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Carbon Footprint Reduction and Strategic Benefits of Energy Efficiency: A Case Study in the Healthcare Sector

Mehmet Yorulmaz, Tuğba İmat Taş

Dept. Of Health Management, Selçuk University, Konya, Türkiye

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Corresponding author
Mehmet Yorulmaz,
mtyorulmaz@hotmail.com

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Abstract: This study investigates the impact of a solar photovoltaic (SPV) system on electricity consumption and carbon emissions in a private hospital. In 2024, the system produced 7,122,802.80 kWh of renewable electricity, preventing approximately 3,148 metric tons of CO_2e emissions and reducing total electricity costs by 72.3%. Data were analyzed using national tariff coefficients and emission factors published by the Energy Market Regulatory Authority (EPDK) and the Turkish Electricity Transmission Corporation (TEİAŞ). The results show that SPV integration effectively lowers both energy expenditures and carbon intensity in healthcare operations. This case demonstrates the technical feasibility and economic advantage of renewable energy adoption in energy-intensive institutions.

Keywords: Carbon emissions, Cost reduction, Electricity consumption, Renewable energy, Solar photovoltaic system.

1. Introduction

The use of energy dates back to ancient times in human history. In early periods, fossil fuels were utilized, and in later centuries, renewable resources came into play. Since the Industrial Revolution, energy has increasingly become a dominant element of power (Özalp, 2025). Around 3200 BC, the ancient Egyptians harnessed wind power to cross the Nile River, while by 200 BC, windmills were used in China and the Middle East for water pumping. It is also known that the Romans used geothermal and solar energy for heating water, whereas the Greeks employed waterpower for grinding grain (Katterbauer, Yılmaz, & Meral, 2025).

Energy sources such as coal, oil, and natural gas-commonly referred to as fossil fuels-originated from the remains of plants and animals that lived millions of years ago and have provided most of the global energy production. However, this use has led to the release of large amounts of greenhouse gases into the atmosphere, and the surpassing of critical concentration thresholds by these gases has triggered abnormal temperature increases. The use of fossil fuels has intensified global warming and accelerated climate change, which now represents one of the most serious environmental challenges facing modern society (Sağır, 2024). The excessive carbon emissions resulting from fossil fuel consumption have caused severe ecological damage and made irregular climate-related migrations increasingly widespread. It is projected that, within the next fifty years, desertification driven by climate change will accelerate globally, and Turkey's southern regions, in particular, will be seriously affected by this process (Özalp, 2025). Human-induced activities such as industrial operations, transportation, agriculture, and energy consumption contribute to significant greenhouse gas emissions (CO_2, CH_4, N_2O, fluorinated gases, etc.), thereby accelerating global temperature rise (Sürmeli, 2025).

The growing impacts of climate change caused by global temperature increases have further clarified the relationship between energy consumption and environmental sustainability (Nasırli & Behdioğlu, 2025). In this context, the carbon footprint is defined as the total amount of greenhouse gases emitted into the atmosphere throughout the life cycle of a product, service, or activity, expressed in carbon dioxide equivalents (CO_2e). This calculation encompasses not only direct emissions (e.g., exhaust gases from vehicles) but also indirect emissions (e.g., those resulting from electricity consumption) (Gezer, 2025).

Jeremy Rifkin has described the crucial role of energy resources in the development and transformation processes of the Industrial Revolution: the First Industrial Revolution was driven by steam power, the Second by oil-based energy, and the ongoing Third Industrial Revolution is characterized by a transformation toward renewable energy sources (Kılıç, 2023). In the 19th century, environmental problems, particularly in developed countries, led the environmental movement to approach the concept of sustainability more comprehensively (Öztürk & Göktepe, 2024). In this regard, the 1972 United Nations Conference on the Human Environment in Stockholm—with the participation of 113 countries—was the first global conference organized on environmental issues. Subsequently, major international agreements were adopted, including the 1992 United Nations Framework Convention on Climate Change (UNFCCC), the 1997 Kyoto Protocol, the 2009 Copenhagen Accord, and the 2014 U.S.-China Joint Agreement (Akın, 2025).

