

# Economic Analysis and Modeling Process of Photovoltaic Power Systems

**Abstract.** The importance of renewable energy sources is increasing in our world. Solar energy is the most natural, unlimited, ergonomic, environmentally friendly, useful and available everywhere source among of the renewable energy sources. The installed capacity of solar energy in electricity generation is increasing rapidly all of the countries. The most important part of photovoltaic power installed projects is cost-effective of projects for these systems installations because millions of dollars are being invested to it. This study is crucial in this respect. An example of location is determined and is designed for photovoltaic installation according to the European Commission Photovoltaic Geographical Information System for the city of Van where is the east of Turkey. Needs of the system, system equipments, design style and how it should be established are indicated and worked while considering the geographical coordinates of the location. A detailed study has been prepared taking into consideration all these data. It is a fact that such a system designing would serve as an example for all photovoltaic applications in the world.

**Streszczenie.** W artykule zaprezentowano ekonomiczne aspekty instalacji sieci elektrycznej bazującej na ogniach fotowoltaicznych. Przedstawiono przykład instalacji we wschodniej części Turcji. (Analiza ekonomiczna i modelowanie systemu zasilania bazującego na ogniach fotowoltaicznych)

**Keywords:** Photovoltaic Design, Geographic Description, Solar Applications

**Słowa kluczowe:** energetyka słoneczna, ogniwa fotowoltaiczne.

## 1. Introduction

Renewable energy is a sustainable and clean source of energy derived from nature. Renewable energy technology is one of the solutions, which produces energy by transforming natural phenomena (or natural resources) into useful energy forms. Concern about the development of applications of, and the teaching about, renewable energies have increased markedly in recent years. Some university centers have established complete courses on renewable energies [1]. Annual renewable Energy investment has increased fourfold to reach \$120 billion in 2008. In the four years from end-2004 to end-2008, solar photovoltaic (PV) capacity increased six fold to more than 16 gigawatts (GW), wind power capacity increased 250 percent to 121 GW, and total power capacity from new renewable increased 75 percent to 280 GW, including significant gains in small hydro, geothermal, and biomass power generation. During the same period, solar heating capacity doubled to 145 gigawatts-thermal (GW<sub>th</sub>), while biodiesel production increased six fold to 12 billion liters per year and ethanol production doubled to 67 billion liters per year [2].

Alternative energy plays an elementary function in resolving environmental pollution and warming problems. The environmental issue has been rising in the worldwide scale such as global warming by exhausting carbon dioxide. The production of dangerous greenhouse gas emissions and consumption of world energy resources become a serious problem. The problems with energy supply and use are related not only to global warming but also to such environmental concerns like as air pollution, acid precipitation, ozone depletion, forest destruction, and radioactive substance emissions [3]. Human activities are mainly blamed for the substantial discharge of CO<sub>2</sub>. Global discharge of CO<sub>2</sub> related to human activities topped 2.6 billion tons in 2002 and is expected to reach 4.2 billion tons per year in 2030 [4]. To prevent these effects, some potential solutions have evolved including energy conservation through improved energy efficiency, a reduction in fossil fuel use and an increase in environmentally friendly energy supplies [3].

Among various technologies of sustainable energy sources, photovoltaic (PV) appears quite attractive for electricity generation because of its noiseless, no carbon dioxide emission when operating, scale flexibility and rather simple operation and maintenance [5]. Also, the solar

energy has a significant influence on a large part of the world. Solar energy generation installations, energy generating costs and studies on energy generation are indicated that solar energy will be power of the future.

Photovoltaic panels with semi-conductor technology can be used in many variety areas converting solar energy into electrical energy. The photon energy is obtained from solar energy and converts energy to electrical energy, however, efficiency of solar panels in use today is fairly but the continuous research shows that efficiency of solar panels will be increased efficiency and this situation will make economic use of solar panels

## 2. Global photovoltaic markets and production capacity

Renewable energy industries boomed during most of 2008. Global solar PV production increased by 90 percent to 6.9 GW in 2008 [2]. Depletion of conventional fossil fuel energy sources and variety lots of environmental problems is caused that the world focus on the photovoltaic (PV) system and these systems have been increasing around the world. The photovoltaic (PV) field has given rise to a global industry capable of producing many gigawatts (GW) of additional installed capacity per year [6]. Fig. 1 shows that PV market demand in 2009. World solar photovoltaic (PV) market installations reached a record high of 7.3 gigawatts (GW) in 2009 and representing growth of 20% over the previous year. The PV industry generated \$38.5 billion in global revenues in 2009, while successfully rising over \$13.5 billion in equity and debt, up 8% on the prior year. Market size continued to increase in 2010, with a recent forecast of 2010 market size at 16.3 GW. Japan's market grew 109% to make it the fourth largest market [7]. Demand by European countries, Germany, Italy and Czech Republic being the main markets, accounted for 5.60 GW, constituting 77 percent of world demand [8]. These developments are indicated that electrical generation with photovoltaic panels will play an important role in the future and lots of researches are estimated that photovoltaic electricity generation will be energy of the future because of photovoltaic systems developments will increase and focusing more and more on the industry that is poised for exponentially decrease their cost.



