

Economic Analysis of Domestic Electricity Production by Roof-Top Photovoltaic Systems in Two Provinces of Turkey

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Abstract

Solar radiation of the location and applied incentives in the country are effective factors on photovoltaic system investments' feasibility. In this study, domestic electricity production by grid connected roof-top photovoltaic systems has been analyzed regarding to economic aspects. The two pilot provinces having the highest solar radiation in Marmara Region (Istanbul) and Mediterranean Region (Antalya) in Turkey were selected according to solar energy potential atlas (GEPA). As an autonomous load the average daily consumption of 11.45 kWh was determined for a four-person household and roof-top photovoltaic systems with capacity of 3 kW, 4kW and 5kW were simulated by using HOMER software. It was analyzed whether or not conducted incentives in Istanbul and Antalya was sufficient and under what conditions roof-top photovoltaic systems investments were feasible. Roof-top photovoltaic systems investments in Istanbul and Antalya was economically not feasible due to pay back period of 16.0-16.8 years and 12.9-13.5 years respectively. Regarding to environmental issues photovoltaic systems with capacity of 5kW in Istanbul and Antalya, reduction of CO₂ emissions per detached house has been calculated around 3 tons and 3.5 tons respectively.

Keywords

PV system, Solar radiation, Electricity Production, HOMER, Turkey,

1 Introduction

As at the end of 2013, 30.6% of total electricity production has been obtained from renewable energy sources (including hydroelectric power plants) in Turkey [1]. However, photovoltaic systems have constituted only 0.1% of this share (30.6%). Compared to the EU countries, the grid-connected photovoltaic systems has been implemented approximately 10 years later in Turkey. In 1998, the first implementation of grid-connected PV system has took place with capacity of 4.8 kW by General Directorate of Electrical Power Resources Survey and Development Administration in Didim Province [2].

The potential implementation capacity of PV systems in Turkey is assumed as 450-500 GW regarding to annually solar radiation of 2738 hours [3]. Although Turkey has high solar energy potential, its investments on solar energy have stayed behind EU countries due to lack of infrastructural development and legal regulation gaps. According to statistics conducted by Unlicensed Electricity Generation Association (LI-DER), 1995 applications for PV systems having capacity of lower than 1000 kW have been accepted. The cumulative installations of PV systems having capacity of lower than 1000 kW have reached to 1.476.823 kW by the end of 2014 [4].

In Turkey, photovoltaic systems are usually used for

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lighting of parks and gardens and traffic signals and in rural areas where the electricity distribution systems are not available. Regarding to cumulative installed capacity of PV systems in Turkey, the current situation has been assessed and the projection of coming years has been made by Vice president of International Solar Energy Society -Turkey Section (GUNDER) Mr Osman Özberk given in Figure 1 [5].

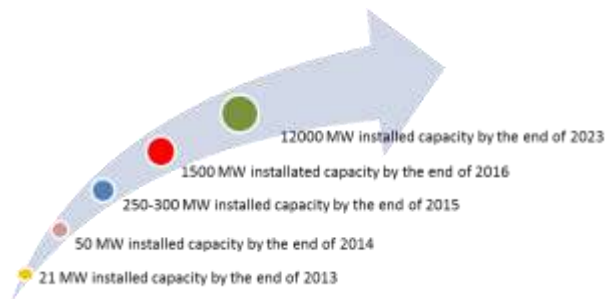


Fig. 1 The current situation of installed capacity of PV systems in Turkey and their projection of coming years

2 Incentives mechanisms in Turkey

In order to increase renewable energy share in the electricity production, legislations including Turkish national incentives mechanisms are given in Figure 2. For the first time, feed-in tariff and special discounts for generation of electricity from renewable resources have been put into practice by The Law No. 5346 on the Use of Renewable Energy Resources for Generating Electricity dated 10/05/2005 [6]. Within this law, the feed-in tariff will be the average marketing price of previous year determined by Energy Market Regulatory Authority (EPDK). Moreover, 50% discount on permits, lease, and servitude right related with state-owned land allocation will be implemented whereas exemption from paying the forestation and erosion control revenue and the forest villagers' development revenue will be provided. The feed-in tariffs will be valid for 7 years and can be increased by Council of ministries to 20% (as a maximum) annually.