In 2015, with the participation of over 130 countries, the Paris Agreement marked the first global commitment to reducing greenhouse gas emissions. The years 2015–2020 were designated as the planning and preparation period for countries' Nationally Determined Contributions (NDCs) (https://www.mfa.gov.tr/paris-anlasmasi.tr.mfa). Beginning in 2020, the Agreement set a goal to limit the global temperature increase to well below 2°C above pre-industrial levels-preferably to 1.5°C—and to achieve net-zero emissions in the second half of the century (Telli, 2025). By 2024, Turkey's average temperature had reached 15.6°C, which is 1.7°C above the 1991–2020 average, marking the highest temperature recorded in the past 54 years. Furthermore, monthly average temperature records were broken in January, April, June, and July 2024, making both the winter and summer seasons historically the hottest on record (Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, General Directorate of Meteorology, 2025). The Presidency of the Republic of Türkiye (TCCB) has pledged to reduce greenhouse gas emissions by 41% compared to the reference scenario by 2030 and to achieve net-zero emissions—carbon neutrality-by 2053 (Sert, Çetin, & İnce, 2025). Additionally, on October 29, 2021, the Ministry of Environment and Urbanization was renamed the Ministry of Environment, Urbanization and Climate Change (Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, n.d.).

As a result of climate change, it is anticipated that vector-borne diseases, water- and food-borne infections, heat stress–related health problems, zoonotic diseases, food insecurity, and malnutrition risks will increase, along with higher incidences of air pollution, hydro-meteorological disasters, and mental health problems. Unless effective preventive measures are taken, the negative impacts of the carbon footprint on climate change and human health are expected to persist in the future (Baş, 2025).

Ritchie, Rosado, and Roser (2023), in their analysis titled "CO_2 and Greenhouse Gas Emissions" on the Our World in Data platform, reported that global CO_2 emissions amount to 37.79 billion tons, with Asia (excluding China and India) accounting for 22.6 billion tons, Europe 4.99 billion tons, the United States 4.91 billion tons, and Türkiye 432.08 million tons. Based on these figures, Türkiye ranks 16th in the world in terms of carbon emissions (Özalp, 2025). Turkey's electricity consumption trend is generally characterized by irregularity and volatility (Çunkaş & Taşkıran, 2011).

In Türkiye, the healthcare sector faces significant challenges regarding energy consumption, water use, material demand, and waste management. Calculations indicate that the sector consumes approximately 10 billion kWh of electricity and 1.5 billion m³ of water annually, generates 1.5 million tons of waste, and contributes around 6 million tons of carbon emissions (Pınarcı, Güven, & Eren, 2025). In this context, one of the main challenges faced by healthcare institutions is effective energy management (Kahveci, 2025). Within the hospital sector, environmentally friendly building practices under the "green hospital" concept can yield 25% to 50% savings in energy use, nearly one-third reductions in carbon emissions, and up to 50% reductions in water consumption. Moreover, solid waste generation can be reduced by approximately 70%, and maintenance and repair costs can be lowered by about 13% (Hoşgör, 2014).

Considering all this information, this study seeks to demonstrate, using current and reliable data, the environmental damage caused globally by fossil fuel–based energy production and to examine the potential impact of solar-powered electricity generation on reducing carbon emissions. Recent modeling studies in Türkiye have emphasized the role of meteorological and environmental factors-such as solar irradiance, temperature, wind speed, and air pollution-in determining photovoltaic system performance. For instance, Özbeyaz (2025) developed a dual-axis solar tracking system and demonstrated that the inclusion of air pollution indicators ($PM_{2.5}$ and PM_{10}) in predictive models significantly improved the accuracy of solar power generation forecasts. Within this framework, the study evaluates how renewable energy sources-particularly in high-consumption areas such as the healthcare sector-can play a strategic role in sustainable energy management. Accordingly, it emphasizes that solar energy technologies are not only a means of supporting energy supply security but also a fundamental tool for achieving carbon-neutral goals.

2. Materials and Methods

This section describes the study design, system specifications, data sources, and key input parameters used to assess the energy and environmental performance of the SPV system.

2.1 Study Design

This study adopts a quantitative case study design, focusing on a single private hospital located in the Karatay District of Konya Province, Türkiye. The aim is to assess the environmental and economic impact of a grid-connected solar photovoltaic (SPV) system on hospital-level electricity consumption and carbon emissions within the 2024 calendar year. The case study approach enables an in-depth, contextualized evaluation of energy efficiency outcomes in a real-world, energy-intensive institutional setting.

2.2 Research Site and System Characteristics

The SPV system examined in this study is located within the boundaries of Acıdort Neighborhood, Karatay District, Konya Province, at the geographic coordinates of 37.968771°N latitude and 32.800985°E longitude. The site is situated at an altitude of approximately 1,020 meters and operates under a semi-arid continental climate. A total of 9,150 photovoltaic panels has been installed, and the system's technical capacity parameters are presented in the table below.

