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ROOF-TOP INTEGRATED PHOTOVOLTAIC ASSESSMENT FOR SUSTAINABLE CITIES

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Abstract

Sustainable cities become more popular in recent years, due to increasing amount of people who demand to live in communities which are environmentally, socially and economically resilient. Especially, in a world, where natural sources are at the edge of depletion and the threat of greenhouse gas emissions becomes undeniable, setting sustainability goals for communities plays a vital role. Providing cheap, accessible, clean and reliable energy for the inhabitants of cities by using renewable sources is the key to create sustainable communities. This paper focuses on roof-top integrated photovoltaic systems which are installed and operated by end-users to meet the needs of power in cities. A case study is conducted in Istanbul to make financial assessments in order to find out whether it is worth for investing such technologies. The results and discussions reveal that despite environmental benefits, the payback period of such systems is too high for an investor, which leads to the fact that additional incentives must be provided by the Turkish government.

Keywords: Sustainability, energy, management.

SÜRDÜRÜLEBİLİR ŞEHİRLER İÇİN ÇATI ENTEGRE FOTOVOLTAİK SİSTEMLERİN DEĞERLENDİRİLMESİ

Öz

Çevresel, sosyal ve ekonomik açıdan esnekliği olan topluluklar içinde yaşamak isteyen nüfus gün geçtikçe artmakta ve bu sebeple sürdürülebilir şehirler son zamanlarda daha popüler olmaktadır. Özellikle, doğal kaynakların tükenme sınırında olduğu ve sera gazı salınımının inkâr edilemez bir tehdit haline dönüştüğü yerlerde, topluluklar için sürdürülebilirlik hedefleri oluşturulması hayati

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önem taşımaktadır. Şehir nüfusu için sürdürülebilir topluluklar yaratılmasının anahtarı yenilenebilir kaynaklar kullanılarak ucuz, ulaşılabilir, temiz ve güvenilir enerji sağlanmasıdır. Bu çalışma, belirtilen amaçlar doğrultusunda şehirlerdeki enerji ihtiyacını karşılamak üzere son kullanıcı tarafından kurulan ve kullanılan, çatıya entegre edilerek ışığa maruz kaldığında elektrik üreten fotovoltaik sistemlere odaklanmaktadır. Çalışmada, bu teknolojilere yatırım yapılmasının gerekliliğini ölçmek amacıyla İstanbul'da bir gerçek hayat çalışması yürütülerek finansal değerlendirmeler yapılmıştır. Elde edilen sonuçlar, çevresel faydalarına rağmen ilgili sistemin geri ödeme periyodunun yatırımcı açısından uzunluğunu ortaya çıkarmış ve hükümet tarafından ek teşviklerin sağlanması gerekliliğini vurgulamıştır.

Anahtar Kelimeler: Sürdürülebilirlik, enerji, yönetim.

1. Introduction

It is possible to hear the terms "sustainability and sustainable development" more frequently due to global problems faced by human kind such as the continuous use of fossil fuels which are considered as the major driving forces for global warming. Kuhlman and Farrington (2010) define sustainability as maintaining welfare over a long period and the report of United Nations (1987) defines sustainable development as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Based on these facts, unsustainable activities can be described as human activities that may harm the worlds' delicate balance. Another important point would be considering economic and social aspects in addition to the environmental ones for achieving sustainability targets. Therefore, evaluating problems by just taking one or two of these aspects into account is not sufficient to meet sustainability goals (Strange & Bayley, 2008).

Although sustainable development has always been handled on a global basis, Capello, Nijkamp and Pepping (1999) state that there is a close connection between local and global processes which indicates both perspectives are needed in order to achieve sustainable development. The reason behind this is highly related with the increasing demands for food, energy and supplies by cities. According to the report of OECD (2010), it projected that about 60% of total population will be living in cities worldwide by 2030, which was about 50% in 2010. Moreover, it is obvious that cities are also recognized to be the sources of producing new technology and economic growth, which makes them more important in order to find local quality of life strategies.

