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A feasibility study of grid-connected photovoltaic systems in Istanbul, Turkey

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ABSTRACT

The application of renewable energy sources in electric power systems is increasing. There is a growing need for economic evaluation to inform photovoltaic (PV) allocation decisions for a range of decision-makers. In this study, power output and temperature data collected from PV modules in Istanbul, Turkey in 2009 have been analyzed to determine solar power generation potential. In addition to the measurements, technical and commercial parameters were also used to perform the evaluation. Different tariffs such as time-of-use and feed-in tariffs were considered in this study.

Contents

1. Introduction

The importance of solar photovoltaic (PV) systems has increased with the rapid growth of the solar industry over the past several years. With the availability of PV systems, it is now possible to manage demand to control the energy consumption on the customer's side. Although PV systems are an expensive option for generating electricity when compared with other systems, this technology has been supported because of its potential benefits, which can be classified as customer-related benefits, electric utility-related benefits and environmental benefits. Earning revenue by selling PV electricity can be listed as an example of customer-related benefits. Examples of electric utility-related benefits are reduced transmission and distribution costs and losses, peak shaving and meeting peak demand. CO_2, NO_x and SO_2 savings can be listed as the main environmental benefits of PV systems [1].

The demand for electricity differs in each area and therefore depends on numerous factors, such as the price of electricity, the weather conditions, the time of day, the type of day and the season. The load profiles describe the variation of the electricity demand with time. The hourly load profile provides crucial information on how electricity is used. The installation of a solar PV system will reduce electricity demand and consumption, and this reduction will change the load profile. However, electricity users (consumers) will not have any constraints on their energy consumption choice. The integration of user demand and local PV generation patterns can help to achieve the optimal use of PV electricity.

The process of managing the consumption of energy to optimize available and planned generation resources is called Demand Side Management (DSM). The most widely accepted

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definition of DSM is the following: "Demand Side Management is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load" [2]. The major benefits of DSM are reducing the generation margin, improving transmission grid investment and operation efficiency, and improving distribution network investment efficiency. These benefits and challenges of DSM were discussed in [3]. An important part of the DSM process involves the evaluation of demand-side-to-supply-side alternatives and vice versa [4]. The combination of Demand Side Management (DSM) and PV systems that are grid connected with small-scale electricity storage provides an Active Demand Side Management (ADSM) scheme. In this concept, both PV system operators and consumers connected to the same grid can profit through cooperative strategies [5–7]. Castillo-Cagigal et al. implemented a PV hybrid technology to perform ADSM. Their system consisted of grid connected-type inverters with small-scale electricity storage and an automatic control system (ADSM and battery controller). In recent years, many researchers have focused on the DSM problem. Matallanas et al. implemented a distributed ADSM controller based on artificial neural networks (ANNs) to maximize self-consumption in the residential sector. They considered several ANNs based controllers located at different appliances in a house provided with local PV energy generation [8]. The impact of smart appliances and variable prices on the electricity bills incurred by a household was also investigated using a simulation model in [9]. According to their results, the savings from equipping households with smart appliances are moderate compared to the required investment.

A large area of Turkey is suitable for the utilization of solar energy because the country is geographically well situated with respect to solar energy potential. It is located on the Southeast corner of the European and Midwest border of the Asian continents and lies in between the latitudes of 36° and 42° N. According to the sunshine duration and radiation data measured by the Turkish State Meteorological Service from 1971 to 2000, Turkey's annual mean total sunshine hours number 2573 (the daily mean is 7 h), and the mean total radiation is 1474 kW h/m^2-year (daily 4 kW h/m^2) [10]. The global irradiation and solar electricity potential for Turkey are shown in Fig. 1. The color legend in the figure helps to visualize the potential global horizontal irradiation in the region. The data for monthly radiation levels in Turkey are also shown in Fig. 2 [11]. In summer, the radiation is greater than 5 kW h/m^2 per day. Common practice in Turkey is to use solar energy to heat water, greenhouses and to dry agricultural products. Solar panels (flat-plate solar collectors) are used in 3–3.5 million homes mostly in the Mediterranean, Aegean and the Southeastern regions. Photovoltaic systems in Turkey are mainly installed in areas where electricity transmission is not economically feasible. Some examples for PV applications are forestry observation towers, the transfer stations of Telecommunication Companies, and emergency call facilities and traffic management systems on the highways. In addition, various research associations have PV systems. The electricity produced from solar energy is still less than 1% of the national energy production in Turkey. Due to the new regulatory measures such as feed-in tariffs, purchase obligation, connection priority, reduced license fees, exemptions from license obligations for small-scale generators, and reduced fees for project preparation and land acquisition, a rapid increase in the use of PV systems is to be expected [12–14].

