The Use of Renewable Energy in Residentials by Means of PV Systems for Approaching Sustainability

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ABSTRACT

Solar as the most abundant available energy possesses the ability to mitigate change of climate. Various solar technologies have been developed so far and have reached different levels of maturity and applications serving a variety of purposes in many parts of the world. Although solar energy constitutes a small quantity of the sum of energy consumed, technologies in solar markets are developing with a fast pace.

Solar technology is desirable regarding being friendly to the environment and ecology, and having positive impacts socially. Due to the intensive competitions in the market of solar-based technologies, technical developments, and support of the public and governments, a gradual reduction in the cost of these technologies has been observed over recent previous decades.

Among all energy users, buildings specifically the residential ones are assumed as major consumers. Therefore, due attention should be paid to this sector to create satisfaction for users and generating efficient use of energy resources. To achieve this goal, PV systems can be utilized both for producing electricity and providing thermal comfort which consequently end up in sustainability. Many countries have initiated taking measures to promote the use of PV systems in buildings and have achieved different levels of success. North Cyprus is among the countries which have faced an energy crisis due to lack of reliable resources of energy. To tackle this problem, utilizing PV technology is suggested as an option. It would serve a broad range of purposes such as rising the level of comfort and living standard of the residents, enhancing the sustainability of buildings, decreasing the use of fossil fuels and consequently reducing pollution.

Inspired by the existing problems and challenges in this particular area in terms of demand and supply of energy, and considering the preliminary steps taken for the introduction and implementation of PV systems, the present study aims at investigating the degree of economic efficiency of photovoltaic systems in terms of their effect on the economy of households in North Cyprus. The research seeks to find out if PV systems are sufficiently sustainable to be introduced as sources of electricity generation and as alternatives to conventional technologies to the public in North Cyprus. Moreover, a comparative approach is employed to find out the differences and similarities between the level of economic efficiency and thermal comfort provided by PV systems in two countries: Italy (which is considered the second PV user in the world) and Northern Cyprus. A questionnaire containing Yes/No and Likert-scale type questions was designed to probe the status of photovoltaic systems in two contexts of Italy and North Cyprus and to explore the views and level of satisfaction of residential PV users, with a special focus on economical issues and the provided thermal comfort.

The data analysis showed that the majority of PV users are satisfied with the application of the system in terms of its economic efficiency and thermal comfort provided. Moreover, PV panels can be introduced and utilized as one of the most efficient technologies on the way towards achieving sustainability.

Keywords: Solar Technology, PV Systems, Thermal Comfort, Sustainability

ÖZ

Güneş enerjisi en çok kullanılan yenilebilir enerji kaynağı olarak iklim değişikliğinin etkilerini azaltmak için elverişlidir. Çeşitli güneş teknolojileri şimdiye kadar geliştirilmiş olup, dünyanın birçok yerinde çeşitli amaçlarla uygulamaları farklı seviyelere ulaşmıştır. Güneş enerjisi enerji tüketilen toplam olarak az miktarda olsada, piyasalarda güneş teknolojileri hızla gelişiyor.

Güneş teknolojisi çevre ve ekoloji dostu olmakla beraber, sosyal anlamda olumlu etkileri nedeniyle tercih edilir. Güneş-tabanlı teknolojiler, teknik gelişmeler ve kamu ve hükümetlerin destek pazarında yoğun yarışmalar nedeniyle, bu teknolojilerin maliyeti kademeli olarak azaltılması son yayınlanan yıl içinde gözlenmiştir.

Tüm enerji kullanıcılar, binalar arasında özellikle konutlar en fazla enerji tüketicisi olarak kabul edilir. Bu nedenle, kullanıcılar için memnuniyetin sağlanması için, bu sektöre ödenen destekler ve enerji kaynaklarının verimli kullanımı artıracaktır. Bu hedefe ulaşmak için, PV sistemleri elektrik üretimi ve sürdürebilirlik açısından ısıl konforu sağlar. Birçok ülke binalarında PV sistemlerinin kullanımını yaygınlaştırmak için önlemler alarak farklı düzeylerde başarılar elde edilmiştir . Kuzey Kıbrıs'da güvenilir enerji kaynak yetersizliği nedeniyle, enerji krizi ile karşı karşıya olan ülkeler arasında yer almaktadır. Bu sorunu çözmek için, kullanılan PV teknolojisi bir seçenek olarak önerilmektedir. PV teknolojileri, konfor ve yaşam standardının artırılması binaların sürdürülebilirliği için, fosil yakıtların kullanımı azaltılması ve dolayısıyla kirliliğin azaltılması gibi amaçlarla geniş bir yelpazede hizmet verecektir.

Bu çalışmada; talep ve enerji temini açısından mevcut sorunlar ve zorluklardan yola çıkarak, PV sistemlerinin tanıtımı ve uygulanması için alınan önlemler, fotovoltaik sistemlerin ekonomik verimlilik derecesi incelenmesi sağlanacaktır.

Anahtar Kelimeler: Solar Teknolojisi, PV Sistemleri, Termal Konfor, Sürdürülebilirlik

To my dear family

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS And ABBREVIATIONS

PV	Photovoltaic
€/kWp	Euro per Kilowatt-Peak
BOS	Base Operating System
BOS	Balance of System
CdTe	Cadmium Telluride
COP	Coefficience of Performance
CPV	Concentrating PV
c-Si	Crystalline silicon
DOE	Department of Energy
EC	The European Parliament and the European Union Council
EJ/yr	Exajoule (10^{18} Joules) per Year
EREC	Efficiency and Renewable Energy Clearinghouse
EU	European Union
FIT	Feed in Tariff
GC	Green Certificate
Ge	General Electric
GHG	Greenhouse Gas
GW	Gigawatt
IBC	Interdigitated Back Contact
ICT	Information and Communication Technology
IEA	International Energy Agency
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers

IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
KIB-TEK	Cyprus Turkish Electricity
LCA	Life Cycle Assessment
LCOE	Levelized cost of electricity
LCOH	Levelized Cost of Heat
MJ	MegaJoule
MW	MegaWatt
Mwh	Megawatt Hour
Nm	NanoMeter
O&M	Operation and Maintenance
OECD	Organization for Economic Co-operation and Development
OPV	Organic PV
Ppm	Parts Per Million
SEI	Solar Energy International
Mm	Micro-Meters

Chapter 1

INRODUCTION

Energy is the indispensible ingredient of modern societies. However, consumption of energy brings about concerns in terms of global warming, emission of CO_2, limitation of existing sources of energy, etc. On the other hand, constant growth of the world's population leads into more consumption of energy which intensifies the concerns.

Therefore, as a remedy to tackle the above mentioned challenges solar which is considered to be the most abundantly available resource of energy is introduced. Our planet, Earth, intercepts solar energy with a rate that is roughly 10.000 times larger than the rate of the energy consumed by people. Almost all countries, though not equally, can benefit from advantages of solar energy.

To capture the potentials of this source of energy, technologies are competitively growing in the market. Solar technologies are able to provide electricity, cooling, heating, and fuel for a large variety of applications. For whatever purpose these technologies are employed, they provide positive social effects and reduce environmental damage.

Nowadays, the majority of countries supply their required electricity through traditional sources of energy, i.e. fossil fuels, which suffer from a couple disadvantages such as high inconstant prices, insufficient security, environmental effects, etc. As these sources of nonrenewable energies are depleting, the cost of generation and delivery of electricity rises. Hence, in order to decrease the degree of pollution and reliance on fossil fuels, resources of renewable energies should be deployed particularly for the sake of generating electricity.

Solar energy technologies offer two means of generating electricity namely photovoltaic cells (PV) and concentrating solar power (CSP) plants. The first device is used for the direct conversion of solar energy into electricity; and the second, provides the heat engine and generator with high temperature heat to be converted to electricity.

Recently, generation of electricity using PV panels has become more prevalent worldwide. For example, statistics shows that between the years 2003 and 2009 the production of PV has increased by 50%. By the end of the year 2009, the capacity of production of PV power was 22 GW which reached the value of 35 GW by the end of 2010, i.e. within a year.

One of the common usages of photovoltaic systems is in buildings, especially in the residential sectors which are considered as major consumers of energy. PV panels, in this case, can serve two primary purposes; that is, generating electricity and providing thermal comfort for the residents.

The economic aspect of utilizing PV systems is of great importance to the potential users due to the fact that the initial cost of installing such a system is high. Therefore, the users (i.e. the owners/ builders of houses) need to make sure that they will receive the payback either economically or in terms of the provided thermal comfort.

In sum, considering recognized advantages of PV mentioned above, it can be implied that utilizing PV systems in the structure of buildings is a significant approach towards sustainability as regards economy and environment.

1.1 Statement of the Problem

Implementation of photovoltaic systems which are based on renewable technologies in buildings and, generally, in residential sectors are in its exploratory stage. A few number of countries throughout the world have equipped their buildings with technologies using renewable energies. Since a great amount of energy is consumed by residential sectors and consequently their contribution to the production and emission of CO_2 is high, utilization of photovoltaic systems in buildings seems to be a vital measure.

Recently, consciousness of the world has been raised towards environmental issues and global climate change. Moreover, living sustainably necessitates addressing environmental, social, and economic needs of people. Therefore, currently more attention is being paid to solar as a renewable energy which seems to be able to meet energy demands of the present century.

Regarding the increase in electricity demands, and taking environmental concerns into account a source of energy should be deployed which guarantees access to the supply of electricity and enables economic growth. Therefore, as Hamilton (2001, p.3) propose low-cost electricity can be provided, and the potential privileges of upgrading grid infrastructures can be maximized through investment in renewable energies. One of the technologies which has significant potentials contributing to meeting the energy demands and addressing economic and environmental concerns is PV.

North Cyprus is among the countries which have faced energy crisis due to lack of reliable resources of energy. To tackle this problem utilizing PV technology is suggested as an option. It would serve a broad range of purposes such as rising the level of comfort and living standard of the residents, enhancing the sustainability of buildings, decreasing use of fossil fuels and consequently reducing pollution.

1.2 Aim of the Research

The present study aims at investigating the degree of economic efficiency of photovoltaic systems in terms of their effect on the economy of households in North Cyprus. The research seeks to find out if PV systems are sufficiently sustainable to be introduced as sources of electricity generation and as alternatives to conventional technologies to the public in North Cyprus. It also intends to propose practical ways of promoting use of PV systems, encouraging the government and people to invest in implementation of photovoltaic.

1.3 Research Questions

To be able to achieve the aims of the study as mentioned above, the survey attempts to explore the following questions:

1. Are photovoltaic systems implemented in residential buildings economically efficient?

2. Do photovoltaic systems contribute to approaching sustainability?

1.4 Scope of the Study

The present survey includes two case studies conducted in North Cyprus and Italy. The focus of the study is on the economic efficiency and sustainability of photovoltaic systems, meanwhile addressing issues such as environmental and health concerns, level of comfort and satisfaction of the users.

1.5 Limitations of the Study

Since use of PV is not prevalent in North Cyprus, finding buildings which are equipped with this system is difficult and poses limitations in terms of the number of potential users who could participate in the survey.

1.6 Significance of the Study

The study is expected to be a contribution to the field of architecture regarding factors to be taken into consideration in the process of designing a building. It will raise awareness of the government authorities, communities, research sectors, and other stake holders towards the significance of utilizing PV systems regarding their effects on the environment, economy, and people's living standards.

1.7 Methodology

To conduct the present study, a qualitative approach was adopted. A questionnaire containing Yes/No and Likert-scale type questions was designed to probe the status of photovoltaic systems in two contexts of Italy and North Cyprus and to explore the views and levels of satisfaction of residential PV users, especially regarding economical issues and the provided thermal comfort. The collected data, then, is analyzed descriptively and elaborated on in ‘Data Analysis’ section. To back up the collected data through questionnaire implementation, photographs of selected integrated PV systems are taken in both contexts, and a deep literature search and review is conducted to allow a more in-depth analysis of the data.

1.8 Literature Review

1.8.1 The Potential of Solar Irradiation as Energy Source

Resource of solar energy is almost unlimited. It is obtainable and can be utilized worldwide. However, an essential step in designing applicable systems of energy conversion is to estimate the amount of radiation to which collectors are exposed.

Burger (2012) is one of the scholars who have described the features of solar irradiance. Sun emits electromagnetic radiation which is called ‘solar irradiance’. Beyond atmosphere of the earth, the solar irradiance emitted to a surface which is perpendicularly exposed to the sun’s rays is almost constant over a year (considering the mean distance between the Earth and the Sun).

The value of this radiance is now estimated to be 1,367 W/m² (Tyagi V, Kaushik S &Tygai S, 2012, p.1384). These rays are in fact electromagnetic waves which can be defined as fluctuations in electric and magnetic fields. The range of wavelengths spread by solar irradiance varies from 0.25 to 3 μm. Solar irradiance consists of visible light (40%), ultraviolet rays (10%), and infrared radiation (50%).

Since solar irradiance interacts with the atmosphere containing clouds, water vapor, aerosols, etc. which change in terms of temper and geography, its evaluation is more difficult. Atmospheric circumstances naturally decrease the solar irradiance by approximately 35% on clear and dry days and by roughly 90% on cloudy days which lowers the average of solar irradiance. Based on the area of the surface, the average of the radiance is estimated to be 198 W/m^2.

As it is demonstrated in figure 1 the solar irradiance which reaches the surface of the Earth is constituted of two principal components, that is, “beam solar irradiance on a horizontal surface, which comes directly from the sun’s disk, and diffuse irradiance, which comes from the whole of the sky except the Sun’s disk” (Brinkworth & Sandberg, 2006, p.80)

Numerous ways are suggested for assessing the global potential of solar energy as a resource. The irradiance amount on the surface of the Earth, both land and ocean, that serve the theoretical purposes of energy is called the theoretical potential, and is approximated at 3.9×106 EJ/yr (Sorensen, 2004, p. 30).

