Environmental assessment of rainwater harvesting and solar system for agriculture

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Abstract

As a result of increasing industrialisation and the use of machines, the demand for both energy and water are increasing. As a result, it is necessary to develop sustainable environmental structural systems in both energy production and irrigation water. This, in turn, requires the most accurate use of existing water resources and the immediate implementation of sustainable agricultural systems. Despite this, none of the agricultural enterprises are yet using systems such as rainwater harvesting and solar power techniques. The main aim of this research is to find effective results in terms of savings and to contribute to the prevention of water scarcity in the future. At the same time, the advantages of environmentally friendly zero-energy roofs and rainwater collection systems are evaluated. Elazig province of Turkey was selected for this study. When the benefits of the solar power plant to be built on the relevant farm and an average tree are compared in terms of reducing the CO₂ emissions, it was found that the contribution of this plant would be equal to that of planting 113,506 trees.

Keywords: CO₂, emissions, energy, rainwater, renewable energy, solar;

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1. Introduction

Nomenclature

| Symbol | Description                  |
|--------|------------------------------|
| \(Q_m\) | mean monthly harvestable rainwater |
| \(R\)    | mean monthly average rainfall  |
| \(A\)    | catchment areas of the roots   |
| \(C\)    | the run-off coefficient        |
| \(B\)    | a yield efficiency coefficient |

With the increase in demand for energy, the use of fossil energy sources and foreign-source dependence increases. Renewable energy sources have become more important due to the use of fossil-based sources and the release of harmful gases into the environment [1]. Solar energy is one of the most important renewable sources of energy in Turkey, due to its geographic location. Since Turkey is located between 36° and 42°N latitudes and 26° and 45°E longitudes and is close to the equator, its solar energy potential is promising [2].

Photovoltaic (PV) panel technologies and production have improved rapidly in Turkey due to the high solar radiation and it is an environmentally friendly energy source. Lately, researchers have indicated that PV production is going to be the leading source of electric production in near future. Solar PV system-based generation has grown by 40% worldwide, despite the pandemic [3]. With this increase in the production of solar PV plants around the world, the need for successful applications and analysis programmes for large and medium-sized grid-connected solar PV plants are increasing. Also, performance analyses of these systems and various simulation programmes to measure the energy they will produce have been designed [1]. The PVsyst software is one of these simulation programmes. The intensity of solar energy coming from outside the Earth’s atmosphere is constant, 1,370 W/m², and on Earth, the intensity is between 0 and 1,100 W/m² [4], [5].

Being informed of a region’s solar radiation data is important for the efficiency and design of solar PV systems, planar collectors and other solar collector systems. The sunshine duration in the Earth’s atmosphere is measured at meteorological stations. Monthly average estimates of daily global solar radiation can be made using correlations of these data, and many models for these estimates can be derived from various Angstrom-type equations. Many experimental models have been developed to measure the solar radiation level. Also, different parameters such as cloudiness, sunshine duration and ambient temperature are used in the development of these models [6]. Solar energy is an endless source of energy and is more environmentally friendly compared to other energy sources. The energy extracted from renewable sources will greatly reduce the emission of greenhouse gases that harm the environment. The main advantages of the system are the reduction of \(CO_2\) emissions and the prevention of any air emissions or waste products during power generation [7].
With the increasing need for water in urban areas, rainwater collection systems that offer the efficient use of water in terms of the continuity and effective use of water resources have become more prominent [8]. The collected rainwater can be used in many areas such as garden irrigation, greenhouse cultivation and agricultural cleaning that do not require the use of drinking water. The use of rainwater by storing it in a tank before use for various purposes is called a rainwater collection system. In addition to the positive environmental effects of rainwater harvesting (RWH) systems, there are many economic benefits such as reducing water consumption in urban areas. RWH systems often consist of an impermeable roof (harvest surface), a storage tank (storage volume) and a transport system (trough system) between the roof and the tank. The collection, storage and use of rainwater from roofs are simple ways to reduce the demand for both public water supplies and waste treatment plants. The system design and planning of RWH are important in terms of affecting the initial investment cost and payback period of the system [9].

1.1. Purpose of the study

In this study, the amount of energy to be produced and the amount of emission to be prevented with the panels to be built on the roof of an agricultural operation have been investigated. We will examine with examples how the roof of the buildings can be utilised. Most importantly, we will examine the economic benefits, as well as the ecological and environmental effects, of solar energy and rainwater harvested from roofs. This study is thought to especially benefit farmers and investors, who are the actors of agricultural production.