The main objective of this paper is to evaluate the grid-connected solar PV systems in Istanbul. Istanbul (latitude=40.58N, I longitude=29.05E and elevation=39 m), is one of Turkey's most populated cities and one which is experiencing rapid economic growth. It is located in the northwestern part of Turkey, and the major power plants in this region are natural gas power plants. Since the

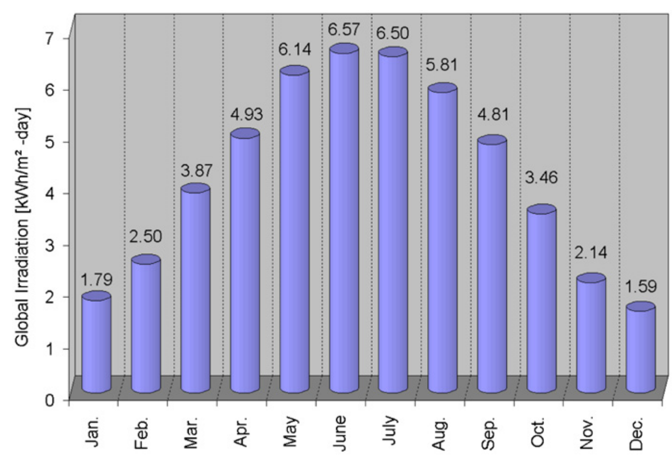

Fig. 2. Monthly radiation in Turkey [11].

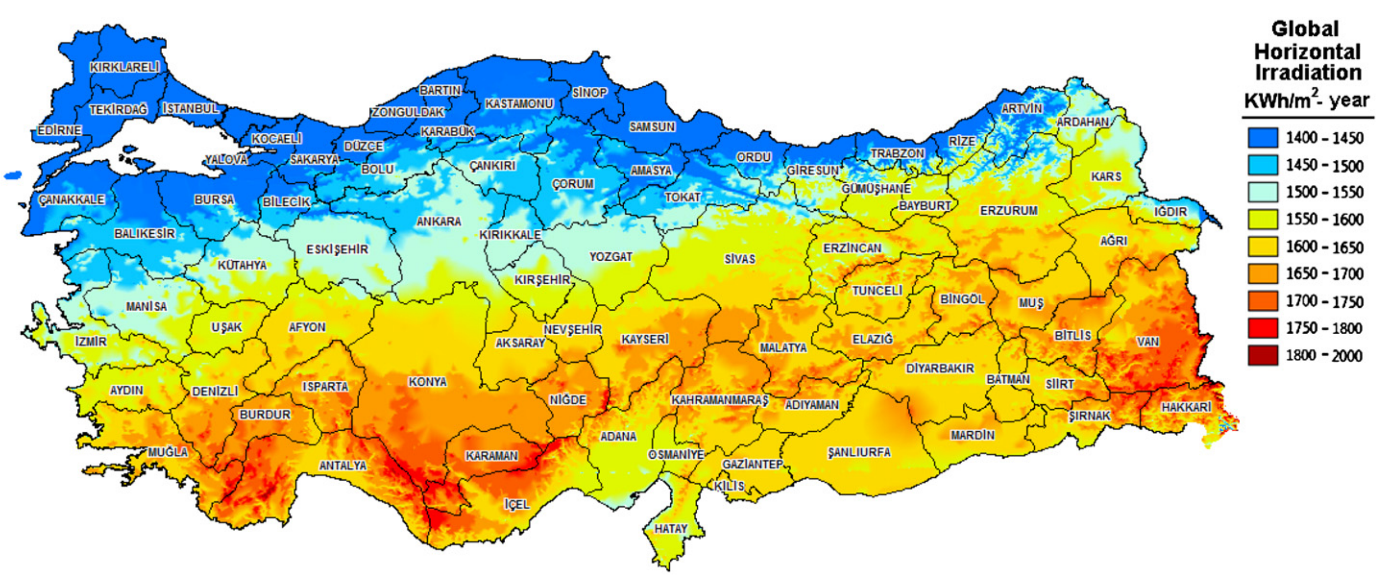

Fig. 1. The global irradiation and solar electricity potential for Turkey [11].

tariffs impact on PV system economics will determine the net benefits and the costs for customers, different tariff structures are also considered in the analysis. Such a study will help the investors when they want to install a PV system. Both the hourly load data gathered from electricity providers in Istanbul and the solar radiation data collected using the experimental setup at the Technical University of Istanbul for 2009 were used for the study because such information is essential for the cost-benefit analysis of solar power systems. In addition to the measurements, technical and commercial parameters were also used to perform the evaluation. The different tariffs, such as time-of-use and feed-in tariffs were considered in the study.

The remainder of this paper is organized as follows: "The data acquisition system for solar system data collection" section provides information about the data acquisition system used for solar system data collection. In "The impact of PV systems on electricity demand section, the impact of PV systems on electricity demand is introduced. "Economic evaluation" section presents the economic evaluation of the system in detail. The cost-benefit analysis obtained for different tariffs and the investment cost are also provided and discussed in the subsections. Finally, conclusions are provided.

2. The data acquisition system for solar system data collection

The solar radiation data are very important in determining the amount of electricity generated by PV modules. Solar radiation data is typically generated by the solar radiation model based on the meteorological data. There are several approaches to modeling solar radiation and to forecasting solar irradiance in the literature [15–29]. The developed models which calculate global solar radiation are generally empirical models, and use various climatic parameters such as extraterrestrial radiation, sunshine hours, mean temperature, maximum temperature, and soil temperature as well as elative humidity, number of rainy days, altitude, latitude, total precipitation, cloudiness and evaporation. These models can also be categorized in four groups; linear models, polynomial models, angular models, and other models [17].