The Ministry of Energy and Natural Resource has enacted Energy Efficiency Law numbered 5627 and dated 18/04/2007 which identify the range of feed-in tariff (5 Euro cent/kWh – 5.5 Euro cent/kWh) to be determined by EPDK annually. Within the law, the validity of the feed-in tariffs has been increased to 10 years whereas the discount on permits, lease, and servitude right related with state-owned land allocation has been increased to 85% [7]. In addition, electricity generation facilities using renewable resources are exempt to obtain license if their capacity is equal or lower than 200 kW and they are using the produced electricity for their own needs.

Without considering of purpose of usage, the license exemption for electricity generation facilities using renewable energy resources has been put into practice in line with Electricity Market Law numbered 5784 and dated 09/07/2008 if their capacity is equal or lower than 500 kW [8].

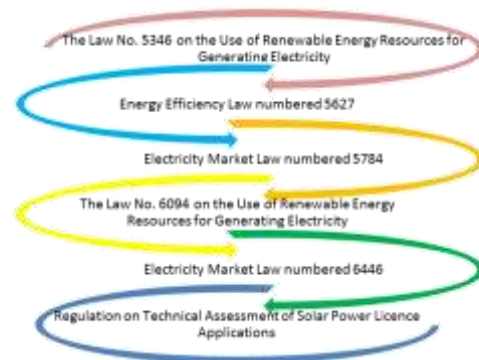


Fig. 2 Turkish Legislations including incentives mechanism

Within the Law on the Use of Renewable Energy Resources for Generating Electricity numbered 6094 and dated 29/12/2010, the feed-in tariffs has been increased and determined regarding to type of renewable energy resource. Additional incentives which is valid for 5 years has been also provided if the identified components of systems are manufactured in Turkey. The incentives provided by the Law numbered 6094 are summarized in Table 1 [9]. The maximum available incentives for 5 years is 20 US\$ cent/kWh if the selected mechanical or electromechanical components are manufactured in Turkey.

Table 1 The incentives provided by the Law numbered 6094

Incentive	Detail	Validity
Feed-in tariffs for electricity generated from solar energy	13.3 \$ cent/kWhour	Up to 10 year
Manufacturing in Turkey	Production of PV Panel Integration and Solar Structural Mechanics	Up to 5 year
	PV modules	
	Cells Constituting the PV Modules	
	Inverter	
	Material on the PV Module that Focuses Solar Ray	

The license exemption for electricity generation facilities with capacity of equal or lower than 1000 kW has been put into practice in line with Electricity Market Law numbered 6446 and dated 14/03/2013 [10]. The Ministry of Energy and Natural Resource has enacted Regulation on Technical Assessment of Solar Power License Applications which aims to identify procedures and principles for technical assessment.

Solar radiation of the location and applied incentives in the country are effective factors on photovoltaic system investments' feasibility. In this study, domestic electricity production by grid connected roof-top photovoltaic systems has been analysed regarding to economic aspects. The two pilot provinces having the highest solar radiation

in Marmara Region (Istanbul) and Mediterranean Region (Antalya) in Turkey were selected according to solar energy potential atlas (GEPA). As an autonomous load the average daily consumption of 11.45 kWh was determined for a four-person household and roof-top photovoltaic systems with capacity of 3 kW, 4kW and 5kW were simulated by using HOMER software. It was analysed whether or not conducted incentives in Istanbul and Antalya were sufficient and under what conditions roof-top photovoltaic systems investments were feasible. Systems having payback period of 7 years and below were considered as favourable investments. In order to decrease payback period, different scenarios including increasing feed-in tariff (25%, 50%, 75% and 100%), decreasing initial cost (25% and 50%) and both of them were evaluated.

