ITU A|Z • Vol 13 No 2 • July 2016 • 5-22

Energy, economic and environmental analyses of photovoltaic systems in the energy renovation of residential buildings in Turkey

Suzi Dilara MANGAN[1], Gül KOÇLAR ORAL[2]
[1] dilaramangan@yahoo.com • Department of Architecture, Faculty of Architecture, Istanbul Aydin University, Istanbul, Turkey
[2] kgul@itu.edu.tr • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey

Received: May 2016 • Final Acceptance: July 2016

Abstract

The energy and environmental problems, which have arisen due to the significant increase in energy consumption, require the implementation of energy efficiency measures in the building sector which is the main source of primary energy consumption in Turkey. In this regard, in order to decrease the energy demand of buildings, supporting for in situ energy production and promoting the use of renewable energy sources, which are contributing causes to the self-sustainable buildings, take precedence over the other measures for resolving the energy related challenges of Turkey and dealing with the sustainability issues. Therefore, this paper aims to introduce a study on the assessment of the energy potential of the photovoltaic (PV) system considering a multi criteria evaluation which involves both economic convenience and environmental impacts. This study was conducted for five climate zones of Turkey through an evaluation that accounts for the crucial parameters related to the energy, economic and environmental analysis which have considerably impact on the promotion of PV system applications in terms of the energy renovation of existing residential buildings. The findings of the study can serve to underscore the potential PV profitability concerning the achievement of low carbon economy target of Turkey.

Keywords
Residential building energy renovation, Photovoltaics, Optimum design, Energy performance analysis, Economic analysis, Environmental impact.

doi: 10.5505/itujfa.2016.05668

1. Introduction

The rapidly growing use of world energy has already raised awareness over the extensive use of renewable energy sources in terms of minimising energy related environmental impacts and increasing the security of energy supply by reducing the dependence on imported fuel supplies. Thus, most of developed and developing countries have been stimulating the use of renewable energy sources through governmental programmes or incentives to ensure the diversification of the energy sources and to reduce the CO_2 emissions for all sectors (industry, building, transportation and others). Among these sectors, buildings are responsible for more than 40% of global energy used and as much as one-third of global greenhouse gas emissions both in developed and developing countries (UNEP SBCI 2009).

On the other hand, an important decision for governments and companies is whether or not to establish renewable energy systems in a given place, and to decide which renewable energy source or combination of sources is the best choice (Banos et al. 2011). The main renewable energy technologies have been evaluated regarding sustainability indicators in a number of research projects based on the techno-economic analysis (Liu et al. 2012; Bakos et al. 2003; Celik 2006; Batman et al. 2012; Chong et al. 2011; Chandrasekar and Kandpal 2004; Gunerhan and Hepbasli 2007; Esen et al. 2006) or on the more fundamental energy system simulation models and experimental studies (Celik and Acikgoz 2007; Beccali et al. 2009; Zogou and Stapountzis 2011; Ozgener and Hepbasli 2005; Xi et al 2011; Esen and Yuksel 2013).

To reduce energy consumption and achieve low carbon intensity in the residential building sector, the priority should be given to initiate actions conducive to energy sustainability and self-sufficiency. Buildings have to become a more integrated part of the energy generation system by the utilisation of renewable energies to generate electricity. Solar energy is obviously environmentally advantageous relative to any other energy source, and the basis of any serious sustainable development programme (Wang and Qui 2009). Technically, solar energy has resource potential that far exceeds the entire global energy demand (EPIA 2007; Kurokawa et al. 2007). Among various solar energy technologies of sustainable energy sources, photovoltaic (PV) appears quite attractive for electricity generation because of its noiseless, no CO_2 emission when operating, scale flexibility and rather simple operation and maintenance (Ho et al. 2009). The consistent cost reduction experimented by the PV industry as a consequence of volume markets, associated with the possibility of installing PV systems directly at the point of energy use, and the development of PV modules suited for building integration make PV an ideal technology for deployment in the urban environment (Dos Santos and Rüther 2012). The PV system has proved to be an effective option in helping countries to meet their CO_2 reduction and renewable energy generation targets (Ren et al 2009).

Total feasible PV power is calculated as 450-500GW considering the total feasible area for PV systems in Turkey (4800km^2), total solar radiation (1650kWh/m^2-year) and total sunshine duration (2738 h). Electricity energy demand of Turkey in 2030, predicted to be 600 TWh, could be met by this calculated PV power (UCTEA 2013). Despite the huge solar energy potential, PV applications in Turkey have started more slowly with around 2MW installed in 2012 and PV contribution to electricity consumption is 0.01% (IEA 2013b).

Furthermore, in Turkey, most of the common types of projects of mass production residential buildings are being developed and constructed by TOKI (Housing Development Administration of Turkey). These buildings in which an energy efficient approach has been disregarded for years, cause a gradual increase in heating and cooling energy consumption. More than one-third of energy consumed in Turkey is used for heating and cooling (MEU 2012). In regards to national economics, it is essential to contribute to the self-sustainable residential buildings, including existing and newly constructed buildings that are capable of producing their own energy for satisfying the required comfort conditions. The installation of PV systems in residential buildings is a possible option for fulfilling the energy targets and decreasing the dependency on energy imports.

This study is aimed at evaluating the influence of grid-connected PV systems on the existing heating and cooling energy consumption of multi-storey residential buildings and related mitigation of CO_2 emissions and the actual economic viability of residential applications. For this purpose, the electrical energy potential of the most common types of PV systems, roof mounted PV and PV facades, were calculated and compared with the total energy consumption of the residential buildings in terms of assuring adequate electricity generation and the economic convenience of the investment, as well as the environmental benefits concerning the different climate zones.

2. Methodology

The proposed methodology aims to evaluate the potential benefits of residential PV applications in terms of real outcomes of investments through a complex combination of energy, economic and environmental considerations on a life cycle basis. The methodology is based on several consecutive calculation phases to determine the potential of PV systems in temperate humid, temperate dry, hot humid, hot dry and cold climate zones of Turkey in terms of the energy renovation of existing residential buildings. These calculation phases, concerning the energy, cost and environmental analyses, are described as follows:

- Energy analysis:
  - Definition of the reference building,
  - Calculation of the heating and cooling energy consumption,
  - Calculation of the overall energy performance indicators of the reference building;
    - Primary energy consumption,
    - CO_2 emissions related to energy consumption,
  - Definition of the PV system;
    - Determination of the PV system type,
    - Determination of the available surfaces for PV system applications,
    - Determination of the availability of and access to solar radiation related to the climate, inclination, latitude, orientation,
    - Determination of the type of PV modules concerning efficiency,
    - Sensitivity analyses for the determination of optimum tilt angle and row distances,
  - Calculation of the annual energy generation by PV systems,
- Economic analysis:
  - Calculation of the costs of PV systems,
  - Calculation of the potential savings,
  - Calculation of the benefits of PV systems due to the gains for decreasing energy consumption, incentives and sold electricity,
  - Calculation of the economic performance indicators;
    - Net present value (NPV),
    - Discounted payback period (DPP),
  - Calculation of the economic performance of PV systems,
  - Sensitivity analyses for the most significant parameters;
    - Discount rate,
    - Energy price development,
    - Selling electricity price (feed-in tariff),
    - Cost of greenhouse gas emission,
- Environmental analysis:
  - Calculation of the overall energy performance indicators of PV systems;
    - Energy payback time (EPBT),
    - Energy return factor (ERF),
    - The potential for CO_2 mitigation.