Another related widely used term is technical potential which refers to the solar irradiance output amount which can be obtained by practices and technologies (Brinkworth & Sandberg, 2006, p. 89).

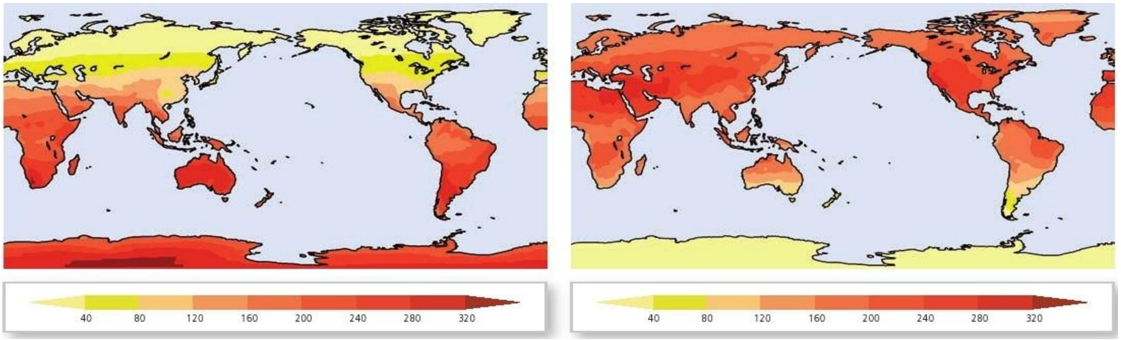


Figure 1: The Global Solar Irradiance

Note: The global solar irradiance (W/m2) at the Earth’s surface obtained from satellite imaging radiometers and averaged over the period 1983 to 2006. Left panel: December, January, February. Right panel: June, July, August (ISCCP Data Products, 2006, p.3021-3031).

1.8.2 The Global Technical Potential of Solar Radiation

The quantity of solar energy that could be collected and employed for human consumption strikingly relies on different local elements such as availability of land, meteorological conditions and quests for energy services. Certainly, the technical potential changes across different parts and areas of the Earth; thus, the methods of assessment essentially vary in different regions. For PV, it's presumed that almost 98% of the total technical potential originates from PV plants which are centralized and the proper land space on the Earth for PV utilization reaches 1.67% of the entire land area on average (Figure 1) and it is predicted that the technical potentials in 2050 will be 1,689 EJ/yr for photovoltaics. Sorensen (2004, p. 30) analyzed a number of PV studies and showed that various technical potentials which range from 338 to 14,778 EJ/yr are reported. The main difference discovered among the studies is the result of the availability of land areas allotted and differences in the efficiencies of power conversions utilized. Therefore, it is difficult to assess the technical potential of solar energy which is used for heating.

The development of newly advanced energy-efficient glazing is the major driving force for this growth (Sorensen, 2004; p. 30).

Some fundamental principles for enhancing deployment of passive solar heating in residential spaces are listed as follows (Brinkworth & Sandberg, 2006, p.89):

1. Buildings should be well protected in terms of insulation to reduce heat losses.
2. They should posses an efficiently responsive heating system.
3. Buildings need to be facing the Equator, that is, the glazing is supposed to be focused on the equatorial dimension.
4. They should not be shaded by other buildings in order to make profit of the sunshine in midwinter (Passive solar energy gain).

The processes of designing passive solar measures have undertaken a fast change period; most of them are driven by the modern technologies which are becoming affordable. For instance, double-glazed windows which are argon-filled and low in emissivity are currently the main glazing systems used in Canada. However, not long ago, the price of this type of glazing was roughly 20 to 40 percent higher compared to regular types of double glazing. Designing larger window areas has been made possible due to modern glazing technologies and systems of solar control (Brooks, 2012, p. 45).

In most climates, it might be necessary to cool the space during the summer unless effective passive solar energy gain control is used. Recently, the contributing impact of passive solar cooling in decreasing discharge of CO_2 has been revealed. Experimental works show that sufficient insulation can lower the need of energy to cool a building over hot season by up to 50%. Besides, adding phase-change materials to the building envelope which has already been insulated can decrease the demand of cooling energy up to 15 percent (Brooks, 2012, p. 45).

Applications of passive solar systems can be divided into two major categories:

A. multi-storey residential buildings;
B. Two-storey residential buildings which can be either detached or semi-detached (Athienitis, Bambara, O'Neill & Faille, 2011, p.139).

The design of fenestration systems in buildings used as workplaces is largely on the basis of daylighting and the emphasis is typically on decreasing loads of cooling (Yoo & Lee, 1998, p.151-161).

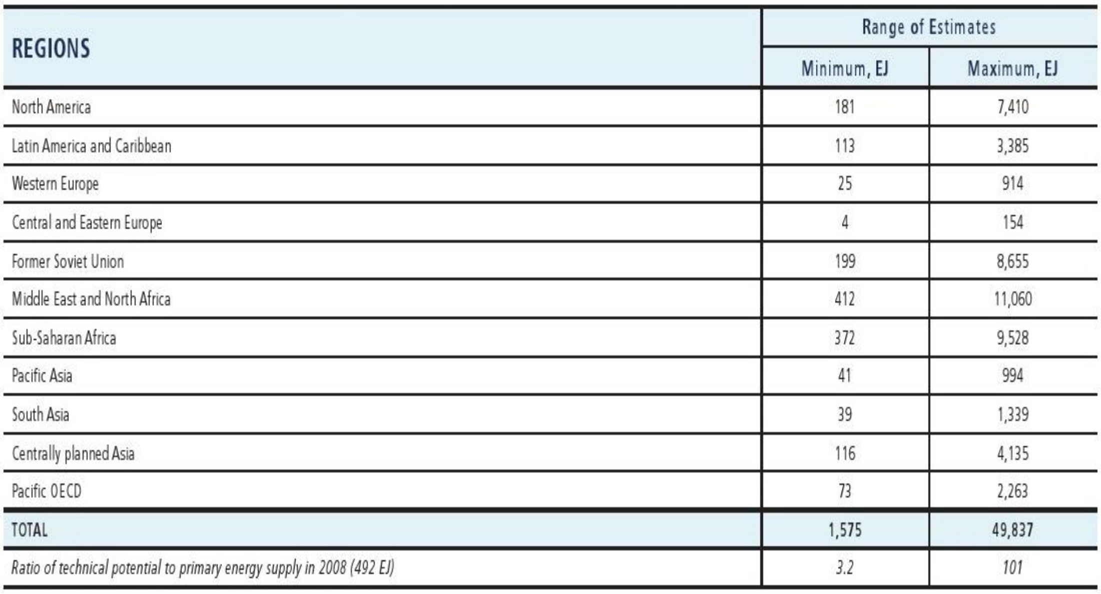
Furthermore, the designers of residential or commercial buildings may keep the idea of using natural or hybrid ventilation systems in their minds and try to use methods and approaches for cooling or supplying fresh air in combination with designs for employing daylight during the year and solar gains throughout the heating season. Such buildings benefit from temperatures of low degrees at summer nights by using techniques which employ hybrid ventilation (both natural and mechanical) (Stone, 1993, p. 23). In 2010, the role which passive solar measures and energy efficiency have played in the design and construction of solar housing characterized as net-zero-energy is noticeable. These homes can produce the required amount of electrical and thermal energy they spend over a year (Burger, 2012, p.12).

One of the essential factors in developing affordable net-zero-energy homes is passive solar energy gain. Based on the ‘Passive House Standard’, passive solar gains in residential sectors are presumed to lower the heating load up to roughly 40 percent. It is interesting to know that in European countries, according to the Energy Performance of Buildings Directive recast, all newly built buildings must be almost zero-energy by December, 31, 2020, while it is also mentioned that states which are members of European Union (EU) should set intermediate targets and objectives for 2015.

1.8.3 The Regional Technical Potential of Solar Radiation

Table 2.1 illustrates minimum and maximum range which is estimated for total technical potential of solar energy in different regions, but it does not differentiate the means by which solar irradiance is transformed to power. For the amounts estimated as minimum, it is assumed that the irradiance of clear sky in one year, sky clearance, and the land available for installing solar collectors are the least possible. On the contrary, for the estimates considered as the maximum amounts, the yearly irradiance of clear sky, sky clearance, as well as, the employed available lands is presumed to be the most. As Table 1 specifies, the global technical potential of solar radiation attributed to solar energy is significantly greater in comparison with the primary energy which is being currently consumed (Cheyney, 2011, p.97).

Table 1: Annual Total Technical Potential Of Solar Energy For Various Regions Of The World, Not Differentiated By Conversion Technology



REGIONS	Range of Estimates	
	Minimum, EJ	Maximum, EJ
North America	181	7,410
Latin America and Caribbean	113	3,385
Western Europe	25	914
Central and Eastern Europe	4	154
Former Soviet Union	199	8,655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	372	9,528
Pacific Asia	41	994
South Asia	39	1,339
Centrally planned Asia	116	4,135
Pacific OECD	73	2,263
TOTAL	1,575	49,837
Ratio of technical potential to primary energy supply in 2008 (492 EJ)	*3.2*	*101*

(Razykova, Ferekides, Morelb, Stefanakos, H.S. Ullal & Upadhyaya, 2011, p.1582; Table 5.19)

Note: Basic assumptions used in assessing minimum and maximum technical potentials of solar energy are given in (Cheyney, 2011, p, 43).

- Annual minimum clear-sky irradiance relates to horizontal collector plane, and annual maximum clear-sky irradiance relates to two-axis-tracking collector plane;
- Maximum and minimum annual sky clearance assumed for the relevant latitudes.

1.8.4 The Impact of Climatic Change on Solar Radiation Potential

Atmospheric content of water vapor, cloud coverage, precipitation, and turbidity are influenced by changes in climate as a result of an enhancement in the amount of greenhouse gases. Consequently, these changes can influence the resource of solar energy across different parts of the world. Alterations in main climate variables such as cloud coverage and solar irradiance at the surface of the Earth are assessed by utilizing climate patterns and models and by taking anthropogenic forcing for the 21st century into account (Sunpower, 2012, p.33). Findings of these studies revealed that variation patterns of mean global solar irradiance per month do not go beyond 1% across some areas of the earth, and vary depending on their model. Presently, the fact that regional solar energy resources are substantially affected by global warming is not indicated in any other evidence (Sunpower Cooperation, 2010, p.67).

1.8.5 Information Data about Resources of Solar Radiance

To calculate and optimize the output of energy and economic practicality and feasibility of solar systems, detailed data of solar irradiance assessed at the site of the installed solar system is required. Hence, overall global solar energy which is available and the proportion of its principal composing elements known as “direct-beam irradiation” and “diffused irradiation” should be realized. Moreover, occasionally, it is crucial for the irradiance generated by ground reflection to be considered. The other factors to be regarded are seasonal availability patterns, irradiation variability, and temperature during a day on site. To achieve validity in terms of statistics these types of measurements need to be made through several years (Aberle, 2009, p.417).

In regions where ground measurements of solar irradiance are dense and well-maintained, accurate and sophisticated information about the domestic solar irradiance can be provided by gridding these measurements. Since the ground-based sites in many regions of the world are not adequate, irradiance measurements which are satellite-based are implemented as information sources. It should be noted that the satellite-based measurements are not as accurate as ground-based ones. Therefore, the products dealing with satellite radiation need to be validated by ground-based measurements which are believed to be more accurate. Currently, the solar irradiance of the surface of the Earth is assessed with an accuracy of 15 W/m2 on a regional scale (Caltech Media Relations, 2010).

There are many national and international institutions and organizations such as “the World Radiation Data Centre (Russia), the Bureau of Meteorology Research Centre (Australia), the National Aeronautics and Space Administration (NASA, USA), the National Renewable Energy Laboratory (USA), the German Aerospace Center (Germany), the Brasilian Spatial Institute (Brazil), and the Centro de Investigaciones Energéticas, Medioambientalesy Tecnológicas (Spain), National Meteorological Services” that render information about solar resources (Byabato & Muller, 2006, p.1).

Table 2 introduces a number of projects which collect, process, and archive information about resources of solar radiance on the surface of Earth. They provide the collected data and information in formats and metrics which are both accessible and comprehensible (Eiffert, 2003, p. 8).

Table 2: International And National Projects That Collect, Process And Archive Information On Solar Irradiance Resources At The Earth's Surface

Available Data Sets	Responsible Institution/Agency
Ground-based solar irradiance from 1,280 sites for 1964 to 2009 provided by national meteorological services around the world.	World Radiation Data Centre, Saint Petersburg, Russian Federation (wrdc.mgo.rssi.ru)
National Solar Radiation Database that includes 1,454 ground locations for 1991 to 2005. The satellite-modelled solar data for 1998 to 2005 provided on 10-km grid. The hourly values of solar data can be used to determine solar resources for collectors.	National Renewable Energy Laboratory, USA (www.nrel.gov)
European Solar Radiation Database that includes measured solar radiation complemented with other meteorological data necessary for solar engineering. Satellite images from METEOSAT help in improving accuracy in spatial interpolation. Test Reference Years were also included.	Supported by Commission of the European Communities, National Weather Services and scientific institutions of the European countries
The Solar Radiation Atlas of Africa contains information on surface radiation over Europe, Asia Minor and Africa. Data covering 1985 to 1986 were derived from measurements by METEOSAT 2.	Supported by the Commission of the European Communities
The solar data set for Africa based on images from METEOSAT processed with the Heliosat-2 method covers the period 1985 to 2004 and is supplemented with ground-based solar irradiance.	Ecole des Mines de Paris, France
Typical Meteorological Year (Test Reference Year) data sets of hourly values of solar radiation and meteorological parameters derived from individual weather observations in long-term (up to 30 years) data sets to establish a typical year of hourly data. Used by designers of heating and cooling systems and large-scale solar thermal power plants.	National Renewable Energy Laboratory, USA. National Climatic Data Center, National Oceanic and Atmospheric Administration, USA. (www.ncdc.noaa.gov)
The solar radiation data for solar energy applications. IEA/SHC Task36 provides a wide range of users with information on solar radiation resources at Earth's surface in easily accessible formats with understandable quality metrics. The task focuses on development, validation and access to solar resource information derived from surface- and satellite-based platforms.	International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC). (swera.unep.net)
Solar and Wind Energy Resource Assessment (SWERA) project aimed at developing information tools to simulate RE development. SWERA provides easy access to high-quality RE resource information and data for users. Covered major areas of 13 developing countries in Latin America, the Caribbean, Africa and Asia. SWERA produced a range of solar data sets and maps at better spatial scales of resolution than previously available using satellite- and ground-based observations.	Global Environment Facility-sponsored project. United Nations Environment Programme (swera.unep.net)

1.8.6 The Impact Of Photovoltaic Panels On Sustainability

1.8.6.1 Definition of Sustainability

Sustainability has been defined differently covering different perspectives since its coinage by Brundtland Commission in 1987. Sustainability is viewed as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Goossens, 2012, p.39).

