EXPERIMENTAL INVESTIGATION OF SOLAR/WIND HYBRID SYSTEM FOR IRRIGATION IN KONYA, TURKEY

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In this study, an experimental research for agricultural irrigation was completed for a renewable hybrid power generation system consisting of photovoltaic (PV) panels and wind turbine which can be considered as an alternative to diesel generators used for pumping applications. Generated electricity was used to power a 300 W DC-driven submersible pump at 2.5 m depth of the ground level. Overall efficiencies of the wind turbine and cell efficiencies of the PV panels in July 2011 were calculated as 33.3% and 10.07%, respectively. It was observed that the daily mean of produced electricity by the system in July was enough to pump daily average 44.1 m^3*/day of water from the depth of 2.5 m and totally 1368* m^3 *of water during the month. It was calculated that the amount of pumped water is sufficient to meet water need of the agricultural products that were 12.4 decares (da) of sugar beet, 13.0 da of potatoes, 13.4 da for corn, 13.6 da green bean and 10.8 da for sun flower with the drip irrigation method. It was demonstrated that the renewable hybrid energy system enables to save the 10410 US dollars on energy in twenty-year period after the basic payback period of 5.7 years. In addition the Net Present Value (NPV) and Internal Rate of Return (IRR) of the project were found to be 7361 USD and 12.6%, respectively.*
Key words: *Hybrid, irrigation, photovoltaic, solar energy, water pumping, wind energy*

1. Introduction

Water is the primary source of life for mankind and one of the most basic necessities for development. The rural demand for water has increased six fold, at the same time the average rainfall has decreased dramatically in many arid countries in the last decade [1]. Albeit groundwater seems to be the only solution of the mentioned issue, it encounters some obstacles since the water table level is decreasing, making traditional pumping applications ever further difficult [2].

Some of the land used for agriculture in the world and also in Turkey has no access to an electricity grid. Therefore, mechanical power from tractors or diesel generators facilitate the irrigation from wells, streams or canals [3]. For instance, seventy million farms in India use diesel powered irrigation systems. As a consequence, a large amount of energy is consumed during the pumping application causing an increase in the product cost.

As water pumping has a long history, many methods have been developed to pump water with a minimum effort. These methods have employed a variety of power sources, namely human energy, animal power, hydro power, wind power, solar power and fossil fuels for small generators. Water has been pumped by using mechanical power of wind energy for centuries [4] and by using solar energy for the last half century [5].

For different regions and locations, climatic conditions including solar radiation and wind speed are always changing [6-7]. Hybrid application systems are promising substitutions which diminish this unwanted instability. Renewable hybrid systems are combination of renewable technologies or supported with conventional systems. As the wind and PV technologies advance, the hybrid systems are becoming more promising, more reliable and cheaper than stand-alone wind or PV systems [8]. Hybrid systems improve load factors and save maintenance and replacement costs, as the renewable resource components complement each other. Renewable hybrid systems can provide a reliable power source for many applications including water pumping.

In addition, the installed capacity of hybrid systems is not designed for the worst-case scenarios due to the fact that power does not come from a single source, what reduces the installation cost of the power system. A deal of research has been carried out on wind, solar and hybrid energy systems. Some of them are related to stand alone hybrid usage of renewable energy sources [9], size optimization [10], economics of the hybrid systems [11], seawater desalination [12], optimization [13], home/village/industrial usage [14], telecommunication power plants [15] and lighting applications.

In the literature some studies are concerned with the usage of renewables for the water pumping purpose [16]; however, it is not encountered in any study that does evaluate the adequacy of water in agricultural areas using solar/wind based hybrid power generation system. What is more, most of them depend on numerical simulations without experimental data. The aim of this study is to experimentally determine and assess the agricultural area amount depending on the crop type for the irrigation usage when the electricity need of pumping system can be satisfied by designed small size hybrid system where irrigation canals, lakes or ground water sources are available. For this purpose, a solar-wind powered hybrid system was designed and established to Selcuk University Technology Zone. In addition, Konya is the biggest city in Turkey according to land area and has the biggest farming lands which are used for grown fruit and cereal.

