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Environmental assessment of rainwater harvesting and solar system

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Abstract

Water and energy are the most basic needs in every field, from production to consumption. To meet our energy needs, non-environmentally friendly and non-renewable resources are generally used. The danger of global warming is apparent around the world, which needs to be protected from carbon-based fuels. Climates are changing as CO_2 has a greenhouse effect on the atmosphere. For this reason, precipitation and temperatures are outside the seasonal norms. It is also highlighted now that countries should meet their energy needs on their own after the current wars on a global scale. Among the renewable energy options, the solar energy system is the most easily applied, environmentally friendly alternative energy source. This study will discuss the advantages of the solar energy system obtained from the roof of an existing agricultural enterprise. Problems caused by global warming are now felt seriously in our country. One of these problems is the need for water. Our country is considered to need agricultural water, especially in the Central Anatolia, Southeastern Anatolia, and Eastern Anatolia regions. It is foreseen that there will be global food crises in the future. Already in the current wars, grain crises have emerged. In addition to global climate change, our country must be able to meet its food, water, and energy needs in the face of the effect of wars. For this reason, agricultural enterprises and other structures to be built should be entirely environmentally friendly. It is necessary to obtain designs that will meet energy and water needs. This requires the most careful use of existing water resources and implementing sustainable agriculture systems as soon as possible. With the effect of global warming and wars, it is necessary to reduce the foreign dependency of the energy and food sectors. For this reason, it is essential that the roofs of agricultural enterprises both produce energy and store rainwater.

Keywords: Solar energy; Rainwater harvesting; CO_2 emissions; Agricultural irrigation.

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1. Introduction

One of the essential issues in managing water resources is the protection of these resources, and the other is their sustainable use [1]. Sustainability means being able to adapt to changing conditions and also leave a trace. It applies to sustainable building, and interior design to use resources efficiently and bring them into the future. Consumption has increased rapidly over time, and today, as a result of the existing resources not meeting current energy needs, new solutions are being sought. Sustainable approaches have been developed, primarily by increasing mechanization and reducing water use in agricultural areas, directing human beings to resources where they can use and produce energy more efficiently.

Renewable energies are among the clean energies because they are inexhaustible and are environmentally friendly as they do not pollute the environment.

Solar energy is the largest source of energy in the world. It is clean, accessible, endless, and easily harvested on roofs or the ground. It has been greatly preferred in recent years due to the limitation of fossil resources and the effects of environmental and global climate change. Turkey's solar energy potential has increased considerably in recent years.

Since renewable energy sources are clean and do not emit harmful gases to the environment, they are preferable to fossil sources. However, fossil-based energy consumption has also increased due to the increasing energy demand [2]. Turkey is a bridge connecting Europe and Asia. It has geographical coordinates of 39°00' North and 35°00' East and is located in the southeastern part of Europe and the southwestern part of Asia. Its neighbouring countries are Bulgaria, Greece, Syria, Iraq, Iran, Azerbaijan, Armenia, and Georgia. Turkey has a large amount of solar energy potential compared to other European countries. It has a significant position in terms of average sunshine duration and solar radiation (7.2 hours/day and 309.6 cal/m^2). The highest solar energy potential is in the southeastern Anatolia region [3].

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 photovoltaic production will soon be the leading source of electric output. Despite the pandemic, solar PV system-based generation has grown by 40% worldwide [4]. With this increase in the global production of solar PV plants, the need for successful applications and analysis programs for large and medium-sized grid-connected solar PV plants is increasing. Also, performance analyses of these systems and various simulation programs to measure the energy they will produce have been designed [2]. Solar photovoltaic technology is one of the most important renewable energy sources. Therefore, it is necessary to develop software tools to determine the potential energy output characteristics and operating performance of PV systems. Software tools related to hybrid photovoltaic systems can be classified into four categories: pre-feasibility, dimensioning, simulation, and open architecture research tools. The energy which the PV module will produce depends on the PV materials and the sun's rays, but it will decrease over time, usually due to humidity, thermal cycling, and ultraviolet radiation. At the same time, PV modules may suffer some permanent deterioration, such as corrosion, discolouration, delamination and breakage, and cracking cells. Besides these problems, the environmental factor of dust can temporarily but significantly reduce the energy produced by a PV module. However, the PV performance can be maintained by cleaning the PV panels. Umar et al. discuss ten photovoltaic simulation softwares, including SAM, PVsyst, HOMER, PV*SOL, RETScreen, Solarius PV, HelioScope, Solar Pro, SOLARGIS, and PV F-Chart. These different types of software will help to evaluate the performance and economic potential of the photovoltaic system, to simplify the design process and maximize the use of renewable energy sources, as well as to compare the performance and power generation costs [5].