With this methodology, an integrated approach is discussed to enhance the energy performance of existing residential buildings; the opportunities for solution oriented application of PV systems are defined; and their impacts on energy savings and environmental sustainability of the reference building for five climate zones of Turkey are assessed. Thus, the calculation procedure related to the determination of solar energy potential becomes more beneficial. As the calculation not only contributes to the specific evaluation of building code requirements, it also helps to develop future building policies both from a medium and long term perspective for Turkey by providing an outlook on the necessary further steps towards an energy effective renovation of existing residential buildings.

2.1. Energy analysis
2.1.1. Definition of the reference building

In Turkey, the Housing Development Administration of Turkey (TOKI) undertakes a significant role for nationwide investments in the building sector and especially in residential buildings. TOKI embarked on a construction programme that delivered 500,000 units built to earthquake resistant standards between 2006 and 2011. However, in a development process which echoed the earlier experience of many European countries, the emphasis was on volume and speed of production rather than on quality standards. Much of the production was in the form of peripheral estates of high rise blocks, with a low priority for environmental standards (Kocabas 2013). Contrarily, by the United Nations Development Programme (UNDP) project Promoting Energy Efficiency in Buildings in Turkey, TOKI, one of the partners of this project, will have a significant effect on reforming the residential building industry based on identified energy efficiency investments (UNDP 2011).

Therefore, an existing mass housing project, constructed by TOKI in Istanbul, was selected as a reference building to evaluate the potential of PV systems concerning the energy renovation of existing buildings. This project was designed on 25,312m^2 as 7 blocks, 408 flats. A specified block was accepted as the reference building for the calculations (Figures 1-2). The building height is 48.28m, the floor area is 573m^2 and has four apartments per storey (Figure 3a).

Figure 1. *Satellite view of the existing mass housing project.*

Figure 2. *General view of the existing mass housing project.*

The building envelope is constituted of two types of external walls. Type 1 and type 2 consist of a 20cm aerated concrete block and a 20cm reinforced concrete block, respectively. The window type is double glazed (4mm clear glass+12mm air+4mm clear glass, U:2.725W/m^{2}K) and PVC frame (60mm, U:1.912W/m^{2}K). The transparency ratios (the ratio of the window area to the facade area) are 14%, 15%, 24%, 30% for the north and south, east and west directions, respectively. The characteristics of the opaque elements

Table 1. *Characteristics of existing opaque elements.*

Construction	Material Layers (from outside to inside)	U Value (W/m^{2}K)
External wall (type1)	0.03m cement rendering + 0.05m extruded polystyrene + 0.2m aerated concrete block + 0.02m gypsum plaster	U_{wall_1}=0.371
External wall (type 2)	0.03m cement rendering + 0.05m extruded polystyrene + 0.2m concrete + 0.02m gypsum plaster	U_{wall_2}=0.576
Ground floor	1m reinforced concrete+ 0.03m concrete+0.04m extruded polystyrene+0.03m concrete +0.05 m screed + 0.01m parquet	U_{floor}=0.513
Flat roof	gravel + roofing felt +0.05m expanded polystyrene+ EPDM +0.04m concrete+0.14m reinforced concrete +0.02m gypsum plaster	U_{roof_1} =0.547

Table 2. Characteristics of climate zones of Turkey.

Climate Zones	Representative City	Latitude-Longitude (°)	Heating Degree Days	Cooling Degree Days	Global Horizontal Radiation (kWh/m²a)
Temperate humid	Istanbul	40.97-28.82	1886	2152	1465
Temperate dry	Ankara	40.12-33.00	3307	1338	1417
Hot humid	Antalya	36.70-30.73	972	3345	1798
Hot dry	Diyarbakir	37.88-40.20	2086	2843	1718
Cold	Erzurum	39.95-41.17	4785	856	1555

of the building envelope are shown in Table 1.

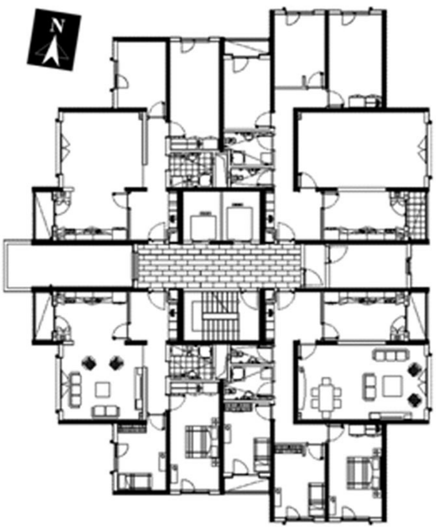
The reference building was assumed to be located in different climate zones of Turkey. These climate zones have been classified according to the results of previous scientific research projects carried out in Istanbul Technical University (Zeren 1987; Berkoz et al. 1995; Yilmaz et al. 2006). The characteristics of climate zones are shown in Table 2.

2.1.2. Calculation of the heating and cooling energy consumption

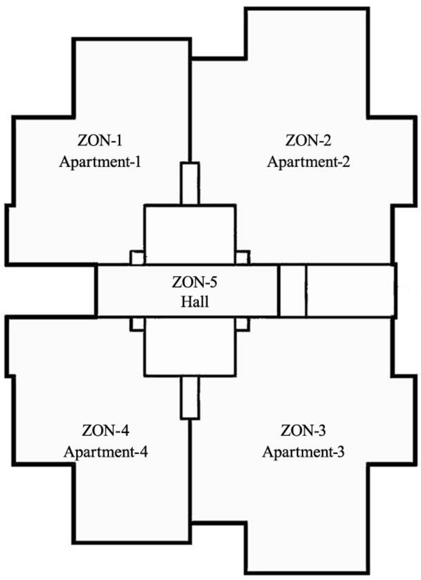
Energy use calculations have evolved from steady state heat loss and semi-static monthly energy demand calculations to complex dynamic energy performance simulation tools which can model annual energy use over very short intervals (hours, minutes, even to a fraction of a second). Simulation programmes have been compared in various papers, and detailed building energy simulation practice is extensive not only within the research community but also in the building industry (Hernandez and Kenny 2010).

In this study, annual heating and cooling energy consumption was calculated with an energy simulation building using a dynamic energy simulation programme "DesignBuilder" that is a user-friendly visual interface of Energy Plus (DesignBuilder 2011). To perform energy simulations, outdoor climate data for five climate zones of Turkey corresponds to a typical meteorological year (TMY).

According to environmental control, each apartment area and hall were accepted as a zone, means heated/cooled area (Figure 3b). The core units (stairs, elevators, fire stairs) were accepted as unconditioned areas. For Zones 1-2-3-4 (apartments), the comfort value for the indoor temperature was assumed to be 21°C for the heating period and 25°C for the cooling period. For Zone



(a)



(b)

Figure 3. *Plan view of the reference building (a) and conditoned zone areas (b).*

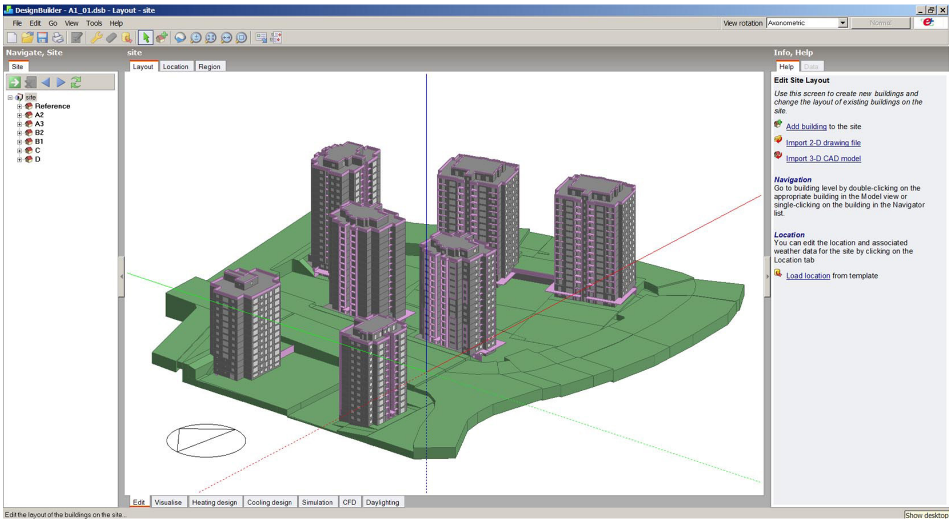


Figure 4. *DesignBuilder's user interface with a 3D view of the reference building.*

5 (hall), the heating set point temperature was accepted as 18°C. The heating system type was a hot water radiator central heating system and $COP_{heating}$ (coefficient of performance) was accepted as 0.65. The fuel type was natural gas. $COP_{cooling}$ was accepted as 4.50 and the fuel type was electricity.

