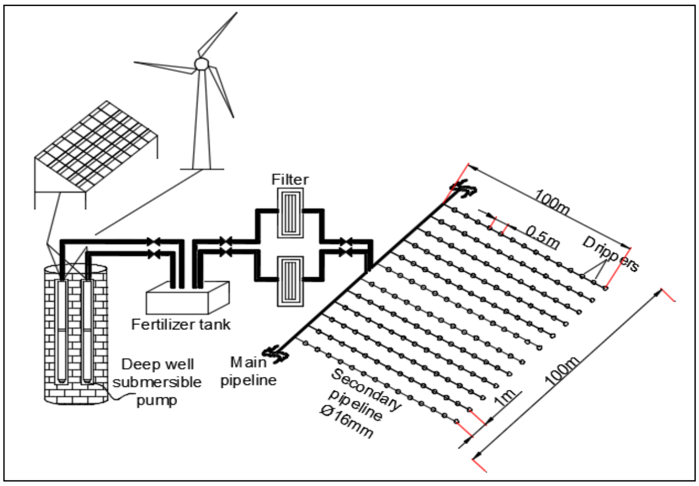

Figure 1. Schematic View of the Irrigation System

It is assumed that two deep well submersible pumps with a brand of Impo Sk 408/23 are used to meet the irrigation need of the agricultural land. The submersible pumps used are pumps with a capacity of 5.5 HP (4kW), single-phase (220V), 50 Hz, with a water flow rate of 12 m^3/h from 41m depth (İmpo water pump, 2021). Assuming that the pumps operate for eight hours a day, the electrical load required for irrigation was determined as 64 kWh/day. In addition, it is assumed that the electricity load of a house with an electrical load of 11.25 kWh/day, which can accommodate a farmer family of 4 and will be close to land area, will be met by the hybrid energy system to be established.

2.3. Wind and Solar Energy Potential of the Studied Region

Wind speed and solar radiation values of the studied region were obtained from the HOMER Pro software. The HOMER Pro software obtains this data from the NASA Surface meteorology and Solar Energy database. Monthly Average Solar Global Horizontal Irradiance (GHI) and Monthly Average Wind Speed data of the studied region are presented in Tab.1.

Table 1. Wind-Solar Data of the Studied Region

Month	Clearness Index	Daily Radiation ($kWh/m^2/day$)	Monthly average wind speed (m/s)
January	0.478	2.060	5.030
February	0.504	2.870	5.430
March	0.532	4.080	4.710
April	0.503	4.850	4.240
May	0.548	6.040	3.830
June	0.594	6.890	3.960
July	0.634	7.160	4.460

August	0.616	6.250	4.640
September	0.609	5.070	4.330
October	0.552	3.460	4.730
November	0.503	2.320	4.660
December	0.438	1.700	4.910
Average	0.543	4.400	4.580

When Table 1 is examined, it is seen that the annual Clearness index of the region is 0.543, the annual average GHI value is 4.400 kWh/m^2/day and the annual average wind speed is 4.580 m/s.

2.4. HOMER Pro Software and Examined System Elements

2.4.1. HOMER Pro Software

The HOMER Pro x64 3.11.2 (Microgrid software) software used in this study is software developed by HOMER (Hybrid Optimization of Multiple Energy Resources) by the United States National Renewable Energy Laboratory (NREL) to design and optimize microgrids (HOMER Pro, 2021). HOMER Pro can model the physical behavior of a micropower system, its life cycle cost (total net present cost), which is the sum of the system's initial cost of installation and operating costs over the system's specified lifetime. It allows the comparison of different design options within the framework of technical and economic values (Sekuçoğlu, 2012; Yımaz, 2008).

2.4.2. Solar Panel

The solar panel examined in the system is the CS6X-325P model polycrystalline solar panel produced by Canadian Solar Max Power. Panels; capacity is 0.325 kW, nominal operating temperature is 45 ºC, and efficiency is 16.94% (Canadian Solar panel, 2021). It has been accepted that the initial installation and replacement cost of 1 kW of solar panels is 6600 ₺, and the annual maintenance or repair costs are 60 ₺ (Canadian Solar panel price, 2021).

2.4.3. Maximum Power Point Tracking (MPPT)

The MPPT is a device ensuring that the voltage and current values of the energy coming from the solar panels are fixed and sent to the batteries, preventing the batteries from being overcharged and reverse current from the batteries to the panels. It has been accepted that the initial investment and replacement cost of 1 kW of MPPT device are 2000 ₺ (MPPT device price, 2021).