The intensity of solar energy from outside the Earth's atmosphere is constant, at 1370 W/m^2; on Earth, the power is between 0 and 1100 W/m^2 [6,7]. The duration of sunshine around the world are measured at many meteorological stations. It is crucial to know the solar radiation data of a region for the effective design of photovoltaic systems (PV), planar collectors, and other solar energy collector systems. Correlations can provide monthly average daily global solar irradiance estimates of these data. Many models of the measured data for these estimations based on sunshine duration are derived from various Angstrom-type equations, and many experimental models have been developed to detect the level of solar radiation. In addition, different parameters such as cloudiness, sunshine duration, and ambient temperature are used to obtain these models [7]. Solar energy is a clean, continuous and environmentally friendly energy source, and most of the environmental problems arising from the use of traditional fuels are not replicated in solar energy [8].

Carbon dioxide (CO_2) emissions from fossil-based energy production and the amount of CO_2 in the atmosphere have increased approximately 1.3 times in the last century, and the greenhouse effect caused by CO_2 in the atmosphere has increased the average global temperature by 0.7 °C in the same period. An increase of 1 °C in this temperature causes seasonal and climate change. An increase above 3 °C may cause melting of polar ice caps, rising sea levels, drying up of lakes, and agricultural drought. For this reason, it will be necessary to turn to natural and alternative sources such as the sun [8].

Changes in precipitation regimes due to climate changes caused by global warming result in increasing droughts and floods. With drought, the demand for water increases, and water resources are under pressure. In order to achieve sustainable urban water management, drinking water, sewerage, treatment plants, and rainwater projects should be implemented, and their capital, operating and financial costs should be provided [9]. Today, rainwater collected from roofs to reduce the scarcity of water provides some of the water needed. A rainwater harvesting (RWH) system is a method of collecting this free rainwater and storing it in a tank before reusing it for a specific purpose. The RWH system is typically used for domestic, agriculture, and environmental management. RWH systems are defined as a measure of adaptation to the effects of climate change on water resources. With increasing industrialization and urbanization making the ground impermeable, precipitation cannot reach the groundwater. For this reason, even short-term precipitation can cause flooding. Rainwater harvesting, while enabling the protection and use of water, can also reduce floods and drought, maintain the moisture balance in the air and soil, and significantly reduce water-related energy consumption and greenhouse gas emissions. Rainwater is usually stored from roofs, courtyards, or other compacted, treated surfaces, unfiltered and collected in storage tanks for subsequent use. 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 rainwater tank capacity is one of the most critical design parameters affecting system performance and cost. Therefore, it must be carefully considered and designed to provide the optimum storage capacity according to its location [10].

Aktas et al., in their study, investigated the rainwater harvesting potential of the power plants licensed in Çorum since 2016. The authors showed that the rainwater harvesting potential from a small section of the PV plant is about 118 m^3/year, and the harvesting system would reach 1646 m^3/year when applied to the entire plant. The highest rainwater collection potential was found at two power plants in Derekisla and Alembeyli in the Sungurlu district, with 10129 m^3/year and 11591 m^3/year. The total rainwater harvesting potential of the power plants licensed since 2016 in Çorum has been calculated as 56388 m^3/year. These studies offer an innovative approach by harvesting rainwater from solar power plants with large surface areas to use the water obtained for panel cleaning and agriculture in the fight against climate change and drought [11].

Although there are many PV power plants worldwide, rainwater collection systems on power plants and roofs have not become widespread. Using the water obtained with RWH in agriculture and generating energy from solar power plants are essential in combating climate change and drought. This study aims to allow the most efficient and effective production approaches of PV energy and rainwater systems for all agricultural businesses. In this study, the amount of energy and CO2 emissions produced by the panels on the roof of an agricultural enterprise were investigated. How much energy will be produced and the recycling time will be calculated with the solar energy system installed on the roof. We will also examine the ecological and environmental benefits of building a rainwater system. It is thought that this study will provide significant benefits to farmers and investors, who are the actors of agricultural production.