A crucial element to achieve sustainability is transition from linear movement to cyclical both in terms of technologies and involved processes. Moreover, systems, materials and techniques that do not use up available resources or damage natural cycles should be employed (Goossens, 2012, p.64).

To develop sustainably, economic flourishing, ecological quality, social fairness and equity should be taken into consideration. Companies which set the goal of achieving sustainability are required to address the three social, environmental and economic principles simultaneously.

1.8.6.1.1 Sustainability in Architecture

According to the definition of sustainability presented above, sustainable architecture is an endeavor to meet the present environmental, economic, and social requirements and demands meanwhile preserving or even improving the resources both in terms of amount and quality for the next generations.

The motto of sustainable architecture is to take less from the Earth and offer more to the people. To this end various terms and concepts have been developed such as ‘sustainable design’, ‘green development’, ‘Eco-House’, etc. To achieve these practically, numerous methods and approaches to implement energy efficiency, nontoxic materials, recycled materials, solar power, etc. have been employed.

Constructing buildings, which are efficient as regards resource of energy and are sound environmentally, is possible through adopting green building efforts and practices. In the process of designing and constructing such buildings, economic and environmental concerns and impacts are strictly considered.

Papadakis (2012) claim that the external social consequences a building generates are not sufficiently addressed in standards currently in practice in architecture. Further, she maintains that the aim of sustainable architecture should be "to construct a well-designed building and site environment that is healthy for the occupants, has minimal undesirable impact upon the environment, is effective in the use of natural resources, and is economical and durable" (Papadakis, 2012, p.3592).

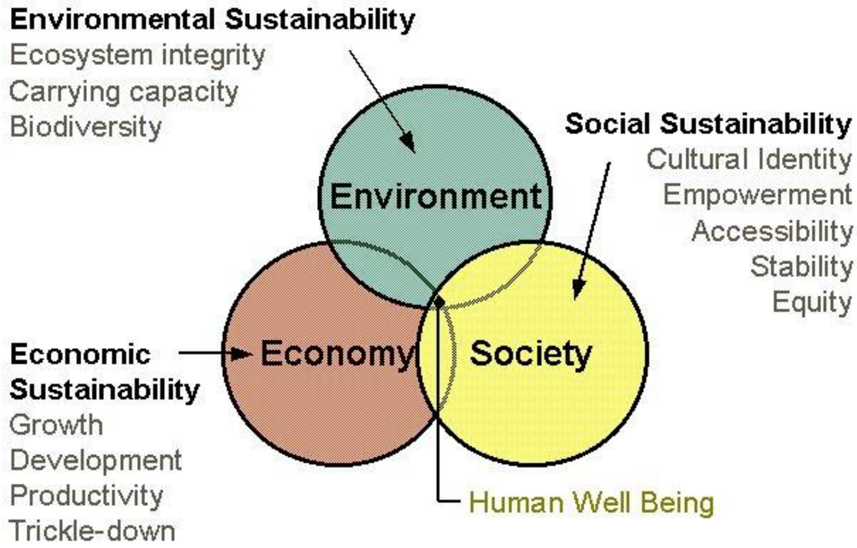


Figure 2: The Three Elements or Pillars of Sustainability (Omer, 2002, P.1257**)**

1.8.6.1.2 Sustainable Buildings

In response to changes in the environment and our shift in the direction of a sustainable future, building design and architecture play a substantial role. Integration of materials, techniques, and approaches that contribute to promoting the quality of environment, vitality of economy, and profits of the society is the primary principle to be considered in achieving sustainability in buildings (See figure 3).

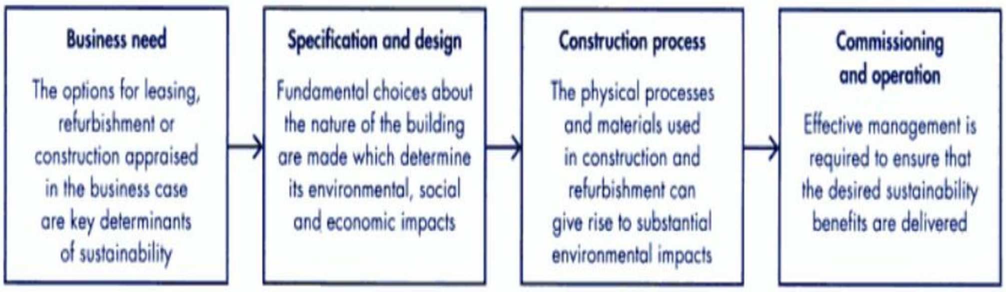


Figure 3: Sustainability And Impact On The Environment (Omer, 2002, p.1257)

For instance, the whole local communities can be affected by the notion of sustainability, or a sustainable building can lessen operating costs through providing efficiency in water and other resources of energy (OECD/IEA, 2010, P.853).

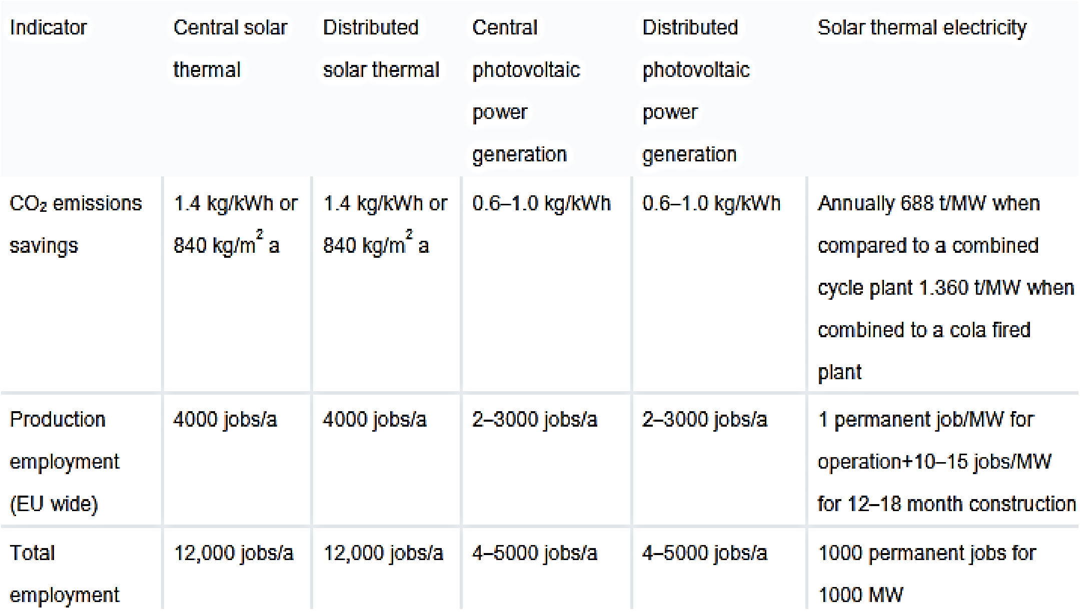
A sustainable building guarantees least damage to the environment by use of resources, energy, water, and land in the most efficient way. For the sake of maximizing the potentials of the sustainable building socially, economically, and environmentally, the process of designing the building should receive significant attention. Designing a building according to sustainability standards and issues can optimize the use of energy through implementation of methods and technologies such as photovoltaic systems which are based on utilization of renewable energy (Stone, 1993, p.23).

1.8.6.2 PV’s Contribution to Sustainable Environment

The inherent feature of the process of generating and transferring energy is affecting the environment for instance land, water, wildlife, air, etc. On the other hand, it has been proven that renewable energies are strikingly benign and harmless, which can be employed as a substitution to harmful fossil fuels (Thomas, Fordham & Partners, 2001, p.151).

Solar as one of the most available resources of energy contributes to the development of sustainability compared with other resources of energy (Table 3). One of the main advantages of solar energy is reducing the emission of CO_2 and other greenhouse and toxic gases, in addition to lowering the required lines for transmitting electricity (Galloway, 2004, p.182).

Table 3: Environmental and Social Indicators of Solar Technologies



Indicator	Central solar thermal	Distributed solar thermal	Central photovoltaic power generation	Distributed photovoltaic power generation	Solar thermal electricity
CO_2 emissions savings	1.4 kg/kWh or 840 kg/m^2 a	1.4 kg/kWh or 840 kg/m^2 a	0.6–1.0 kg/kWh	0.6–1.0 kg/kWh	Annually 688 t/MW when compared to a combined cycle plant 1.360 t/MW when combined to a cola fired plant
Production employment (EU wide)	4000 jobs/a	4000 jobs/a	2–3000 jobs/a	2–3000 jobs/a	1 permanent job/MW for operation+10–15 jobs/MW for 12–18 month construction
Total employment	12,000 jobs/a	12,000 jobs/a	4–5000 jobs/a	4–5000 jobs/a	1000 permanent jobs for 1000 MW

(Eiffert & Kiss, 2000, p.56)

Creating noise is another concerning environmental issue which is addressed in utilizing solar technologies like PVs. Therefore, a building which has employed photovoltaic system can be considered as sustainable, because of contributing to the mitigation of noise up to 25dB (Steele, 1997, p.2).

The International Solar Energy Society in Papadakis (2012) reported the results for damage expenses both per Kg of the polluting material and per kWh. The published results of the studies like Eiffert & Kiss (2000) presented in Table 4 for PV and in

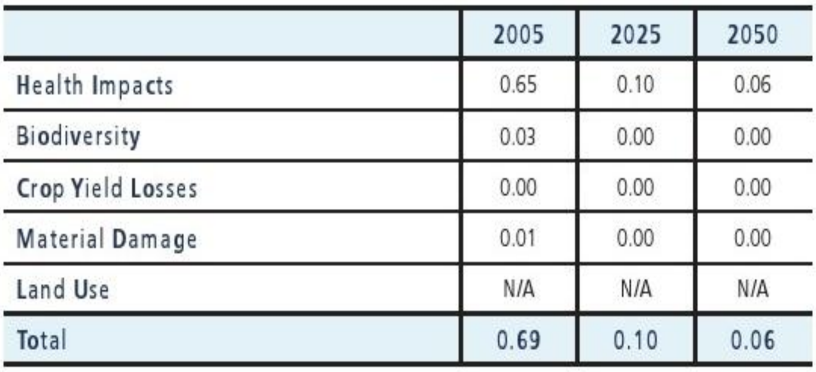
Table 5 for CSP (Concentrating Solar Power) confirm that RE is beneficial (Papadakis, 2012, p.3594).

Table 4: Quantifiable External Costs For Photovoltaic, Tilted-Roof, Single-Crystalline Silicon, Retrofit, Average European Conditions; In US_{2005} Cents/Kwh

	2005	2025	2050
Health Impacts	0.17	0.14	0.10
Biodiversity	0.01	0.01	0.01
Crop Yield Losses	0.00	0.00	0.00
Material Damage	0.00	0.00	0.00
Land Use	N/A	0.01	0.01
Total	**0.18**	**0.17**	**0.12**

(Eiffert & Kiss, 2000, p.58)

Table 5: Quantifiable External Costs For Concentrating Solar Power; In US_{2005} Cents/ Kwh



	2005	2025	2050
Health Impacts	0.65	0.10	0.06
Biodiversity	0.03	0.00	0.00
Crop Yield Losses	0.00	0.00	0.00
Material Damage	0.01	0.00	0.00
Land Use	N/A	N/A	N/A
Total	**0.69**	**0.10**	**0.06**

(Eiffert & Kiss, 2000, p.58)

According to Lund et al (2011), by taking passive solar energy into account, besides decreasing heating loads and related costs many benefits will be provided by higher insulation levels. The low amount of losing heat along with high degrees of insulation, incorporated with large internal thermal mass, forms a much more convenient house since the temperatures are more homogeneous which, in turn, can cause higher levels of efficiency in the device which is generating the heat (Lund, 2011, p.420).