2. Materials and Methods

The experimental setup was established in the premises of Konya Selcuk University Technology Development Zone at 38 °00'06.80" North 32°30'31.70" East coordinates at an altitude of 1136 meters. All the components of the hybrid power station are integrated with solar and wind energy for irrigation purposes as illustrated in Fig. 1. As seen, the produced electricity via the PV modules with a total 480 W capacity and the wind turbine with a 1500 W capacity are regulated by their individual charge controllers and are stored in the battery bank. Four pieces of 12 V and 200 Ah batteries were wired in a serial/parallel arrangement to deliver 300 Ah at 24 V with a total capacity of 9600 Ah. Then, the electricity was transmitted to the pump in order to pump the water from a well to a storage tank. During this process the PV charge controller has a significant role and measures all electrical properties: voltage and current values of input, output and battery group; the occupancy rate of a battery group, consumption of the pump and all data stored in a datalogger during the experiment. In addition to DC electricity line, the stored electricity is inverted to 220V by a 3000 W capacity inverter for AC powered systems. Generated electricity by both wind turbine and PV panels, and electricity consumption of the pump were recorded by the dataloggers during the experiment. The wind speed and solar radiation were also measured by a cup anemometer at height of 10.5 m and a pyranometer in 10 minutes intervals for further process. The volume flow rate of pumped water and its outlet pressure were also measured by a turbine type flowmeter and by a pressure sensor at 1 sec. intervals. The cut-in, rated and cut-off wind speed of the wind turbine were 3.6 m/s, 12.5 m/s and 20 m/s, respectively. All measured variables and their accuracies are given in Tab. 1. In the experiments a DC-driven pump with head height of 5 m and volume flow rate of 5 m^3 was used. PV panels were established on a designed rotating mechanism to change the PV panels' angle from 0° degrees to 80° degrees on horizontal axis. The purpose of this establishment was to adjust the mechanism to get the highest amount of solar radiation on PV surfaces. The Maximum Power Point Tracking (MPPT) was included in the charge controller of the PV system for extracting maximum available power from PV. All electronic devices and batteries were collected in a sheet metal cabinet to protect from environmental conditions.

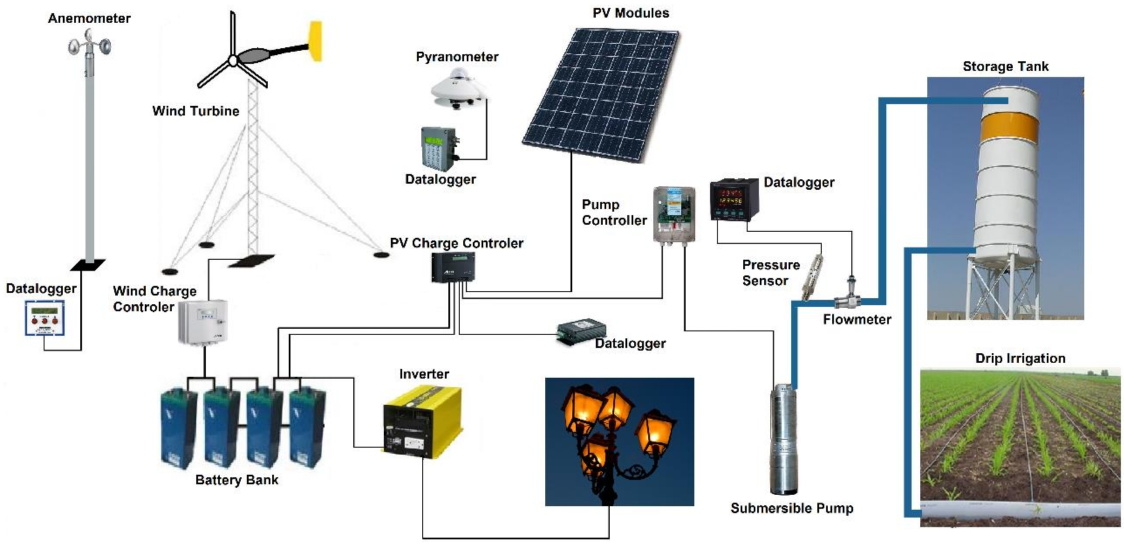

Figure 1. Schematic view of the hybrid drip irrigation system.

Table 1. The collected data and accuracies of the measurement devices of the hybrid system.

Variable	Accuracy
Day of year	-
Time of day – h	-
Solar radiation – I_s (W/m^2)	±1%
PV array DC voltage – V_{pv} (V)	± 0.1V
PV array DC current – I_{pv} (A)	± 0.01A
Wind speed at hub height – V (m/s)	± 0.3 m/s
Wind Turbine DC voltage – V_w (V)	± 0.1V
Wind Turbine DC current – I_w (A)	± 0.01A
Input DC voltage to pump motor – I_{pm}(V)	±1%
Input DC current to pump motor – V_{pm}(A)	±1%
Water pressure – h (bar)	±0.5%
Water flow rate – (Q) m^3/h	±1%

The main reason of the establishing combined solar-wind system is to support each other in case of producing insufficient energy by one of them. Solar radiation changes according to the season and it can be converted into electric energy with only the ratio of 1/3 per day on average. According to the obtained results, solar radiation and wind speed values during summer months occur in greater amounts as the irrigation needs of the crops are higher in the considered region. In addition, enough amount of energy is not obtained to produce electricity continuously due to wind variations and characterization in Konya province. Technical specifications of the PV panel and wind turbine of the installed hybrid system are given in Tab. 2 and Tab. 3, respectively.

Table 2. Wind turbine specifications.