2. Methodology

2.1. Location of study

When installing a solar power plant, the radiation values of the location where the power plant will be installed and the annual sunshine durations must be known. In this study, Elazig province was chosen as the place where the power plant will be established. The facility where the study will be carried out is located at 38°56' N and 39°17' East. In Figure 1, data on the exchange location from the RETScreen program are given.

	Unit	Climate data location	Facility location	Source
Latitude		38.6	39.2	
Longitude		39.3	39.3	
Climate zone		4A - Mixed - Humid		Ground+NASA
Elevation	m	881	891	Ground – Map
Heating design temperature	°C	-8.9		Ground
Cooling design temperature	°C	36.2		Ground
Earth temperature amplitude	°C	25.4		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-0.3	68.3%	44.64	2.21	87.6	1.7	-3.2	567	0
February	0.7	63.0%	47.60	3.02	87.4	1.9	-1.3	484	0
March	5.8	56.2%	49.91	4.13	87.4	2.2	4.3	378	0
April	12.3	53.5%	58.50	5.18	87.3	2.3	10.5	171	69
May	17.0	49.9%	46.81	6.53	87.4	2.2	16.1	31	217
June	22.5	38.1%	14.70	7.85	87.2	2.4	22.6	0	375
July	27.1	30.9%	3.72	7.88	87.0	2.4	28.1	0	530
August	26.6	31.0%	1.86	6.92	87.1	2.1	27.7	0	515
September	21.3	37.3%	8.40	5.61	87.5	2.0	21.6	0	339
October	14.5	52.5%	44.64	3.80	87.8	1.8	13.6	109	140
November	6.8	64.9%	47.70	2.52	87.8	1.8	4.8	336	0
December	1.8	68.8%	47.43	1.88	87.7	1.6	-1.2	502	0
Annual	**13.1**	**51.1%**	**415.91**	**4.80**	**87.4**	**2.0**	**12.0**	**2,579**	**2,184**
Source	Ground	Ground	NASA	NASA	NASA	Ground	NASA	Ground	Ground
Measured at					m	10	0		

Figure 1. Daily solar radiation and climate data for Elazig location with RETScreen Software

This study examines the advantages of constructing solar power plants using the PVsyst program. Thus, it is expected that solar power plants will increase by evaluating the roofs of agricultural enterprises. Figure 2 shows the location where the solar power plant will be installed and the total solar radiation values. The roof area where the solar energy system will be installed is 100×15=1500 m^2. The panel angle was chosen at 10° due to the existing roof slope. The optimized tilt/azimuth angle is 10°/3° and 10°/-177°. Since solar panels will be placed on the roof of the existing agricultural enterprise building, the roof carrying capacity has been calculated. As a result of the calculation of the carrying capacity, it has been seen that the roof is suitable for solar panel application. After the aluminium slats are placed on the existing roof, the panels will be mounted on the laths. If the current capacity of the roof is insufficient for the solar panel, a preliminary project, including retrofitting proposals, should be prepared. Reinforcement works will be inspected at least once on site. The prepared project and static calculations must first be submitted to the competent authority to obtain a building permit, then to the General Directorate of TEDAŞ or the provincial organization of the relevant distribution facility.