In addition to the factors such as seasons, dates and time, geographic locations and the extraterrestrial radiation, solar radiation is also affected by random changes in weather conditions. This randomness and complexity of the weather and surroundings may result in higher prediction errors, and conventional models may not be suitable for forecasting purposes [24]. The application of Artificial Intelligence (AI) techniques can solve the problem, and can provide more accurate results. A review of the application of AI-techniques in solar radiation modeling and forecasting is given in [20]. Several researchers have applied AI techniques to solve complicated problems such as forecasting and modeling of meteorological data, sizing of photovoltaic systems and modeling, simulation and control of photovoltaic systems [18,19].

In recent years, a number of researchers have used artificial neural network (ANN) for the prediction of hourly global solar radiation data [24–27]. In [24], Cao and Lin presented a model for the forecasting of hourly and daily global solar irradiance based on a diagonal recurrent wavelet neural network (DRWNN) and a specially designed training algorithm. A model, which uses current and forecasted meteorological data, was developed for the medium-term solar irradiance forecasting [25]. In the model, the predicted meteorological variables from the US National Weather Service's (NWS) forecasting database were used as inputs to the ANN model.

Some studies have been presented for prediction of solar resource in several cities in Turkey using ANN [21–23]. In [28], an ANN model was used to estimate the solar radiation parameters for seven cities from the Mediterranean region of Anatolia in Turkey. The data obtained by The Turkish State Meteorological Service during 2006 were used to train the ANN model, and the values of 2005, 2007 and 2008 were used as testing data. The obtained results indicated that the ANN model was promising and could be used to predict solar radiation. Ozgeren et al. developed an ANN model based on the multi-nonlinear regression (MNLR) method for estimating the monthly mean daily sum global solar radiation at any location within Turkey [29]. They used the meteorological data of 31 stations spread throughout Turkey along the years 2000–2006. According to their results, the mean absolute percentage error is 5.34%.

The solar radiation models do not feature real-world effects, such as heat, dirt and dust, DC-to-AC inverter conversion efficiency, wiring and weather conditions. In this study, instead of applying the solar radiation models, the power output (i.e., current and voltage) and temperature signals collected from the PV modules are used to obtain real operating conditions for the evaluation of the solar system.

The PV system, which was set-up to charge a lead-acid battery storage system, was installed in 2002. The stored energy is used to illuminate a parking lot. The data acquisition system in Fig. 3 used in the experiments was developed at our Department of Electrical Engineering, and it has been used to collect data since 2002. The photovoltaic panels that generate 2 kW are oriented due south at an angle of 35° from the horizontal. The latitude/longitude locations of the panels are 41° 6.3′N. Latitude, 29° 1.46′E. Longitude.

In this study, the data obtained in 2009 are to be used for the evaluation. The data are presented in the form of graphs, and the results are normalized because the energy value generated by a solar PV system is a function of the PV array's size and efficiency and the availability of the solar resource.

The seasonal variability of global radiation measured in Istanbul is shown in Fig. 4. The dots in the figure show monthly average daily global solar radiations measured in 2009, and the bar graphs show ten-year average of monthly average daily global solar radiation during the period between January 2002 and January 2012. This solar radiation data for Istanbul were taken from Turkish State Meteorological Service for the Goztepe weather station. It can be seen from Fig. 6 that the monthly average solar radiation varies relatively little from year to year. If the annual average value of daily solar radiation is calculated to make a comparison between one year data (2009) and ten-year average data (between 2002 and 2012), it is found that the annual average value of solar radiation is 3.61 kW h/m^2-day in 2009, and 3.56 kW h/m^2-day between 2002 and 2012. Since the difference is very small (around+/−1.5%.), the data collected from the PV

Fig. 3. Solar data collection system.