The DB user interface with a 3D model of the reference building is shown in Figure 4. The calculations of annual heating and cooling energy consumption of the reference building were performed for each of the five climate zones. The results of the calculations were presented as annual heating, cooling and total (including heating and cooling energy consumption) energy consumption per unit floor area (kWh/m^2-a).

2.1.3. Calculation of the overall energy performance indicators of the reference building

In this study, to obtain the overall energy consumptions and related performance indicators, primary energy and CO_2 emissions related to heating and cooling energy consumption were taken into account. To calculate the primary energy consumption, primary energy conversion factors have been applied to each fuel type in accordance with national guidelines. The primary energy consumption can be calculated by:

$$E_{cons,primary} = E_{cons,fuel} \times f_{p,fuel} \qquad (1)$$

where $E_{cons,primary}$ is the primary energy consumption; $E_{cons,fuel}$ is the energy consumption related to the fuel type (kWh/m^2-a) and $f_{p,fuel}$ is the primary energy conversion factor which corresponds to the typical fuel mix for natural gas and electricity production in Turkey. To convert the annual natural gas consumption for heating and annual electricity consumption for cooling into primary energy, the factors 1.0 and 2.36 were used respectively (Official Gazette 2010).

The calculation of energy related CO_2 emissions can be done according to the estimation methods provided by the IPCC 2006. Among these estimation methods, the Tier 2 method concentrates on estimating the emissions from the carbon content of fuels supplied to the country with the country specific emission factors being used. The energy related CO_2 emissions relevant in Tier 2 can be calculated by:

$$CO_2\ Emissions = E_{cons,fuel} \times f_{CO2,fuel} \qquad (2)$$

where $E_{cons,fuel}$ is the energy consumption related to the fuel type (kWh/m^2-a) and $f_{CO2,fuel}$ are the country specific emission factors for the types of fuel (kg eq.CO_2/kWh). For Turkey, the emission factors for natural gas and electricity were taken as 0.2 and 0.55 kg eq.CO_2/kWh respectively (MEU 2013).

2.1.4. Definition of the PV system

PV systems can contribute to a more distributed and efficient system in which buildings can be an element within the energy supply infrastruc-

Table 3. *Characteristics of the modules.*

Technology	Location	Power (Wp)	Module Efficiency (%)	V_{OC} (V)/ I_{SC} (A)	V_{MPP} (V)/ I_{MPP} (A)	Length/ Width (mm)	Frame
Monocrystalline silicon	roof	190	14.9	44.8/ 5.78	35.80/ 5.33	1581/ 809	Aluminium
Amorphous silicon	facade	340	5.9	191.0/ 2.88	151.2/ 2.25	2600/ 2200	-

ture. PV solar energy conversion in urban, grid-connected applications is expected to reach grid parity and become cost-competitive with conventional, utility grid supplied electricity in many parts of the world in the present decade (Urbanetz et al. 2011). For the purpose of this study, grid connected roof mounted PV systems and PV facades were considered to assess the energy potential of PV systems related to the building energy renovation in terms of reduction in electrical energy consumption.

To properly design a PV system, it is necessary to define the available application area for the roof and facades according to their architectural and solar suitability. Architectural suitability mainly includes limitations due to construction (HVAC installations, elevators, etc.), historical considerations, shading effects and use of available surfaces for other purposes. Solar suitability takes into account the relative amount of irradiation for the surfaces depending on their orientation, inclination and distance among PV panels (IEA 2002). In this study, shading effects by the roof configuration itself were omitted and the entire area of a flat roof was assumed an architecturally suitable area for solar utilisation to assess the maximum potential of PV systems. In terms of facades, the west facade had no suitable area to install PV panels due to a high transparency ratio. For the east facade, the shading effect of neighbouring buildings was calculated as being too great. Only the south facade was suitable for PV use because of architectural and solar conditions.

The PV generation is influenced by many factors such as solar irradiation, efficiency of PV and balance of system (BOS). To accurately design PV systems, simulation tools developed for their designing and simulating should be used. In this study, PV*SOL Expert 6.0 software, a dynamic simulation programme with 3D visualisation and detailed shading analysis was used (PV*SOL 2013). All components of PV systems (panels, inverters, etc.) are defined by using electrical equivalent models based on the performance data issued by manufacturers. For the roof mounted PV systems, due to the highest efficiency rate and the limitations of space, mono crystalline silicon (m-Si) PV technology was considered. For the PV facades, amorphous silicon (a-Si) thin film PV technology, the most efficient one in poor light conditions was used. The studied modules and their physical and electrical characteristics are shown in Table 3.

In this study, it was assumed that all PV systems were installed in the conditions that facing south (azimuth equals 0°) and minimum shading effect at any hour of the day in all seasons. For the PV facade, all the modules were at an azimuth angle of N171°E on the blind wall area tilted at 90°. For a roof mounted PV system, the orien-

Table 4. *Characteristics of the PV systems.*

Representative City	Roof mounted PV systems				PV facade systems		
	PV output (kWp)	PV surface area (Wp/m²)	Performance ratio (%)		PV output (kWp)	PV surface area (Wp/m²)	Performance ratio (%)
Istanbul	29.26	148.36	85.20		14.28	55.30	84.30
Ankara	29.26	148.36	86.20		14.28	55.30	84.80
Antalya	29.83	148.36	84.10		14.28	55.30	84.50
Diyarbakir	30.78	148.36	83.20		14.28	55.30	83.20
Erzurum	29.64	148.36	85.00		14.28	55.30	84.70

tation of PV modules faced south. In terms of determining the optimum tilt angle and row distance of the modules, sensitivity analyses were carried out to investigate their influence on energy generation and to determine the optimum values based on maximum efficiency throughout the whole year considering the final PV system yield and performance ratio. The optimum tilt angles determined for the PV panels based on the analysis results are 31° for Istanbul, Ankara and Diyarbakir, 32° for Antalya and 30° for Erzurum. Based on the analyses performed in terms of both final PV system yield and optimisation of energy generation, values with which yield loss caused by shading is minimum should be considered as suitable shading distances between module strings for all climate zones. The characteristics of PV systems defined for flat roof and facade in respect to the results of sensitivity analyses and the other assumptions mentioned above are shown in Table 4.

2.1.5. Calculation of the annual energy generation by PV systems

The annual energy generation by the defined PV systems concerning each of the five climate zones was calculated by using PV*SOL Expert according to the above assumptions and the results of sensitivity analyses. Generated electricity is fully exported to the grid and considered as reduction of consumption.

In Turkey, more than one-third of energy consumed is used for heating and cooling in buildings. In recent years, depending on the increase of outdoor air temperatures in summer, cooling loads and cooling energy costs have been higher than the heating ones. Therefore, in this study, to determine the reduction in the existing energy consumption, the calculated annual energy generation by PV systems were compared with existing cooling energy consumption and total (heating and cooling) energy consumption of the reference building.