2. Materials and methods

2.1. Study area and feasibility results of the PV software

Elazig province of Turkey was selected for this study. The facility where the study will be carried out is located at 38.655049°N longitude and 39.347600°E latitude coordinates. An evaluation was made after a solar energy system was built on a roof of an existing agricultural business in this region. As seen in Figure 1, the roof area where the solar energy system was built is 105x62:6510 m² and 35x30 1050 m², and the panel angle is 10° due to the roof slope. The optimised tilt angle is 10°. The carrying capacity of the existing roof was calculated. Static calculations were examined and it was found that the carrying capacity was suitable. After the aluminium laths were placed on the existing roof, the panels will be mounted on the laths. If the current capacity of the roof is calculated to be suitable for the solar panel roof mounting, a static suitability report is prepared. If the capacity is insufficient due to the addition of solar panels or any other reason, a preliminary project containing reinforcement proposals should be prepared. Reinforcement works are to be examined on-site at least once.

The prepared project and static calculations should be first submitted to the authority who is authorised to obtain the building permit, and then to the General Directorate of TEDAS or the provincial organisation of the relevant distribution facility. The existing roof is examined by the technical personnel and the drawings of the roof elements are made. The locations where the solar panel will be mounted are decided. The carrying capacity is examined. Architectural and static projects of the relevant building are provided. The transmission line cost was also calculated.
3. Results

The findings of this study are shown and explained in the ensuing paragraphs.

Figure 1. Total solar radiation and agricultural business

Figure 2 graphically shows the performance ratio of the energy produced for the whole month of the year. The average performance rate is 0.897.

Figure 2. Simulation of the energy generation plant
The numerical analysis of the power plant was made using the PVsyst V6.81 software. A solar power plant with 1,174 kWp was inspected. In solar energy systems, parameters such as location, slope, direction, geographic coordinates, modules and inverter quality are affected by the energy production of the PV panel. In this study, PV software (Perez model) was used to predict the solar radiation on the surface. With the PV software, the solar radiation is measured as watts per square meter (W/m²) in SI unit systems.

Table 1 shows the balances between and main outputs of grid-connected PV systems. The yearly global horizontal radiation is 1,591.5 kWh/m². The yearly global energy at the collector is 1,579.8 kWh/m². The energy available at the output of the PV array is 1,710.9 MWh. The energy delivered to the grid is 1,677.2 MWh. The yearly average efficiency of the system is 11.6%. The average temperature is 13.24°C.

The highest PR was recorded in January with 98%, and in July with 84.8%. The yearly average PR is 89.7%. In Table 1, the yearly total generation of the PV programme was found to be 1,672.2 MWh as a result of the numerical analysis.

|                | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray MWh | E_Grid MWh | PR     |
|----------------|----------------|----------------|----------|----------------|----------------|------------|------------|--------|
| January        | 59.5           | 30.72          | -0.99    | 59.1           | 57.7           | 70.0       | 68.5       | 0.980  |
| February       | 77.9           | 38.46          | 0.92     | 77.3           | 76.0           | 91.1       | 89.3       | 0.975  |
| March          | 122.0          | 59.04          | 7.20     | 121.0          | 119.1          | 137.9      | 135.3      | 0.944  |
| April          | 144.0          | 65.77          | 12.03    | 142.9          | 140.9          | 158.3      | 155.2      | 0.918  |
| May            | 182.7          | 70.36          | 17.17    | 180.6          | 178.3          | 193.7      | 180.8      | 0.888  |
| June           | 206.6          | 77.45          | 22.95    | 205.1          | 202.7          | 214.3      | 210.1      | 0.865  |
| July           | 213.5          | 73.58          | 27.53    | 211.9          | 209.4          | 217.2      | 212.9      | 0.848  |
| August         | 197.9          | 64.04          | 27.21    | 196.6          | 194.1          | 202.7      | 198.4      | 0.853  |
| September      | 156.7          | 51.69          | 20.93    | 155.7          | 153.5          | 165.4      | 162.7      | 0.880  |
| October        | 110.0          | 48.18          | 14.79    | 109.2          | 107.4          | 120.9      | 118.7      | 0.918  |
| November       | 67.6           | 32.43          | 6.72     | 67.2           | 65.7           | 77.3       | 75.7       | 0.951  |
| December       | 53.6           | 28.40          | 1.54     | 53.2           | 51.8           | 62.4       | 61.0       | 0.969  |
| Total Year     | 1,591.5        | 640.12         | 13.24    | 1,579.8        | 1,556.5        | 1,710.9    | 1,677.2    | 0.897  |
3.1. Pay off time of the facility