2.4.4. Wind Turbine

The wind turbine examined in the study is a wind turbine with a capacity of 10 kW and an EO10 model produced by the Eocycle Company (Wind turbine technical data, 2021). The rotor diameter of the turbine is 15.81 m, the hub height is 16 m and the life span is 20 years. In addition, environmental temperature effects were also taken into account in the calculations. It has been assumed that the turbine's initial installation and replacement costs are 120,000 ₺, and the maintenance and repair costs are 2,500 ₺ per year.

2.4.5. Storage

In the examined system, 12 V and 83.4 Ah lead-acid batteries with 1 kWh capacity were used. The efficiency of the batteries is 80%, the maximum charging current is 16.7 A, and the maximum discharge current is 24.3 A. It is assumed that one of the batteries is 750 ₺ and the annual maintenance costs are 75 ₺. Also, the initial state of charge is 100% and the minimum state of charge is 40%.

2.4.6. Converter

A converter with inverter and rectifier features was selected for the system. For the initial installation and replacement cost of the converter, 1kW is assumed to be 1,500 ₺. The lifetime of the inverter is 15 years, the efficiency is 95%, the relative capacity of the rectifier is 100% and the efficiency is 95%.

2.5. Hybrid Energy Model

Schematic representation of hybrid system designed by HOMER Pro software is presented in Figure 2.

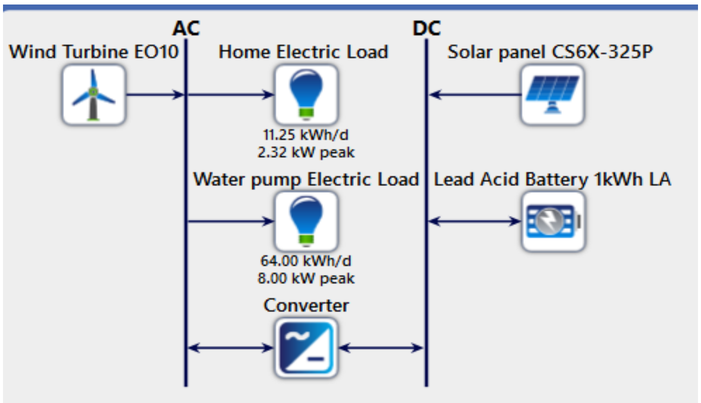

Figure 2. Designed Hybrid System Model

The lowest net present cost value (NPC) and the lowest unit energy cost (COE) were considered to select the most appropriate system. Also, in financial calculations, the nominal discount rate is 16.5% and the expected inflation rate is 14.90%. In this case, the real discount rate is determined as 1.39% by the HOMER Pro software. In addition, the project life is assumed to be 25 years.

3. Results and Discussion

According to the designed hybrid system model, 12,350 simulations were performed by the HOMER Pro software. Among these simulations, the two systems with the lowest energy unit cost and net present cost values were found to be more efficient than the other proposed systems. While the first system has solar panels, the second system does not have solar panels and MPPT devices, and produces energy only with a wind turbine. A comparison of these systems is presented in Table 2.

Table 2. Hybrid System Models

Components	1st model	2nd model
Solar panel (kW)	22.1	-
MPPT (kW)	8	-
Wind Turbine EO10	1	2
Lead Acid Battery (kWh)	138	464
Converter (kW)	13.3	13.2
Dispatch	CC	CC
COE (₺)	1.53	3.39
NPC (₺)	882,950	1.95x10^6
Operating cost (₺/yr)	22,754	64,089

Initial capital (₺)	405,336	607,731

When Table 2 is examined, in the 1st model, the initial investment cost, net present cost (NPC), unit energy cost (COE) and annual operating and maintenance costs of the system to be installed with several types of equipment, including a solar panel with a capacity of 22.1 kW, an MPPT with a capacity of 8 kW, a wind turbine with a capacity of 10 kW, a lead-acid battery with a capacity of 138 kWh, and a converter with a capacity of 13.3 kW will be calculated as 405.536 ₺, 882,950 ₺, 1.53 ₺ and 22,754 ₺, respectively. Model 1 is the most suitable in terms of COE and NPC among the other proposed models. In this respect, the first model was taken as a basis in the examinations.

3.1. Cost Analysis

A summary of the costs according to the components used in the model is given in Table 3.

Table 3. Cost Summary of Components

Components	Capital (₺)	Replace.(₺)	O&M (₺)	Salvage (₺)	Total (₺)
Solar panel	145,876.36	0.00	27,836.39	0.00	173,712.75
MPPT	16,000.00	13,002.64	0.00	-3,774.43	25,228.21
Wind Turbine	120,000.00	91,004.59	52,475.99	-63,693.50	199,787.09
Battery	103,500.00	168,623.95	217,250.61	-36,623.76	452,750.81
Converter	19,959.27	16,220.20	0.00	-4,708.43	31,471.04
System	405,335.63	288,851.38	297,563.00	-108,800.11	882,949.90

It can be seen from Table 3 that the highest cost belongs to solar panels, followed by wind turbines and batteries.