3 Data of İstanbul and Antalya Provinces

Solar energy potential atlas (GEPA) of Turkey prepared by General Directorate of Renewable Energy is given in Figure 3. In order to assess the impacts of solar radiation on pay back period of photovoltaic systems, Istanbul province located in north region and Antalya province located south region have been selected since the solar radiation value is increasing from north region to south region in Turkey.

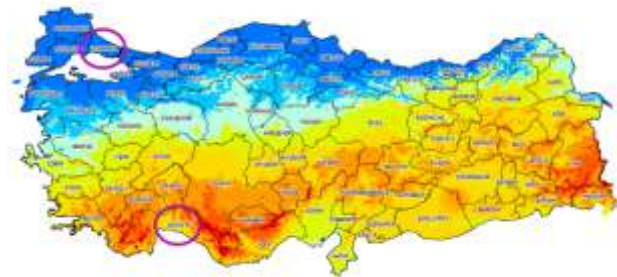


Fig. 3 Solar Energy Potential Atlas of Turkey

Sunlight duration and solar radiation of İstanbul and Antalya are given in Table 2.

Table 2 Sunlight duration and solar radiation of İstanbul and Antalya [11]

Province	Sunlight duration (hours/year)	Solar radiation (kWh/m ² -year)
Istanbul	2444.1	1612
Antalya	3010	1646

4 Data used in HOMER

In this study, the HOMER (Hybrid Optimization of Multiple Energy Resources) software has been used to evaluate design of grid connected PV systems having capacity of 3kW, 4kW and 5kW in two pilot provinces. As an autonomous load the average daily consumption, 11.45 kWh was determined for a four-person household. The daily load profile showing the hourly electric demand is given in Figure 4.

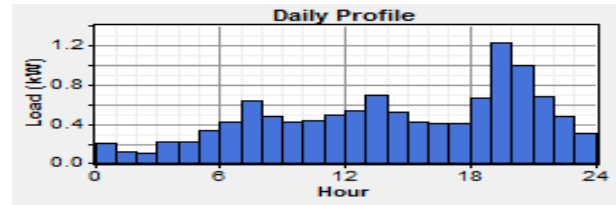


Fig. 4 Daily load profile used in the model

The seasonal profile used in the model is given in Figure 5.

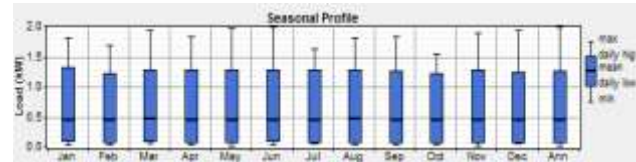


Fig. 5 Seasonal profile used in the model

Schematic diagram of PV system components described in HOMER is given in Figure 6.

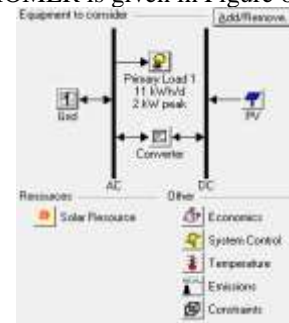


Fig. 6 Components of PV systems in HOMER

The use of storage battery was not considered since the photovoltaic systems in İstanbul and Antalya were designed as a grid-connected system. HOMER enabled to provide the radiation data of each selected province from Climatological Solar Radiation Data Sets of National Renewable Energy Laboratory (NREL) or NASA Surface Meteorology and Solar Energy Data Sets through internet connection [12].

Coordinates of selected provinces is given in Table 3. The annual optimal angle of panel facing south is approximately equal to 0.9 multiplied by the latitude which are lower than 65° [13]. Since Turkey is located in northern hemisphere, PV panels are fixed at south side of the roofs. Fixed angle of roof-top panels to be installed in İstanbul and Antalya have been calculated according to latitude (Table 3).