Table 1 Installed Capacity Parameters of the Solar Photovoltaic System (SPV System)

Parameter	Value	Unit
Total DC Power (Direct Current Capacity)	4,209.00	kWp
Total AC Power (Alternating Current Capacity)	3,200.00	kWe
Grid-Connection Limited AC Capacity	3,200.00	kWe

The values presented in Table 1 indicate the installed capacity parameters of the hospital's solar photovoltaic system (SPV). As summarized in Table 1 the total DC power capacity of 4,209 kWp represents the maximum theoretical generation power of the solar panels, while the total AC power capacity of 3,200 kWe indicate the amount of active power that can be transferred to the grid via inverters. Additionally, the limited AC capacity value represents the maximum power that the system can feed into the grid, as determined by legal connection limits set by the Energy Market Regulatory Authority (EPDK) and the Turkish Electricity Transmission Corporation (TEİAŞ). These data show that the system's DC/AC ratio is approximately 1.31. HelioScope (2025) notes that maintaining a DC/AC ratio of around 1.25 is a common and economically viable practice.

The solar photovoltaic system analyzed in this study has a total installed DC capacity of 4,209 kWp and an AC output power of 3,200 kWe. The contracted power capacity has been set at 3,200 kW. The system is grid-connected through inverters and operates at a capacity limit of 3,200 kWe, in compliance with TEİAŞ technical standards.

2.3 Data Collection

Electricity consumption and generation data were obtained from the hospital's automatic meter reading (AMR) system and cross-verified using inverter output logs. Solar irradiation data were retrieved from the Photovoltaic Geographical Information System (PVGIS) for the specific geographical coordinates of the installation site (37.968771°N, 32.800985°E). National electricity tariffs, distribution charges, and carbon emission factors were sourced from official databases published by the Energy Market Regulatory Authority (EPDK) and the Turkish Electricity Transmission Corporation (TEİAŞ). The data collection period spanned January 1 to December 31, 2024.

- **Analytical Techniques**

The analysis consists of three core components:

1. **Energy Balance Analysis**

- Monthly electricity consumption (C) and solar generation (P) values were compared to compute grid import/export dynamics (i.e., net-metering).
- Surplus and deficit periods were identified based on the condition P >C or C > P.

2. **Cost-Benefit Analysis**

- Electricity cost calculations were performed by multiplying kWh values by sector-specific tariff coefficients.
- Total savings were computed by comparing electricity expenditures in SPV-supported and grid-only scenarios.
- Taxes (municipal energy consumption tax and VAT), power capacity charges, and distribution fees were included to reflect the full cost structure.

3. **Carbon Emission Reduction Estimation**

- Avoided CO_2e emissions were calculated using the official national emission factor of 0.442 kg CO_2e per kWh (ETKB,2022; TEİAŞ, 2022).
- Total annual avoided emissions were estimated as:

  CO_2e savings $=$ SPV generation (kWh) $\times 0.442$ kg CO_2e/kWh

Calculations were performed using Microsoft Excel with embedded formulas, and all data entries were cross-checked by two independent researchers to ensure accuracy.

2.4 System Performance Evaluation

To assess the operational efficiency of the installed photovoltaic system, monthly Performance Ratio (PR) values were calculated for the year 2024. PR is a critical indicator used in solar energy systems to measure how effectively the available solar irradiation is converted into actual electricity production. It accounts for

losses due to temperature, inverter efficiency, wiring, and other system components.
In this study, monthly total solar irradiation values (kWh/m²) were retrieved from the Photovoltaic Geographical Information System (PVGIS), while energy generation data (kWh) were obtained from the hospital's automatic meter reading (AMR) system. The PR for each month was computed using the ratio of actual energy output to the theoretical maximum based on solar potential.

Table 2 System Performance Ratio (PR) Based on Irradiation Sensor Data for 2024

2024 / Month	Total Energy Generation (AMR Data) (kWh)	Total Solar Irradiation (kWh/m²)	System Performance Ratio (PR) (%)
January	290,767.05	85.07	81.20%
February	473,118.98	133.59	84.14%
March	605,532.38	165.59	86.88%
April	661,287.38	183.95	85.41%
May	696,379.95	194.54	85.04%
June	798,539.18	226.91	83.61%
July	802,742.03	223.00	85.52%
August	776,927.03	222.81	82.84%
September	659,312.33	195.67	80.05%
October	671,082.30	183.37	86.94%
November	413,536.73	111.33	88.25%
December	273,577.50	72.46	89.70%