PV systems do not produce noise or employ non-renewable resources throughout operation. Nevertheless, two issues are considered as important matters:

1) The release of pollutants and using energy throughout the full lifecycle of manufacturing, installing, operating and maintenance of PVs and their disposal;

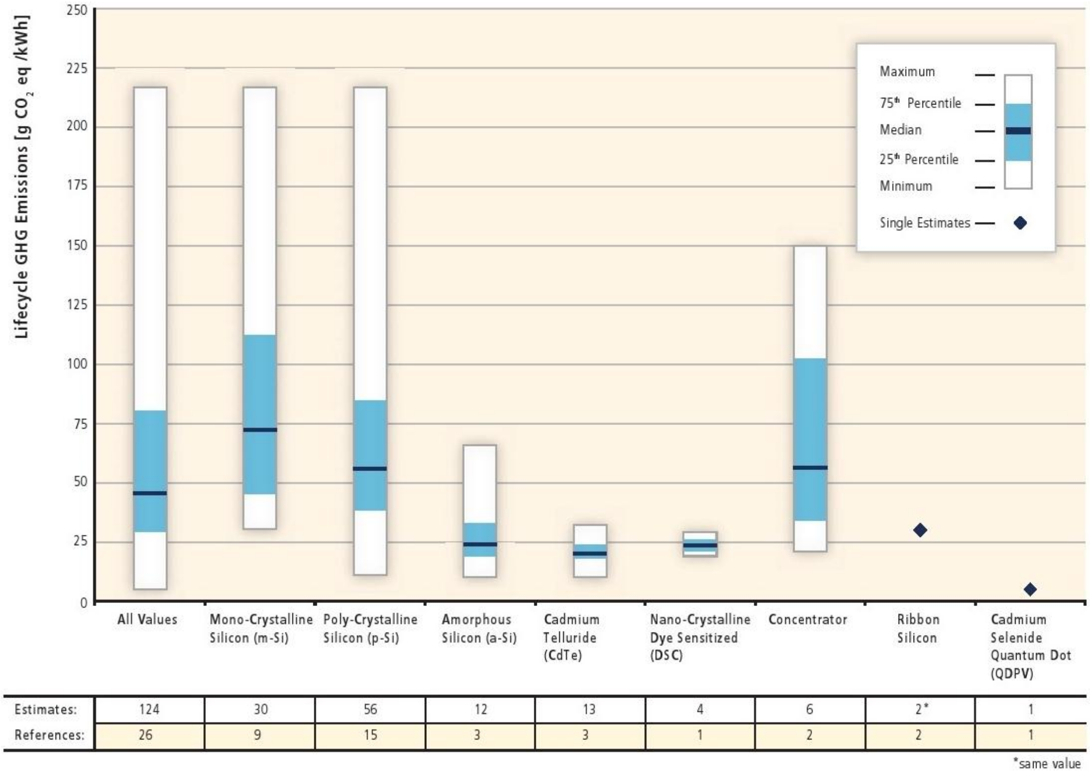
2) Recycling the materials of the photovoltaic module when the system is disintegrated.

The PV industry, in its production line, employs some explosive, toxic gases such as green house gases (GHGs), along with acidic liquids which their amount and inclusion largely depends on the type of the cell; though rough control approaches are employed to reduce the release of dangerous elements during the process of production of the module.

Regarding lifecycle of GHG releases, the result of a literature review of PV-related lifecycle Assessment (LCA) research studies which have been published since 1980 and conducted by the National Renewable Energy Laboratory is illustrated in Figure 4.

The lifecycle GHG emission is estimated to be about 30 and 80 g CO_2 eq/kWh, with potentially significant outliers at higher values (Figure 4).

The variability in estimates is due to the differences which exist in context of the studies (solar resource, technological vintage), methods (LCA system boundaries), and technological performance (efficiency, silicon thickness). It is estimated that the energy payback for PV is between 2.0 and 2.5 years, provided that they are exposed to moderate solar irradiation levels (Eiffert & Kiss, 2000, p.58; Boulanger, 2005, p.7).



	All Values	Mono-Crystalline Silicon (m-Si)	Poly-Crystalline Silicon (p-Si)	Amorphous Silicon (a-Si)	Cadmium Telluride (CdTe)	Nano-Crystalline Dye Sensitized (DSC)	Concentrator	Ribbon Silicon	Cadmium Selenide Quantum Dot (QDPV)
Estimates:	124	30	56	12	13	4	6	2*	1
References:	26	9	15	3	3	1	2	2	1

*same value

Figure 4: Lifecycle GHG Emissions Of PV Technologies(unmodified literature values, after quality screen) (Hamilton, 2001, p. 3)

See Annex II for details of the literature search and citations of literature contributing to the estimates displayed. Generally, release of GHG and other pollutants are decreased without experiencing further environmental risks.

1.8.6.3 PV's Contribution to Sustainable Economy

PV is known as a costing technology because its economic effect and value can be assessed exactly after the design of the system is completed. However, its expenses should be evaluated along with its benefits and cost efficiencies (Eiffert & Kiss, 2000, p.58).

To evaluate the appropriateness of utilizing PV a variety of factors such as life cycle, efficiency, costs of operation and maintenance, etc. should be analyzed.

1.8.6.4 Payback Analysis of Photovoltaic

Payback for PV can be defined as the minimum duration of time in which the investment cost of PV can be recovered, or the time period in which an equal amount of electricity is generated (Eng & Gill, 2008, p.97).

To calculate the time of payback some fundamental information about the price of the system, cost of operation, and the value of the generated electricity are required. The graph illustrates the influence of the PV system and prices of electricity on the payback time of the PV as an operation of the value of the produced electricity (US $ cents per kWh). As it can be seen, the payback is faster when the solar system is cheaper and the rate of electricity is higher (See figure 5).

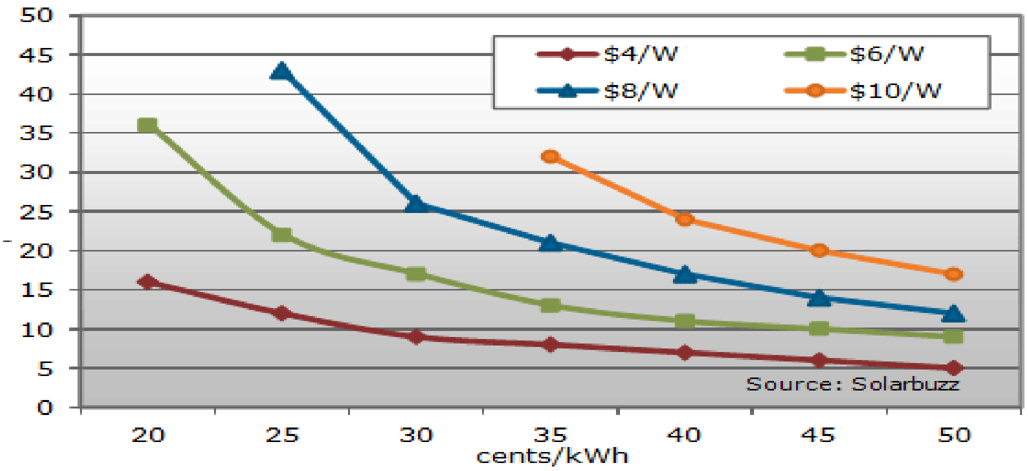


Figure 5: Payback Period of Installed Solar Photovoltaic Systems (Assuming 5 sun-hours and 5% discount rate) (Source: Chakravarty, 2011, p.12)

For instance, if the rate of electricity is US $ 0.20 per kilowatt hour and the installed cost is US $ 4.00 per Watt, the payback time will be approximately more than 15 years. Time of payback can be under the influence of factors such as weather or the price of the system. In regions which are exposed to sun less the time of payback lengthens.

1.8.6.5 PV's Contribution to Social Sustainability

The quality of increasing demands for energy and decreasing GHG (Green House Gases) emissions can be considered as potentials of solar energy, but because of public concerns among some groups, solar technologies have encountered resistance.

Concerns about visual impacts rose due to the required area of land for CSP. Another visual concern which exists is about distribution of solar systems in built-up areas, which in turn might face more resistance for being deployed on cultural or historical buildings in contrast to modern ones (Chow, 2003, p.2035).

According to Clarke (2006), one of the concerns during the construction period is noise; but such effects would be moderated by adapting good work practices and in the site-selection phase (Clarke, 2006, p. 1132).

More utilization of consumer-purchased systems still encounter obstacles regarding the costs, funding structures which might be puzzling, and confusions about reliability of the system and requirements and conditions for maintenance (Mah, 1998, p.4-5).

It is mentioned that influential marketing plans for solar technologies such as broadcasting impacts compared to traditional power production facilities, contributing to a safe energy supply and environmental profits have been helpful in raising social approval and increasing enthusiasm to invest in them (Mah, 1998, p.4-5).

One of the benefits of solar technologies can be the fact that they improve the opportunities of health and livelihood for many poor people around the world (Mah, 1998, p.4-5).

In areas such as delta regions and remote mountainous zones for which connection to a main network is impossible, residential solar systems and PV-powered network can offer favorable economic electricity. According to Balfour (2011) the appliance prevalent in households which are electrified is electric lights, and accessibility of lighting is generally perceived as the major profit of electrification.

Benefits of improving light quality are listed as increased reading by household members, home-based enterprise activities after dark and study by children which may lead to creating income opportunities and increased education for the household (Mai, Llein, Carius, Wolff, Lambertz, Finger & Geng, 2005, p.65).

It is clear that street lights which are powered by solar energy and lights that are used for community buildings can improve the level of security and create gathering places such as community meetings or classes during night. A very important issue is the application of PV systems in disasters in order to provide comfort, care and safety to victims.

Solar home systems can have a great impact on families' life style for example it brings power televisions, radios and cell phones, which in turn results in having more access to information, news, and also distance education.

There is also a potential in solar technologies to stop widespread factors leading to disease and death in poor regions. The technologies of solar desalination and purification of water can be helpful in stopping the high occurrence of diarrheal disease caused by lack of access to drinking water supplies (Roberts and Guariento, 2009, p. 27).

1.8.7 Potential Deployment of Pv Solar Systems

Predictions for the future utilization of direct solar energy might be miscalculated and undervalued; because direct solar energy covers a varied range of technologies and uses, and many of them are not properly discussed in the literature of energy scenarios (Sick & Erge, 2008, p.23-24).

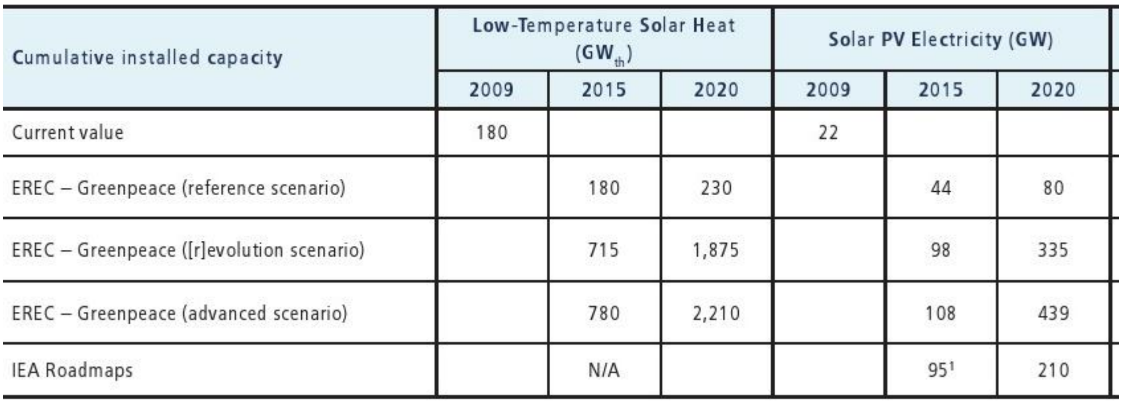
1.8.7.1 Near-term Forecasts

Support of the market for the various solar technologies differs primarily based on the type of the technology and the region it is applied to. It would cause very different inceptions and obstacles for being competitive with present technologies. However, the prospect utilization of solar technologies toughly relies on support of public for developing markets, which can then decrease costs as a result of learning.

This is very crucial to bear in mind that, learning-related cost cuts, at least partially, depend on real production and utilization volumes, passage of time, and research and development activities (Deutsche Gesellschaft für Sonnenenergie, 2008, p.72).

Table 6 shows the results of a number of scenarios for the development in solar utilization capacities in the near future, until 2020. Passive solar gains are excluded from these statistics, because demand would be decreased in this technology and cannot be considered as a component of the supply chain.

Table 6: Evolution Of Cumulative Solar Capacities Based On Different Scenarios Reported In Erec-Greenpeace And Iea Roadmaps



Cumulative installed capacity	Low-Temperature Solar Heat (GW_{th})			Solar PV Electricity (GW)		
	2009	2015	2020	2009	2015	2020
Current value	180			22		
EREC – Greenpeace (reference scenario)		180	230		44	80
EREC – Greenpeace ([r]evolution scenario)		715	1,875		98	335
EREC – Greenpeace (advanced scenario)		780	2,210		108	439
IEA Roadmaps		N/A			95[1]	210

(Source: Deutsche Gesellschaft für Sonnenenergie, 2008, p.72)

Several countries have set long term goals for the progressive utilization of solar technologies. If the following terms and policies are implemented, they will be able to drive the worldwide markets up to the year 2020. Following two cases are touched upon:

- China: It is estimated that 15% of the total demand of energy in China would be provided by non-fossil fuels by 2020. The target solar capacity installed in China is set as 1.800 MW by 2020. However, it is argued that these goals are too low, and there is a likelihood of reaching 20 GW.

- Europe: 20% renewable energy is set as the target for 2020 and it is expected that generated electricity by PV reach 12% by the same year.

1.8.7.2 Long-term Deployment of PV Solar Systems in the Context of Carbon Mitigation

The Fourth Assessment Report of IPCC (Intergovernmental Panel on Climate Change) predicted the available resource of solar energy as 1,600 EJ/yr for PV and 50 EJ/yr for CSP. This estimation was considered as one of the very unreliable predictions by concentrating principally on solar energy. Figure 6.1 (a) shows results for the worldwide provision of solar energy. Figure 6.1 (b) illustrates the generation of solar thermal heat, and figure 6.1 (c) presents solar PV electricity generation, all at the global scale.

Between 44 and about 156 various long-run scenarios underlie these figures according to a variety of modelling terms and covering an extensive range of assumptions about increase in the energy demand, cost and availability of competing low-carbon technologies, and cost and accessibility of renewable energy technologies (including solar energy) (Deutsche Gesellschaft für Sonnenenergie, 2008, p.73).