Parameter	Value
Blade diameter	3.0 m
Weight 30 kg	76 kg
Start-up wind speed 3.1 m/s	3.6 m/s
Rated wind speed	12.5 m/s
Peak/ Rated power	1500 W
Number of blades	3
Material of blades	Polypropylene and carbon fiber composite
Generator	permanent magnet alternator
Output Voltage	24 V DC

Table 3. PV Panel specifications.

Parameter	Value
Peak power	120 W
Number of pieces	4
Open circuit voltage	41.6 V
Short circuit current	3.8 V
Peak power voltage	33.4V
Peak power current	3.5V
Nominal operating cell temperature (NOCT)	49 /°C
Maximum system output voltage	600V

2.1. The output power of the PV panels

The output power of the PV generator $\dot{P_{pv}}$ is given by the following equation [17]:

$$\dot{P_{pv}} = A_{Pv}\, I_s\, \eta_{pv} \tag{1}$$

where η_{pv} is the PV panel's total efficiency, A_{Pv} is the total area of the PV panels (m^2) and I_s represents the amount of solar radiation on tilted module plane (W/m^2).

2.2. The power output of wind turbine

The fundamental equation governing the electrical power capture of the wind turbine generator is given by [18].

$$\dot{P_w} = 0.5\rho_a A_w \eta_w V^3 \tag{2}$$

Where ρ_a is the air density (kg/m^3), A_w is the area swept by the rotor blades, V is the average wind velocity (m/s), η_w represents overall efficiency of wind turbine and is calculated according to the power produced by the wind turbine and measured wind speed distribution of the region.

2.3. The volumetric flow rate of pumped water

The ideal hydraulic power to drive a pump depends on the mass flow rate, the liquid density and the differential height. It is explained that either it is the static lift from one height to another, or the friction head loss component of the system can be calculated as follows [19]:

$$\dot{Q} = (\dot{P}_h \, \eta_p)/(\rho_w g h) \qquad (3)$$

where $\dot{P}_h$ is the power needed by the pump and it is generated by the hybrid system for this application. $\dot{Q}$ is the volumetric flow rate (m^3/s), ρ_w is density of pumped water (kg/m^3), g is gravitational acceleration (m/s^2), h is the manometric head including all minor and major pressure losses (m) and η_p is the overall pump efficiency.

2.4. Irrigation need

There are a lot of irrigation applications such as a conventional surface, a sprinkler, a drip irrigation method etc. The methods apart from the drip irrigation one cause more evaporation of water and, thus, wasting a great amount of water. The drip irrigation requires higher costs of investment; notwithstanding, it is especially preferred to use in greenhouse and garden applications and to grow higher economic valued crops due to it's less labor need. In order to determine the monthly irrigation demand it was necessary to know the average monthly rainfall of a region [20].

$$IN = WN - NR \qquad (4)$$

The irrigation water need of any crop *(IN)* in each month is the difference between the crop water need *(WN)* and the natural rainfall amount during the growing season *(NR)*.

3. Results and Discussions

3.1. Solar Data

Turkey has a perfect geographical location to use solar energy. According to General Directorate of Electrical Power Resources Survey and Development Administration, in Turkey the average total annual sunshine duration is 2640 hours (daily average 7.2 hours) and average total radiation of 1311 kWh/m^2-year (daily total 3.6 kWh/m^2day) has been identified. Although there are some statistical methods to predict solar radiation, it is necessary to measure the solar radiation locally to obtain experimental results [21]. In this study, the solar radiation in the year 2011 was recorded by a calibrated pyranometer established to the same location on the horizontal axis. During the observation period the average solar radiation was found to be 1736 kWh/m^2-year and the maximum hourly average radiation has occurred as 1110 W/m^2 at 14:00 on 1th June, 2011. It can be concluded that the average solar radiation increased with sunshine and reached the maximum during noon hours. Later it was decreasing with decreasing solar sunshine during the evening hours and ends shortly before sunset. Before sunrise and after sunset the solar radiation values are zero. As it can be seen in Fig. 2 the solar radiation is higher in the summer months from June to July when the irrigation needs are also higher and overlaps for all crops need which affects positively the implementation of the designed hybrid system.