To establish the level of integration of PV systems, the produced electricity and the energy consumption can be coupled by means of the energy cover factor C_{PV} (Cellura et al. 2012; Verbruggen et al. 2011):

$$C_{PV}= \frac{E_{pv}}{E_{cons}} x\ 100 \qquad (3)$$

where E_{pv} is the yearly energy generation by the PV system (kWh/a) and E_{cons} is the electricity energy consumption (kWh/a).

2.2. Economic analysis

2.2.1. Calculation of the costs of PV systems

The charge, due to the cost of investment of PV systems, is known to be much higher than the other renewable energy sources. The initial investment cost of grid connected PV systems can be expressed by the following equation:

$$C_{inv}= C_{syst} + C_{ins} - C_{sub} \qquad (4)$$

where C_{inv} is the initial investment cost of the PV system, C_{syst} is the total cost of the PV panel and BOS (including inverter, array support and cabling), C_{inst} is the cost of installation and C_{sub} is the amount of the financial subsidies.

2.2.2. Calculation of the potential savings

To evaluate the gain for the potential savings, the electricity tariffs issued by the local authority for electricity can be used. The electricity savings have to be calculated considering the difference between the existing electricity consumption and the energy consumed E_{cons} including the PV energy generation.

In this study, the fixed rate electricity tariff, issued by the TEDAS (Turkish Electricity Distribution Company) for electricity for domestic consumers was used to calculate the existing electricity energy consumption cost. The average cost of residential electricity for the fixed rate tariff was 0.109 Euro/kWh in Turkey in 2013. The gas tariffs for domestic consumers related to each representative city were taken by the responsible gas distribution companies. The average cost of residential gas was

0.030 Euro/kWh in Turkey in 2013.

2.2.3. Calculation of the benefits of PV system due to the gains for decreasing energy consumption, incentives and sold electricity

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 incentivise renewables. The feed-in tariff mechanism has different prices for different renewable sources (Batman et al. 2012; Baris and Kucukali 2012; Tukenmez and Demireli 2012; Erturk 2012). The regulated price for a solar energy project is set at 0.133 US$/kWh (0.10Euro/kWh). If components 'Made in Turkey' are used, the tariff will increase by up to $0.067 (€0.052), depending on the material mix (TGNA 2011).

2.2.4. Calculation of the economic performance indicators

The results of cash flows are generally expressed by means of some indicators such as net present value (NPV), internal rate of return (IRR) and discounted payback period (DPP) to specify the effectiveness of installing the PV systems on buildings. Generally accepted indices of the investment projects effectiveness (NPV, DPP, IRR) need to calculated under condition, that cash flows has a fuzzy form for objective substantiation of the investment decision (Borlakova 2014). To appraise the PV systems, a discounted cash flow (DCF) can be complex, but this approach is suited for the numerous cash flow events in PV operations. Energy cost and growth rate, PV panel annual output, annual degradation, inverter replacement cost, maintenance expenses and other influences can be individually controlled. Some inputs are a challenge to define precisely, but a DCF can easily check value sensitivity by stressing different assumptions and building a value range based on best, most likely and worst cases (Finlay 2013).

In this paper, in order assess the degree of the economic convenience of the investment based on life cycle, NPV and DPP methods are used to summarize cash flows accurately in PV system life and provide a value range based on sensitivity assumptions. The NPV can be calculated by the following equations:

$$NPV = \sum_{t=1}^{N} \frac{EC_t}{(1+i)^t} - C_{inv} \quad (5)$$

where EC_t is the energy cost for year t (Euro), i is the discount rate, N is the lifetime of the PV system (year) and C_{inv} is the initial investment cost of the PV system (Euro). The cost of the PV modules and inverter are taken as the initial investment cost. EC_t can be calculated by the following equation:

$$EC_t = p_{pv} \times E_{pv} \quad (6)$$

where p_{pv} is the PV electricity tariff for the PV system (Euro/kWh) and E_{pv} is the amount of the PV energy generation (kWh/a).

The DPP can be calculated by the following equations:

$$\sum_{n=1}^{t} \frac{|\Delta EC_t|}{(1+i)^n} \geq C_{inv} \quad (7)$$

where ΔEC_t is the cost of energy savings for year t (Euro).

2.2.5. Calculation of the economic performance of PV systems

The economic performance of PV systems requires an accurate analysis based on the evaluation of multiple issues mentioned above such as initial cost, potential savings, annual income and expenses, support mechanisms. These issues show a great variation from country to country. The economic convenience of PV system applications relies heavily on the local conditions concerning the available solar radiation, selling and purchasing electricity prices, PV system costs, etc.

In this study, the economic performance of PV systems was calculated also considering:

- a yearly degradation rate in the efficiency of the PV panels during the first ten years equals 1% , until the end of the lifetime of PV 0.5% of the nominal initial value, based on manufacturers' warranties;
- an inflation rate of 3.23% (TSI 2013),

Table 5. *Overview on sensitivity analyses conducted.*

Scenario No	Parameter	Value for basic calculation	Value for sensitivity analysis
Sc1	Discount rate	6 %/a	3% /a (EC 2012)
Sc2	Energy price development	-	30%/a (EUROSTAT 2013)
Sc3	Discount rate & energy price development	6%/a, 0	3%/a, 15%/a
Sc4	PV electricity selling price	0.10 Euro/kWh	0.20 Euro/kWh
Sc5	Cost of greenhouse gas emission	0 Euro/tCO_2	20 Euro/tCO_2 until 2025 35 Euro/tCO_2 until 2030 50 Euro/tCO_2 beyond 2030 (EC 2012)

- a current value of 6% of the discount rate,
- PV electricity selling price 0.10 Euro/kWh (TGNA 2011).

In Turkey feed-in tariff mechanism for different renewable sources including solar energy is applied for the first ten years of the operation, and there is no other guarantee after this period. However, these periods are usually long, covering a significant portion of the working life of the installation (Candelise et al. 2010). Long-term tariff mechanisms are needed so that an investor can obtain a return on investment without substantial risk and because RETs are typically capital-intensive with long pay-back periods (Ayompe and Duffy 2013).Therefore, the cash flows for 30 years which is the estimated maximum lifetime of PV systems (IEA 2006; Alsema and de Wild-Scholten 2005) and also the specified period of time for the assessment of renovation measures related to residential buildings in the Cost Optimality Delegated Regulation (EC 2012) were calculated regarding all the above economic factors. The year of 2013 is taken as the base year of analysis. The initial investment costs were calculated in correspondence with the Turkish market prices of components considering the cost for labour and fitter's gain. The value added tax (VAT) was not taken into account for the cost calculation.

2.2.6. Sensitivity analyses for the most significant parameters

Cost calculations with many assumptions and uncertainties are generally accompanied by sensitivity analysis to evaluate the robustness of the key input parameters. Therefore, to determine the sensitivity of the calculation results to changes in the applied parameters, sensitivity analyses should at least address the impact of different energy price developments and the discount rates, ideally also other parameters which are expected to have a significant impact on the outcome of the calculations (EC 2012). In this study, sensitivity analyses were carried out for the following significant parameters to highlight the effects on the revenues of the each PV systems and consequently the importance of promoting the implementation of PV projects:

- Discount rate,
- Energy price development,
- PV electricity selling price (FIT),
- Cost of greenhouse gas emission.