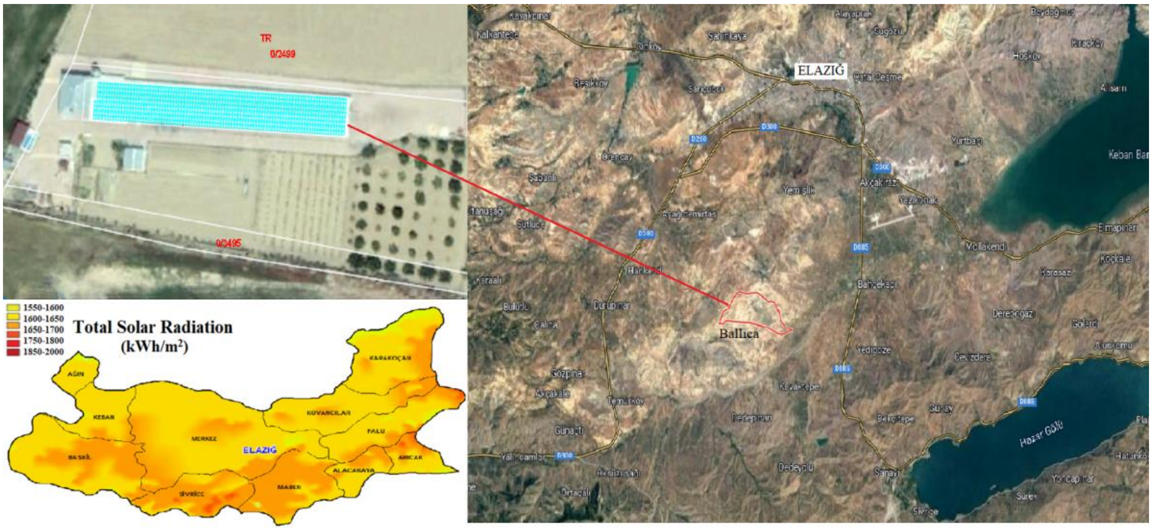

Figure 2. Total solar radiation and agricultural business

2.2. PV Software

PVsyst is a PC software package for designing and simulating PV systems. The software was developed by the University of Geneva, Switzerland, and is widely used by the solar industry, developers, and academia. Numerical analysis of the power plant was made using the PVsyst V6.81 software as shown in Figure 3 [12].

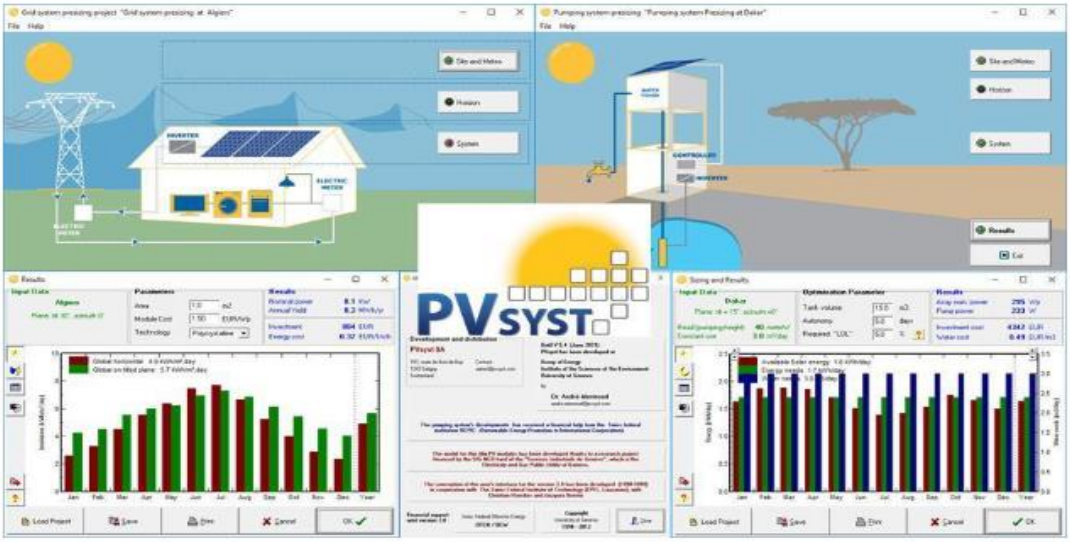

Figure 3. PV Syst software [12]

A solar energy system with a power of 260 kWp will be installed on the roof of the agricultural enterprise. Parameters such as location, slope, direction, geographic coordinates, modules, and inverter quality in solar energy systems affect the energy production of the PV panel. For this reason, the location of the roof of the existing agricultural enterprise is significant. For this study it is suggested that the roofs of new agricultural enterprises and buildings should be constructed accordingly in terms of their carrying capacity and location. In this study, PV software (Perez model) was used to estimate the solar radiation at the surface. In SI unit systems with PV software, solar radiation is measured in watts per square meter (W/m^2).

Table 1 shows the main outputs of the grid-connected PV systems and the balances between them. The annual global horizontal radiation is 1618.2 kWh/m^2. The annual global energy in the collector is 1606.2 kWh/m^2. The energy available at the output of the PV array is 363.69 MWh. The energy supplied to the grid is 358.17 MWh. The average temperature is 13.24 °C.