Sustainable development plays an important role for urban planners and decision makers for some time, since societies must take steps to make social and economic improvements in a way which does not harm the surrounding environment (Cruz & Amado, 2015). Ibrahim, Omar and Mohamad (2015) define the sustainable city as a city in which good transportation, employment, education, civic amenities, infrastructure, medical care, clean environment and other needs of population are provided by benefiting all the sectors. Based on this definition, urban sustainability goals are closely related with maximization of positive effects to the society such as creating more jobs to society, increasing returns in energy use or providing better medical services and minimization of negative effects such as solving traffic congestion or lowering environmental pollution. Thus, improving the socio-economic standard by not harming the environment is the main goal of sustainability in cities.

According to Capello, Nijkamp and Pepping (1999) the main element for urban sustainability is implementing and applying a sustainable energy policy, since most of the activities in cities are energy related. This can be achieved either by using energy saving measures or using the power generated from renewable energy technologies. Many different researches such as Zhang and Cladeira (2015) as well as Evans, Strezov and Evans (2009) have been conducted to determine the best actions to create environmental energy strategies. The conclusions of these researches suggest that using renewable energy for electricity production can significantly reduce environmental risks caused by fossil fuel based power plants. Furthermore, investing in renewable energy technologies become more and more attractive among investors due to its economic benefits, which is also an important step to provide cheap, reliable, ecological and accessible energy for the inhabitants of cities all over the world (Siemens, 2014).

Photovoltaic energy technologies provide promising opportunities for renewable electricity production due their fast and easy integration as well as their aesthetic design. Especially the advantage of dual use such as using the roof-tops of buildings is important for urban planners. However there are important factors to be considered before investing in such technologies. For example, as stated by Long and Geng (2015), the success of a photovoltaic project is highly related with the cost of photovoltaic panels. The panels cost corresponds to 41% - 54% of total cost of such a project.

This paper focuses on photovoltaic technology which is used to produce electricity by harnessing the energy of the sun. A case study will be introduced to make a complete building-integrated photovoltaic assessment in order to find potential power generation, availability of adequate sources as well as to carry out financial and emission analyses. The results will helpful for policy makers to make decisions whether to use these technologies or not in order to achieve sustainability targets.

2. Literature Review

Photovoltaic Module Orientation

Since photovoltaic panels collect solar radiation for producing electricity, it is important for them to be orientated in a way that they are exposed to direct sunlight. When the sunlight is perpendicular to the panel surface, its output becomes maximized. However, determining the optimum orientation for a photovoltaic project may be hard since it can change according to the season as well as the latitude, on which the project will be conducted (Armendariz-Lopez et al., 2016).

Different studies have been performed to find the best tilt angle for different locations on earth. For example, the research conducted by Asl-Soleimani, Farhangi and Zabihi (2013) was aimed to find the optimum angles for an experimental photovoltaic setup in Tehran, Iran. The results show that the maximum output of that photovoltaic system is observed with a slope of 29°. In another study performed by Hussein, Ahmad and El-Ghetany (2001), computation simulations have been used to find the best angle for Cairo, Egypt. The outcome of this research, which is 20–30°, is compatible with the findings of Asl-Soleimani, Farhangi and Zabihi (2013).

The issue of determining the azimuth is also as important as finding the tilt angle. One of the most comprehensive studies about this issue is performed by Hiraoka et al. (2003), in which three different photovoltaic systems facing to three different orientations have been taken into account with the same tilt angle of 26.5°. According to the analyses the annual data coming from all orientations corresponds to 70% compared to the panels facing to south side. Furthermore, Nakamura et al. (2001) found that south orienting panels with a tilt angle of 30° in Shizuoka, Japan provide the optimal results.