Figures 6 (a) to 6 (c) show the results of solar energy deployment under these scenarios for 2020, 2030 and 2050 for three different ranges of GHG concentration stabilization, based on the IPCC's Fourth Assessment Report: >600 ppm CO2 (Baselines), 440 to 600 ppm and <440 ppm), all by 2100. Results are reported for the median scenario, the range of 25 to 75 %, and the results of the minimum and maximum scenario (Sick & Erge, 2008, p.86).

It is important to state that the much smaller set of scenarios that reports solar thermal heat production in comparison to the full set 44 of 156 that reports solar primary energy, illustrates substantially higher median deployment levels of solar thermal heat of up to about 12 EJ/yr by 2050 even in the baseline cases. On the contrary, electricity production from solar PV and CSP is predicted to remain at very low levels. The image alters with progressively low GHG concentration stabilization levels which show primarily higher median contributions from solar energy than the baseline scenarios. By 2030 and 2050, the median deployment levels of solar energy reach 1.6 and 12.2 EJ/yr, respectively, in the intermediate stabilization categories III and IV that result in atmospheric CO_2 concentrations of 440-600 ppm by 2100 (Sick & Erge, 2008, p.86).

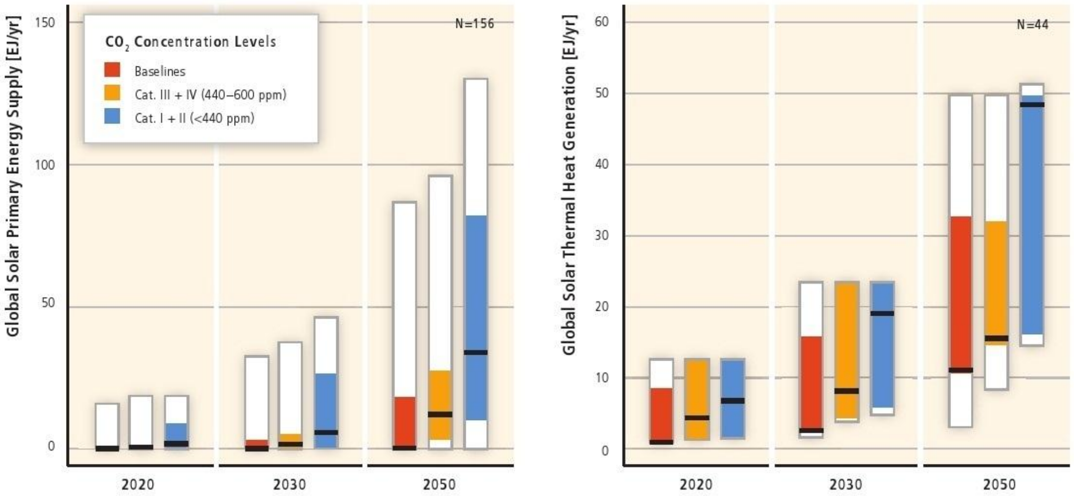
In the most ambitious stabilization plan category, where CO_2 concentrations remain below 440 ppm by 2100, the median contribution of solar energy to primary energy supply reaches 5.9 and 39 EJ/yr by 2030 and 2050, respectively. The results of the plan propose a solid dependence of the utilization of solar energy on the climate stabilization level, with significant growth which is expected to occur in the median cases until 2030 and particularly until 2050 in the climate stabilization scenarios. By breaking down the development through individual technology, it seems that solar PV deployment is mainly dependent on climate policies to reach high levels of utilization (Deutsche Gesellschaft für Sonnenenergie, 2008, p.74).

At the global level the ranges of solar energy utilization are highly enormous, also compared to other renewable energy sources demonste a very extensive range of assumptions about the prospect development of solar technologies in the reviewed scenarios. In the majority of base-line scenarios the solar utilization remains low until 2030, with the 75th percentile reaching 3 EJ/yr and few scenarios show higher levels. By 2050, this narrow range of deployment in the baselines vanishes. The 75th percentile shows approximately a 30-fold growth in comparison with the median baseline, reaching 15 EJ/yr or even higher levels in the uppermost quartile. A mixture of growing prices of fossil fuels with more optimistic assumptions about cost reductions for solar technologies is probable to be in charge for the higher levels of baseline utilization (Roberts & Guariento, 2009, p.27).

In the most ambitious climate stabilization scenarios, the 75th percentiles of the solar primary energy supply by 2030 reach up to 26 EJ/yr, a fivefold increase compared to the median of the same category and the highest estimates even reach up to 50 EJ/yr.

For 2050 the equivalent numbers are 82 EJ/yr (75th percentile) and 130 EJ/yr (maximum level), which can be attributed to a large extent to solar PV electricity generation which reaches deployment levels of more than 80 EJ/yr. The share of solar PV in global electricity generation in the most extreme scenarios reaches up to about 12% by 2030 and up to one-third by 2050, but in most of the scenarios stays in the single digit percentage range (Montoro, Vanbuggenhout & Ciesielska ,2011, p.17-18).

Policies to decrease GHG emissions and/or increase RE supplies seem to be essential in order to attain the higher levels of deployment intended by some of these scenarios, and those policies need to be satisfactory regarding economic predictability and attractiveness in order to motivate considerable private investment (Tiwari & Mishra, 2012, p.132 -133).



(a) Global Solar Primary Energy Supply

(b) Global Solar Thermal Heat Generation

(c) Global Solar PV Electricity Generation

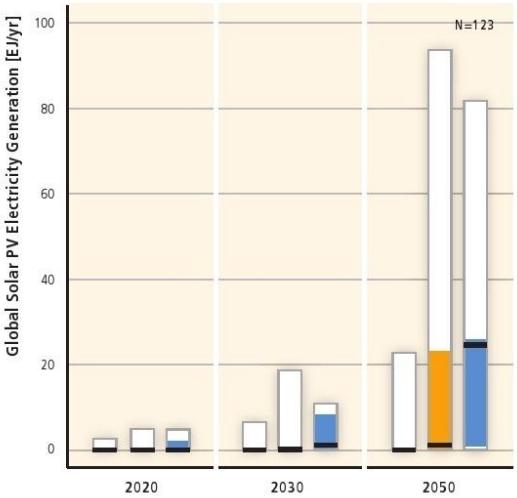


Figure 6: Global Solar Energy Supply and Generation in Long-Term Scenarios
Note: (median, 25th to 75th percentile range, and full range of scenario results; colour coding is based on categories of atmospheric CO2 concentration level in 2100; the specific number of scenarios underlying the figure is indicated in the right upper corner): (a) Global solar primary energy supply; (b) global solar thermal heat generation; (c) global PV electricity generation (Kiss, 1993, p.13).

1.8.8 Photovoltaic Technologies and Applications

In Photovoltaic (PV) solar systems electricity is produced by using the photovoltaic effect.

Light hitting a semiconductor (silicon) produces electron-hole pairs which are detached spatially by an internal electric field created by generating special impurities into the semiconductor on both sides of interface which is called a p-n junction. This generates negative charges on one side and positive charges on the other side of the interface. This process results in creating a voltage. The generated current flows from one side of the cell to the other when connected to a load (Roberts and Guariento, 2009, p.27).

A ratio of output power from the solar cell with unit area (W/cm^2) is in fact the transformation efficiency of a solar cell to the incident solar irradiance. Properties of the absorber material and device design is a key factor in defining the maximum potential efficiency of a solar cell .Multi-junction approach is a technique that increases the efficiency of solar cells that piles certain absorber materials that can take in larger amount of the solar spectrum (Mallick 2004, p.319).

PV cells can be made of organic or inorganic materials. Silicon or non-silicon materials are the basis for inorganic cells which are categorized as two types of wafer-based cells or thin-film cells. Wafer-based silicon is in turn categorized into two types (Kiss & Kinkead, 1993, p.14):

1. Monocrystalline

2. Multicrystalline

1.8.8.1 Photovoltaic Systems

The PV module, along with the “BOS” components form a photovoltaic system which is constituted of storage devices, an inverter, system structure, charge controller and the energy network (Deutsche Gesellschaft für Sonnenenergie, 2008, p.75).

BOS components for grid-connected functions are not desirably developed in order to match the lifetime of PV modules at the component level. Furthermore, costs of installation and BOS component must be decreased.

Additionally, in the modern networks of energy, devices for saving huge amounts of electricity (over 1 MWh or 3,600 MJ) will be adjusted to large PV systems (Deutsche Gesellschaft für Sonnenenergie, 2008, p.75).

To guarantee the quality of system, performance assessment, including on-line and off line analysis of PV systems is essential. A useful strategy that can be employed by PV systems in order to increase their presence in energy network is using a technology matched with the electricity grid and energy demand and supply. Technology should be developed to predict the volume of power generation and to maximize the function of storage (Deutsche Gesellschaft für Sonnenenergie, 2008, p.75).

1.8.8.2 Photovoltaic Panel Types

The primary ingredient of PV cells is silicon. Three types of cells are distinguished in general as thin film, monocrystalline, and polycrystalline. Thin film PVs are recognized as the least expensive type yielding the lowest efficiency among others (Luque & Hegedu, 2011 p.49).

1.8.8.2.1 Monocrystalline Silicon PV Panels

Monocrystalline PV modules are known as the first generation of silicon modules yielding more efficiency in comparison with others. The rate of efficiency of these panels is between 12-18%. Monocrystalline panels are typically produced in large size sheets which can be cut to fit the device. Their composing cells are small and render the smallest panels a certain needed wattage. The only deficiency attributed to these panels is being more expensive than polycrystalline panels. These modules can be applied in regions where exposure to solar irradiation is low or the space is insufficient. The life expectancy of Monocrystalline PV panels is estimated to be between 15 and 20 years (See figure 7).

Figure 7: A Solar Cell Made Of A Monocrystalline Silicon Wafer (Razykova, Ferekides, Morelb, Stefanakos, H.S. Ullal & Upadhyaya ,2011, p.1584)

1.8.8.2.2 Polycrystalline Silicon PV Panels

Instead of one single cell, a series of cells and a casting process is used in Polycrystalline panels. The silicon is heated to reach a high temperature and then is cooled. Through this process an irregular multicrystal is created. The produced block of silicon is cut into slices of 0.3 mm. The cell is typically coated with an anti-reflective layer which makes it appear in blue color. While this layer reflects the minimum amount of irradiation; it is able to absorb the most (See Figure 8 and 9).

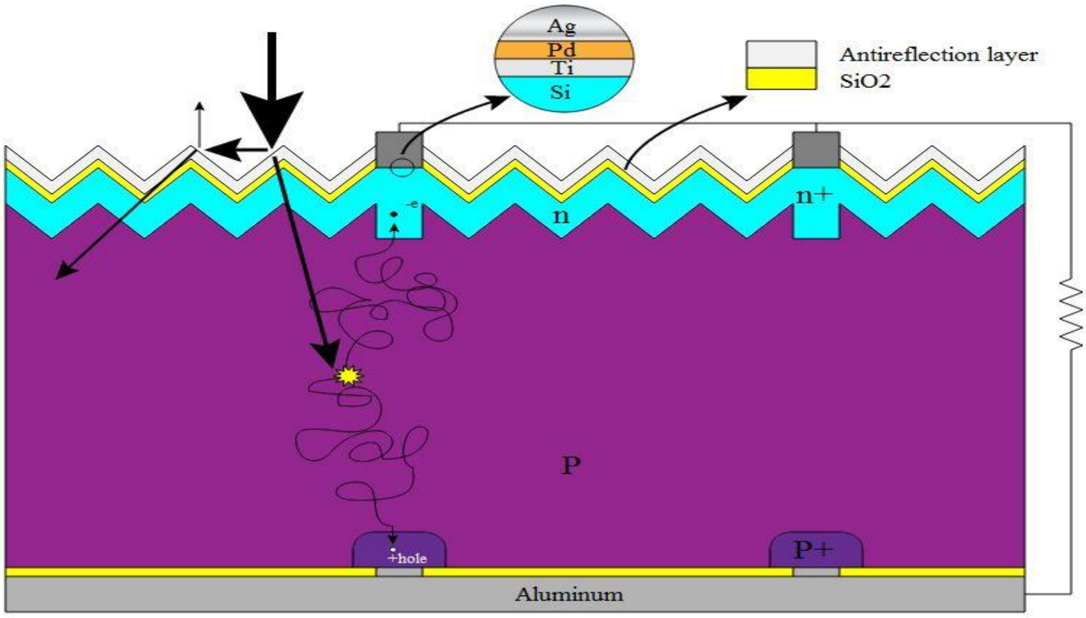


Figure 8: Polycrystalline Silicon PV Panels Detail (Bloem 2012, p.63)

Although the price of polycrystalline photovoltaics is lower than monocrystalline type of panels, the efficiency they yield is between 11% and 16% which is less than monocrystalline’s.

Normally these modules appear in larger sizes compared to monocrystalline panels assuming the produced wattage is equal. Their performance is better in regions with direct solar irradiance but temperatures over 70 ^{0}C decrease the efficiency of the module.