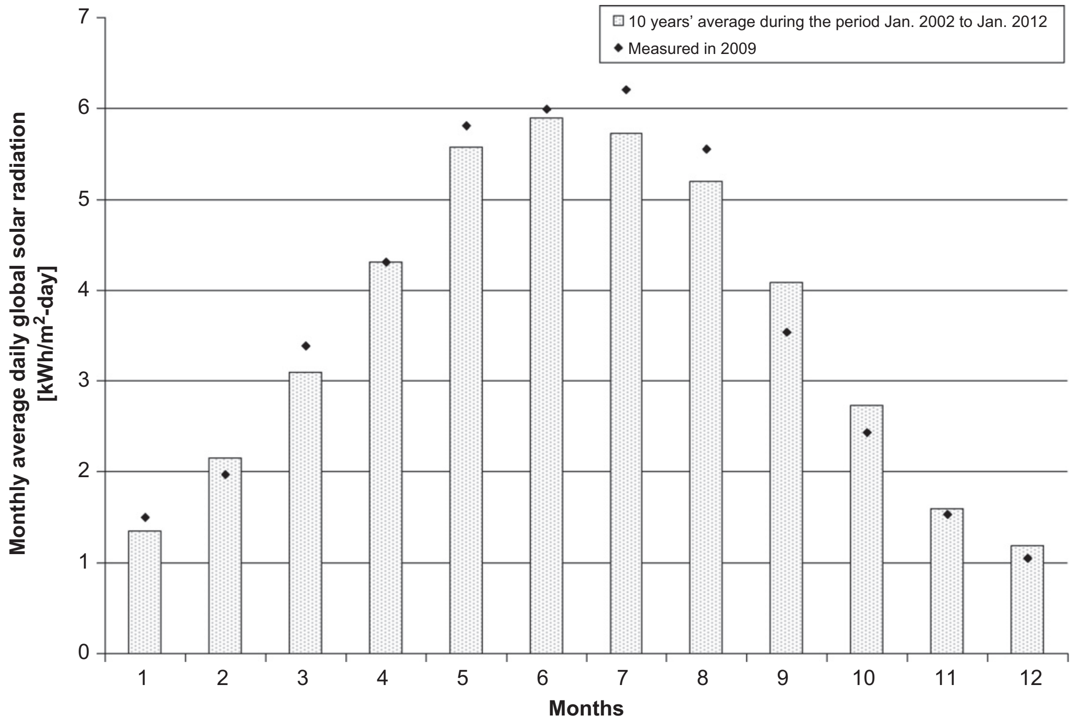

Fig. 4. The measured values of global radiation at Istanbul.

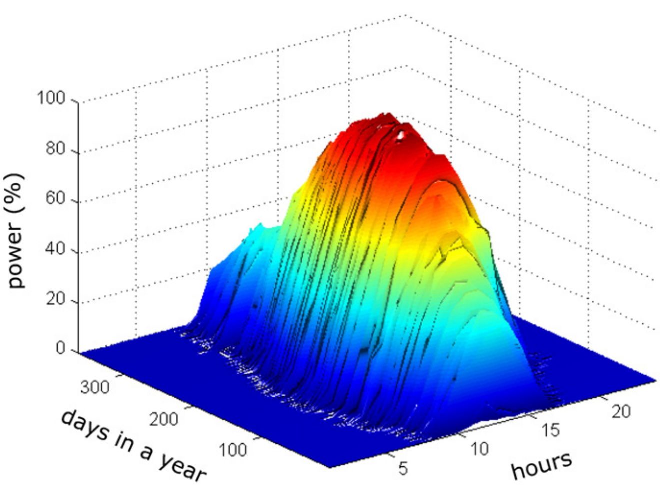

Fig. 5. Hourly collected power outputs from the solar PV system in 2009.

modules in 2009 can be used for the feasibility study of grid-connected PV systems in Istanbul.

The power output from the solar PV system varies throughout the day, and the patterns and peak values vary depending on the seasons. The variations of the hourly collected power outputs can be seen in Fig. 5. The variations of the peak power outputs of solar modules are also given in Fig. 6. It can be inferred from these figures that weather conditions affect power outputs, and that the profiles vary from moment to moment. The daily output profile is higher in the summer because there are more hours of sunlight and the angle of the sun is higher during the day.

3. The impact of PV systems on electricity demand

The detailed load profiling gives electricity planners crucial information regarding demand. Such information has been used for demand-side management, system planning, and tariff design. By knowing the load profile, distribution companies and/or customers can plan improvements and future investment scenarios [30,31]. In this study, the load profile data obtained with the support of the Bosphorus Electricity Distribution Company (BEDAS) are used for the evaluation of the solar PV systems that would be installed in Istanbul, Turkey. Intelligent meters were used to measure the real and reactive power consumption of customers in intervals of 15 min. A total of 365 day (one year) of measurements were collected from the distribution transformer located near the PV modules. The evaluation was performed over a period of one year from January 1, 2009 to December 31, 2009. It was assumed that 1000 customers, each with a 500 W PV rooftop unit, were supplied by a 2 MVA transformer. The total surface area of a 500 W monocrystalline solar panel is approximately 5 m^2 [32].

A normalization, which is the conversion of demand values in kW to per-unit values to obtain homogeneous curves, is performed by dividing all measured values by the peak power of the measured load profiles. This process also converts the original measurements to unitless variables [33]. The peak power of the measured load profiles was 1066 kW. An example of a daily load profile obtained on Wednesday, January 21, 2009, is illustrated in Fig. 7. It is found that the peak loading for customers occurs from 1:00 p.m. to midnight. Fig. 8 shows the daily load profile obtained on a summer day: Wednesday, July 1, 2009. The demand reaches a peak at 1:00 p.m., while the off-peak loading is occurred at 6:00 a.m. In Fig. 8, it is found that the power consumption mainly occurs after 10:00 a.m. during the summer.

The contribution of the PV system to the demand savings can also be seen from Figs. 7 and 8. The area filled with a hatch pattern in the figures shows the demand saving obtained by using a PV system. Although this contribution is limited in the winter (Fig. 9), the peak summer load coincides with the maximum PV output, and demand savings are maximized. The amount of energy derived from nonrenewable sources drops almost to zero on weekend afternoons (Fig. 10).