Table 1. Simulation of the energy production plant

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR
January	59.5	30.72	-0.99	59.0	55.2	14.38	14.16	0.929
February	79.8	38.46	0.92	79.2	75.4	19.4	19.11	0.933
March	121.9	59.04	7.20	120.8	116.1	28.87	28.44	0.911
April	148.1	65.77	12.03	147.1	142.4	34.23	33.70	0.887
May	185.9	70.36	17.17	184.5	178.8	41.87	41.24	0.865
June	209.7	77.45	22.95	208.0	202.4	45.61	44.91	0.836
July	216.4	73.58	27.53	214.8	208.9	46.11	45.40	0.818
August	199.4	64.04	27.21	198.1	192.3	42.77	42.12	0.823
September	159.8	51.69	20.93	158.6	153.4	35.12	34.59	0.844
October	113	48.18	14.79	112.2	107.1	25.85	25.47	0.879
November	69.7	32.43	6.72	69.3	65.2	16.40	16.15	0.902
December	54.9	28.40	1.54	54.5	50.6	13.09	12.88	0.914
Total Year	1618.2	607.2	13.24	1606.2	1547.8	363.69	358.17	0.863

In Figure 4, the performance ratio (PR) of the produced energy is shown graphically for each month of the year. The average ratio is 0.863. The highest PR recorded in February was 86% due to the low module temperature, and the lowest PR of 64% was obtained in July due to the high temperature of the PV module. The table above shows the total annual generation of the PV program to be 358.17 MWh according to the numerical analysis. The performance ratio (PR) is the ratio of the final PV system yield (Y_f) and the reference yield (Y_r) [13].

$$PR = Y_f / Y_r \quad (1)$$

The month-to-month energy generation with the losses and distinctive sorts of field losses that happen within standalone photovoltaic frameworks throughout the year are shown in Fig. 4b.

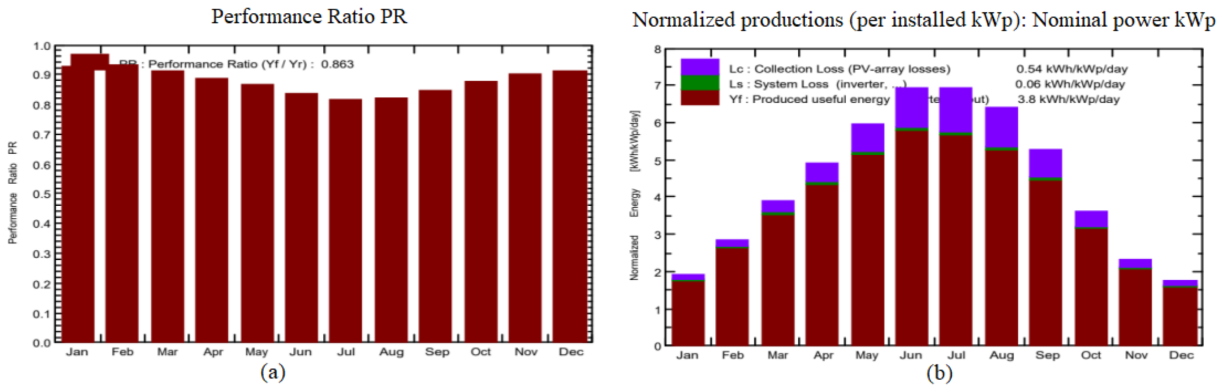

Figure 4. Monthly Normalized productions with losses and Performance Ratio

According to the results obtained with the PVsyst software, the facility produces 358,170 kWh of energy per year. The annual income of the solar energy system is calculated as ₺235.707($33,000). The cost coverage period of the facility is also calculated, considering that there will be a 1% energy loss every year. When the annual income of the facility is divided by the cost, it is seen that the solar power plant pays for itself in 4.1 years.

3. Carbon emission

The level of development and energy consumption of a countries are an inseparable whole. As energy consumption increases, carbon emissions increase; therefore, economic expansion is all about carbon emissions. As economic growth increases, innovative technologies are required to protect the environment, increase the use of emerging energy resources and minimize carbon emissions.