Legislation

It is definitely a must for governments to implement laws and regulations in order to encourage entrepreneurs to invest in renewable energies. Therefore, many different governments have taken serious steps to increase private & public renewable energy investments that can be used to generate electricity to meet the demand of grid. However, the availability issues of renewable sources make it harder for governments to create a sustainable energy production policy. Dimakis et al. (2011), states that a policy, which supports the end users to generate their own power, may resolve this issue. Roof-top integrated systems provide promising opportunities on that matter. These systems definitely play a significant role for creating an urban environment, in which energy that is needed in the city can be produced. In order to do that, inhabitants of the cities must be encouraged to install photovoltaic systems, which can reduce their electric bill as well as carbon footprint.

In 2005, the first guidelines were published about Turkey's renewable power production in order to create a win-win solution for economic and environmental benefits. The legislation for electricity generation are determined based on installed power capacities mainly divided into two sections; production with license (>1MW) and production without license (<1MW). It is identified that 13.3 US cents per kWh will be paid for the investor, who can provide electricity for the grid. Moreover, there are different incentives for investors, who use domestic products.

Payback Period

Although reducing Carbon-dioxide emissions is one of factors which have an impact on people who invest in photovoltaic systems, the main factor that drives these investments is definitely financial benefits. It is vital for photovoltaic industry to create and develop technologies which is affordable and has a low payback period when properly installed. So, the capital costs as well as the electricity rate and the available solar radiation plays an important role for the financial assessment. Moreover, technical considerations are highly important while dealing with payback periods. Total installed power capacity effects the potential power generation for a photovoltaic system. Therefore, it is important to have some sort of balance between the costs and the installed power capacity.

Many different researches have been carried out to determine the time of the return of investment. It actually depends on many different factors such as government incentives, the year the systems are installed and geographic locations as well as technical issues. For instance, the results of the study of Wilson and Young (1996), in which two building integrated photovoltaic systems in UK have been evaluated, show that the payback period are 7.4 and 12.1 for the simulated scenarios. Another research conducted in Italy indicates that payback periods for residential photovoltaic systems are generally between 4.4 and 6.8 years (Yapa et al., 2014).

Technical Challenges

It is obvious that there are lots of technical aspects that must be considered during installation of a photovoltaic system, which are handled by engineers of the solar companies. Neither the investors nor the governments bother with these technical aspects. However, it is important for decision makers in a government to determine any technical issues that can become a problem with the current grid and distribution infrastructure in the country.

The renewable energy generation concept proposed in this paper is based on generating power by end-users with photovoltaic units. This means that end-users are allowed to sell the excess electricity through the grid. This new exporting electricity approach may pose technical challenges which must be dealt with. Many distribution systems all around the world have been designed in accordance with the concept of power flow in one direction (Orioli & Gangi, 2015). Thus, there is a possibility of overvoltage in the low-voltage distribution network. This brings serious risks that can even affect conductors and transformers by overloading them. Different researches have been conducted in order to overcome the safety problems caused by overvoltage. The major methods are basically active power curtailment, reactive power control and energy storage installation (Mirhassania et al., 2015).

CO2 Emissions

It is important to evaluate the impacts on environment caused by human kind. The emerging threat of today's world is the increasing amount of CO_2 due to various kinds of activities, especially energy production from fossil fuels. Renewable energy technologies play a major role in reducing emitted amount of CO_2 in time. This actually triggered the search for cheap and reliable renewable technologies (Bento & Moutinho, 2016).

The ability of easy to integrate by end-users makes photovoltaic systems to be more attractive to meet sustainability goals. The investors should know the amount of contribution to the environment by investing such technologies. Therefore it is important to measure net CO_2 reductions achieved by replacing fossil fuel based energy production systems (Amponsah, Troldborg & Kington, 2014).

3. Methodology

The objective of this study is to determine costs and payback period as well as power produced and the reduction of CO_2 achieved by using a roof-top integrated photovoltaic system in Istanbul. The procedure employed in this study consists of seven different parts.