The discount rate, a financial variable to represent the time value of the money, affects the present values of costs and revenues that occur in different time periods. Assumptions on the energy price development have influence on the expected profitability of the investment analysis. Also, yearly increments in energy prices can be regarded as an effective tool to promote the PV systems. The PV electricity selling price determined by the FIT is the other most cost-effective tool to encourage the installation of PV systems for electricity generation at the least cost. By determining the financial value to each tone of CO_2 emission mitigation from the PV system during its lifetime is the other promoting factor to enhance the implementation of PV projects.

Sensitivity analyses related to the parameters above were taken into account as different scenarios were defined by the varying values over the base case assumptions shown in Table 5. While assessing the influence of a defined scenario related to one of the mentioned parameters, the other parameters were kept to the values assumed for basic calculation.

2.3. Environmental analysis

2.3.1. Calculation of the overall energy performance indicators of PV systems

The installation of the photovoltaic system is also an environmental benefit and considered "sustainable" because it replaces the energy provided by fossil sources. However, although the PV system operation is free from energy consumption, most of the components of the PV system are manufactured using fossil fuel intensive materials and processes (Boustead and Hancock 1979; Sharma and Tiwari 2013). Therefore, it is important to consider the whole life cycle in order to accurately evaluate the environmental impacts of PV systems. The most widely used energy indicators such as the energy payback time (EPBT) and the energy return factor (ERF), and environmental indicators such as the potential for CO_2 mitigation, can be used to evaluate the sustainability of PV systems.

The energy indicators of EPBT and ERF express the balance of the energy generated with regard to the energy that is consumed during its manufacture and assembly (and even recycling) (Bayod-Rujula et al. 2011). The EPBT is expressed in years and defined as the ratio of the total energy input during the system life cycle and the annual energy generation during the system operation. The ERF is dimensionless and defined as the ratio of the total energy generation during the system operation lifetime and the total energy input during the system life cycle (Alsema and Nieuwlaar 2000; IEA 2006). These energy indicators can be expressed as the following equations (Alsema 1998):

$$EPBT = \frac{E_{in}}{E_{PV}} \tag{8}$$

$$ERF = \frac{E_{PV} \times N}{E_{in}} = \frac{N}{EPBT} \tag{9}$$

where E_{in} is the primary energy input required to manufacture the PV system (kWh), E_{PV} is the amount of energy generation by the PV system (kWh/a) and N is the lifetime of the PV system (year).

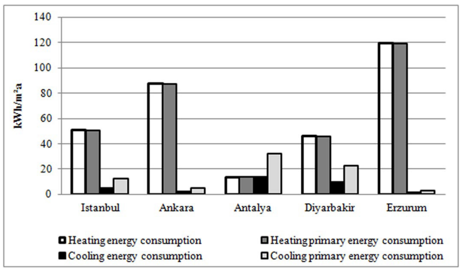
In this study, energy input is considered as manufacturing of PV modules and BOS components such as inverter, array support and cabling. The PV module itself is not the only item to be considered even though the most energy is required for its production. Thus, the primary energy requirements of a PV system cannot be assessed without considering the effect of BOS components (Nieuwlaar and Alsema 1997). To carry out these calculations, precise information related to the gross energy requirement (GER) and lifetime is required. The considered gross energy requirements and lifetime related to the PV modules and BOS are shown in Table 6.

To be able to compare the annual energy generated by the PV system in operation with the energy required for the manufacturing, it is necessary to express both quantities in the same form as primary energy or final energy by using an average grid efficiency value. For Turkey, an average grid efficiency value has not been estimated in the mix of the generation systems of electricity. In this study, the commonly agreed value for Western Europe Mainland medium voltage grid, has been estimated as 31%, was used (IEA 2006; Alsema and de Wild-Scholten 2005). This value concretely results in the need to use an average 3.23 kWh of primary energy to supply 1kWh of electricity through the grid to a medium voltage consumer (IEA 2006; ecoinvent database).

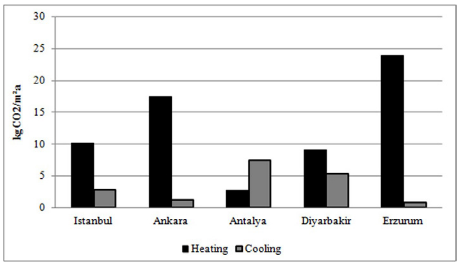
The environmental indicator of the

Table 6. *Gross energy requirements and lifetime related to the PV modules and BOS.*

Element	Gross energy requirements	Lifetime (year)
Monocrystalline silicon module	3700MJ/m² (Alsema and de Wild-Scholten 2007)	30 (IEA 2009)
Amorphous silicon module	1889 MJ/m² (Alsema 1998)	30 (IEA 2009)
Array support + cabling	100MJ/m² (Alsema and de Wild-Scholten 2006)	30 (IEA 2009)
Inverter	1930 MJ/kWp (Alsema and de Wild-Scholten 2006)	15 (IEA 2009)



(a)



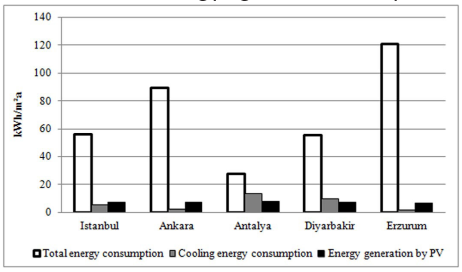
(b)

Figure 5. *Annual energy and primary energy consumptions (a) and annual CO2 emission (b).*

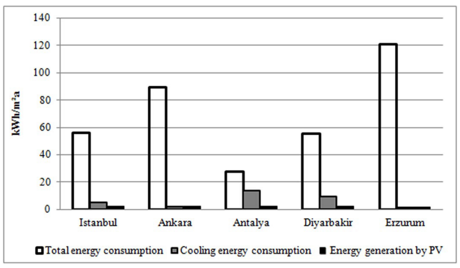
potential for CO_2 mitigation is defined as the quantity of greenhouse gas emissions that will be avoided by the PV systems. It is expressed in tons of CO_2 per kWp installed. This environmental indicator can be calculated with the following equation (IEA 2006):

$$P_{CO2} = \frac{E_{PV} \times f_{PV} \times N}{PV_{out}} \qquad (10)$$

where P_{CO2} is the potential for CO_2 mitigation (kg eq.CO_2/kWp), E_{PV} is the amount of energy generation by the



(a)



(b)

Figure 6. *Annual energy generation by roof mounted PV systems (a) and PV facade (b).*

PV system (kWh/a), f_{PV} is the specific avoided emission factor for the energy generation by the PV system (kg eq.CO_2/kWh), N is the lifetime of the PV system (year) and PV_{out} is the PV system output (kWp).

3. Calculation results

Figure 5 shows the calculated annual energy consumption, annual primary energy consumption and annual CO_2 emission concerning the heating and cooling energy requirements of the reference building assumed in five climate zones -temperate humid, temperate dry, hot humid, hot dry, cold- of Turkey. From the comparisons among the climate zones, it can be seen that corresponding ranking orders of annual energy consumption, annual primary energy consumption and annual CO_2 emission in the five climate zones are all similar. In Erzurum and Ankara, heating related energy and primary energy consumption and CO_2 emission are more than the other three cities. In terms of cooling related energy and primary energy consumption and CO_2 emission, the values for Antalya and Diyarbakir are more than the other cities. The reason is that more energy consumption for space heating in Ankara and Erzurum is required and more energy consumption for space cooling in Antalya and Diyarbakir is needed.