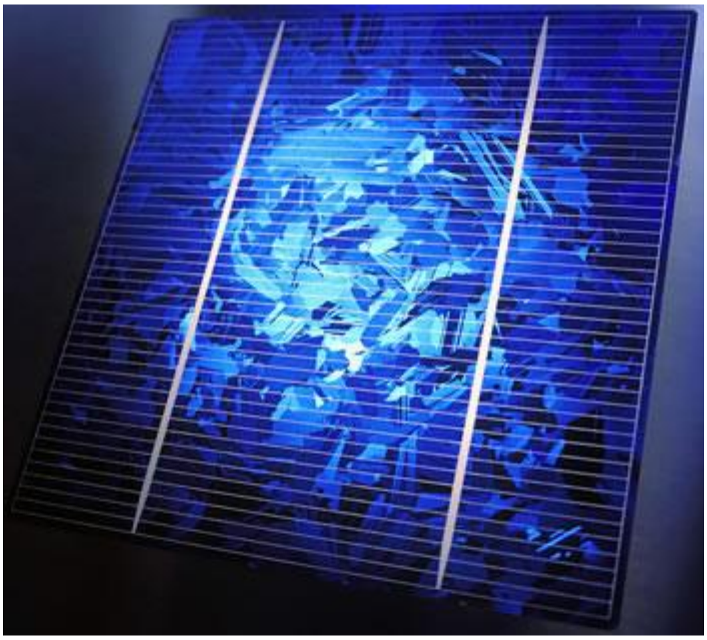


Figure 9: Polycrystalline Silicon Pv Panels (Bloem , 2012 , p.63)

1.8.8.2.3 Amorphous Silicon Thin Film PV Panels

The second generation of photovoltaic modules introduced to the market is amorphous silicon (Thin film). No crystalline is used in its structure and can be incorporated into various materials as a semiconductor film. The advantage of this type of modules over the previously introduced ones is being low cost and versatile.

Since thin film modules are in the shape of thin layers, they can be applied to different materials, be custom-sized and curved. The main drawback of these panels is the low rate of efficiency of 5-7 % (see figure 10).


Figure 10: Thin Film Panel Example (Sick & Erge, 2008, p.18)

Thin film panels are able to work efficiently exposed to either diffused or direct irradiation. Therefore, if they are utilized in shady places their loss of efficiency is insignificant. This implies that they are appropriate options to be utilized in vertical elements of buildings such as walls. Moreover, high temperatures do not have negative impact on them.

Both rigid and flexible thin film panels in various colors are available in the market to be applied for different functions and in different sites (see Figure 11). Since they do not need large amounts of raw materials, and are suitable for automated production can be identified as low cost panels.

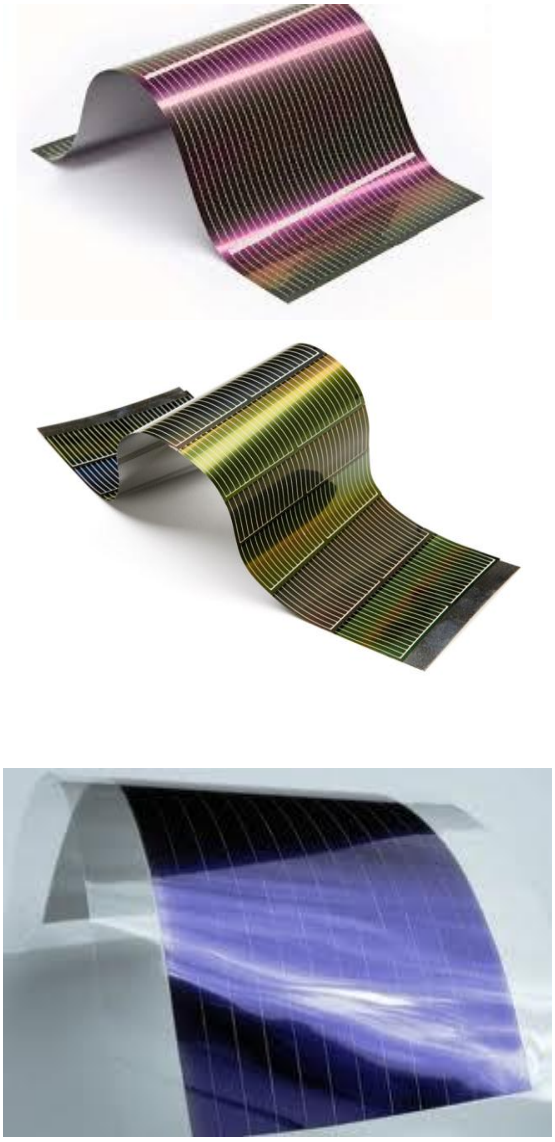


Figure 11: Thin Films In Different Colors (Sick & Erge , 2008 , p.19)

1.8.8.3 Photovoltaic Applications

Photovoltaic applications are categorized into two main classes:

1. PV systems that are not connected to the traditional power grid (off-grid)
2. PV systems that are connected to the power grid (grid-connected)

Moreover, a smaller but stable market is available for applications of consumers. In the unelectrified regions of developing countries, there is a good opportunity for off-grid PV systems from the economic application perspective. The proportion of different off-grid and connected systems in the "PV Power Systems Program" countries is shown in Figure 12.

From the overall capacity which was installed in those countries in the year 2009, according to IEA report in 2010 only about 1.2% of the systems were off-grid that now constitute 4.2% of the total capacity of installed PV in the "IEA PVPS" countries.

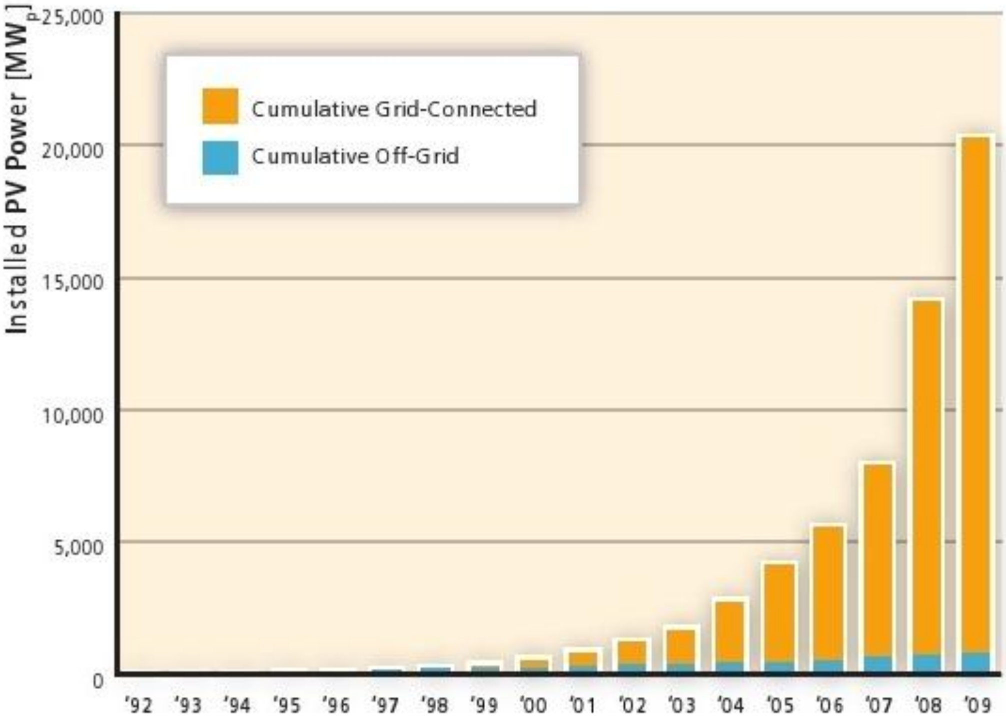


Figure 12: Historical Trends In Cumulative Installed PV Power Of Off-Grid And Grid-Connected Systems In The OECD Countries (Solar Energy International (SEI), 2004, p.4) . Vertical axis is in peak megawatts.

Allocating energy is possible in a PV mini-grid system for villages which are placed in isolated regions where houses are not built far from each other. In these cases the power can flow in the mini-grid with minimum losses. Availability of energy, dynamic behavior and reduction of storage needs are the listed technical advantages regarding electrical performance of centralized systems for local power supply.

Among the systems, ‘Centralized PV’ systems (mini-grid) are considered as the cheapest alternatives for certain types of services. These systems are applicable for avoiding and reducing use of diesel generators in distant regions (Solar Energy International, 2004, p.6).

Off-grid (stand-alone) PV systems operate differently from batteryless grid-connected systems. That means the utility does not supply the electricity. These systems necessitate the participation of their owners. Concerns such as planning for further future development, having a source of energy as back up in cases of high demand of energy or insufficient solar generation. Maintenance, servicing equipments, and etc. are done on the site, and the owner of the system is in charge of all costs and expenses (see figure 13).

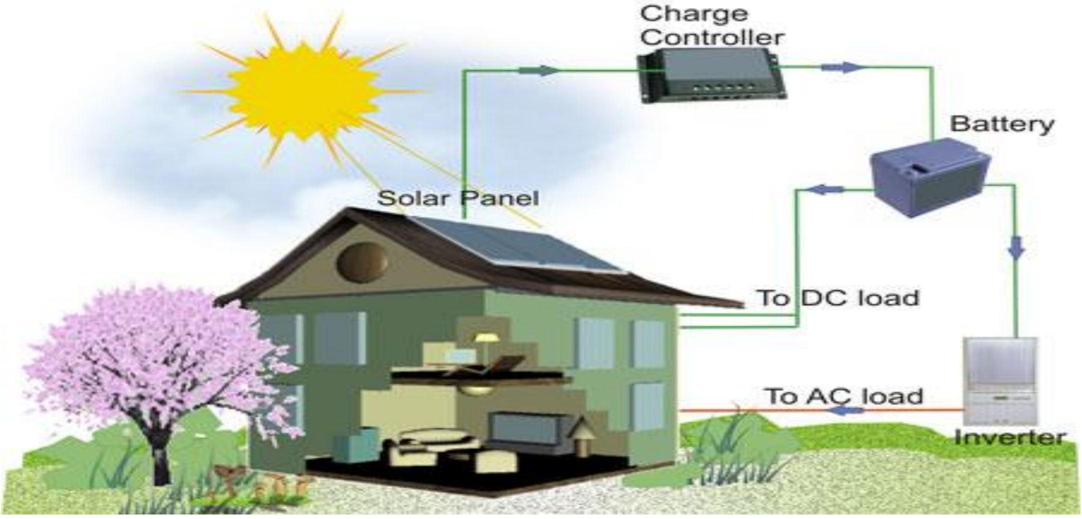


Figure 13: Off-Grid Solar (Solar Energy International, 2004, p.6)

In ‘Grid-connected PV’ systems electricity is transformed from direct current to alternating current by an inverter and after the produced power is supplied to the power (electricity) network. Energy storage is not needed in these systems because the grid is functioning as a buffer and lower system expenses are expected (Boulanger, 2005, p.7).

For different installation situations all around the world the ratio of the average annual performance is between 0.7 and 0.8 and progressively grows higher to around 0.9 for certain applications and technologies.

There are two categories of ‘Grid-connected’ PV systems based on their application: A) Distributed and B) Centralized. The aim of installing grid-connected distributed PV systems is to provide the electricity network or a grid-connected consumer directly with power.

These systems might be:
On or incorporated into the consumer’s building;
On commercial and public buildings;
In the built environment (e.g. Motorway sound barriers) (Shah, 1995, p.501).

Several advantages are listed for these systems:

1. As the systems are installed at the point of use, losses due to distribution in the network are decreased.
2. If the system is incorporated into an already existing structure, no extra area of land is needed for the Photovoltaic, and expenses of installing the systems can be lessened.

3. As in building-integrated PV, the array of the photovoltaic can be used as a roofing or covering material (Sick & Erge, 2008, p.18&19).

The higher level of sensitivity to grid interconnection matters, such as unintended islanding and overvoltage is a common mentioned disadvantage for this system .On the other hand, much advancement have been made to lessen these effects, and now, inverters play the role of the “anti-islanding effect” by standards of Institute of Electrical and Electronics Engineers (IEEE) and Underwriter Laboratories (SERG ,2008, p.59).

Grid-connected centralized PV systems function as a centralized power station. Provided power by this system is not for a particular customer, the other important point is the fact that the system is installed only to provide bulk power (Deutsche Gesellschaft für Sonnenenergie, 2008, p.75).

From the economic perspective the advantages of these systems can be identified as the:

1. Operating cost by bulk buying;
2. Optimization of installation;
3. Balance of systems at a large scale;
4. Cost effectiveness of the photovoltaic components.

Furthermore, because it is possible to have maintenance systems with monitoring equipment, which in turn can be a smaller portion of the overall system cost, the consistency of centralized PV systems is assumed to be more than distributed PV systems (Dufo-López & Bernal-Agustín, 2005, p.33).

As solar energy can be incorporated into the building envelope and using energy preservation methods as well as operating strategies of smart-building, over the last decade many efforts have been focused on this integration, ending up in the technology of ‘net-zero’ energy building (Bala& Siddique, 2009,p.137).

Chapter 2

EVALUATION OF PV PANELS IN NORTH CYPRUS

Cyprus ranks the third among largest Mediterranean Islands. It is located at “358N of the Equator and 338E of Greenwich” (Inoxmare, 2011, p.68). The climate in North Cyprus is typical Mediterranean which is hot and dry in the summer and mild in the winters. The average of temperature is about 28 C in the summer and 11C in the winter. There are no reserves of gas or oil in Northern Cyprus, therefore, the fossil energy primarily in the forms of petrol and gas is imported to the island.

Due to restrictions in the supply of energy generating the required electricity has always been a challenging issue to the responsible authorities and people. To review the process and challenges of electricity generation in North Cyprus, Ibrahim and Ibrahim and Altunc (2012) has produced a timeline table which summarizes the critical points and issues related to electricity in the island.

Table 7: Timeline of Electricity in North Cyprus (Ibrahim and Altunc, 2012)

1903	First small generator -- used to meet only the administrative demand in Nicosia (*Lefkoşa* in Turkish), capital of Cyprus. Followed by a second small generator -- used to meet the medical needs. No power was generated for public use.
1912	After 1912, electricity was served to the public.