The annual revenue of the solar energy system is calculated as €1,050,925, as seen in Table 1. It produces 1,677,100 kWh energy per year. Panel factories provide a 25-year product warranty. The period it would take for the facility to cover the cost was calculated as well, also because there will be an energy loss of 1% each year. When the yearly revenue of the facility is divided by the cost, the solar power plant was found to pay itself off in 4.9 years. So, it was seen that this is an investment that pays for itself in a short time. In Turkey, the government already covers up to 50% of the expenses of agricultural facilities and guarantees the purchase of the energy they produce. Thus, the payoff period of the facility is reduced by half. Agricultural businesses can be supported; their prices can be reduced; and their production capacities can be increased.

|       | E_Grid kWh | Amount consume | Electricity purchase | Distributio n fee | Funds (%) | Monthly electricity | Monthly SPP | Billing price |
|-------|------------|----------------|----------------------|-------------------|-----------|---------------------|-------------|---------------|
| January | 68,500     | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €45,715.22  | €41,857.26    |
| February | 89,300     | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €57,773.37  | €53,915.42    |
| March   | 135,300    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €85,039.31  | €81,181.35    |
| April   | 155,200    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €96,170.92  | €92,312.96    |
| May     | 189,800    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €116,590.8  | €112,732.88   |
| June    | 210,100    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €129,289.5  | €125,431.63   |
| July    | 212,900    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €130,952.8  | €127,094.87   |
| August  | 198,400    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €122,741.7  | €118,883.78   |
| Septemb | 162,200    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €101,118.5  | €97,260.59    |
| October | 118,700    | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €75,527.58  | €71,669.62    |
| Novembe | 75,700     | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €49,835.53  | €45,977.57    |
| Decembe | 61,000     | 4.681          | €0.5940              | €0.2123           | 3         | €3,857.96           | €40,169.24  | €36,311.29    |
| Total Year | 1,677,100 | 56.172         | €0.5940              | €0.2123           | 3         | €46,295.00          | €1,050,925.00| €1,004,629.24 |
3.2. Carbon emission

Carbon emission occurs when the carbon in nature is released into the atmosphere. Carbon emissions generally occur as a result of human activities. The main reason behind climate change is that greenhouse gases (such as carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbon and sulphur hexafluoride) accumulated in the atmosphere increase the temperature level of the earth. These gases that are released into the atmosphere cause the average temperature on Earth to rise. As a result of this, the Earth is at serious risk because of global warming. The main reasons behind the increase in carbon emissions in recent years are uncontrolled industrialisation, ever-increasing energy demand, increasing urbanisation, decreasing forest areas, intensive animal husbandry activities and uncontrolled greenhouse gas emissions.

If carbon emissions are not reduced, it is possible to pollute and damage almost everything from our diet to the air we breathe. In Turkey, the effects of global warming have begun to show as changes in the climate exacerbated and the average temperature has increased. Therefore, necessary studies regarding reducing emissions of such gases that are released into the atmosphere should be carried out. In particular, increasing industrialisation and the use of machinery in agriculture increases the use of fossil fuels, and this causes an increase in carbon emissions. Therefore, providing energy to agricultural businesses and factories via panels is a very important investment to reduce carbon emissions.

Every 1 kWh of electricity produced corresponds to 0.846 pounds of CO₂. Based on this, the amount of reduced CO₂ with the help of panels in farms would be:

\[ \text{CO}_2 \text{reduced} = \text{[The amount of energy produced annually (kWh) × 0.846]} = 1,677,100 \times 0.846 = 1,418,827 \] pounds of carbon [10]. The reduction in CO₂ emissions this facility would provide was calculated as 1,418,827 pounds. An average tree absorbs approximately 25 kg of CO₂ per year to perform photosynthesis, thus benefiting the environment. When the benefits of the solar power plant to be built on the relevant farm and an average tree are compared in terms of reducing the CO₂ emissions, it is seen that it is equivalent to planting 113,506 trees.
3.3. Rainwater harvesting

In this study, the potential of rainwater to be collected from the roof of the facility was examined. In Elazig province, monthly average daily total rainfall values and coordinates for the years 1980–2020 were obtained from the General Directorate of Meteorology. Based on the average values of past years in Table 3, the longest sun duration in Elazig province was 11.6 hours in July. In the table, temperature and rainfall data for Elazig province are also given. The average temperature is 13.1°C. The average total rainfall is 406.7 mm.