Fig. 1. PV market demand in 2009 [7].

The countries with most installed photovoltaic power currently are Germany, Japan, Italy and the USA, which are being the biggest photovoltaic module producing countries as well. The 90% of the whole photovoltaic modules produced in the world are produced in the USA, Japan and the European Union (EU) countries. The EU countries have set a target of 3000 MW of installed photovoltaic power by the year 2010. The increase in the production rate of photovoltaic modules has been 15% annually in the last decade. Most of these photovoltaic modules were used in stand-alone applications in places where the grid-connection was non-existent [9].

### 3. Economic evaluation of photovoltaic energy systems

In the early days of photovoltaic panels, some 50 years ago, the energy required to produce a PV panel was more than the energy the panel could produce during its lifetime. During the last decade, however, due to improvements in the efficiency of the panels and manufacturing methods, the payback times were reduced to 3–5 years, depending on the sunshine available at the installation site. Today the cost of photovoltaic is around \$2.5 US per watt peak and the target is to reduce this to about \$1 US/W peak by 2020 [10]. Table 1 shows that PV technology state-of-the-art and major objectives/milestones for the next 10 years (numbers and ranges are indicative because of the spread in technologies, system types and circumstances, etc.)

Table 1. PV technology state-of-the-art and major objectives/milestones for the next 10 years (numbers and ranges are indicative because of the spread in technologies, system types and circumstances, etc.) [11].

	2007	2010	2015	2020	
Turn-key price large systems (€/Wp)	5	2,5	2	1,5	
PV electricity generation cost in Southern EU (€/kWh)	0.30	0.13	0.10	0.07	
Typical PV module efficiency range (%)	Crystalline silicon	13-18%	15-20%	16-21%	18-23%
	Thin films	5-11%	6-12%	8-14%	10-16%
	Concentrators	20%	20-25%	25-30%	30-35%
Inverter lifetime (years)	10	15	20	>25	
Cost of PV + small-scale storage (€/kWh) in Southern EU (grid-connected)	--	0.35	0.22	<0.15	
Energy pay-back time (years)	2-3	1-2	1	0.5	

As of January 2010, there are now 398 solar module prices below \$3.00 per watt (€2.25 per watt) or 29.1% of the total survey. This compares with 368 price points below \$3.00 per watt (€2.28 per watt) in December [7]. Production cost is the cost per kW required for photovoltaic power generation. Unit cost is the average of monthly cost. Therefore, it is more economically efficient if production cost

is smaller than the sales cost. The calculation of production cost was based on the following equation [12];

$$(1) \quad \text{Product cost (\$/kWh)} = \frac{\text{expense per year (\$/year)}}{\text{power output per year (kWh/year)}}$$

Annual expenses could be divided into invested capital's collection cost and administrative and maintenance expenses. In the invested capital's collection cost, the study applied a discount rate of 7% and calculated its durable years as 30 years [12]. Fig. 2 shows that Solarbuzz Retail Module Price Index [7].

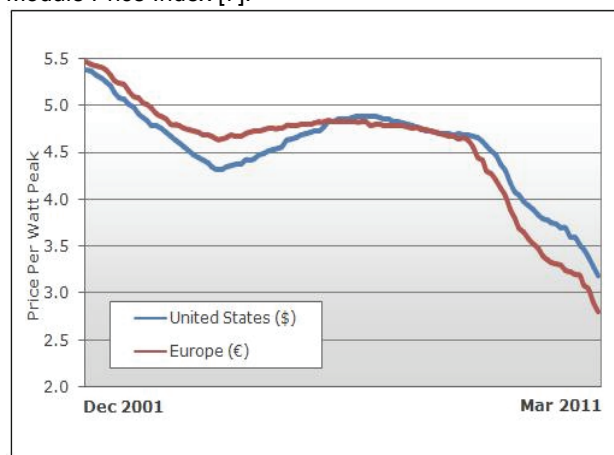


Fig. 2. Solarbuzz Retail Module Price Index

These actions generally require a greater initial investment. For example, the use of a photovoltaic installation for providing hot water for washrooms has been estimated to increase the initial cost of a building by 5%. However, the energy savings that can be achieved have two advantages: (a) in the medium and long term, it compensates the original investment through reduced costs; (b) by saving on conventional energy, it implies in turn a reduction in atmospheric pollution [13].