Table 8: Timeline of Electricity in North Cyprus (Ibrahim and Altunc, 2012) (continued)

1914	Britain annexed Cyprus (after being ruled by the Ottomans since 1571). Cyprus was before under British Administration from 1878 – 1914 without annexation.
1922	Electricity generation, after being included in the British government's agenda, expanded to other districts of Cyprus. Each district generated their own electricity and the power plants were not connected together.
1952	Centralization of the power plants.
1963	Fights between the Greek and Turkish Cypriots led to a physical separation between the two communities. Turkish Cypriots having no power generating plants turned to independent small power generators. The Electricity Office (*Elektrik Dairesi* in Turkish) was established as a state office serving the Turkish Cypriots.
1974	After the war between the Turkish and Greek Cypriots in 1974, Cyprus was divided into two parts. South Cyprus continued to supply 80-90% of electricity consumed in North Cyprus at no charge due to a mutual agreement. As a result the electricity price in North Cyprus was very low (until 1995). The revenue collected from electricity consumers in the North was mostly used to pay the repair expenses and the salaries of its personnel. Very little went to investments in generating capacity.
1975	Turkish Federated State of Cyprus was declared. Cyprus Turkish Electricity Authority, Kıb-Tek was established. The first power generation plant was built in Dikmen (20 MW gas turbine diesel).
1977	The second 20 MW gas turbine diesel power plant was built at Teknecik.

Table 9: Timeline of Electricity in North Cyprus (Ibrahim and Altunc, 2012) (continued)

1977-1981	Because the power supply from the South continued, the power stations were in operation for only half an hour per week for trial purposes.
1982	After a request from the South, the generators were put into operation for two hours a day.
1985	10 MW gas turbine diesel power plant, which was already in use in Turkey, was disassembled and put to operation at Teknecik.
1988	The gas turbine generators were in operation for 16 hours a day, supplying 15% of the consumption in the North.
1994	Electricity supply from South Cyprus was phased out, marking the beginning of a period of power outages. The three gas turbines were operated with full capacity. The first of the two 60 MW steam turbine fuel-oil power plant was built at Teknecik. After being in operation for only two months, a huge explosion in the boiler caused serious damage to the power plant.
1995	The second 60 MW steam turbine fuel-oil power plant was built at Teknecik. Kıb-Tek generated 90% of electricity consumed in North Cyprus and increased the price from USD 0.02/kWh to USD 0.06/kWh.
1996	The repair of the first 60 MW steam turbine fuel-oil power plant was completed and put back into operation. On March 17, 1996, South Cyprus terminated supplying electricity to the North. The electricity demand of the North was mostly supplied by the two 60 MW steam turbine fuel-oil power plants and the gas turbine diesel power plants were used for the peak load.

Table 10: Timeline of Electricity in North Cyprus (Ibrahim and Altunc, 2012) (continued)

2003	On April 23, 2003, borders opened between North and South Cyprus. In September, 2003, a private company, Aksa Enerji Uretim A.S., started generating electricity from its two 17.5 MW capacity fuel oil fired diesel plants at Kalecik and selling its output to Kıb-Tek at a present price. Aksa’s installed capacity at Kalecik has eventually reached 5×17.5 MW. Despite an average growth rate of about 10% in electricity production, the frequency of outages remains high.
2006	During January 2006, the Teknecik power plant had technical problems and needed major repairs leading to outages of prolonged duration. For couple weeks electricity was supplied by South Cyprus.
2007	For the period of 1997-2008 annual growth in electricity consumption is around 6% due to rapid growth in the construction sector and low electricity tariffs in North Cyprus. 4×17.5 MW diesel plants installed at Teknecik
2011	The older gas turbines are phased out. As of January 22, 2011, the 2x17.5 MW units purchased in 2008 have not been used due to insufficient capacity on the transmission lines. On July 11, 2011, the largest power plant in South Cyprus (793 MW) was destroyed by an explosion in an arms depot. Kıb-Tek signed an agreement to sell electricity to SouthCyprus.
2012	Solar energy plant project in Serhatköy financed by EU to generate at least 1.5 million kWh of electricity annually.

A local utility company named Cyprus Turkish Electricity Authority (KIB-TEK) which is state-run is responsible for the generation, distribution and selling electricity to all sectors. Generation capacity of KIB-TEK is 175 MW in total. The company relies on steam power plants which are oil fired and gas turbines which use diesel fuel.

North Cyprus does not have any rules or regulations to enforce designing environment friendly systems of energy. Sync KIB-TEK has got financial difficulties uses a cheap type of oil which includes high amounts of sulfur for power production. Imposing environmental limitations on the company and forcing them to utilize oil that is low in the content of sulfur will double the company’s financial problems and have consequences for the consumers.

2.1 Solar Energy and Photovoltaic in North Cyprus

Solar energy in North Cyprus abounds even in winters. Ibrahim and Altunc (2012) contend that the renewable energy source which is most available in North Cyprus is solar that can be easily utilized in photovoltaic conversion. The development of this technology has been rapid in the previous three decades.

Developed countries mainly use grid connected type of systems, but in North Cyprus installation of stand- alone systems is common because connection to the grid costs about US$ 1000 for each dwelling. Moreover, if poles need to be erected, the owner will be charged US$ 150 for each pole.

The average generation of energy by a typical PV module is approximately 8 times more than the rated power in summer in North Cyprus, but it reduces to 2.5 times the rated power in the winter.

Both the utility and owner benefit from residential PV systems which are grid connected or backed-up by battery. Utilizing these systems gives the owner the privilege of not having any electricity bills and gaining benefit through selling the surplus energy to the connected utility.

Using the energy of batteries in battery backed-up PV systems reduces the peak and enables the utility to manage the energy demand. This is considered as an advantage particularly at peak hours and in the winter (Ibrahim and Altunc, 2012).

The European Union has recently announced that it intends to initiate a solar energy project and invest €4 million in it. They believe that the use of sources of renewable energy should be promoted and public need to become aware of the existence of alternative sources of energy.

The project is expected to generate at least 1.5 million kWh of electricity annually (Ibrahim & Altunc, 2012).

2.2 PV Status in North Cyprus

Utilization of photovoltaic technology in residential sector is still in its infancy in North Cyprus and only a limited number of buildings can be found using this system for generation of electricity. Similar to many other countries, half of the total energy consumed in North Cyprus is attributed to the residential sector. According to a report delivered by State Planning Organization (DPÖ), approximately 71.45% of the buildings are equipped with the system of solar thermal heating to be used only for heating water. Although this system is totally different from PV, its utilization can be considered as an indicator of public awareness towards necessity of use of renewable energies such as solar.

2.3 PV Market in North Cyprus

PV market is in its initial phases of development in North Cyprus. Among all available PV panels, 'monocrystalline' panels are more common because of being relatively cheap, more durable and able to yield more efficiency. Off-grid systems are more appealing because otherwise, that is, in case of utilization of grid-connected PVs permission of the government is required to incorporate a two-way electricity meter in to the system.

2.4 PV Strategies and Regulations in North Cyprus

With a focus on safety and regulations issued by European Union, selection and installation of PV panels should follow certain standards in terms of the efficiency yielded by the device and the amount of the energy generated. For example the life-cycle of the module should be at least 25 years with a minimum performance of 90% during the first 10 years. The minimum acceptable efficiency of the panel is set to be 15%. Feed-in Tariff programs are also offered as incentives to motivate PV utilization. Moreover, to encourage integration of PV into buildings in the private sector, 25% of the initial costs and expenses is granted to the user.

2.5 Case Studies in Italy and Northern Cyprus

Case Studies in Italy

Figure 14: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 15: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 16: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 17: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 18: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 19: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 20: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 21: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 22: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 23: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 24: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Figure 25: Residentials PV Panels Install in San Giovanni In fiore, Italy.

Case studies in Northern Cyprus

Residentials PV Panels Install in Northern Cyprus, lefkoşa

Figure 26 :Dereli Öğrenci Konutları, lefkoşa

Figure 27:Dereli Öğrenci Konutları, lefkoşa

Figure 28:Dereli Öğrenci Konutları, lefkoşa

Figure 29:Dereli Öğrenci Konutları, lefkoşa

Figure 30: Cengiz Topal 5,28 kWp Off-Grid Sistem Vadili

Figure 31: Cengiz Topal 5,28 kWp Off-Grid Sistem Vadili

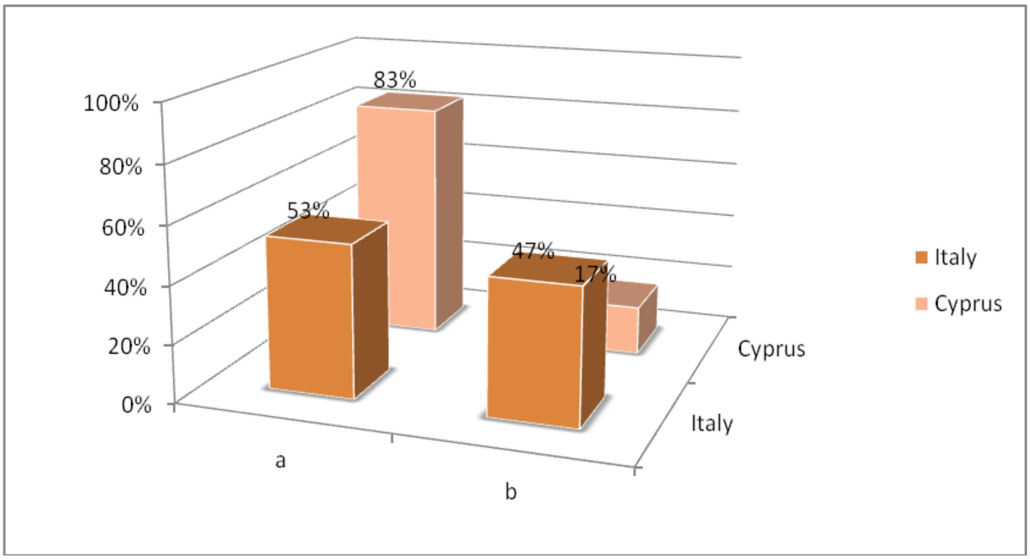
Figure 32: Cemsa Karting

Figure 33: Cemsa Karting

2.5.1 Questionnaire and Analysis

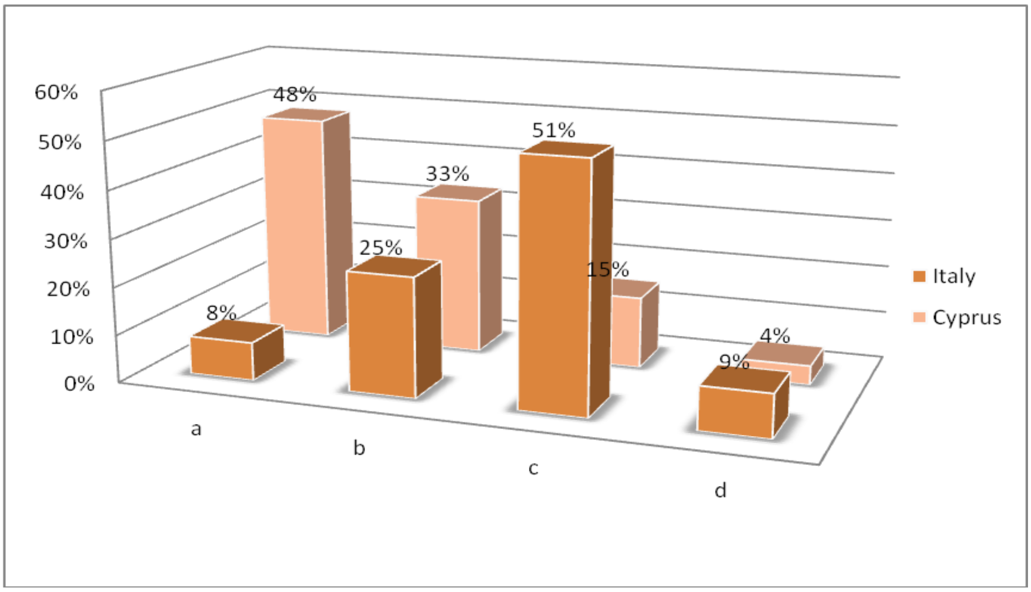
1. Which of the options below describes the situation of the PV system in your building?