Table 3 Coordinates of selected provinces and fixed angle of panels

Province	Region	Latitude (North)	Longitude (South)	Fixed angle of panels
Istanbul	Marmara	40° 59.91'	28° 52.94'	36
Antalya	Mediterranean	36° 53.05'	30° 42.34'	32.4

Roof-top PV panels having capacity of 3kW, 4 kW and 5 kW and inverters having same capacities (respectively) have been evaluated in HOMER. Initial

capital cost of 3 kW PV systems is varying between 2610 EUR (3393 US\$) and 3960 EUR (5148 US\$) considering the investments in European countries including Germany, France, Greece and Italy [14]. Within the study, it was assumed initial capital cost is 1500 US\$/kW and maintenance and operation cost is 40 US\$ for PV systems having capacity of 3 kW. Initial capital cost of inverters has been identified as a result of marketing survey [15]. Initial capital costs of PV panels and inverters and maintenance-operation costs of the PV system are given in Table 4.

Table 4 Initial capital costs of PV panels and inverters and maintenance-operation costs of the PV system

Capacity	PV panel – capital cost (US\$)	Inverter capital cost (US\$)	Maintenance and operational cost (US\$)
3kW	4500	1500	40
4kW	6000	1750	53
5kW	7500	2350	66

The lifetime of panels and inverters were assumed 20 years as well as project duration. Therefore, replacement cost has been not identified in the model. The efficiency of panels and inverters has been identified as 15% and 94%, respectively.

In Turkey, the maximum feed-in tariff for generated electricity from solar resources is 20 \$ cent/kWh if the PV module and PV cell are produced in Turkey according to the Law on the Use of Renewable Energy Resources for Generating Electricity (Table 5) whereas 14.75 \$ cent/kWh is the electricity consumption price [16]. In the model, feed-in tariff was identified as 15.2 \$ cent/kWh, because it was assumed the PV module and PV cell would be imported (not manufactured in Turkey).

In Turkey, feed in tariffs and incentives for local manufacturing are valid for 10 years and 5 years respectively. Validity of feed in tariffs in Germany, France and Italy are 20 years whereas 25 years in Spain. In the model, it was assumed the validity of feed in tariffs is 20 years in Turkey as well as other European countries.

5 Results of Scenarios

Istanbul has the highest solar radiation in Marmara Region as well as Antalya in Mediterranean Region in Turkey according to solar energy potential atlas (GEPA). Daily radiation and clearness index of Istanbul and Antalya obtained from HOMER are given in Figure 7.

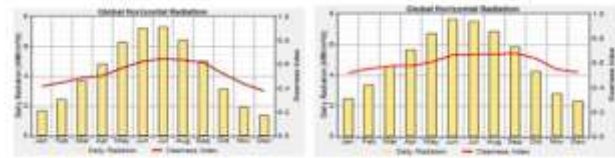


Fig. 5 Daily radiation and clearness index of Istanbul (left) and Antalya (right)

Monthly average electricity produced by PV systems having capacity of 3kW, 4 kW and 5 kW and monthly average electricity purchased from grid in Istanbul and Antalya are given in Figure 8.

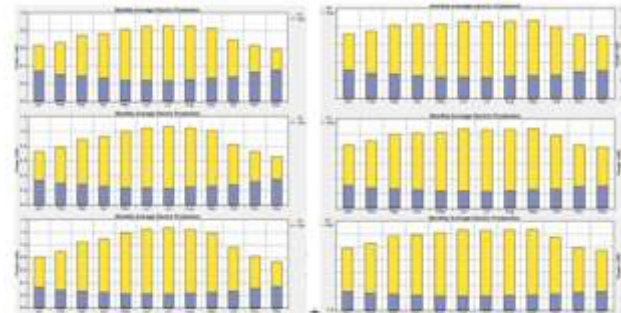


Fig. 8 Monthly average electricity produced (yellow bars) by PV systems having capacity of 3kW, 4 kW and 5 kW (from top to bottom) and monthly average electricity purchased from grid (blue bars) in Istanbul (left) and Antalya (right)

Results of HOMER regarding to current situation for PV systems to be installed in Istanbul are given in Table 5. The current initial capital costs of PV systems and current valid fees in tariffs in Turkey did not make PV systems investments attractive in Istanbul. The payback period of PV systems to be installed in Istanbul is varying between 16 to 16.8 years regarding to capacity of the systems.