In photovoltaic systems, the System Performance Ratio (PR) serves as a key indicator of how effectively the installed capacity and available solar potential are converted into actual electricity generation. The analysis of 2024 operational data shows that the system's PR values ranged between 80.05% and 89.70% throughout the year. These figures indicate that the facility maintained a consistently high level of efficiency, with total production losses remaining within acceptable operational limits.
During the first quarter of the year (January–March), although solar irradiation levels were relatively low, the PR values ranged from 81% to 87%, indicating efficient utilization of available sunlight. This result reflects improved module efficiency and limited thermal losses under cooler ambient temperatures, allowing the system to achieve near-optimal conversion performance even under reduced solar exposure.
In the spring and summer months (April–August), a slight decrease in PR values was observed, fluctuating between 82% and 85% despite higher irradiation levels. This pattern can be attributed to elevated panel surface temperatures that reduce cell efficiency, as well as increased DC/AC conversion and transmission losses at higher generation capacities. The observed performance decline remains within normal operational expectations for photovoltaic plants operating under hot and dry climatic conditions.
From September onward, PR values initially dropped to around 80%, reflecting the combined effects of seasonal soiling and reduced irradiation balance, before rising again in the last quarter (November–December) to 88–89%. This late-year recovery demonstrates that the system's components operated stably, maintenance was effectively executed, and inverter performance remained robust under varying seasonal conditions.
Overall, the average PR value for 2024 was approximately 85%, which is classified as "high performance" according to international photovoltaic standards (IEC 61724). These results confirm that the system maintained its design efficiency, operating with reliable stability and high conversion effectiveness throughout the year despite changing climatic conditions.

2.5 Electricity Tariff and Cost Inputs

Electricity cost calculations in this study are based on official unit price tariffs approved by the Energy Market Regulatory Authority (EPDK). These tariffs are categorized by consumer type and include separate charges for energy consumption during daytime, peak, and nighttime periods, as well as distribution charges. Since hospitals fall under the "Public and Private Services Sector", this category's pricing model was used in all relevant analyses. The table below summarizes the sector-based electricity tariffs effective as of January 1, 2024, and serves as the primary input for calculating monthly and annual electricity expenses under both grid-only and SPV-supported scenarios.

Table 3 Sector-Based Tariffs Approved by the Energy Market Regulatory Authority (EPDK)

	Sector-Based Tariffs Approved by the Energy Market Regulatory Authority (EPDK) and Effective as of January 1, 2024					
	01/01/2024	**Sector-Based Consumer Tariffs (kr/kWh)**				
Distribution System Users	**Distribution System Users**	**Retail Single-Time Energy Charge**	**Daytime Retail Energy Charge**	**Peak Period Energy Charge**	**Nighttime Energy Charge**	**Distribution Charge**
	Medium Voltage					
	Dual-Term					
	Industry	298.4576	302.3210	487.0179	153.2520	37.9163
	Public and Private Services Sector and Others	275.5610	278.5817	451.6047	140.9145	59.0916
	Residential	119.2748	121.8171	214.4121	47.7707	58.5300
	Agricultural Activities	166.0829	168.0581	280.8049	77.9626	48.6664
	Lighting	252.7690				56.7151

Source: Energy Market Regulatory Authority [EPDK]. (2024). *Tariff tables for electricity billing purposes.* https://www.epdk.gov.tr/Detay/Icerik/3-1327/elektrik-faturalarina-esas-tarife-tablolari

According to Table 3, the energy charges for each consumer category are determined at different unit prices depending on the daytime, peak, and nighttime periods. In addition to the energy charge, a separate distribution charge is also applied. The category titled "Public and Private Services Sector and Others" generally includes institutions such as hospitals, educational organizations, and public service providers. In this context, the electricity tariff applicable to hospitals is based on a medium-voltage and dual-term tariff structure, compared to other sectors. The relatively higher unit prices applied during daytime and peak hours indicate that electricity demand is also higher during these periods. Therefore, in institutions such as hospitals that require continuous 24-hour energy supply, a significant portion of electricity costs arises from these time intervals. For the remaining six-month period of the year, the distribution charge was set at 0.939251tl/kWh.

In the public and private services sector, the "retail single-time energy charge" is specified as 275.5610 kr/kWh, corresponding to approximately 2.76tl per kilowatt-hour (kWh) of electricity consumed. When the distribution charge (59.9916 kr/kWh ≈ 0.60tl/kWh) is added, the total cost rises to approximately 3.35tl/kWh.

In addition to conventional electricity pricing, this study also considered the "Green Tariff" structure regulated by EPDK. The green tariff represents the unit cost of electricity sourced from certified renewable energy systems and applies to consumers who choose to purchase electricity generated entirely from renewables. In this context, hospitals operating under the public and private services sector category are subject to both energy and distribution charges, along with a monthly power capacity charge based on their contracted demand. The green tariff values provided below were used to assess the cost-effectiveness and regulatory positioning of the solar photovoltaic (SPV) system under Türkiye's renewable energy policy framework.