| Table 3. Average annual precipitation data for the period of 1938–2016 |
|---------------------------------------------------------------|
| **ELAZIG** | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Dec | Annual |
| Measurement Period (1938–2016) |
| Average temperature (°C) | -1.0 | 0.5 | 5.4 | 11.9 | 17.1 | 22.2 | 27.3 | 26.2 | 22.1 | 14.0 | 7.4 | 1.8 | 13.1 |
| Average high temperature (°C) | 2.8 | 4.8 | 10.7 | 17.7 | 23.9 | 29.4 | 34.4 | 34.3 | 29.7 | 21.1 | 12.5 | 5.5 | 18.8 |
| Average lowest temperature (°C) | -4.0 | -3.0 | 0.7 | 6.3 | 10.8 | 15.3 | 19.4 | 19.6 | 14.8 | 8.8 | 3.1 | -1.3 | 7.5 |
| Average sunbathing duration (hours) | 2.5 | 3.5 | 4.9 | 6.4 | 8.7 | 11.0 | 11.9 | 10.0 | 9.2 | 6.7 | 4.4 | 2.3 | 38.1 |
| Average rainy number of days | 12.1 | 11.5 | 12.4 | 12.3 | 12.4 | 4.0 | 1.1 | 0.7 | 2.2 | 7.2 | 9.1 | 11.6 | 95.1 |
| Monthly total precipitation average amount (mm) | 40.4 | 42.4 | 53.7 | 63.8 | 51.1 | 11.2 | 2.3 | 0.8 | 7.9 | 40.0 | 48.4 | 43.7 | 406.7 |

RWH potential for our study was calculated using the monthly balance approach. Mean monthly harvestable rainwater \((Q_m)\), mean monthly average rainfall \((R)\) and catchment areas of the roots \((A)\) were calculated as a function of the product of the percentage of roof area used for RWH and the run-off coefficient \((C)\) are given in Eq. (1). The average rainfall ‘\(R\)’, dependent roof area ‘\(A\)’ and gutters and collection system from leakage and overflow representing a yield efficiency coefficient ‘\(\beta \cdot C\)’ by multiplying each time it is the volume of rainwater is collected in step [11]:

\[
Q_m = R \ast A \ast \beta \ast C
\]

(1)

The run-off coefficient value ranges between 0.80 and 0.9 for the building’s rooftop constructed from concrete cement materials. The run-off coefficient of 0.80 was employed to account for evaporation loss and a possible first flush of the rooftop.

Total roof space = 6,510 + 1,050 = 7,560 m²
Amount of rainfall = 406.7 mm
\[ Q_n = 7,560 \times 0.9 \times 0.8 \times 0.4067 = 2,214 \text{ m}^3 \]

According to these, the total roof space has been calculated as 7,560 m² and the total amount of rain falling on the roof has been calculated as 2,214,000 litres.

4. Discussion

The solar energy system to be mounted on the roof is modelled and simulated by entering data using the PVsyst software. When the analysis data of the programme is examined, it is concluded that the system will produce 15,339,360 kWh of energy for 10 years. A feasibility study was conducted on the applicability of the solar energy system on an existing roof. The depreciation period of the system is calculated to be 4.9 years. Considering the pay-off period, the investment will pay for itself in a short time.

The reduction in CO₂ emissions this facility would provide was calculated to be 1,418,827 pounds. When the benefits of the solar power plant to be built on the relevant farm and an average tree are compared in terms of reducing the CO₂ emissions, it was found that the contribution of this plant would be equal to that of planting 113,506 trees. This study concludes that solar power plants will contribute to roof implementation and will be an environmentally friendly investment.

As for the RWH, the total roof space was calculated as 7,560 m² and the total amount of rain falling on the roof was calculated as 2,214,000 litres. With the RWH system, the irrigation water requirement of the facility will be provided, it will be an environmentally friendly system and our water resources will be protected.

5. Conclusion

The world is currently facing drought and global warming. From production to consumption, the most basic need in all areas is water and energy. The need for solar energy from renewable energy sources is growing as it reduces global warming and climate change. It is aimed to reduce CO₂ emissions that harm the environment with a solar energy system. Solar energy systems are an inexhaustible and environmentally friendly resource compared to fossil-derived energy sources. The most important advantages of the system are the reduction of CO₂ emissions, while the absence of waste products during energy production is one of its important advantages.

Currently, the need for water is a serious problem, as drought increases. Due to the lack of water, agricultural land is gradually declining. As a result of increasing industrialisation and the use of machines, the demand for both energy and water are increasing. As a result, it is necessary to develop sustainable environmental structural systems in both energy production and irrigation water. This, in turn, requires the most accurate use of existing water resources and the immediate implementation of sustainable agricultural systems. This research aimed to find effective results in terms of savings and contributing to the prevention of water scarcity in the future. The aim of this research has thus been achieved.
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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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