Figure 6 shows the calculated annual PV generation for each of the five climate zones in comparison with the total and cooling energy consumptions (final energy) of the reference building. From the comparisons among the climate zones, it can be seen that although higher electricity generation was obtained in Antalya, the representative city of the hot humid climate

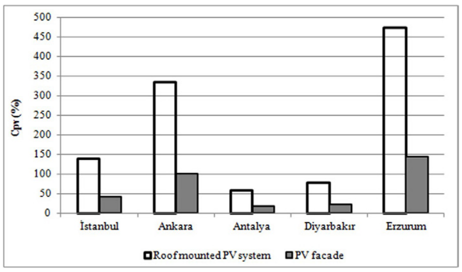


Figure 7. *Annual energy cover factor concerning the cooling energy consumption.*

zone, it depends on a high solar irradiation value, the generated electricity in other climate zones was nearly similar to the calculated generation value for Antalya and in the cold climate zone was the most outstanding one. From Figure 6a and Figure 6b it can be seen that the annual energy generation by the roof mounted PV system is higher than the annual energy generation by the PV facade. The discrepancy of energy generation potential between both of the PV systems was also found for the energy cover factor of each PV system, which is the ratio of electricity generation and the electrical energy consumed for space cooling.

Figure 7 clearly depicts this condition by the percentage of annual cooling energy consumption of the reference building that can be covered by the PV systems on a flat roof and south facade with regard to the five climate zones of Turkey. In comparison to the PV facade, the energy generation and corresponding energy cover factor of the roof-mounted PV systems were calculated too high mainly due to the capability to optimise tilt angle, no shading and less limitation of space for the installation of a PV system. From the comparisons among the climate zones, a roof mounted PV system generates 1.4, 3.3 and 4.7 times energy of the cooling energy consumptions in Istanbul, Ankara and Erzurum, respectively. These results considerably depend on less energy consumption for space cooling in these representative cities of temperate humid, temperate dry and cold climate zones of Turkey, respectively. On the other hand, high energy consumed for space cooling in Antalya and Diyarbakir, PV system supplies the 58.17% and 77.04% of electrical energy required, respectively. In terms of PV facades, the cooling demand coverage reaches the limit of 17.51%, 21.43% and 41.87% in Antalya, Diyarbakir and Istanbul, respectively. Although the PV facade seems less efficient than roof mounted PV systems, the PV system generates 1.0 and 1.4 times energy of consumed for space cooling in Ankara and Erzurum, respectively.

The economic convenience of investment of each PV system related to the base case assumptions for the

Table 7. *The calculation results of the economic performance of each PV systems.*

Representative City	Roof mounted PV systems			PV facade systems		
	Initial cost (Euro/kWp)	NPV (Euro)	DPP (year)	Initial cost (Euro/kWp)	NPV (Euro)	DPP (year)
Istanbul	1,500	13,969	14.5	1,500	-3,967	-
Ankara	1,500	15,538	13.9	1,500	-3,609	-
Antalya	1,500	18,893	12.9	1,500	-2,267	-
Diyarbakir	1,500	13,927	14.8	1,500	-4,703	-
Erzurum	1,500	9,010	16.8	1,500	-5,240	-

Table 8. *The calculation results of the sensitivity analysis for roof mounted PV systems as mean NPV of investment in Euro.*

Scenario No	Representative city				
	Istanbul	Ankara	Antalya	Diyarbakir	Erzurum
Base case	13,969	15,538	18,893	13,927	9,010
Sc1	37,414	39,618	44,679	38,279	30,676
Sc2	11,354,475	11,663,647	12,492,085	11,793,148	10,489,281
Sc3	1,120,381	1,151,961	1,235,813	1,163,141	1,031,495
Sc4	72,192	75,341	82,932	74,403	62,817
Sc5	30,095	32,101	36,629	30,676	23,913

Table 9. *The calculation results of the sensitivity analysis for PV facada as mean NPV of investment in Euro.*

Scenario No	Representative city				
	Istanbul	Ankara	Antalya	Diyarbakir	Erzurum
Base case	-3,967	-3,609	-2,267	-4,703	-5,240
Sc1	3,105	3,608	5,493	2,071	1,316
Sc2	3,416,857	3,487,394	3,751,646	3,271,910	3,166,166
Sc3	329,778	336,984	363,975	314,973	304,172
Sc4	13,595	14,313	17,005	12,119	11,042
Sc5	898	1,355	3,071	-44	-730

Table 10. *The calculation results of the energy and environmental indicators of PV systems.*

Representative City	Roof mounted PV systems				PV facade systems		
	EPBT (year)	ERF (number of times)	P CO2 (tCO2/kWp)		EPBT (year)	ERF (number of times)	PCO2 (tCO2/kWp)
Istanbul	5.2	16.7	37.5		11.3	7.6	23.2
Ankara	5.0	17.2	38.5		11.1	7.8	23.7
Antalya	4.8	18.0	40.5		10.3	8.4	25.4
Diyarbakir	5.2	16.5	37.0		11.8	7.3	22.2
Erzurum	5.7	15.2	34.2		12.2	7.1	21.5

representative cities of the five climate zones is summarised in Table 7. Results presented as NPV of investment in Euro and DPP of investment in years show that even though the initial investment cost of PV facade represents approximately half of the initial investment cost of the roof-mounted PV system, negative NPVs are observed and correspondingly the PV facade cannot recover the initial investment in a 30 year calculation period concerning all climate zones. In terms of a roof-mounted PV system, positive NPVs are achieved for all climate zones and DPP varies between 12.9 and 16.8 years. The highest NPV and the lowest DPP are found in Antalya (18,893 Euro, 12.9 years); conversely the lowest NPV and the highest DPP are found in Erzurum (9,010 Euro, 16.8 years) among the other cities.

In order to highlight the influence on the economic convenience of PV systems, sensitivity analyses related to the discount rate, energy price development, electricity selling price (FIT) and cost of greenhouse gas emission were carried out as different scenarios, referred to as Sc1, Sc2, Sc3, Sc4 and Sc5 respectively for the representative cities of the five climate zones. The calculation results of the economic performance of each PV system compared with the base case are presented as NPV of investment in Euro in Tables 8-9. From analysing Table 8 and Table 9, it can be inferred that the increment of final NPV of investment for each PV system varies over a very wide range as to the five scenarios. In particular, although negative NPVs are observed according to the base case assumptions, the possible economic viability of the PV facade is clearly described by all scenarios. From the comparisons among the scenarios, it can be seen that Sc2 related to energy price development as specified in (EUROSTAT 2013) displays a higher contribution to the final NPV of investment. Due to the increasing energy demand, yearly increments in energy price seem to make PV systems more profitable in the long-term assessment. In terms of Sc1, observing the results, it can be found that a lower discount rate (3% as specified in EC 2012) increases the economic convenience of investment between 2.4 and 3.4 times of the base case. Besides Sc1, Sc2 and Sc3 relevant to the discount rate and/or energy price development, Sc4 involving a two times higher selling PV electricity price than the base case tariff provides between 4.4 and 7.0 times of increment of NPV investment. This result is especially significant for Turkey to increase the existing incentive set in 2010 for the solar based generation system (0.10 Euro/kWh) equal to the electricity purchasing price for 2013. Also to promote the installation of PV systems, the results of the Sc5 scenario considering carbon prices according to recommended values by EC 2012 represents the significant influence of the 2.7 times (maximum value) higher NPV of investment.