Carbon emissions are the average greenhouse gas emissions generated during the manufacturing, transportation, use, and recycling products. The carbon emission data per capita from 1990 to 2020 in Turkey, according to TUIK, are shown in Figure 5. According to the greenhouse gas inventory results, the total greenhouse gas emission in 2020 increased by 3.1% compared to the previous year. It was calculated as 523.9 million tons (Mt) CO_2 eq. The total greenhouse gas emission per capita was calculated as 4 tons of CO_2 eq in 1990, 6.2 tons of CO_2 eq in 2019, and 6.3 tons of CO_2 eq in 2020 [14].

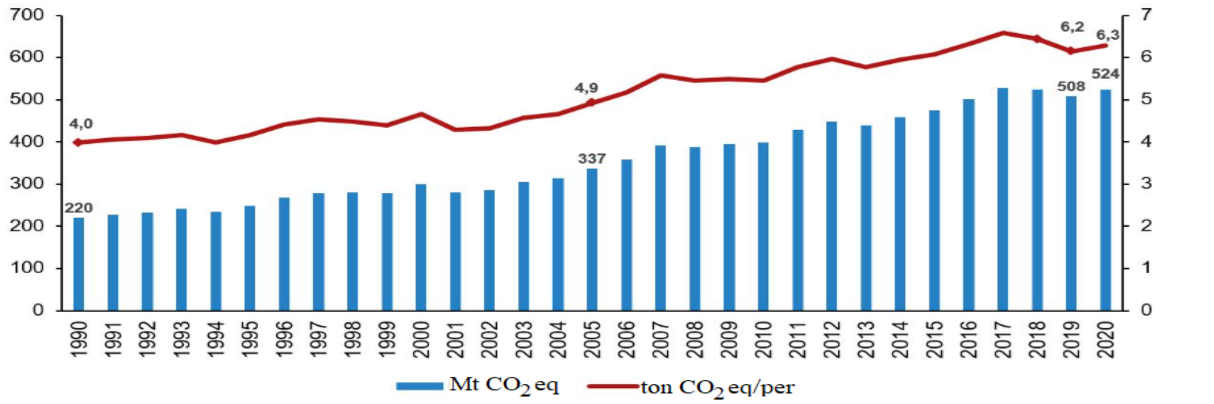

Figure 5. The carbon emission data per capita from 1990 to 2020 in Turkey, according to TUIK

Greenhouse gases (such as carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbon, and sulfur hexafluoride) accumulating in the atmosphere as a result of the use of fossil-based energy sources cause global warming and climate change. These gases released into the atmosphere are causing the average global temperature to rise. The world faces severe risks such as global warming, primarily due to the CO2 gas released into the atmosphere. The main reasons for increasing carbon emissions in recent years are uncontrolled industrialization, constantly increasing energy demand, increasing urbanization, decreasing forest areas, intensive livestock activities, and uncontrolled greenhouse gas emissions [15].

Since Turkey is among the developing countries, its energy needs have increased considerably. Greenhouse gas emissions have also increased considerably due to increasing industrialization, urbanization, and the number of vehicles. As a result of this, the effects of global warming have started to show themselves in Turkey, climate change has intensified, and the average temperature has increased. For this reason, studies must be carried out to reduce the emissions of such gases into the atmosphere. If carbon emissions are not reduced, they can pollute and damage almost everything, from our diet to the air we breathe. Therefore, providing clean energy to agricultural enterprises and factories through panels is an essential investment in reducing carbon emissions [14, 15].

Every 1 kWh of electricity produced corresponds to 0.846 pounds of CO_2 (0.384 kg). Based on this, the amount of CO_2 reduced with the help of panels in farms would be:

CO2 reduced = [the amount of energy produced annually (kWh) × 0.846] = 358170 × 0.846=303011.82 pounds of carbon [16].

The reduction in CO_2 emissions this facility would provide was calculated as 303011 pounds. A typical hardwood tree can absorb as much as 48 pounds of carbon dioxide per year. 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 CO_2 emissions, it is seen that it is equivalent to planting 631274 trees.

4. Rainwater Harvesting

The solar energy system on the roof of the agricultural enterprise in the province of Elazig is significant for a sustainable future, in which it is essential to meet the water needs of agricultural enterprises. Some of the water requirement is met by storing the rain falling on the roof. Precipitation is a significant parameter in the evaluation of the rainwater system. The monthly average total precipitation values and coordinates for 1980–2021 were obtained from the General Directorate of Meteorology [17]. The annual average total precipitation for Elazig is 397.033 mm. Considering the course of the 42-year precipitation data in Figure 6, it is seen that the precipitation trend is variable. The highest annual precipitation was 605 mm in 1988, and the lowest precipitation was 205 mm in 1990.