Table 4 Sectoral Green Energy Tariff Structure Approved by EPDK (Excluding Taxes, Funds, and Levies)

Green Tariff Approved by the Energy Market Regulatory Authority (EPDK) and Effective as of January 1, 2024, Excluding Taxes, Funds, and Shares			
Transmission System Users			
	Green Energy Charge		
	kr/kWh		
	312.4942		
Distribution System Users			
Consumers Receiving Energy from the Authorized Supply Company			
	Green Energy Charge	**Distribution Charge**	**Capacity Power Charge**
	kr/kWh	**kr/kWh**	**kr/Ay/kW**
Medium Voltage			
Dual-Term			
Industry	312.4942	37.9163	1.2601
Public and Private Services Sector and Others	312.4942	59.0916	2.0288

Source: Energy Market Regulatory Authority (EPDK). (2024). *Tariff tables for electricity billing purposes.* https://www.epdk.gov.tr/Detay/Icerik/3-1327/elektrik-faturalarina-esas-tarife-tablolari

Table 4 represents the "Green Tariff Excluding Taxes, Funds, and Shares" approved by the Energy Market Regulatory Authority (EPDK) and effective as of January 1, 2024. In this context, the capacity charge applicable to the institution is set at 2.0288 kr/month/kW. This charge, defined by EPDK, represents the fixed cost component that medium-voltage, dual-term consumers in the public and private service sectors are obliged to pay on a monthly basis according to their contracted capacity. The capacity power charge is independent of electricity consumption or generation and is intended to cover the operational cost incurred by the grid operator to maintain continuous power delivery (EPDK, 2024). In short, it constitutes a fixed obligation arising from the consumer's grid-connected status.

According to Table 4, the term "green energy" refers to the supply of electricity generated from renewable energy sources by the electricity provider to the end user. Similarly, the distribution charge refers to the infrastructure utilization cost associated with the transmission of electricity from the generation source (e.g., a solar power system or other power plant) to the point of consumption, such as hospital facilities. For unlicensed producers, the distribution charge is 0.3693 kr/month/kWh. These two components form the fundamental elements of the unit cost of electricity. In energy-intensive healthcare institutions such as hospitals, the adoption of green energy sourced from renewables significantly contributes to carbon emission reduction, with only a marginal impact on total energy costs.

3. Results and Discussion

This section presents the results of the photovoltaic system's operational performance, carbon emission reduction, and economic impact on the hospital's energy costs. The findings are interpreted in relation to national regulatory tariffs and compared across conventional grid-based and SPV-supported scenarios. The outcomes are supported by quantitative data provided in the following tables.

According to Table 5, the calculations based on the hospital's monthly electricity consumption and generation data for 2024, together with the tariff coefficients and reference rates published by the Energy Market Regulatory Authority (EPDK), reveal the impact of the solar photovoltaic system (SPV) on grid electricity consumption and its economic performance. In the table, the amount of electricity consumed

(C) and electricity generated (P) for each month are compared, while the differences—specifically, P > C (indicating excess generation) and C > P (indicating net grid draw)—are presented separately. This approach provides insights into both the technical and economic performance of the system's net generation–consumption balance. Within the scope of the analysis, the total monthly consumption costs were calculated by taking into account the EPDK's published distribution charge, national energy tariff, and power capacity charge. Accordingly, the "Distribution Charge for Consumption" column was obtained by multiplying the electricity drawn from the grid (in kWh) by the applicable distribution charge rate, while the "Energy Charge for Consumption" column was derived by multiplying the same consumption amount by the national energy tariff. The sum of these two components represents the gross monthly electricity cost.

Table 5 Monthly Energy Performance of the SPV System (Year:2024)

	Electricity Consumption (kWh)	Electricity Generation (kWh)	Excess Generation (P > C)	Net Grid Draw (C > P)	Distribution Charge for Consumption (kr/kWh)	Distribution Charge for Generation (kr/kWh)	National Energy Tariff (kr/kWh)	Power Capacity Charge (TRY)	Distribution Charge (TRY)	Energy Charge (TRY)
January	513,719.96	290,767.05		222,952	0.590916	0.36932	2.756	20.29	303,565	1,415,607
February	478,594.31	473,118.98		5,475.33	0.590916	0.36932	2.756	20.29	282,809	1,318,815
March	537,327.50	605,532.38	68,204.88		0.590916	0.36932	2.756	20.29	317,515	1,480,660
April	513,602.78	661,287.38	147,684.60		0.590916	0.36932	2.756	20.29	303,496	1,415,284
May	531,223.25	696,379.95	165,156.71		0,590916	0.36932	2.756	20.29	313,908	1,463,839
June	587,894.90	798,539.18	210,644.28		0.590916	0.36932	2.756	20.29	347,397	1,620,003
July	640,462.16	802,742.03	162,279.87		0.939251	0.36932	3.067	32.25	601,555	1,964,068
August	622,755.95	776,927.03	154,171.08		0.939251	0.36932	3.067	32.25	584,924	1,909,769
September	566,986.77	659,312.33	92,325.55		0.939251	0.36932	3.067	32.25	532,543	1,738,745
October	548,688.74	671,082.30	122,393.57		0.939251	0.36932	3.067	32.25	515,356	1,682,631
November	493,023.51	413,536.73		79,486.78	0.939251	0.36932	3.067	32.25	463,073	1,511,926
December	499,275.63	273,57.50		225,698.1	0.939251	0.36932	3.067	32.25	468,945	1,531,099