In terms of environmental benefits, energy indicators comprising EPBT, ERF and the potential of CO_2 mitigation as an environmental indicator were calculated using Eqs. (8), (9) and (10), respectively for simulated on-site performance to show comparative assessment potential value of each PV system in the five climate zones. From Table 10, it can be noticed that the lowest value for EPBT, the highest value for both ERF and the potential of CO_2 mitigation can be achieved by the roof mounted PV system compared to overall energy performance indicators of PV facade. It is shown that the potential value of EPBT for the roof mounted PV system is in the range of 4.8-5.7 years which is approximately half of the range of EPBT related to the PV facade. In terms of ERF, roof mounted PV systems are expected to produce between 15.2 and 18.0 times the amount of energy required to manufacture during the whole lifetime, which is comparatively higher than obtained with the PV facade. As to the potential of CO_2 mitigation, roof mounted PV systems can avoid during their whole lifetime up to 40 tons of CO_2 for each kWp installed. The corresponding figure for PV facade is limited to 25 tons of CO_2 per kWp installed. Observing Table 10 it can be inferred that the results concerning the lowest value for EPBT, the highest value for both ERF and the potential of CO_2 emission are found in Antalya (4.8 years, 18 times, 40.5 tCO_2/kWh, respectively), the representative city of the hot humid climate zone.

4. Conclusion

It is shown that residential building energy renovation using PV systems holds a great amount of benefits related to energy, economic and environmental aspects. The share of electricity demand coverage concerning space cooling would bring energy savings and consequently result in avoiding bill cost and also providing income by selling PV electricity, as well as less CO_2 emission. Furthermore, it is worth highlighting that to make buildings an integrated part of the generation system, proper architectural design of a building plays a crucial role by providing installation not only for a PV system but also for other systems based on renewable energy sources. In this study, the whole existing flat roof is assumed to be an architecturally suitable area to show the maximum potential of PV generation by the roof mounted PV system for the five climate zones of Turkey. However, the design of the existing reference building underlines the difficulties for optimum PV system application regardless of the holistic energy efficient approach and great advantages of extensive use of renewable energy sources especially solar energy in Turkey. TOKI, which plays the major role in producing residential buildings, have to rapidly inaugurate a sustainable, climate sensitive and energy efficient design framework which certainly makes a significant impact on the national addressed targets concerning energy, economy and environment and also on the increment of public awareness.

This study provided an overview of the potential of a solar PV system to promote the installation of this system not only as an option for the energy renovation of existing residential buildings but also as a design criterion for new building construction in the five climate zones of Turkey through a complex combination of energy, economic and environmental considerations. The findings detect that total energy consumption coverage including heating and cooling energy consumption varies from a range of 6% (in Erzurum) to 30% (in Antalya) for roof mounted PV systems. By PV facades, this coverage ratio can be up to approximately 9% and the best value is found in Antalya. In terms of economic convenience, even though less incentive is undertaken to encourage PV energy compared to the other countries' support mechanisms, with the roof mounted PV system, positive NPVs are achieved for all climate zones and DPP varies between 12.9 and 16.8 years. In terms of PV facade, negative NPVs are observed and correspondingly the PV facade cannot recover the initial investment during the calculation period of 30 years for all climate zones. Conversely, the economic viability possible of the PV facade is clearly defined by all scenarios concerning the discount rate, energy price development, electricity selling price (FIT) and cost of greenhouse gas emission. Furthermore, the increment of the final NPV of investment for each PV system varies over a very wide range as to five scenarios compared to base case assumptions. Additionally, each PV system may pay back the primary energy input and the potential for CO_2 mitigation is in the range of 25-40 tons of CO_2 per kWh installed. All in all, the assessment of the PV system especially underlines the existing potential to achieve a low carbon and low fossil fuel economies target for Turkey.

The evaluated results are crucial for the range of decision makers and especially for policy makers not only in terms of achievement of sustainable economic growth and the decrease of dependency on energy imports but also fulfillment of the obligations specified by the UNCFF-Kyoto and EU harmonisation processes. Therefore, related legal laws, regulations, national action plans and support mechanisms will have to be developed to overcome the longstanding barriers in the way of energy renovation of existing residential buildings and also to provide comprehensive technical knowledge and multi objectives leading to the architect/engineer and building user with a holistic approach.

Acknowledgements

This study was supported by a grant from the Scientific Research Centre of Istanbul Technical University (Project No: 36983).

References

Alsema, E. (1998). Energy requirements of thin-film solar cell modules-a review. Renewable and Sustainable energy reviews 2 (4), 387-415.

Alsema, E.A., Nieuwlaar, E. (2000). Energy viability of photovoltaic systems. Energy Policy 28 (14), 999-1010.

Alsema, E.A., de Wild-Scholten, M.J. (2005).The real environmental impacts of crystalline silicon PV modules : an analysis based on up-to-date manufacturers data. 20th European PV Solar Conference, Barcelona.

Alsema, E.A., de Wild-Scholten, M.J. (2006). Environmental impacts of crystalline silicon photovoltaic module production. 13th CIRP International Conference on Life Cycle Engineering, Leuven.

Alsema, E.A., de Wild-Scholten, M.J. (2007). Reduction of the environmental impacts in crystalline silicon module manufacturing. 22nd European Photovoltaic Solar Energy Conference, Milan.

Ayompe, L.M., Duffy, A. (2013). Feed-in tariff design for domestic scale grid-connected PV systems using high resolution household electricity demand data. Energy Policy 61, 619-627.

Bakos, G.C., Soursos, M., Tsagas, N.F. (2003). Technoeconomic assessment of a building-integrated PV system for electrical energy saving in residential sector. Energy and Buildings 35 (8), 757-762.

Banos, R., Manzano-Agugliaro, F., Montoya, F.G., Gil, C., Alcayde, A., Gómez, J. (2011). Optimization methods applied to renewable and sustainable energy: a review. Renewable and Sustainable Energy Reviews 15 (4), 1753–1766.

Baris, K., Kucukali, S. (2012). Availibility of renewable energy sources in Turkey: current situation, potential, government policies and the EU perspective. Energy Policy 42, 377–391.

Batman, A., Bagriyanik, G., Ayges, Z.E., Gul, O., Bagriyanik, M. (2012). A feasibility study of grid-connected photovoltaic systems in Istanbul, Turkey. Renewable and Sustainable Energy Reviews 16 (8), 5678-5686.

Bayod-Rujula, A.A., Ortego-Bielsa, A., Martinez-Gracia, A. (2011). Photovoltaics on flat roofs: Energy considerations. Energy 36 (4), 1996-2010.

Beccali, M., Finocchiaro, P., Nocke, B. (2009). Energy and economic assessment of desiccant cooling systems coupled with single glazed air and hybrid pv/thermal solar collectors for applications in hot and humid climate. Solar Energy 83 (10), 1828-1846.

Berkoz, E., et al. (1995). Energy efficient housing and settlement design, Project No:INTAG201. The Scientific and Technical Research Council of Turkey, Istanbul Technical University, Istanbul.

Borlakova, A. (2014). Environmental and Economic Evaluation of the Investment Projects Basing on Fuzzy Sets Theory. World Review of Business Research 4 (1), 212-227.

Boustead, I., Hancock, G.F. (1979). Handbook of Industrial Energy Analysis. Ellis Horwood Limited, Chichester.

Candelise, C., Gross, R., Leach, M.A. (2010). Conditions for photovoltaic deployment in the UK: the role of policy and technical development. Journal of Power and Energy 224 (2), 153–168.

Celik, A.N. (2006). Present status of photovoltaic energy in Turkey and life cycle technoeconomic analysis of a grid connected photovoltaic-house. Renewable and Sustainable Energy Reviews 10 (4), 370–387.

Celik, A.N., Acikgoz, N. (2007). Modelling and experimental verification of the operating current of mono-crystalline photovoltaic modules using four- and five-parameter models. Applied Energy, 84 (1), 1-15.

Cellura, M., Di Gangi, A., Longo, S., Orioli, A. (2012). Photovoltaic electricity scenario analysis in urban contests :An Italian case study. Renewable and Sustainable Energy Reviews 16 (4), 2041-2052.

Chandrasekar, B., Kandpal, T.C. (2004). Techno-economic evaluation of domestic solar water heating systems in India. Renewable Energy 29 (3), 319-332.