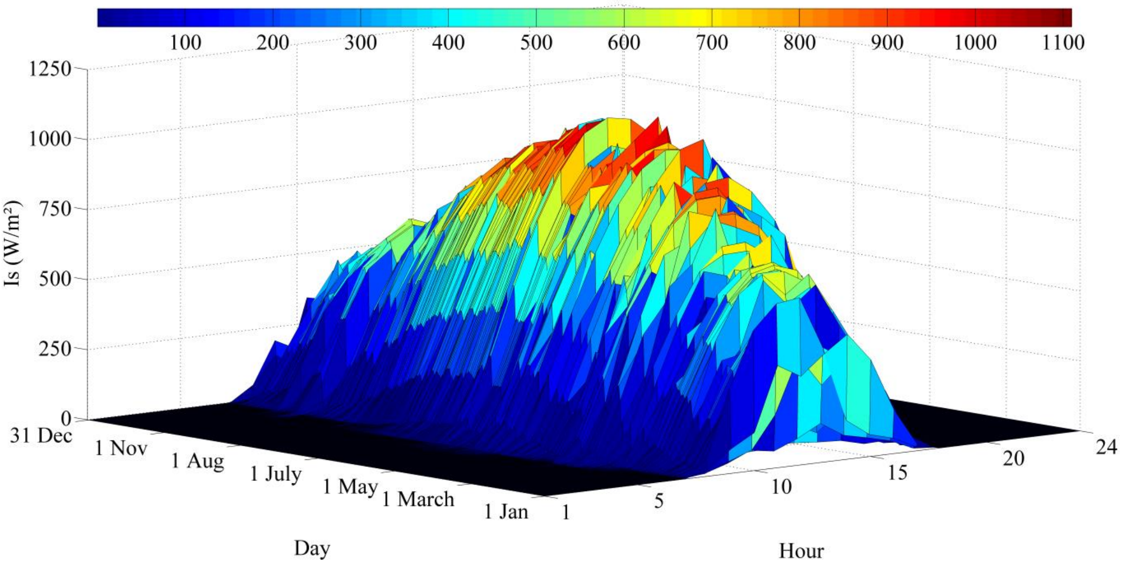

Figure 2. Daily and hourly variations of the solar radiation on horizontal surface in 2011.

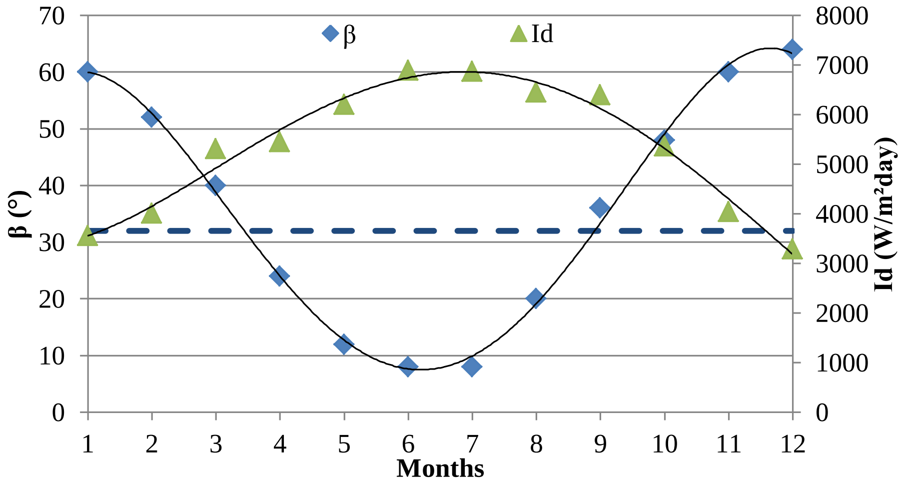

Figure 3. Optimum tilt angle *(β)* and daily total radiation *(I_d)* variations for Konya.

There are some main factors that have an impact on an amount of generated energy of a solar PV system. One of them is its angle with a horizontal surface. The sun most of time is relatively high in the sky and, therefore, to ensure that a PV panel maximizes its exposure to direct sunlight it should be mounted at an angle *(β)*. In this study, Koronakis model [22] and The Photovoltaic Geographical Information System PVGIS [23] were used to calculate the solar data on tilted surfaces to find the optimum angle for every month. Fig. 3 depicts the optimum tilt angle and monthly average of daily total solar radiation for all months in Konya to get the best output from PV panels. It was observed that the optimum angle is lower on summer months while it is higher during the winter season. The optimum tilt angle in Konya according to take maximum radiation found to be 32° on yearly average after calculating the optimum angle to obtain maximum energy, PV panels were arranged at the calculated angle for each month during the experiment period. For instance in the summer months the optimum angles in June and July are 8° whereas it is 20° in August. The pyranometer was also located at the same angle with PV panels during the experiment period.

The water need of the crops reaches a peak in summer months. To consider irrigation via the solar and wind energy, the most important time interval is the summer season when the water need of the crops are a maximum. In this study, the daily mean total radiation *(I_d)* was measured as 6480 W/(m^2day), 7737 W/(m^2day) and 7100 W/(m^2day) in June, July and August respectively with a pyranometer oriented towards south and tilted at optimum angles surface such as the PV panels.

The daily average solar radiation on the PV panels' surface (I_g) and hourly average generated electricity by 480 W capacity PV panels (P_{pv}) in summer months (June, July and August) are represented in Fig. 4. It can be concluded that electricity production is directly increasing with solar radiation. The daily average production by PV panels for June, July and August were found to be 2413 W_h, 2841 W_h and 2625 W_h, respectively. The hourly average efficiency of the PV cells (η_{PV}) along summer months is calculated as 10.07%.