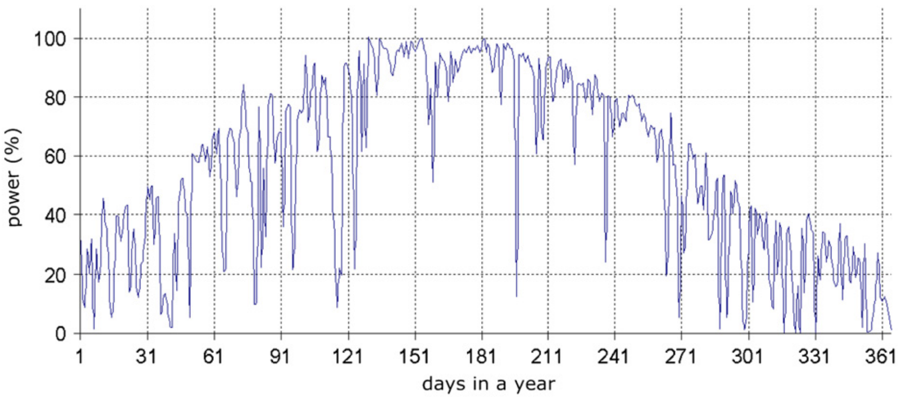

Fig. 6. Variation of the peak power outputs of solar modules in 2009.

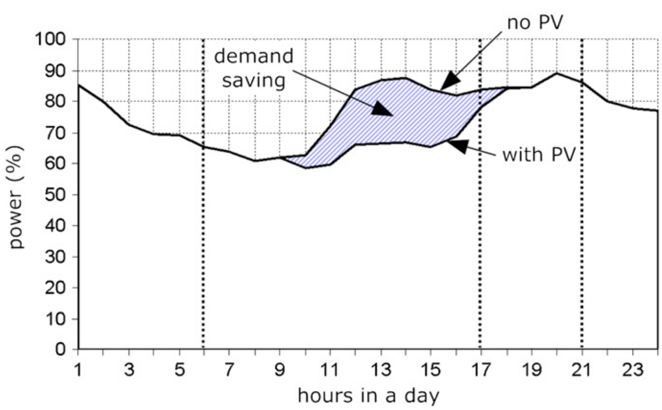

Fig. 7. The daily load profile obtained on January 21, 2009.

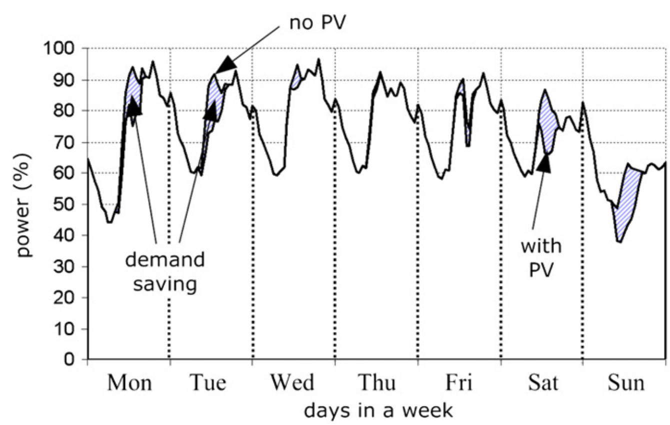

Fig. 9. The weekly load profile obtained in winter January 12–18, 2009.

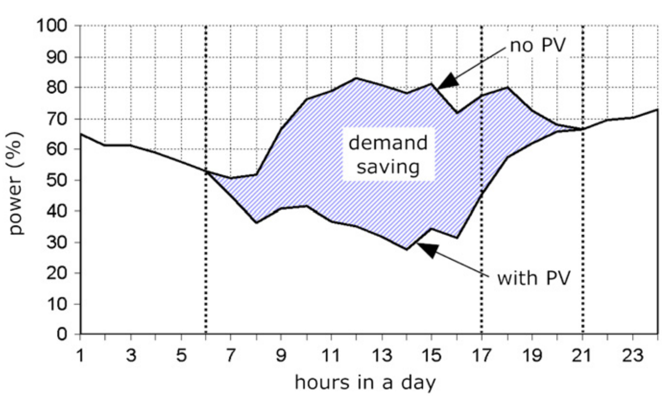

Fig. 8. The daily load profile obtained on July 1, 2009.

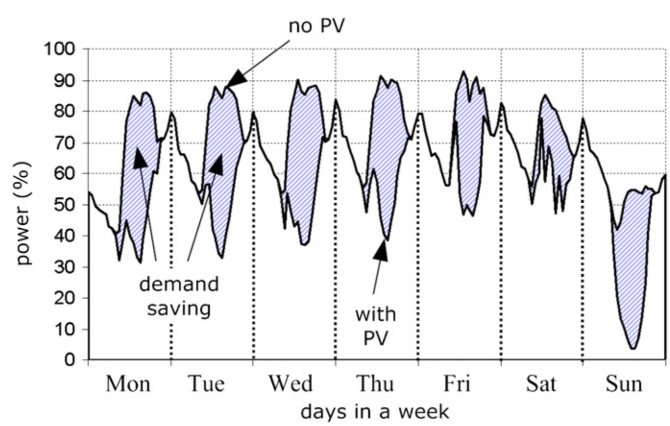

Fig. 10. The weekly load profile obtained in summer July 20–16, 2009.