Solar Data Acquisition

The solar data used in the simulation model for the case city was obtained by the software RETScreen. It is a green energy software package that is developed for policy and decision makers to perform financial and technical assignments for renewable energy, energy efficiency and cogeneration (combined heat & power) projects. This software is useful to detect the viability of such projects and it provides the ability to compare their results with the conventional ones. Figure 1 shows the section of necessary data including for the selected location.

Country - region		Turkey	
Province / State		n/a	
Climate data location	See map	İstanbul	
Latitude	°N	41,1	
Longitude	°E	29,0	Source
Elevation	m	21	NASA
Heating design temperature	°C	0,5	NASA
Cooling design temperature	°C	26,6	NASA
Earth temperature amplitude	°C	13,7	NASA

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	6,1	73,1%	1,47	100,2	5,9	6,2	371	0
February	5,7	70,4%	2,23	100,1	6,2	6,0	345	0
March	7,6	67,5%	3,49	100,0	5,4	8,0	324	0
April	11,8	65,2%	4,83	99,7	4,6	12,1	187	53
May	16,2	63,2%	6,35	99,7	4,2	17,1	56	192
June	20,6	61,9%	7,27	99,6	4,0	22,0	0	319
July	23,1	62,3%	7,41	99,5	4,6	24,7	0	405
August	23,3	62,6%	6,33	99,6	4,9	25,0	0	412
September	20,5	60,7%	4,86	99,8	4,7	22,2	0	316
October	16,5	64,6%	2,89	100,2	5,6	17,6	46	202
November	11,5	68,7%	1,75	100,2	5,5	12,1	195	45
December	7,6	73,1%	1,25	100,2	5,9	8,0	322	0
Annual	14,3	66,1%	4,19	99,9	5,1	15,1	1.845	1.945
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at				m	10	0		

Figure 1: Solar Radiation data for İstanbul (RETScreen Software, NASA based)

Consumption Analysis

The average household electricity consumption for Turkey in 2014 was 2339 kWh/per household which is indicated in figure 2 (World Energy Council, 2016). In this case study the average consumption was taken as 3164 kWh. The monthly distribution has been carried out in accordance with the fact that the consumption increases in summer season.

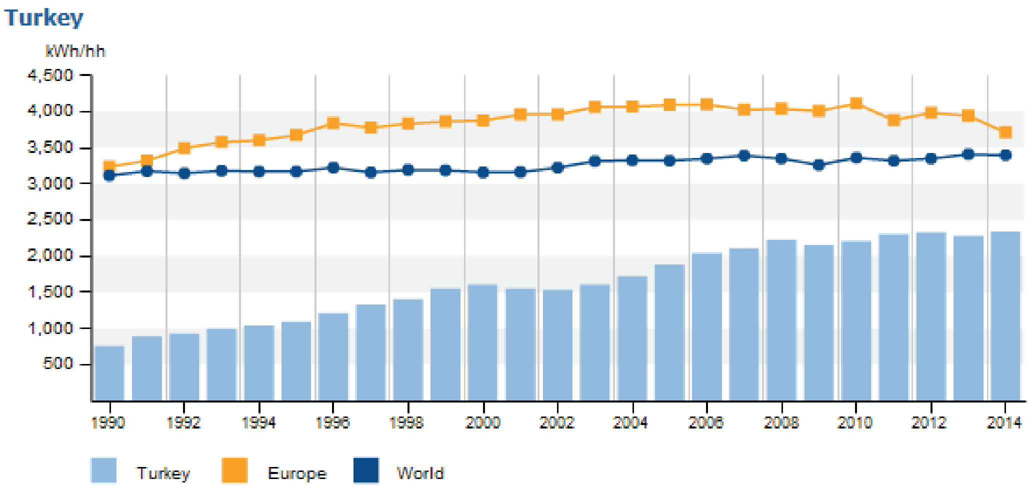

Figure 2: Average power consumption data per household

The method of the research work is mostly based on the application of RETScreen 4 Software. Different worksheets are provided by the Software including energy modelling, cost & emission analysis and financial summary. Most complicated calculations are performed in the energy modelling section, in which the energy delivered by the photovoltaic system is calculated. The software benefits from unique specific algorithms for reducing the input requirements while providing a sufficient level of accuracy.