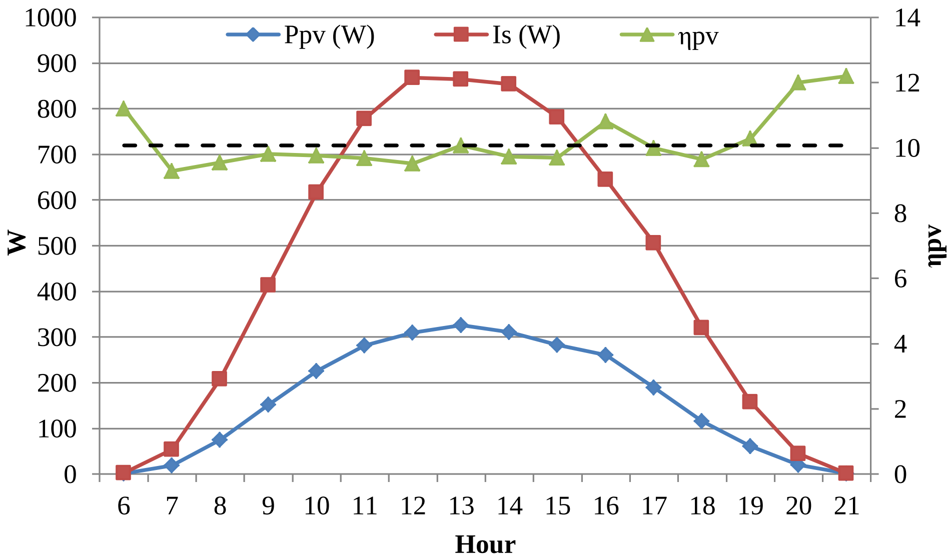

Figure 4. Average hourly variation of the solar radiation and power output of the PV panels along summer months

3.2. Wind Data

In order to determine the wind energy potential of the region, a wind speed measurement mast was established in accordance with the land's geographic conditions. The wind speed data were collected from in 2011. According to international standards, all the readings were repeated with 10 sec. intervals and on average, minimum and maximum values and their standard deviations were recorded to the datalogger at 10 minutes intervals during the measurement period. The monthly mean wind speed measured by anemometer, located at the same mast height (10.5 m) as the wind turbine hub, were found to be 3.76 m/s, 4.66 m/s and 4.05 m/s in June, July and August, respectively. Hourly average variation of the wind speed data in July is given in Fig. 5, when the water need gets its peek value for all crop types considering the worst case.

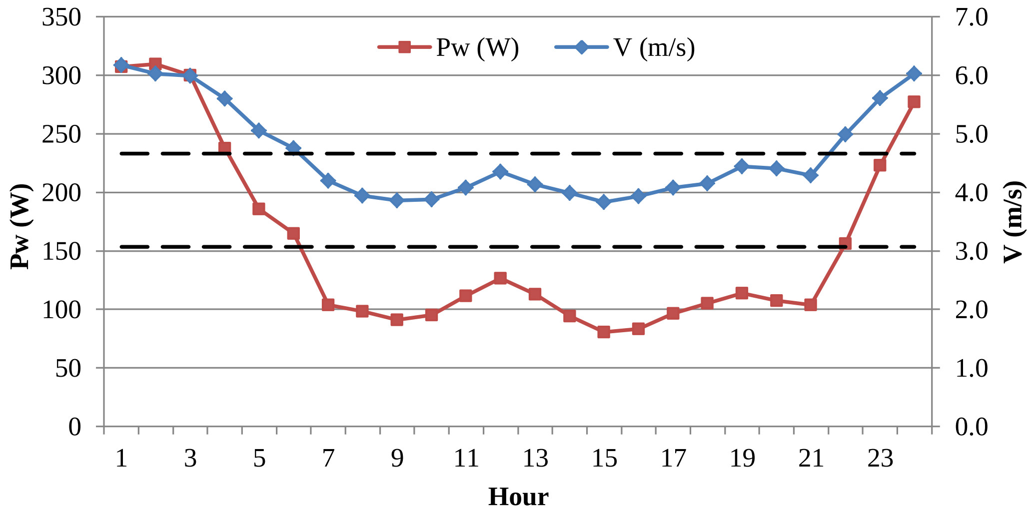

Figure 5. The hourly average wind speed and produced electricity by wind turbine along July 2011.

The experimental results show that the hourly average wind speed increases from 17:00 until midnight and then it remains at this level till 3:00. Then it decreases gradually till 7:00 in the morning and remains at this level in the day time. Although the average wind speed was 4.66 m/s, it was observed that the wind speed was higher than 10 m/s especially during nighttime providing electric energy production by the wind turbine.