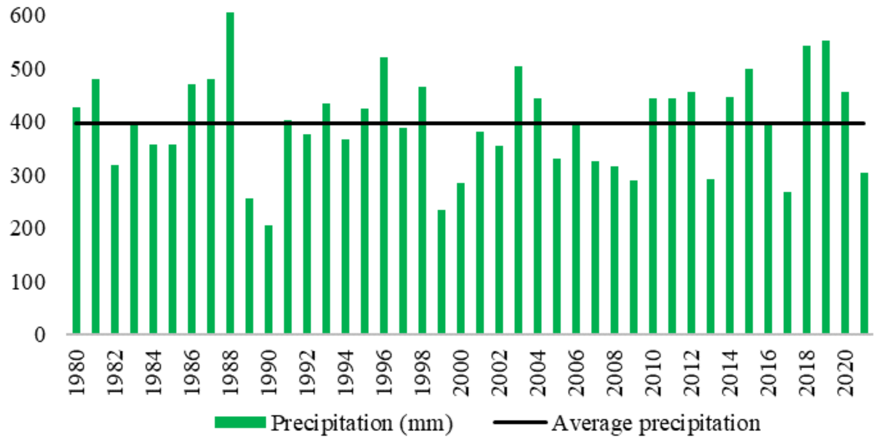

Figure 6. Average annual precipitation data for the period 1980-2021

Rainwater harvesting potential for our study was calculated using the monthly balance approach. In determining the amount of water to be obtained in rainwater harvesting, information such as the roof coefficient, the precipitation amounts of the location to be made, and the collection area where the harvest will be made is needed. The average monthly harvestable rainwater to be collected from the roof surface is shown in Equation 2;

$$Q_m = R * A * \beta * C \qquad ...(2)$$

Q_m : Mean monthly harvestable rainwater

R : Mean monthly average rainfall

A : Catchment areas of the roots

C : The runoff coefficient: its value ranges between 0.80 to 0.9 for building's roof top constructed from concrete cement materials. The runoff coefficient of 0.80 was employed to account for evaporation loss and a possible first flush of the rooftop. The average rainfall "*R*" dependent roof area "*A*" and gutters and collection system from leakage and overflow represent a yield efficiency coefficient "β, C" by multiplying each time "*t*" is the volume of rainwater is collected in step: [15].

Total roof space=100*15=1500 m^2

Amount of rainfall = 397,033 mm

Q_m = 1500 *0.9*0.8* 0.397033 =428,79 m^3

According to these, the total roof space has been calculated as 1500 m^2 and the total amount of rain falling on the roof has been calculated as 428790 liters.

5. Conclusions

Recently, with the increase in energy and water needs, countries have turned to environmentally friendly systems to increase their agricultural productivity and sustainability. Solar energy and rainwater harvesting are such systems and are very easy to apply in agricultural areas and buildings. Rainwater systems prevent the floods that can occur as a result of climate change and drought. At the same time, the water needs of agricultural enterprises can be met with RWH. As a result of fossil-based energy consumption, global warming and drought are increasing. For this reason, agricultural areas and buildings should adopt solar energy in energy production in order to reduce their carbon emissions.

The annual income of the solar energy system is calculated as ₺235,707($33,000). It produces 358,170 kWh of energy annually and it is calculated that the solar power plant pays for itself in 4.1 years.

This facility's reduction in CO_2 emissions has been calculated as 303011 pounds. When the benefits of the solar power plant to be installed on the related farm are compared with the average tree in terms of reducing CO_2 emissions, it is seen that it is equivalent to planting 631274 trees.

In this study, the total roof area was calculated as 1500 m², and the total amount of rain falling on the roof was calculated as 428790 litres. With the RWH system, the irrigation water needs of the facility will be supplied, it will be an environmentally friendly system, and our water resources will be protected.

Nomenclature

Q_m	mean monthly harvestable rainwater
R	mean monthly average rainfall
A	catchment areas of the roots
C	the runoff coefficient
B	a yield efficiency coefficient
PR	performance ratio
Y_f	the ratio of the final PV system yield
Y_r	the reference yield

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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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