Table 5 Results of HOMER regarding to current situation for PV systems in Istanbul

Results	3kW panel – 3 kW inverter	4kW panel – 4 kW inverter	5kW panel – 5 kW inverter
Initial capital cost (\$)	6050	7750	9650
Price of electricity produced (\$/kWh)	0.088	0.068	0.057
Net present value (\$)	7503	4961	8166
Renewable energy share (%)	61.1	46.3	33.8
Energy demand of household (kWh)	4124	4124	4124
Electricity produced by panel (kWh/year)	4696	3462	2627
Electricity purchased from grid (kWh/year)	2433	2363	2305
Renewable electricity used for household demand (kWh/year)	1669	1761	1819
Renewable electricity sold to grid (kWh/year)	2181	3373	4598
Pay back period (year)	16.8	16.0	16.3

In order to decrease the payback period of PV systems investments, the scenarios including increase of 25%, 50%, 75% and 100% in feed in tariffs have been evaluated. However, pay back periods did not result in below 7 years. Therefore, it was assumed that initial capital cost decreases 25% and feed in tariffs increase 25% and 50%. Although payback period decreases, 7 years and below is not achieved in these scenarios. Evaluation results for PV systems to be installed in Istanbul have showed that payback period could decrease to lower than 7 years if the initial capital cost decrease

50% and current feed in tariffs are applied. Scenario results for PV investment in Istanbul are given in Table 6.

Table 6 Scenario results for PV investment in Istanbul

Results	3kW panel – 3 kW inverter	4kW panel – 4 kW inverter	5kW panel – 5 kW inverter	
Initial capital cost (\$)	6000	7750	9650	
Pay back period (year)	Current situation	16.8	16.0	16.3
	increase of 25% in feed in tariffs	13.6	12.6	12.6
	increase of 50% in feed in tariffs	11.5	10.4	10.3
	increase of 75% in feed in tariffs	9.89	8.91	8.73
	increase of 100% in feed in tariffs	8.71	7.78	7.57
Decrease of 25% in initial capital cost (\$)	4500	5815	7300	
Pay back period (year)	Decrease of 25% in initial capital cost	10.9	10.4	10.6
	Decrease of 25% in initial capital cost and increase of 25% in feed in tariffs	9.84	9.03	8.94
	Decrease of 25% in initial capital cost and increase of 50% in feed in tariffs	8.55	7.55	7.4
Decrease of 50% in initial capital cost (\$)	3000	3875	4925	
Pay back period	Decrease of 50 % in initial capital cost	6.44	6.2	6.31

Results of HOMER regarding to current situation for PV systems to be installed in Antalya are given in Table 7. The current initial capital costs of PV systems and current valid fees in tariffs in Turkey did not make PV systems investments attractive in Antalya. The payback period of PV systems to be installed in Antalya is varying between 12.9 to 13.5 years regarding to capacity of the systems.

Table 7 Results of HOMER regarding to current situation for PV systems in Antalya

Results	3kW panel – 3 kW inverter	4kW panel – 4 kW inverter	5kW panel – 5 kW inverter
Initial capital cost (\$)	6000	7750	9650
Price of electricity produced (\$/kWh)	0.069	0.049	0.037
Net present value (\$)	6320	5380	4788
Renewable energy share (%)	65.6	72.5	77.3
Energy demand of household (kWh)	4124	4124	4124
Electricity produced by panel (kWh/year)	4710	6280	7849
Electricity purchased from grid (kWh/year)	2318	2241	2196
Renewable electricity used for household demand (kWh/year)	1896	1883	1928
Renewable electricity sold to grid (kWh/year)	2812	4019	5450
Pay back period (year)	13.5	12.9	13.1

In order to decrease the payback period of PV systems investments, the scenarios including increase of 25%, 50%, 75% and 100% in feed in tariffs have been evaluated. If the feed in tariffs increase 100%, PV systems investments having capacity of 4 kW and 5kW can be considered feasible.