3.3. Solar wind hybrid system

Hourly variations of the electricity generation by wind turbine (P_w), by PV panels (P_{PV}) and by the hybrid system consisting of a combination of the two systems (P_h) are given by in Fig. 6. As it can be seen, the wind turbine produces more electricity during the night compared to the daytime hours. Similarly, the PV panels generates energy only during daytime hours and reaches its maximum value at noon hours. Wind power can be integrated with solar power successfully resulting in the better continuity of electricity generation.

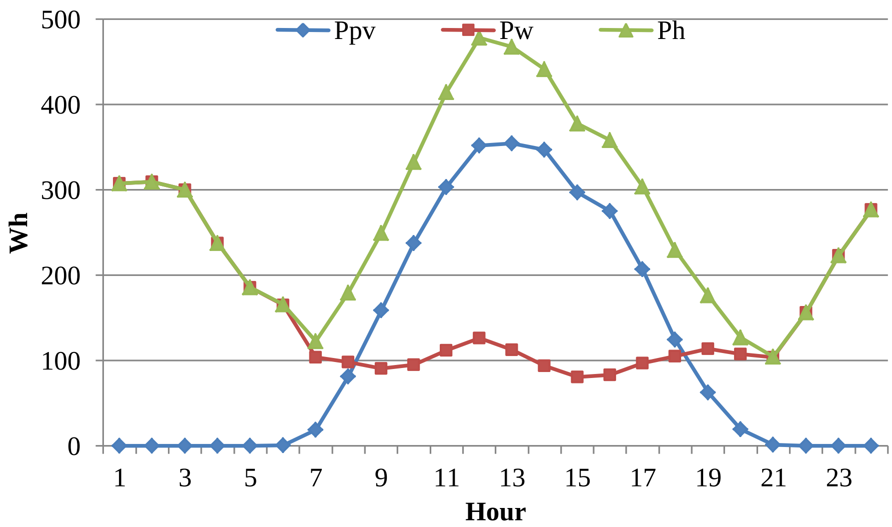

Figure 6. Hourly variations of the electricity production by hybrid system along July.

The daily average total energy production by the wind turbine and PV panels were determined as 3685 Wh/day and 2841 Wh/day, respectively. The hybrid system can generate electric energy during the whole day when compared with single wind and solar energy system. It was demonstrated that the daily mean produced electricity by the system in July was enough to pump daily average 44.1 m^3/day of water from 2.5 m depth and totally 1368 m^3 during the month, which was the most irrigation needed month along a growing season of many crops in Konya. It is observed that the pumped water amount in the evening and night times were lower than the average need when just wind power was available. The pumped water amount was increased after 8:00 by the support of the solar power to the wind power. The volume flow rate of the water was over 3 m^3/h in the afternoon and it tended to decrease after 17:00. Then wind power and the stored electricity in the batteries provided energy to pump water till sunrise.

3.4. Irrigation need

Generally, the water demand for a crop varies in accordance with the type of soil, irrigation methods, rainfall regimes, and other meteorological factors. Water needs for different crops and rainfall variations in Konya province are given in Fig. 7. The total water need for different crops per a growing season in Konya, from experimental results and the real experience, was recorded as 621 mmWc (i.e., a unit of mm water column) for a corn, 577 mmWc for a potato, 858 mmWc for a sugar beet, 701 mmWc for a sunflower and 520 mmWc for a green bean [24]. Monthly average rainfall data of Konya province along 40 years was taken from Turkish State Meteorological Service. The annual total rain amount was 319 mmWc reaching a peak during spring and fall seasons. The amount of irrigation water for the crops during summer season was higher whereas natural rainfall was lower. Therefore, the irrigation was obligatorily required to grow the plants.

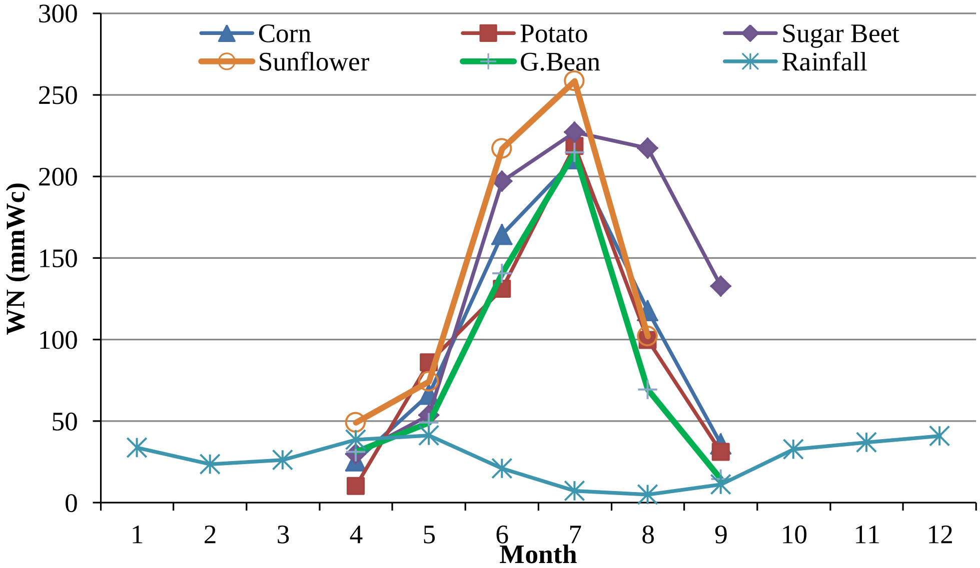

Figure 7. Water needs of different crops and rainfall variations for Konya province.