4. Economic evaluation

An economic evaluation of a PV system should analyze multiple issues, such as initial cost, the potential savings, annual income and expenses, taxation, PV system equipment depreciation and government grants. These issues may vary from country to country and region to region. The economic merit of a PV system heavily depends on the local conditions.

If it is compared with stand-alone PV systems, a grid-connected PV system has additional benefits. First, additional electricity can be drawn from the electricity grid when the solar PV system is not producing enough electricity as a result of low-sunlight conditions. The second is that the electricity produced during periods of high solar radiation, such as hot summer afternoons, can be sold back to the electricity grid.

In this study, the grid-connected solar PV systems in Istanbul were evaluated. The study contains a cost-benefit analysis based on tariffs, which provides the annual electricity cost savings. Both the investment cost associated with solar PV power systems and government grants in Turkey were also discussed.

4.1. Cost-benefit analysis based on tariffs

Electric utilities employ a number of tariffs for electricity pricing, and these tariffs vary from country to country. Depending on the tariffs offered by the utilities, customers can reduce energy costs in a variety of ways, such as by using solar PV systems and smart meters. The Turkish Distribution System BEDAS offers two tariffs that are available to residential customers on a voluntary basis. One of the tariffs applies a fixed rate, another applies time-of-use (TOU) rates that provide an incentive for the customers who can distribute loads to lower-cost times of day and thereby reduce their energy bill. The time periods are defined as follows:

Peak: 5:00 p.m. to 10:00 p.m.
Partial-Peak: 6:00 a.m. to 5:00 p.m.
Off-Peak: All other times (10:00 p.m. to 6:00 a.m.)
The cost function for TOU tariffs can be given as follows:

$$C(\text{kW h}) = \begin{cases} 0.5{*}c{*}\text{kW h} & \text{if } 10:00\ \text{p.m.} £t < 6:00\ \text{a.m.} \\ 0.95{*}c{*}\text{kW h} & \text{if } 6:00\ \text{a.m.} £t < 5:00\ \text{p.m.} \\ 1.5{*}c{*}\text{kW h} & \text{if } 5:00\ \text{p.m.} £t < 10:00\ \text{p.m.} \end{cases} \quad (1)$$

where c is the cost of electricity per kW h for the fixed-rate tariff. The average cost of residential electricity for the fixed-rate tariff was 0.135 US$/kW h in Turkey in 2009.

The power balance equation for the system with PV can be given as follows:

$$\sum_{i=1}^{n} P_{D,i} + \sum_{i=1}^{n} P_{PV,i} = \sum_{i=1}^{n} P_{L,i} \quad (2)$$

where $P_{D,i}$ is the net demand of the ith customer, $P_{PV,i}$ is the installed capacity of the ith customer's PV system, $P_{L,i}$ is the load of the ith customer, n is the number of customers.

Using the total demand figure, the hourly total energy demand from the utility grid can be calculated. The overall daily energy consumption cost is calculated using the following:

$$C_{\text{total}} = \sum_{i=1}^{24} C(\text{kW h}) \times W_{D,\text{total}} \quad (3)$$

where C_{total} is the total daily energy consumption cost $W_{D,\text{total}}$ is the hourly total energy demand from the utility grid.

To evaluate the economic benefits of the solar PV system, which would be installed in Istanbul, Turkey, the overall annual energy consumption costs for different cases are calculated, and the results are presented in the following tables. The tariffs used in the calculations are the following:

– Tariff 1, which applies a fixed rate,
– Tariff 2, which applies time-of-use (TOU) rates

The Feed-inTariff (FiT), with which the customers can acquire an income for every kilowatt-hour of electricity generated and sold back to the grid, is also considered for the systems with solar PV. In Turkey, there are two main regulations concerning the renewable energy support mechanism: the Renewable Energy Law and the Electricity Market License Regulation. The Renewable Energy Law No. 5346 which is the main legislation has a feed-in tariff mechanism to incentivize renewables. The feed-in tariff mechanism having different prices for different renewable sources is applied for the first 10 years of the operation [13,14,34]. There are extra payments for the solar projects which use equipment manufactured in Turkey. These grants and financial support in Turkey are discussed in "Grants and financial support" section.

The energy benefit of the solar PV system is calculated for differently sized PV panels (0.5, 1 and 2 kW) along the annual load duration curve, bearing in mind the corresponding solar PV system output along this curve. The total annual energy consumption costs for the system without any solar PV are also calculated for both tariffs and are given in the tables. The PV system helps the customers earn money for generating their own energy because they purchase much less electricity. When they cannot generate enough electricity for their own needs, they can still purchase electricity from the utility. Customers can also increase their benefits by selling electricity back to the grid. The overall annual energy consumption costs for both of these cases, namely the sale or non-sale of electricity back to the grid also given in the tables.

Using the annual load profile, the total energy consumption is calculated to be 2916,513 kW h/year. As seen from Table 1, the total energy consumption cost is $393,729 in the casein which the customers don't have any PV systems and all use Tariff 1. The cost is calculated to be $366,753 if all of the customers prefer to use Tariff 2. Solar PV systems help customers to reduce their energy usage costs. With a 2 kW solar PV system, the total energy consumption cost is reduced to $280,866 in Tariff 1. If customers can sell the electricity back, the annual energy benefit value (US$/year) will be $160,071, and this amounts to 40.6% of the total cost. In Tariff 2, the magnitude of the decrease is 44.3%.