Electricity Price Forecasting

The electricity price data of Turkey between the years 2000 and 2014 which has been provided by Turkish Electric Distribution Cooperation has been used in this study (TEDAS, 2016). The price data provided does not include some financial assets and costs such as funds or local distribution company costs. It is also important to underline that one time tariff price has been considered.

A non-seasonal ARIMA (0,2,2) model was applied in order to calculate possible yearly price increases. The ARIMA (0,2,2) model below had Akaike information criterion (AIC) as 57.95, AIC with a correction (AICc) as 60.35 and Bayesian information criterion (BIC) as 59.87. R Studio was used for this calculation. Figure 3 indicates electricity price forecasting with the method of Arima.

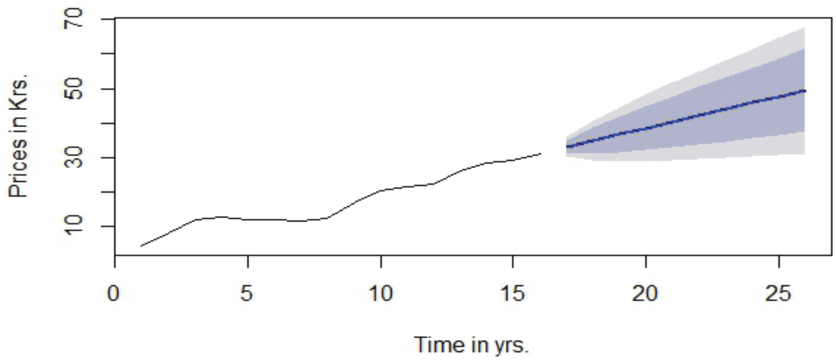

Figure 3: ARIMA (0,2,2) Graph

Renewable Energy Policies and Regulations

The legal documents including incentives and licenses have been analyzed in detail. Major legal regulations are:

- Electricity Market Law No: 6446
- Energy Efficiency Law No: 5627
- Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy Law No: 5346

In order to get license exemption the installed capacity of the photovoltaic system has to be under 1MW. The incentives include Feed-in tariff for a ten year period (0.133 USD/kWh) and additional support of up to 0.67 USD/kWh in case of application with domestic equipment.

Table 1: Margin of Domestic Equipment Applications

PV Panel Integration and Production of Constructional Mechanics	0,8 cents
PV Modules	1,3 cents
PV Cells	3,5 cents
Invertor	0,6 cents
Material for Focusing Sunlight on PV Module	0,5 cents

Design of the System

Popular photovoltaic panel types are the ones which are based on Monocrystalline solar cells (mono-Si) or Polycrystalline silicon, also called polysilicon or poly-Si cells. It is a fact that there is a general statement that monocrystalline solar panels have the highest efficiency rates. However, since they are made out of the highest-grade silicon, there are advantages and disadvantages of each type of the panels. Therefore, panels and their manufacturer should be considered on a case-by-case basis.

In this case study monocrystalline solar cell (mono-Si) based system has been chosen. For a 10 kW on-grid systems, 250 W panel, inverter and related system elements (cables, sockets, panel board, and power distribution unit) and construction elements requirements have been calculated.

Cost Calculation

The factors which have been taken into account for calculating costs have been indicated as below:

- Photovoltaic System Infrastructure
- Transportation
- Labour Costs for installation
- Costs for Project Approval (The project file needs to be prepared and to be submitted to Turkish Electricity Distribution Cooperation and the local electricity distribution company)

Although, request for quotations had been sent to ten local companies, only two of them replied. The infrastructure prices and quotations were determined as from data provided from these two companies.