Fig. 8 presents the monthly irrigation water need that is calculated by subtracting the effective rainfall amounts from the crop water need for all crops during each month of the growing season. For instance, a sugar beet crop grown in Konya has a total growing season of 180 days and its monthly water needs from April to September vary between 30.0 mmWc in April, 53.8 mmWc in May, 197.2 mmWc in June, 227.3 mmWc in July, 217.3 mmWc in August and 132.8 mmWc in September. The cumulative water need of the sugar beet through the growing season (April-September) is 858.4 mmWc. The average rainfall data between 1970-2010 for the area where the crops considered to be grown have been obtained from the Turkish Meteorological Office as 37.5 mmWc in April, 40.5

mmWc in May, 23.2 mmWc in June, 7.8 mmWc in July, 5.6 mmWc in August and 10.6 mmWc in September with the total amount of 124.6 mmWc along the growing season. The monthly irrigation water need for a sugar beet was calculated by the difference between the crop water need and the natural rainfall. The use of irrigation in April is not needed owing to efficient rainfall. The monthly irrigation water needs changes 12.5 mmWc in May, 176.3 mmWc in June, 219.9 mmWc in July, 212.1 mmWc in August and 121.6 mmWc in September. Total irrigation water needs for the crops such as a corn, a potato, a sun flower and a green bean per growing season were found to be 509.3 mmWc, 480.9 mmWc 587.7 mmWc and 402.3 mmWc, respectively.

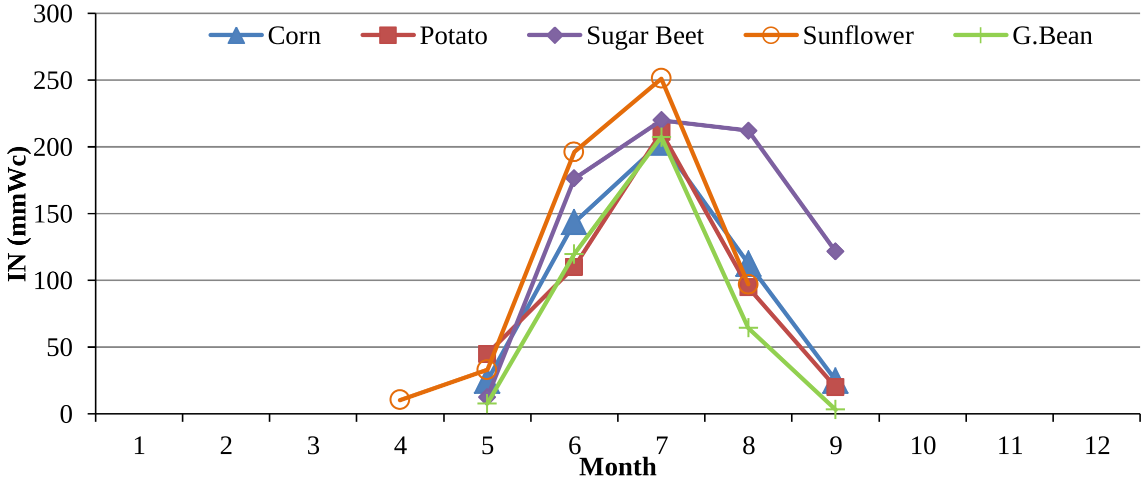

Figure 8. Average irrigation needs of different crops for Konya province along the growing season.

The amount of pumping water per a growing season was converted into water requirement of the different crops per growing season by conventional and drip irrigation methods in Tab. 4. It can be concluded that the drip irrigation method for all considered crops can provide two times more field for the water requirement of the related crops than the conventional irrigation system. Drip irrigation systems reduce the loss of water by conveying or evaporation, and achieve the highest irrigation efficiency up to 90%.

Table 4. Comparison of conventional and drip irrigation systems for the total land area in Decares (1000 m^2).