Table 2 shows the total energy consumption cost in July 2009. The total energy consumption is calculated to be 247,360 kW h for this month. The monthly energy benefit value (US$/month) reaches a maximum value in July because there are more hours of sunlight. If the customers can sell the electricity back and use Tariff 2, the cost can be reduced from $30,914 to $4735. Thus, a cost decrease of 85% can be achieved.

To examine the potential benefits of a single customer having a solar PV system, the total costs per customer were also calculated by assuming that 1000 customers are supplied per transformer. The results for the year 2009 and or the month of July are given in Table 3 and Table 4, respectively.

Table 1
The total annual energy consumption cost (US$).

Case		Tariff 1		Tariff 2	
		Without sell-back	With sell-back	Without sell-back	With sell-back
No PV		393,729	393,729	366,753	366,753
With PV (kW)	0.5	353,997	353,712	326,462	326,189
	1.0	317,396	313,694	289,170	285,626
	2.0	280,866	233,658	250,577	204,498

Table 2
The total energy consumption cost (US$) in July 2009.

Case		Tariff 1		Tariff 2	
		Without sell-back	With sell-back	Without sell-back	With sell-back
No PV		33,394	33,394	30,914	30,914
With PV (kW)	0.5	27,106	27,106	24,369	24,369
	1.0	21,643	20,818	18,612	17,824
	2.0	17,844	8,243	14,201	4,735

Table 3
The monthly average energy consumption cost per customer (US$).

Case		Tariff 1		Tariff 2	
		Without sell-back	With sell-back	Without sell-back	With sell-back
No PV		32.81	32.81	30.56	30.56
With PV (kW)	0.5	29.50	29.48	27.21	27.18
	1.0	26.45	26.14	24.10	23.80
	2.0	23.41	19.47	20.88	17.04

Table 4
The total cost per customer in July 2009 (US$).

Case		Tariff 1		Tariff 2	
		Without sell-back	With sell-back	Without sell-back	With sell-back
No PV		33.39	33.39	30.91	30.91
With PV (kW)	**0.5**	27.11	27.11	24.37	24.37
	1.0	21.64	20.82	18.61	17.82
	2.0	17.84	8.24	14.20	4.73

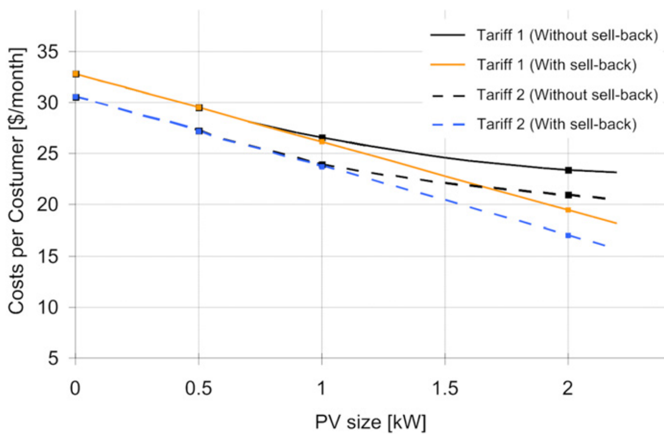

Fig. 11. The change in average energy consumption cost per customer vs PV size.

Table 5
A summary of costs and rates for the PV system.

Component	PV Power [kW]		
	0.5	1.0	2.0
Produced energy [kW h/year]	593	1186	2372
PV module price [US$]	1400	2800	5600
Grid tie inverter price [US$]	200	300	500
Settings, wiring, etc. [US$]	200	300	500
Net investment [US$]	1800	3400	6600
Lifetime (duration) [year]	25	25	25
Interest rate [%]	6.0	6.0	6.0
Total annual cost [US$/year]	140.8	266.0	516.3
Energy cost [US$/kW h]	0.24	0.22	0.22

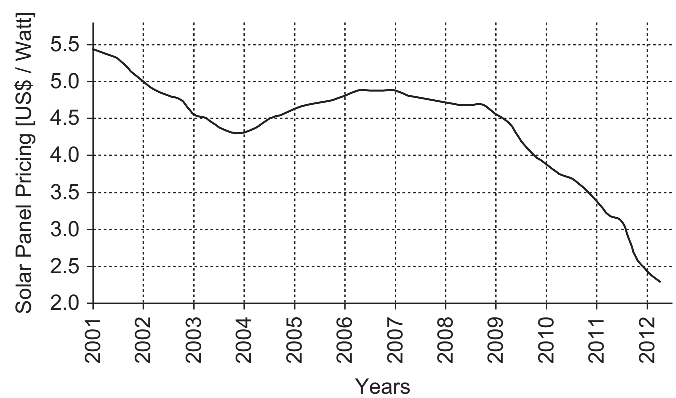

Fig. 12. Solar panel retail price in the US market [35].