Note: P > C indicates months with net energy export to the grid, while C > P indicates net grid import.

An annual evaluation of the data shows that during March, April, May, and June, the SPV's generation exceeded the hospital's consumption, indicating that the system operated as a net electricity producer in those months. This shows that the facility not only met its own energy demand but also supplied surplus electricity to the grid. In particular, in June, with an electricity generation of 798,539.18 kWh and a consumption of 587,894.90 kWh, the generation surplus reached approximately 36% above consumption. In contrast, during the remaining months of the year—particularly in December, January, and November—the system operated as a net electricity consumer due to reduced solar generation and shorter daylight hours. In these months, the C > P difference represents the amount of electricity drawn from the grid, clearly illustrating the seasonal imbalance in SPV generation performance.

These findings highlight that solar photovoltaic system investments are strategically significant, contributing not only to carbon emission reduction but also to lower national energy expenditures and improved energy supply security. Furthermore, evaluating the annual distribution of generation–consumption differentials provides critical data for determining the system's average annual capacity factor and performance ratio (PR).

Table 6 Electricity Consumption Cost Breakdown (Based on Grid Electricity Without SPV Generation) (Year:2024)

	Energy Charge (TRY)	Distribution Charge (TRY)	Power Capacity Charge (TRY)	Municipal Energy Consumption Tax (5%) (TRY)	Value-Added Tax (VAT) (20%) (TRY)	**Total (TRY)**
January	1,415,607	303,565	64,921.76	70,780.34	370,975	**2,225,849**
February	1,318,815	282,809	64,921.76	65,940.72	346,497	**2,078,983**
March	1,480,660	317,515	64,921.76	74,032.98	387,426	**2,324,556**
April	1,415,284	303,496	64,921.76	70,764.19	370,893	**2,225,359**
May	1,463,839	313,908	64,921.76	73,191.94	383,172	**2,299,033**
June	1,620,003	347,397	64,921.76	81,000.16	422,664	**2,535,986**
July	1,964,068	601,555	103,185.21	98,203.38	553,402	**3,320,413**
August	1,909,769	584,924	103,185.21	95,488.45	538,673	**3,232,040**
September	1,738,745	532,543	103,185.21	86,937.24	492,282	**2,953,692**
October	1,682,631	515,356	103,185.21	84,131.57	477,061	**2,862,366**
November	1,511,926	463,073	103,185.21	75,596.31	430,756	**2,584,537**
December	1,531,099	468,945	103,185.21	76,554.96	435,957	**2,615,741**

Table 6 presents the breakdown of electricity consumption costs for the year 2024, calculated solely based on electricity drawn from the national grid, without any contribution from solar power generation. The analysis was conducted to illustrate the hospital's electricity consumption profile, cost composition, and monthly variation trends prior to the commissioning of the solar photovoltaic system (SPV).

Throughout the year, total monthly electricity expenditures ranged between 2,078,983 TRY and 3,320,413.00 TRY, with an average monthly bill of approximately 2.60 million TRY. These figures indicate that the facility operates with high energy intensity, and that electricity expenses constitute a major component of the institution's operational budget.

On a monthly basis, the highest electricity cost was recorded in July (3,320,413 TRY), primarily due to increased cooling requirements and intensified operational workloads. Conversely, the lowest cost occurred in February (2,078,983 TRY), which can be attributed to lower energy demand and relatively reduced electricity tariffs during that period. This variation clearly reflects the seasonal elasticity of electricity demand. As consumption rises during the summer months, total expenditure increases by approximately 60%, highlighting the system's sensitivity to climatic and operational dynamics.

Over the entire year, the average monthly energy charge amounted to approximately 1.59 million TRY, the distribution charge averaged 0.42 million TRY, the power capacity charge averaged 0.084 million TRY, and taxes and regulatory levies (VAT and municipal energy consumption tax) totaled approximately 0.51 million TRY per month. Based on these data, the total annual electricity expenditure in the absence of SPV generation is estimated at approximately 31.26 million TRY. This finding underscores the economic justification and strategic value of integrating renewable energy systems into energy-intensive healthcare facilities.