	Corn	**Potato**	**Sugar beet**	**Sun Flower**	**Green Bean**
Conventional Irrigation	6.7	6.5	6.2	5.4	6.6
Drip Irrigation	13.4	13.0	12.4	10.8	13.6

3.5. Economic Analyses

To perform the economic analysis of the hybrid system at least one year electricity production should be considered. For this purpose, wind characteristics, solar radiation, PVGIS software and meteorological data were used to make the economic analyses. With the wind and solar powered electricity generation systems, energy source cost is free. Therefore, once the project's initial cost has been invested, the only expenditures were maintenance and operation costs [25]. A common way to evaluate the economic merit of an investment is the Basic Payback Period (BPB), which can be used for the economic feasibility analysis of the hybrid system project. In addition, the project lifespan of the turbine and PV panels was taken as 20 years.

$$BPB = (C/AS) \tag{5}$$

where C is the total capital cost and AS is the net annual saving [26].

Another economic analyzing method is Net Present Value (NPV) Method that uses the time value of money to assess long-term projects. The calculation appraises all costs occurring within the project lifetime, including initial set-up costs, maintenance and fuel. All future income and expenditure flows are discounted to the present [26-27]. The NPV is calculated as follows in Eq.6:

$$\mathrm{NPV} = \sum \frac{\mathrm{B} - \mathrm{C}}{(1 + \mathrm{r})^{\mathrm{n}}} \tag{6}$$

where B is the benefit, C is the cost, r is the discount rate taken as %5 for this project, and n is the life cycle year of the project. In addition, %10 of the initial cost taken as salvage income at the end of the project lifespan after 20 years.

Internal Rate of Return (IRR) method is also a widely used method for the preliminary evaluation of projects. The method requires discount rate value r, which makes equal the NPV and the value of the cost and benefit [26-27]. In other words, it is the rate, which would make NPV zero as seen in Eq 7.

$$\sum \frac{\mathrm{B}}{(1 + \mathrm{r})^{\mathrm{n}}} = \sum \frac{\mathrm{C}}{(1 + \mathrm{r})^{\mathrm{n}}} \tag{7}$$

The annual produced electricity by the wind turbine and PV was 635 kWh and 738 kWh, respectively, which were both higher in the summer season comparing to other seasons. Economic analysis was completed according to annual, total generated electricity by the hybrid system, which was 1373 kWh. The investment cost of the all components of the hybrid system, was 4200 USD without the measurement tools and sensors. The hybrid system was considered to be replaced with 6 kW diesel and 6 kW gasoline generators. Fuel consumption of the diesel generator and the gasoline generator was 3.0 L/h (liters per hour) and 2.3 l/h, respectively. The prices of generated electricity by gasoline and diesel generators and details of the economic analyses are given in Table 3. The BPB period for the hybrid system was found to be 3.7 years for gasoline generator and 5.7 years for diesel generator. It is found that the renewable hybrid energy system could save 10410 US Dollars on energy consumption after BPB time as replaced with a 6 kW diesel generator. NPVs of the hybrid system replacing with diesel and gasoline generator were found to be 7361 USD and 11436 USD, respectively. The IRR values were calculated as 21.5% for the gasoline generator and 12.6% for the diesel generator replacement. The mentioned values indicate that it is desirable to undertake this project.

Table 3. Economics of the hybrid system.

Source	**Prices**		**Annual Produced Electricity (kWh/year)**	**Annual Cost/Saving (USD)**	**BPB (year)**	**NPV (USD)**	**IRR %**
	USD /l	**USD /kWh**					
Diesel Generator (6 kW)	1.38	0.53	1373	728	**5.7**	**7361**	**12.6**
Gasoline Generator (6 kW)	1.56	0.78	1373	1071	**3.9**	**11436**	**21.5**

4. Conclusions

In this work, performance characteristics of the small-scale PV/Wind based hybrid electric supply system for the water pumping application in Konya is presented. It was SEEN that totally 1368

m^3 water was pumped during July when was the highest demand for irrigation during growing season. It was calculated that the amount of pumped water was enough to meet water need of the crops that were 12.4 decares (da) of a sugar beet, 13.0 da of a potato, 13.4 da for a corn, 13.6 da a green bean and 10.8 da for a sun flower. It was also seen that the drip irrigation method for all considered crops could satisfy the water requirement of two times larger field than the conventional irrigation system. The proposed system was economically compared with the common used diesel generators and it could be observed that the hybrid energy system could save on energy the 10410 US Dollars for twenty-year period after the basic payback period of 5.7 years. The NPV and IRR values of the project for the diesel generator replacement were found to be 7361 USD and 12.6% respectively which shows that the project can be applied feasibly.

It is expected that the prices, efficiencies, cost and incentives of the wind and solar energy application in Turkey as well as in the World could be more attractive than the conventional system. It can be anticipated that the proposed system will be commonly used in the future since the cost of the renewable energy systems is decreasing and the government supports on them are increasing.

It was found that the hybrid system for the irrigation purposes was especially suitable in remote areas without connection to the electricity grid. Moreover, the designed off-grid hybrid water pumping system could be an alternative to diesel-operated agriculture pumps, portable pumps for drinking water/agriculture and it can be applied in farmhouses, orchards, greenhouses and livestock watering.

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