### 4. Design and installation of photovoltaic power system

This study is discussed a sample of photovoltaic system design and installation. Design of the photovoltaic systems installation has great importance for efficiency of the system because, making faults and some manipulates are negatively affected during the installation of the system. These situation cause additional costs for the system after a certain period of time. This study was designed as a detailed example of the installation of a system. This design will serve as an important example for photovoltaic systems will be installed in the future.

Turkey has a large potential of renewable energy sources. Especially, solar energy potential is very important among other developed countries [14]. The system is design for city of Van where is the east of the Turkey and table 1 and fig. 3, 4, 5 are obtained and designed according to the Joint Research Centre European Commission Photovoltaic Geographical Information System (PVGIS) data. Firstly, geographical location is considered state of the system will be installed because these values is the basis for the installation and the system will be designed as shown in table 2 accordingly to these values that are [15];

Location: 38°29'16" North, 43°21'46" East, Nominal power of the PV system: 1.0 kW (crystalline silicon), Estimated losses due to temperature: 9.5% (using local ambient temperature), Estimated loss due to angular reflectance effects: 2.8%, Other losses (cables, inverter etc.): 14.0%.

Combined PV system losses: 24.4%.

Ed: Average daily electricity production from the given system (kWh); Em: Average monthly electricity production from the given system (kWh); Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m<sup>2</sup>); Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m<sup>2</sup>).

Table 2. The geographic and system design values for indicated location and situation

Fixed system inclination=35 deg., orientation=0 deg.				
Month	Ed	Em	Hd	Hm
Jan	2.26	70.1	2.77	85.7
Feb	2.80	78.5	3.45	96.7
Mar	3.71	115	4.77	148
Apr	3.95	118	5.15	154
May	4.19	130	5.63	175
Jun	4.40	132	6.03	181
Jul	4.37	135	6.09	189
Aug	4.26	132	5.93	184
Sep	4.44	133	6.09	183
Oct	3.75	116	4.98	155
Nov	2.73	81.9	3.50	105
Dec	2.20	68.3	2.72	84.4
Year	3.59	109	4.77	145
Total for year		1310		1740
2-axis tracking system				
Month	Ed	Em	Hd	Hm
Jan	2.70	83.8	3.39	105
Feb	3.37	94.4	4.22	118
Mar	4.72	146	6.16	191
Apr	5.22	157	6.81	204
May	5.88	182	7.89	245
Jun	6.45	193	8.81	264
Jul	6.27	195	8.71	270
Aug	5.73	177	7.95	246
Sep	5.87	176	8.07	242
Oct	4.71	146	6.35	197
Nov	3.32	99.7	4.37	131
Dec	2.66	82.3	3.38	105
Year	4.75	144	6.35	193
Total for year		1730		2320

The system will be designed taking into consideration the values detailed in table 2. Geographic, photovoltaic panels and system information are examined. Energy capacity of the system is indicated that will be produced electricity energy. The diagrams are created by months. In addition to fixed system and 2-axis tracking for photovoltaic installation design were also added to diagrams as shown are fig. 3, 4, 5.