4. Results and Discussions

RETScreen software has been used by considering two major aspects; CO_2 emission and financial analyses. The results were calculated based on the data input parameters to load and network, energy model and cost analysis sections of the RETScreen software. In order to achieve a sustainable solution, proposed system must be not just environmental but also economically viable. Thus, the significant results that must be compared should be the payback period and the amount of CO_2 reductions achieved by building such a system.

Cost Analysis

The software calculates produced energy with and without tilted solar panels. The annual daily average electricity production with tilted panels was calculated as 4.48 kWh/m2 a day, which resulted in an export amount of 11.743 MWh to the grid after the in-house consumptions were reduced. The input parameters are shown in table 2.

Table 2: Solar orientation parameters

Solar Tracking Mode	Fixed
Slope / Azimuth	30º / 30º

The proposed system consists of various types of components, which are all accessible in Turkey. Based on the communication with different suppliers, following costs indicated in table 3 have been found in the case study. Moreover, the expense items are categorized and indicated in table 2, so that a proper evaluation can be carried out.

Table 3: Cost of the proposed system

Project Submission Costs	1480 €
Workforce	484 €
System Components	
Panels	8850 €
Inverter	2655 €
Cables and Sockets	212 €
Other Solar Equipment	516,84 €
Construction Equipment	2920,16 €
Spare Parts	100 €

As indicated by table 3 most of the capital casts are caused by the purchased system components. Solar panels especially can be considered as the major expense that corresponds to 51% of the total project which supports the claims Long and Geng (2015).

Financial and Emission Analyses

The simple payback period was calculated as 9.2 years whereas the equity payback was 8.7 years. The benefit cost ratio was calculated as 3.30 and the internal rate of return was found as 11.3%. Major financial input parameters have been indicated in table 4.

Table 4: Financial Input Parameters

Fuel Escalation Rate	5 %
Inflation Rate	8,5 %
Project Life	25 years
Total Initial Costs	17.218 €

In terms of emissions, it is possible to reduce 6.9 tCO2 emissions annually with such a system by also considering 12 MWh of electricity that is sent to the grid. According to the data of RETScreen, this amount is equivalent to 1.6 acres of absorbing carbon or 2965 litres of gasoline not consumed. This calculation is based on the emission factor of 0.46 CO2/MWh.

This financial viability of the system is also an important indicator for investor to invest such systems. It has been found out that 231 € have been spent to reduce one ton of CO_2 considering the total project life. Table 5 provided to indicate financial viability of the proposed system.

Table 5: Financial Viability

Net Present Value	39672 €
Annual Life Cycle Savings	1587 €/yr
GHG Reduction Cost	231 €/tCO_2

5. Conclusions and Recommendations

It is a well-known fact that immediate precautions must be taken in order to reduce emitted CO2 to environment that is caused by energy related activities and the concept of producing electricity by consumers may be one of the most important parts of the solution. This concept is providing promising opportunities to meet the basic power requirements of sustainable cities. Therefore, researches must be carried out to assess the viability of such projects in different locations and countries, so that the lack of incentives or technical problems can be determined and reported.

It is indicated that the return of investment is more than 8 years, which is very high for an investor. Despite the fact that some residents who plan to live in their houses long term may think to install such a system, most of the consumers will not be interested. The government should definitely provide more incentives to make such a system more attractive. This can be achieved by providing a generation tariff in addition to export tariff for end-users.

To conclude, it has been found out that installing such a system can provide a clean way to provide electricity for the whole city. Not just the producers but also other end-users benefit from such a systems in terms of CO2 emissions. However, this kind of system is not very attractive financially, which is an important disadvantage of photovoltaic systems. The government should take necessary steps to encourage consumers to invest in such products.

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