3.2. Financial Analysis

Among the simulations obtained by Homer Pro software, a base model with a lower initial investment cost than the examined model was taken as a reference, and financial comparisons were made between these models: the base model and examined/current model. Although the reference model has the lowest investment cost, its COE and NPC values affecting the selection of the models are higher than those of the selected one. The properties of the models are compared in Table 4.

Table 4. Components of the Models Compared

Components	Base model	Current model
Solar panel (kW)	16.2	22.1
MPPT (kW)	8	8
Wind Turbine EO10	1	1
Lead Acid Battery (kWh)	166	138
Converter (kW)	14.6	13.3
Dispatch	CC	CC
COE (₺)	1.62	1.53
NPC (₺)	931,750	882,950
Operating cost (₺/yr)	25,831	22,754
Initial capital (₺)	389,553	405,336

According to the financial data obtained for the model examined, it has been determined that the present worth is 48,800 ₺, the simple payback period is 9 years, and the discounted payback period is 9.06 years.

3.3. Energy analysis

The amount of the total electrical energy to be produced in one year by the solar-wind hybrid energy system was determined as 55,765 kWh/yr. Solar panels will generate 41.8 % of this energy, remaining energy (58.2 %) will supply from wind turbines. Moreover, 44.9 % of the energy generated is more than needed, and it can be used to meet the energy demand in greenhouses and residential buildings in the winter season. In addition, the energy that the system cannot meet is 0.05% of the total energy produced, which is negligible. The monthly distributions of electricity generated from solar and wind energies generated are presented in Figure 3.

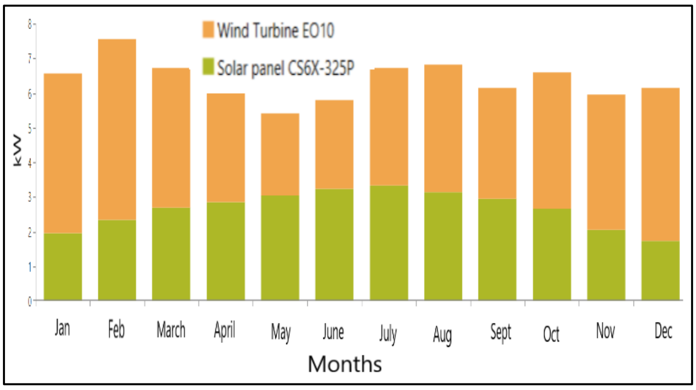

Figure 3. Monthly Average Electricity Production

3.4. Emission Analysis

Since the examined system is based on 100% renewable energy, the system's equivalent greenhouse gas emission value is zero. However, the case of meeting the same electrical load from the grid or diesel generator has also been investigated. In this regard, carbon dioxide (CO_2) of 17,358 kg/yr, sulfur dioxide (SO_2) of 75.3 kg/yr, nitrogen oxides (N_2O) of 36.8 kg/yr will be released into the atmosphere if the electrical load is met from the grid. If the diesel generator meets the electricity need, CO_2 of 33,790 kg/yr, carbon monoxide (CO) of 256 kg/yr, unburned hydrocarbons of 9.31 kg/yr, and particulate matters of 15.5 kg/yr, SO_2 of 82.9 kg/yr and N_2O of 290 kg/yr will be emitted into the atmosphere.

4. Conclusions and Recommendations

In this study, the irrigation energy needs of rural farmland and a farmhouse with no power line are simulated with the solar-wind hybrid energy system by HOMER Pro software. According to the simulation results obtained, it has been determined that the most suitable system model for the region examined consists of polycrystalline solar panels with a capacity of 22.1 kW, an MPPT device with a capacity of 8 kW, a wind turbine with a capacity of 10 kW, a lead-acid battery with a capacity of 138 kWh and a converter with a capacity of 13.3 kW.

It has been determined that the initial investment cost, NPC, COE, and the annual operating and maintenance costs of this system to be established will be 405,536 ₺, 882,950 ₺, 1.53 ₺ and 22,754 ₺, respectively. Moreover, the release of CO_2 influencing considerably to climate system into the atmosphere will be 17,358 kg in one year in case of the required electrical energy is met from the grid instead of the system to be installed.

It has also been determined that if the examined system is installed using only a wind turbine, a wind turbine with a capacity of 20 kW will be needed, and the initial installation cost of the system will be 607,731 ₺. In addition, when the electrical energy needed for the examined region is required to be met only from solar energy, it has been determined that the initial investment cost of the system to be established will be 2,790,000 ₺. For this reason, it has been determined that wind energy has a critical significance for the region examined.

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