It was assumed that initial capital cost decreases 25% and feed in tariffs increase 25% and 50%. Evaluation results for PV systems to be installed in Antalya have showed that payback period could decrease to lower than 7 years if the initial capital cost decrease 25% and feed in tariffs increase 50%. Scenario results for PV investment in Antalya are given in Table 8.

Table 8 Scenario results for PV investment in Antalya

Results	3kW panel – 3 kW inverter	4kW panel – 4 kW inverter	5kW panel – 5 kW inverter	
Initial capital cost (\$)	6000	7750	9650	
Pay back period (year)	Current situation	13.5	12.9	13.1
	increase of 25% in feed in tariffs	11	10.3	10.3
	increase of 50% in feed in tariffs	9.32	8.55	8.47
	increase of 75% in feed in tariffs	8.08	7.33	7.2
	increase of 100% in feed in tariffs	7.14	6.42	6.27
Decrease of 25% in initial capital cost (\$)	4500	5815	7300	
Pay back period (year)	Decrease of 25% in initial capital cost	9.01	8.65	8.8
	Decrease of 25% in initial capital cost and increase of 25% in feed in tariffs	7.53	7.06	7.08
	Decrease of 25% in initial capital cost and increase of 50% in feed in tariffs	6.47	5.97	5.92

6 Environmental improvements resulted in photovoltaic systems to be installed in Istanbul and Antalya

In Turkey, CO₂ emissions per kWh from electricity generation has been identified as 472 g [17]. Considering environmental improvements, the PV systems having higher capacity should be invested instead of the PV systems having lower capacity although they have lower initial capital cost. The amount of CO₂ emissions decreased by PV systems having capacity of 3 kW, 4kW and 5 kW to be installed in Istanbul and Antalya is given in Table 9.

Table 9 The amount of CO₂ emissions decreased by PV systems having capacity of 3 kW, 4kW and 5 kW to be installed in Istanbul and Antalya

Province	Capacity of the PV system	Consumed electricity which is produced by PV system (kWh/year)	Sold electricity which is produced by PV system (kWh/year)	Amount of CO ₂ emission decreased (kg CO ₂ /year)
Istanbul	3 kW	1669	2181	1817
	4 kW	1761	3373	2425
	5 kW	1819	4598	3028
Antalya	3 kW	1806	2621	2089
	4 kW	1883	4019	2785
	5 kW	1928	5450	3482

7 Results and Recommendation

Within the study, two pilot provinces having the highest solar radiation in Marmara and Mediterranean region were selected according to solar energy potential atlas (GEPA). Roof-top photovoltaic systems with capacity of 3 kW, 4kW and 5kW were simulated by using HOMER software. As a result of this study, roof-top photovoltaic systems in Istanbul and Antalya was economically not feasible due to pay back period of around 16 years and 13 years, respectively. It was considered providing incentives mechanisms other than feed-in tariff and support programme especially regarding to roof-top PV systems could be a first step to decrease pay back periods in Turkey. The payback period of investments in each pilot province as varied that was resulted in difference solar radiation. Dissemination of PV

system in Turkey could be accelerated to apply higher feed-in tariff for provinces having lower solar radiation.

Regarding to environmental issues photovoltaic systems with capacity of 5 kW should be preferred which enable to decrease 3 tonnes of CO₂ emissions and 3.4 tonnes of CO₂ emissions per detached house in Istanbul and Antalya, respectively although their initial cost was higher than PV system with capacity of 3 kW. Implementation of roof-top PV systems will be an important step to prevent global warming and reduce the dependence on fossil fuels.

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