In conclusion, the data presented in Table 6 clearly demonstrates the financial burden imposed by grid-dependent electricity consumption on the hospital's cost structure prior to SPV commissioning. This analysis establishes a robust baseline reference for the comparative assessment of post-SPV cost savings and carbon emission reduction outcomes, which are discussed in the following section.

Table 7 SPV-Supported Net-Metering and Electricity Cost Offset Analysis (Year:2024)

	Excess Generation (P > C) and Net Grid Draw (C > P)	Energy Charge (TRY)	Total Distribution Charge (TRY)	Power Capacity Charge (TRY)	Municipal Energy Consumption Tax (5%) (TRY)	Value-Added Tax (VAT) (20%) (TRY)	Total (TRY)
January	222,952.91	614,369.03	410,952.01	64,921.76	30,718.45	224,192.25	1,503,185
February	5,475.33	15,087.82	457,542. 28	64,921.76	754,39	107,661.25	586,521
March	68,204.88	187,945.37	541,151.84	64,921.76	0,00	121,214.72	501,754
April	147,684.60	406,959.68	547,724.07	64,921.76	0,00	122,529.17	246,823
May	165,156.71	455,105.82	571,096.75	64,921.76	0,00	127,203.70	217,095
June	210,644.28	580,451.38	642,314.58	64,921.76	0,00	141,447.27	152,142
July	162,279.87	497,654.12	898,025.01	103185.21	0,00	200,242.04	604,267
August	154,171.08	472,787.35	871,860.39	103,185.21	0,00	195,009.12	602,710
September	92,325.55	283,129.33	776,041.44	103,185.21	0,00	175,845.33	715,317
October	122,393.57	375,337.12	763,201.90	103,185.21	0,00	173,277.42	589,260
November	79,486.78	243,757.43	615,801.04	103,185.21	12,187.87	194,986.31	1,146,219
December	225,698.13	692,135.14	569,983.32	103,185.21	34,606.76	279,982,.09	1,802,405

Table 7 presents the financial analysis derived from the difference between the electricity generated by the solar photovoltaic system (SPV) and the hospital's total electricity consumption throughout 2024. The table includes subcomponents such as the Energy Charge, Distribution Charge, Power Capacity Charge, Municipal Energy Consumption Tax (5%), and Value-Added Tax (VAT), all calculated in accordance with EPDK tariff coefficients. The rows highlighted in orange represent months where net grid consumption (C > P) occurred, while those highlighted in blue indicate months of surplus generation (P > C). This structure reflects the cost dynamics of the monthly net-metering mechanism, where solar generation is offset against grid consumption.

In previous periods, the electricity cost calculations were based solely on gross consumption values, without accounting for SPV generation. In contrast, Table 7 incorporates the net-metered framework, where SPV generation is subtracted from total consumption, and the payable amount is calculated based only on the net electricity imported from the grid. This approach led to substantial reductions in monthly electricity expenditures, particularly between April and August, when solar irradiation levels and photovoltaic output were at their peak.

For example, in May, the hospital's SPV generated 165,156.71 kWh, while the total net payable amount decreased to 217,095 TRY. Conversely, in February, when solar generation was relatively low (5,475.33 kWh), dependence on grid electricity increased, resulting in a higher total payment of 586,521 TRY.

The comparative data from Table 6 indicate that, without SPV contribution, the total electricity expenditure for May would have reached 2,299,033 TRY. However, with the integration of SPV generation and net-metering adjustments, the actual payable amount was reduced to 217,095 TRY. This difference demonstrates a financial advantage of 2,081,938 TRY, corresponding to an approximate 90.5% reduction in total monthly costs.

Such results provide strong empirical evidence of the economic efficiency and environmental benefits of renewable energy systems in healthcare institutions. In addition to reducing operational energy expenses, the adoption of SPV-supported net-metering significantly contributes to institutional sustainability and aligns with Türkiye's 2053 Net-Zero Emission Commitment.