Chong, W.T., Naghavi, M.S., Poh, S.C., Mahlia, T.M.I., Pan, K.C. (2011). Techno-economic analysis of a wind-solar hybrid renewable energy system with rainwater collection feature for urban high-rise application. Applied Energy 88 (11), 4067-4077.

De Jager, D., Rathmann, M. (2008). Policy instrument design to reduce financing costs in renewable energy technology projects. IEA Implementing Agreement on Renewable Energy Technology Deployment (RETD), Paris.

DesignBuilder (2011). User manual of DesignBuilder software 3.0.0.105. < www.designbuilder.co.uk >. Accessed 12 February 2011.

Dos Santos, I.P., Rüther, R. (2012). The potential of building-integrated (BIPV) and building-applied photovoltaics (BAPV) in single-family, urban residences at low latitudes in Brazil. Energy and Buildings 50, 290-297.

Erturk, M. (2012). The evaluation of feed-in tariff regulation of Turkey for onshore wind energy based on the economic analysis. Energy Policy 45, 359–367.

Esen, H., Inalli, M., Esen, M. (2006). Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. Energy Conversion and Management 47 (9-10), 1281-1297.

Esen, M., Yuksel, T. (2013). Experimental evaluation of using various renewable energy sources for heating a greenhouse. Energy and Buildings, 65, 340-351.

EC (2012). European Commission Commission Delegated Regulation, NO:244/2012; supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

EPIA, European Photovoltaic Industry Association (2007). PV to Become a Leading World Energy Market. Retrieved November 1, 2008. http://www.rtcc.org/2007/html/dev solar epia.html.

EUROSTAT. < http://epp.eurostat.ec.europa.eu/statistics_explained/index. php?title=File:Halfyearly_electricity_and_gas_prices2012s2.png&filetime stamp=20130523135053>. Accessed 05 August 2013.

Finlay, J.F. (2013). Valuation Methods for Building-Mounted Solar Photovoltaic Systems: Expert Analysis. Institute for Building Efficiency, Johnson Controls.

Gunerhan, H., Hepbasli, A. (2007). Exergetic modeling and performance evaluation of solar water heating systems for building applications. Energy and Buildings 39 (5), 509-516.

Hernandez, P., Kenny, P. (2010). From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). Energy and Buildings 42 (6), 815-821.

Ho, D.T., Frunt, J., Myrzik, J.M.A. (2009). Photovoltaic energy in power market. IEEE energy market 6th international conference on the European, Leuven.

IEA (2002). Potential for building integrated photovoltaics. International Energy Agency, Photovoltaic Power System Programme, Report IEA-PVPS T7-4.

IEA (2006). Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities. International Energy Agency, Photovoltaic power systems programme, Report IEA-PVPS-T10-02:2006.

IEA (2009). Methodology guidelines on life cycle assessment of photovoltaic electricity. International Energy Agency, Photovoltaic power systems programme, Report IEA-PVPS-T12-01.

IEA (2013a). Trends 2013 in photovoltaic applications, survey report of selected IEA countries between 1992 and 2012. International Energy Agency, Photovoltaic Power System Programme, Report IEA-PVPS T1-23

IEA (2013b). PVPS report a snapshot of global PV 1992-2012. International Energy Agency, Report IEA-PVPS T1-22.

IPCC (2006). Guidelines for national greenhouse gas inventories, Vol.2 Energy. < http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html >. Accessed 08 June 2013.

Kocabas, A. (2013). The transition to low carbon urbanization in Turkey: Emerging policies and initial action. Habitat International 37, 80-87.

Kurokawa, K., Komoto, K., Vleuten, V.D.P., Faiman, D. (2007). Energy from the desert: practical proposals for very large scale photovoltaic systems. Earthscan.

Liu, G., Rasul, M.G., Amanullah, M.T.O., Khan, M.M.K. (2012). Techno-economic simulation and optimization of residential grid-connected PV system for the Queensland climate. Renewable Energy 45, 146–155.

MEU (2012). Republic of Turkey Climate Change Action Plan 2011-2013. The Republic of Turkey Ministry of Environment and Urbanization, Ankara.

MEU (2013). The Republic of Turkey Ministry of Environment and Urbanization, Ankara.

Nieuwlaar, E., Alsema, E.A. (1997). Environmental aspects of PV power systems. IEA PVPS Task 1Workshop, Report No: 97072, Utrecht, The Netherlands.

Official Gazette of Turkish Republic (2010). Calculation method of energy performance of buildings, Ankara.

Ozgener, O. Hepbasli, A. (2005). Experimental performance analysis of a solar assisted ground-source heat pump greenhouse heating system. Energy and Buildings 37 (1), 101-110.

PV*SOL (2013). User manual of PV*SOL Expert software 6.0; < http://www.valentin-software.com/en/products/photovoltaics/12/pvsol-expert >. Accessed 08 May 2013.

Ren, H., Gao, W., Yingjun, R. (2009). Economic optimization and sensitivity analysis of photovoltaic system in residential buildings. Renewable Energy 34, 883-889.

Sharma, R., Tiwari, G.N. (2013). Life cycle assessment of stand-alone photovoltaic (SAPV) system under on-field conditions of New Delhi, India. Energy Policy 63, 272-282.

Ecoinvent database, <http://www.ecoinvent.ch>.

TGNA (2011). The Law on Utilization of Renewable Energy Sources for Generation of Electrical Energy, Law no:6094. The Grand National Assembly of Turkey, Ankara.

TSI, Turkish Statistical Institute, < http://www.tuik.gov.tr/PreHaberBulten leri.do?id=13559>. Accessed 05 August 2013.

Tukenmez, M., Demireli, E. (2012). Renewable energy policy in Turkey with the new legal regulations. Renewable Energy 39 (1), 1–9.

UCTEA (2013). The conclusion of 6th Symposium on Solar Energy, Chamber of Mechanical Engineers, Mersin.

UNDP (2011). Promoting energy efficiency in buildings in Turkey, United Nations Development Programme < http://www.tr.undp.org/ content/turkey/en/home/operations/projects/environment_and_energy/promoting_energy_efficiency_in_buildings_in_turkey/ >. Accessed 12 March 2012.

UNEP SBCI (2009). Buildings and climate change, summary for decision-makers.

Urbanetz, J., Zomer, C.D., Rüther, R. (2011). Compromises between form and function in grid-connected, building-integrated photovoltaics (BIPV) at low latitude sites. Building and Environment 46 (10), 2107-2113.

Verbruggen, B., De Coninck, R., Baetens, R., Saelens, D., Helsen, L., Driesen, J. (2011). Grid impact indicators for active building simulation. IEEE PES Innovation Smart Grid Technologies Conference, Anaheim.

Wang, Q., Qiu, H.N. (2009). Situation and outlook of solar energy utilization in Tibet, China. Renewable and Sustainable Energy Reviews 13(8), 2181–2186.

Xi, C., Lin, L., Hongxing, Y. (2011). Long term operation of a solar assisted ground coupled heat pump system for space heating and domestic hot water. Energy and Buildings 43 (8), 1835-1844.

Yilmaz, Z., et al. (2006). Sustainable strategies in the energy efficient design and construction of building for Turkey and Ireland, Project No:30657. Research Center of Istanbul Technical University, Istanbul.

Zeren, L. (1987). A study on regulation model related to new settlements and buildings energy conservation in Turkey. Istanbul Technical University, Urban and Environmental Planning and Research Center, Istanbul.

Zogou, O., Stapountzis, H. (2011). Energy analysis of an improved concept of integrated pv panels in an office building in central Greece. Applied Energy 88 (3), 853-866.