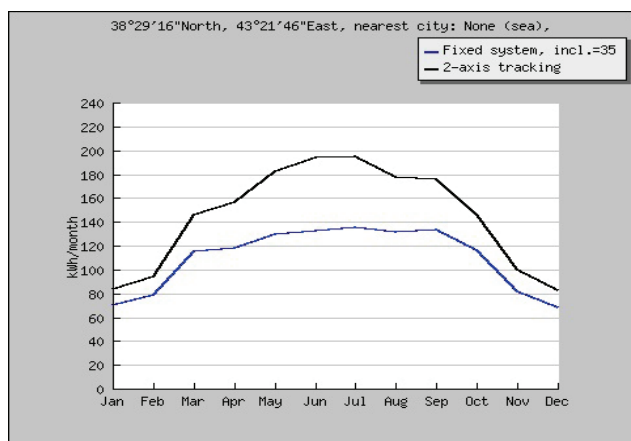


Fig. 3. Monthly energy output from fixed-angle PV system

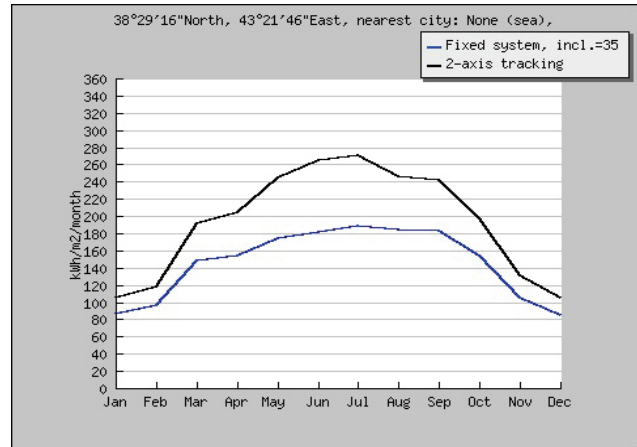


Fig. 4. Monthly in-plane irradiation for fixed angle

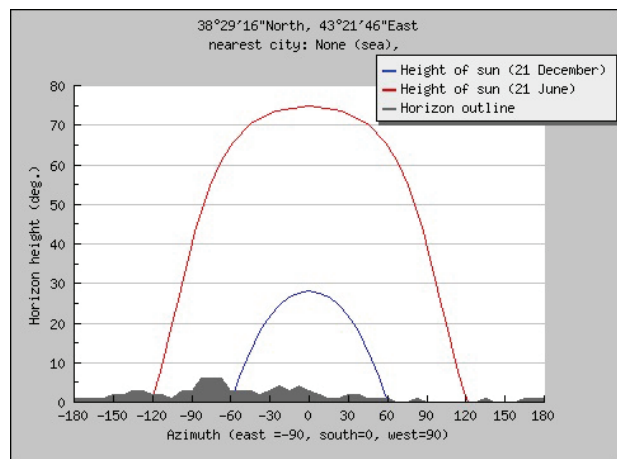


Fig. 5. Outline of horizon with sun path for winter and summer solstice

A typical photovoltaic panel includes a 20 - to 100-Wp photovoltaic (PV) array; a rechargeable battery for energy storage, a battery charge controller, one or more lights (generally fluorescent), an outlet for a television (TV), radio/cassette player, or other low power consuming appliances, switches, interconnecting wires, and mounting hardware [16]. Such this system is generated electricity how much is needed. Also, the system can be grid connected with main system and can sell electricity to other uses. Fig. 6 shows that typical solar home system components and designing.

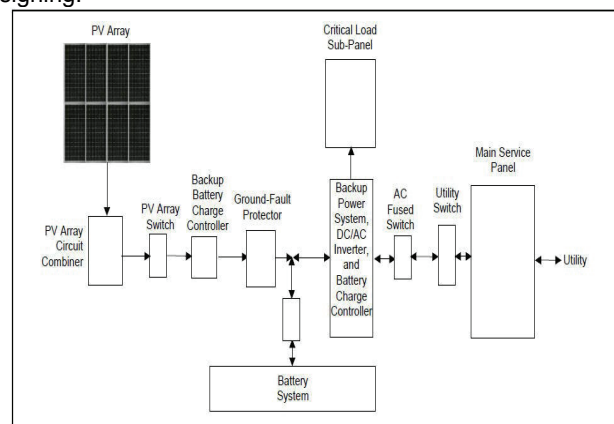


Fig. 6. Typical solar home system components and designing [17].

The cost of the systems are obviously the initial investment to purchase the system, repair and maintenance

expenses, replacement of components like battery, the charge controller, lamps etc. in future within the life time of the module. On the other hand, the financial benefit is the revenue from the system applications. The fundamental principle of appraisal methods is to compare costs against benefits. Although the principle sounds simple but the analysis become somewhat difficult because of the fact that the costs and benefits are spread over a very long period (over 20 years) of time for photovoltaic panel. The cost of the system has to be made up front. But the cost of replacement will be made some time in the distant future, which makes the estimation difficult. But the more controversial issue is to estimate benefit or cost savings over a period of 20 years [16].

Infrastructure prepared for the photovoltaic installation design is considered that is need electrical energy system a family of four as shown in table 3. All equipment that may be required for the system was determined. Application results show that the Energy production of tracking system is more efficient than fixed the system up to 34.5% [18]. System design is intended to be fixed panel system. If the photovoltaic panel system is provided that two axes to follow the sun, energy gain of the system may be much higher than existing system and the system will be able to pay for itself in life time.