Table 8 Monthly SPV Contribution Based on Production and Consumption

	Grid Electricity Imported (kWh)	SPV Electricity Generated (kWh)	Monthly Net Cost Impact (TRY)
January	513,719.96	290,767.05	722,664.33
February	478,594.31	473,118.98	1,492.462.11
March	537,327.50	605,532.38	1,822,801.88
April	513,602.78	661,287.38	1,978,535.65
May	531,223.25	696,379.95	2,081,937.71
June	587,894.90	798,539.18	2,383,843.95
July	640,462.16	802,742.03	2,716,145.64
August	622,755.95	776,927.03	2,629,330.17
September	566,986.77	659,312.33	2,238,375.49
October	548,688.74	671,082.30	2,273,105.53
November	493,023.51	413,536.73	1,438,317.11
December	499,275.63	273,577.50	813,335.87
Total	6,533,555.42	7,122,802.80	22,590,855.43

According to the data in Table 6, the institution's total electricity expenditure for 2024, in the absence of SPV generation, amounted to 31,258,554.46 TRY. However, as shown in Table 7, after net-metering SPV generation against grid electricity consumption, the actual amount paid was 8,667,699.03 TRY. As presented in Table 8, this net difference—derived from the offset between grid consumption (Table 6) and SPV-supported generation (Table 7)—indicates that the institution achieved a total financial saving of 22,590,855.43 TRY, corresponding to an approximate 72.3% reduction in total electricity costs.

This result demonstrates that SPV investments contribute not only to energy supply security but also significantly to institutional financial sustainability. In facilities such as hospitals, which require a continuous and reliable energy supply, renewable energy systems effectively reduce operational expenditures while enhancing predictability in budgetary planning and cost control.

According to the national emission factor published by the Ministry of Energy and Natural Resources (ETKB, 2022) and the Turkish Electricity Transmission Corporation (TEİAŞ, 2022), Türkiye's current grid electricity emission coefficient is 0.442 kg CO_2e per kWh. This factor represents the average carbon intensity of electricity generation in the national grid and is used to quantify avoided emissions resulting from renewable energy production.

As of 2024, the hospital's SPV system generated a total of 7,122,802.80 kWh of renewable electricity. Based on the official emission factor of 0.442 kg CO_2e/kWh, this generation prevented approximately 3,148,287.64 kg CO_2e, equivalent to 3,148.29 metric tons of CO_2e, from being released into the atmosphere. In other words, the SPV system effectively avoided over 3,100 tons of CO_2e emissions, substantially contributing to both the hospital's carbon footprint reduction and Türkiye's 2053 Net-Zero Emission Commitment.

4. Conclusions

This study assessed the environmental and economic implications of integrating a solar photovoltaic (SPV) system in a private hospital located in the Karatay District of Konya Province, Türkiye. The SPV system, with an installed capacity of 4,209 kWp, produced 7,122,802.80 kWh of renewable electricity in 2024. According to the national emission factor of 0.442 kg CO_2e/kWh (TEİAŞ, 2022), this production prevented the release of approximately 3,148.29 metric tons of CO_2e emissions into the atmosphere. Additionally, the hospital achieved a 72.3% reduction in its annual electricity costs through a combination of self-consumption and net-metering mechanisms.

These results underscore the dual advantage of renewable energy in institutional settings: significant cost savings and measurable carbon footprint reduction. In energy-intensive sectors such as healthcare, where 24/7 electricity demand is constant, SPV systems not only lower dependency on fossil-fuel–based grid supply but also enhance resilience against energy price volatility. This aligns with broader findings in the literature that emphasize the role of renewable integration in improving both environmental performance and operational sustainability in the healthcare sector (Baş, 2025; Kahveci, 2025).

The study also provides empirical support for Türkiye's national climate strategy, particularly its 2053 Net-Zero Emission Commitment. Scaling up solar energy adoption in public and private hospitals can meaningfully contribute to decarbonizing the health system-an approach advocated in international climate-health frameworks such as the WHO's "Health Argument for Climate Action" (WHO, 2021). Moreover, from a strategic policy perspective, hospital-level renewable investments align with sustainable public procurement and green building standards.

However, the case study also reveals certain limitations. The analysis is based on a single year of operation and a single institutional setting, which limits the generalizability of results. Seasonal variations, local grid conditions, and differences in institutional energy loads can affect performance outcomes. Future research should incorporate multi-year longitudinal data, conduct comparative analyses across regions or hospital types, and explore the integration of energy storage systems or hybrid configurations (e.g., solar + wind or solar + battery).

In conclusion, solar photovoltaic systems represent a scalable, financially viable, and climate-aligned solution for the energy transition in healthcare infrastructure. Their broader deployment across Türkiye's health sector could play a pivotal role in achieving institutional sustainability targets, enhancing energy security, and supporting national commitments under the Paris Agreement.

Declaration of Ethical Standards

As the authors of this study, we declare that he complies with all ethical standards.

Credit Authorship Contribution Statement

T. İmat, Taş: Validation, Formal analysis, Writing -Original Draft, Visualization.

M.Yorulmaz: Methodology, Software, Validation, Visualization, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declared that they have no conflict of interest.

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Data Availability

The data supporting this study were acquired from a private hospital upon official request.

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