Table 3 shows the average monthly energy consumption costs per customer. According to the results, the average cost for 243 kW h/month energy consumption is calculated to be $17 by using a feed-in tariff and 2 kW solar PV panels. The change in average energy consumption cost per customer vs. PV size is also given in Fig. 11. Moreover, in July, the customer's monthly electricity bill can be reduced to below $5 (Table 4).

4.2. The investment cost of the PV system

The investment cost of solar PV power systems is widely acknowledged to be much greater than that of fossil fuel generation or many other renewable energy sources.

The net total capital cost (C_{net}) can be calculated using the capital cost of PV system equipment (C_{eq}), installation expenses (C_{ins}), taxes (C_{tax}) and subsidies (C_{sub}).

$$C_{net} = C_{eq} + C_{ins} + C_{tax} - C_{sub} \quad (4)$$

The annual cost of the PV system comprises the annual capital recovery cost and annual costs of operation and maintenance, and insurance among others. A summary of costs and rates calculated using Turkish market prices for the PV system is provided in Table 5. In this study, the loan payback was considered as constant annuities, and the annual cost was calculated by considering the loan duration, interest rate and the expected lifetime of the system. The energy cost obtained by dividing the annual cost by the produced energy is also given in the last row of Table 5.

Although the energy cost for a 2 kW PV panel (0.22 US$/kW h) is a little higher than 0.133 US$/kW h, the guaranteed price given for solar electric energy production in Turkey, factors such as the cost savings, subsidies and the decrease in future PV module prices, which can be inferred from Fig. 12, will reduce the energy cost [35]. The potential annual cost savings calculated using the demand savings obtained by the operation of the PV system are approximately 76 $/year when a 1 kW solar PV panel is used.

Since China has a dominant position in the market, and an important portion of the PV panels now being installed in Turkey are imported from China, the cost of solar panels in Turkey follow a similar pattern to that of the USA. The labor cost related to engineering, planning and installing PV systems, which is a large portion of the total system cost, is an advantage in Turkey, because unit labor cost in Turkey is considerably lower than in the developed countries. The current installed PV capacity in the country is insignificant, but many large scale companies are interested in solar park investments, and the Turkish Government has shown a willingness to support the local production of PV panels.

4.3. Grants and financial support

Renewable energy, such as hydraulic, wind, solar, geothermal, biomass, biogas, wave, current and tidal energy, is becoming more and more desirable because of pollution and the decrease in the supply of fossil fuels. Although Turkey has a vast potential for renewable energy sources, the renewable energy market in Turkey is still in an infant state. With the liberalization of the energy market and the improvements in renewable legislation, new investment opportunities in the renewable energy sector have been born.

In May 2005, a law addressing the "Utilization of Renewable Energy Resources for Electricity Production" was enacted by the Turkish Government. The amendments to this law remained on the agenda of the Parliament beginning in 2008 and were approved at the end of 2010. The aim of this law is to increase renewable energy resources utilization and generate low-cost, secure, and high-quality electricity.

The law ensures a purchase guarantee of 0.133 US$/kW h for solar electric energy production for ten years. Some supplementary subsidies for domestic products are as follows: [12,36].

- PV module integration and mechanical solar construction, (+0.008 US$/kW h)
- PV modules, (+0.013 US$/kW h)
- Constituent cells of PV module, (+0.035 US$/kW h)
- Inverter, (+0.006 US$/kW h)
- Material focusing solar energy on PV modules, (+0.005 US$/kW h)

In addition, The Electricity Market Regulatory Authority (EPDK) issued a bylaw on license exemption rules for grid-connected facilities with a maximum of 500 kW of installed power. The bylaw prescribes the financial procedures and principles for supplying energy to the grid, as well as the legislative issues concerned. Another bylaw defining the grid-connection guidelines is currently being prepared by the EPDK.

When these incentives are included in the economic evaluation, the energy cost of PV systems will further be reduced compared with the results found in "Cost-benefit analysis based on tariffs" sections and "The investment cost of the PV system" 4.2.

5. Conclusions

There is an increasing need for economic evaluation to inform photovoltaic (PV) allocation decisions for a range of decision-makers. An evaluation of the solar PV systems that would be installed in Istanbul, Turkey is presented in this paper. Signals such as power outputs, which are collected from the PV modules and substations as a part of an ongoing project, have been used for the evaluation. The different tariffs, such as time-of-use and feed-in tariffs were also taken into consideration, and the effects of using solar PV systems on the annual cost were obtained. The results show that the customers can reduce their electricity payments by more than 40% by installing solar PV systems.

Although the investment cost for solar PV systems is high, factors such as cost savings, subsidies and the decrease in future PV module prices reduce the energy cost. The cost per kW h of electricity is also lower than the guaranteed price given for solar electric energy production in Turkey. One of the benefits of a solar PV system is the ability to meet the summer peak demand. When the utility company applies a tariff structure that has seasonal time-of-use periods, the use of a solar PV power system will be even more beneficial.

The study will be extended to estimate solar power production because forecast information on the expected solar power production is necessary for demand side management. Other future works will feature power system design and operation optimization problems such as the minimization of costs using grid-connected Battery Storage PV systems.

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