Table 3. The need electrical energy system a family of four

Appliance	Numbers	AC or DC Watts (Wh)	Hours Used/Day	Watt Hours/Day (Wh)
Ceiling Fan	1	110	6,0	660
Coffee Maker	1	300	0,3	90
Clothes Dryer	1	1500	0,5	750
Computer	1	70	2,0	140
Computer Monitor	1	120	2,0	240
Dishwasher	1	900	0,5	450
Lights - Compact Fluorescents	9	20	5,0	900
Microwave Oven	1	1,200	0,5	600
Radio	1	70	4,0	280
Refrigerator	1	700	6,0	4200
Television	1	300	6,0	1800
Vacuum Cleaner	1	500	0,2	100
Washing Machine	1	500	0,5	250
<b>Total</b>				<b>10,460</b>

Table 4 shows that necessary equipment for the designed system. European Commission PVGIS data were taken into account for determining equipment. Such a system design will provide a significant contribution to the promotion of system configurations for countries of the world an example. Also, table 5 shows that cost analysis for such a system that is variable for cost analysis was carried out to set an example.

Table 4. The necessary equipment for the designed system

The average amount of electricity 1 kWp installed Power Photovoltaic System can be obtained month of June in Van (kWh / day)	4,40
Required the Board of Solar Power (Wp)	2356
Solar Panel Power for Using (Wp)	175
Number of Solar Panels for Using	13
Covered Area of Solar Panel (m <sup>2</sup> )	16,4
12 V Battery Capacity (Ah) *	2180
Charge Control Device Power (Amps) **	30,9
* %40 According to the Depth of Discharge	
** According to the 2 series x 9 parallel panel connection	

Table 5. The cost analysis of designed system

Materials	Numbers	Cost (€)	Total (€)
Photovoltaic Panel (175 Watt 24 V)	13	510	6630
Battery (200 Ah 12 V)	12	330	3960
Inverter (12/24/48 Volt, 3000 Watt)	1	1180	1180
Charge Control Device (12/24 Volt, 24 Amp)	2	75	150
<b>Total (Euro)</b>			<b>11920</b>

If the system has been establishment to move to the countryside, away from it all, off-grid solar panel system is suitable or the system can used home in the country as a off-grid system. In the design process, 10 kW systems shown in fig. 7.

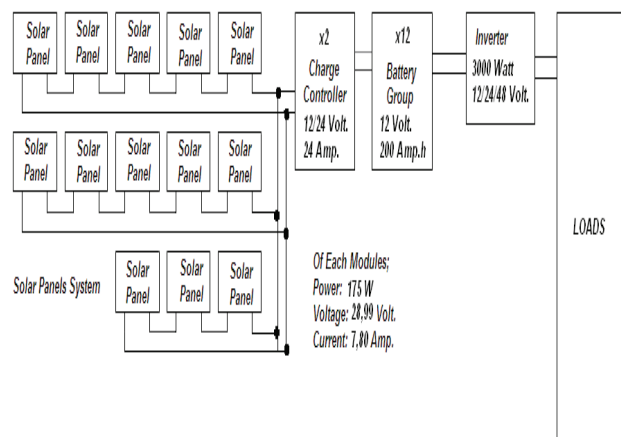


Fig. 7. Design of a 10 kW electrical power needs of a home with photovoltaic systems

## 5. Conclusion

In this paper, we propose an equation for the calculation of photovoltaic electricity costs which is the need electrical energy system a family of four. Calculated the cost of the system is very suitable for investment. Using environmentally-friendly electric power will be reduced also in toxic gas emissions. This situation will reduce the effects of global warming. Taking into account, double-direction to follow the sun in the system and more reduced system costs in a short term, we think that such a systems can be installed anywhere.

The sun is regarded as a good source of energy for its consistency and cleanliness, unlike other kinds of Energy such as coal, oil, and derivations of oil that pollute the atmosphere and the environment. Most scientists, because of the abundance of sunshine capable of satisfying our energy needs in the years ahead, emphasize the importance of solar energy [19]. The photovoltaic (PV) field has given rise to a global industry capable of producing many gigawatts (GW) of additional installed capacity per year [20]. However, a clear edge of competitiveness would be achieved only through further reduction of costs of photovoltaic modules, bringing the costs of systems down to about 1 US\$/Wp. Here, there is still some uncertainty as to the possibility of such cost reductions, knowing that in the past many of the forecasts have proved over-optimistic [21].

The city of Van is selected for photovoltaic energy installation. The installation of cost analysis is more suitable for electricity energy demand. A weather condition is an



important factor. Taking into consideration for such a location photovoltaic installation have long a life time. Therefore, it has weather conditions more suitable to install PV power generation system. The targeted systems are photovoltaic systems that are roof mounted and grid-connected.

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