☐ a) PV is installed on the building I currently live in based on my own decision
☐ b) PV was installed by the previous owner/ builder when I bought this house



2. How long have you been using your PV system?

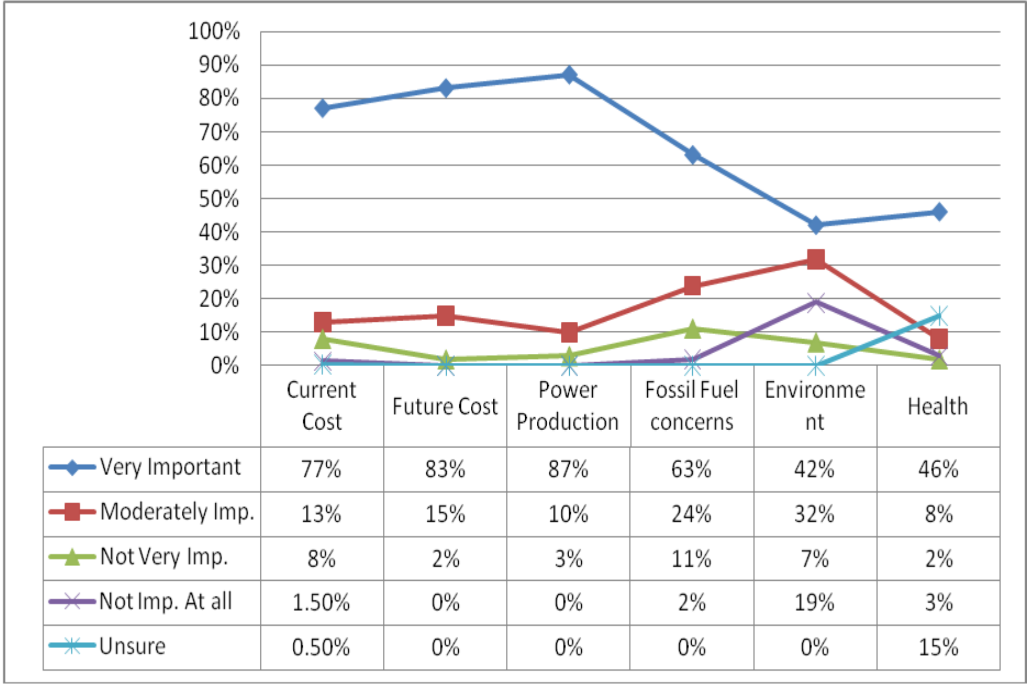
☐ a) Around 1 year
☐ b) 1 year to 4 years
☐ c) 4 years to 5 years
☐ d) More than 5 years



3. How do you evaluate the following factors as contributing to your decision to install a PV system?

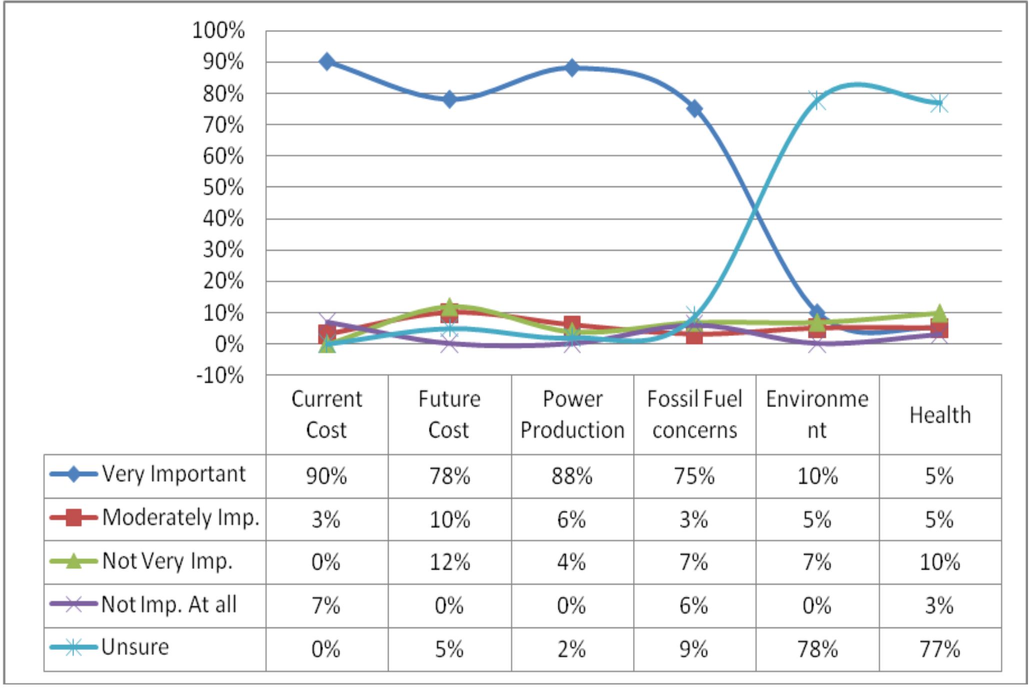
Factors	**Very Important**	**Moderately Important**	**Not Very Important**	**Not Important At All**	**Unsure**
Current electricity cost reduction					
Future electricity cost reduction					
Producing one's own electricity					
Reducing fossil fuels' consumption					
Environmental issues e.g. Global warming					
Health issues					

Italy's Data



	Current Cost	Future Cost	Power Production	Fossil Fuel concerns	Environment	Health
Very Important	77%	83%	87%	63%	42%	46%
Moderately Imp.	13%	15%	10%	24%	32%	8%
Not Very Imp.	8%	2%	3%	11%	7%	2%
Not Imp. At all	1.50%	0%	0%	2%	19%	3%
Unsure	0.50%	0%	0%	0%	0%	15%

Northern Cyprus's Data

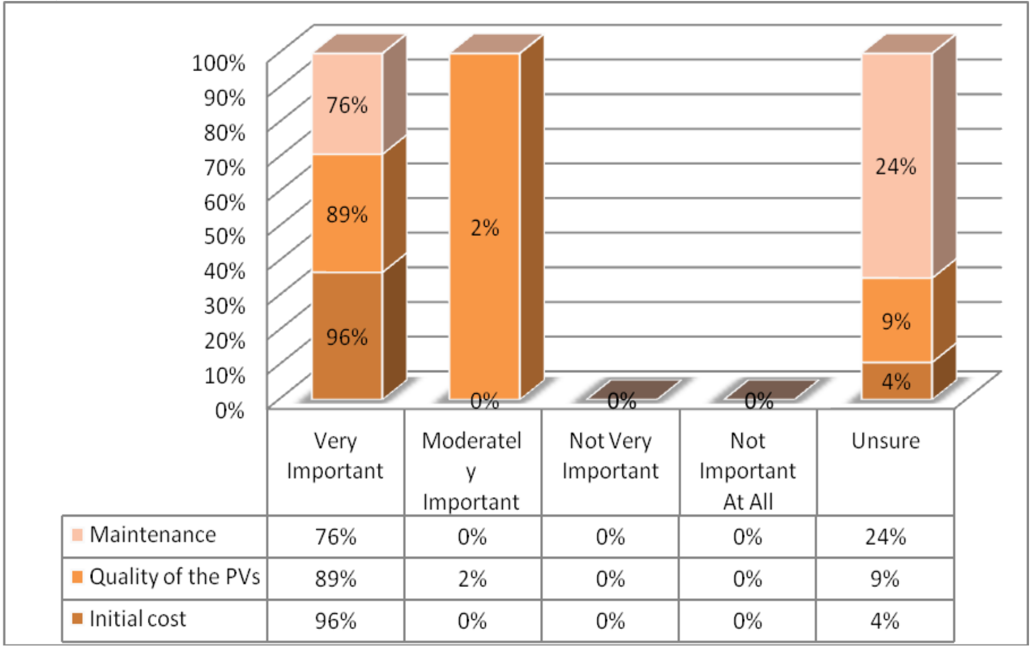


	Current Cost	Future Cost	Power Production	Fossil Fuel concerns	Environment	Health
Very Important	90%	78%	88%	75%	10%	5%
Moderately Imp.	3%	10%	6%	3%	5%	5%
Not Very Imp.	0%	12%	4%	7%	7%	10%
Not Imp. At all	7%	0%	0%	6%	0%	3%
Unsure	0%	5%	2%	9%	78%	77%

4. How important were the following factors before you decide to install the PV system?

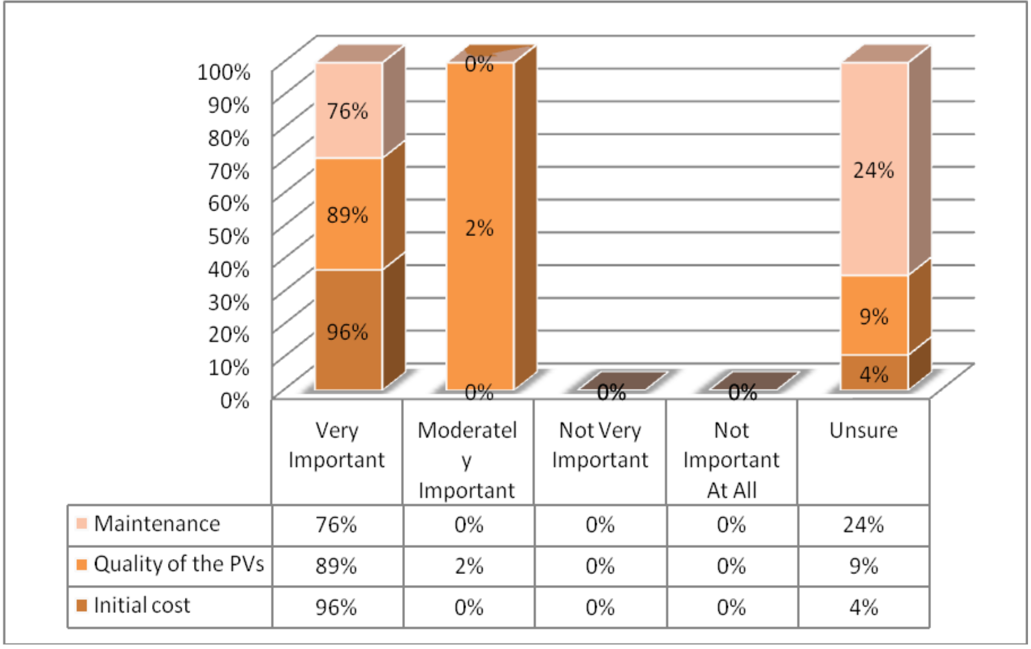
	Very Important	**Moderately Important**	**Not Very Important**	**Not Important At All**	**Unsure**
Initial Cost					
Quality of the PVs					
Maintenance					

Italy's data



	Very Important	Moderately Important	Not Very Important	Not Important At All	Unsure
Maintenance	76%	0%	0%	0%	24%
Quality of the PVs	89%	2%	0%	0%	9%
Initial cost	96%	0%	0%	0%	4%

Northern Cyprus’s Data



	Very Important	Moderately Important	Not Very Important	Not Important At All	Unsure
Maintenance	76%	0%	0%	0%	24%
Quality of the PVs	89%	2%	0%	0%	9%
Initial cost	96%	0%	0%	0%	4%

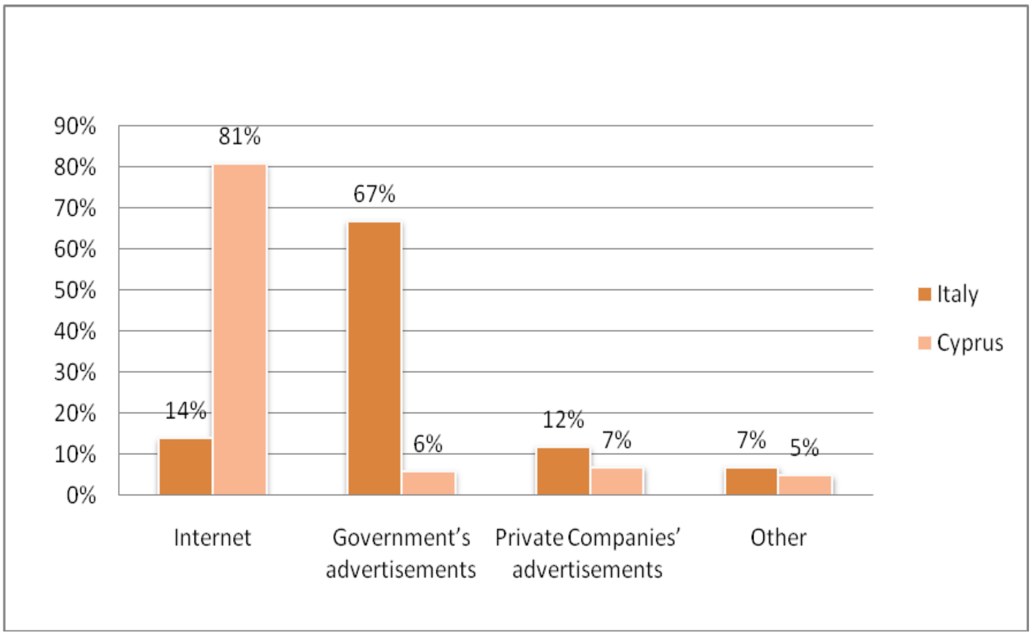
5. How did you find information about PV systems?

☐ Internet

☐ Government’s advertisements

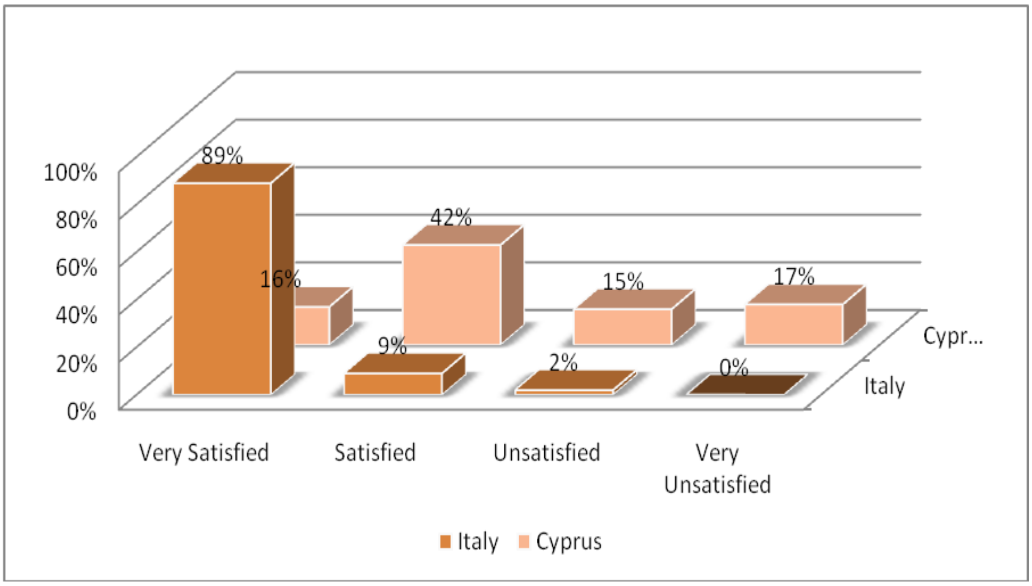
☐ Private Companies’ advertisements

Other: ………………………………………………..



6. The degree of your satisfaction with the performance of your PV system:

☐ Very Satisfied
☐ Satisfied
☐ Unsatisfied
☐ Very Unsatisfied



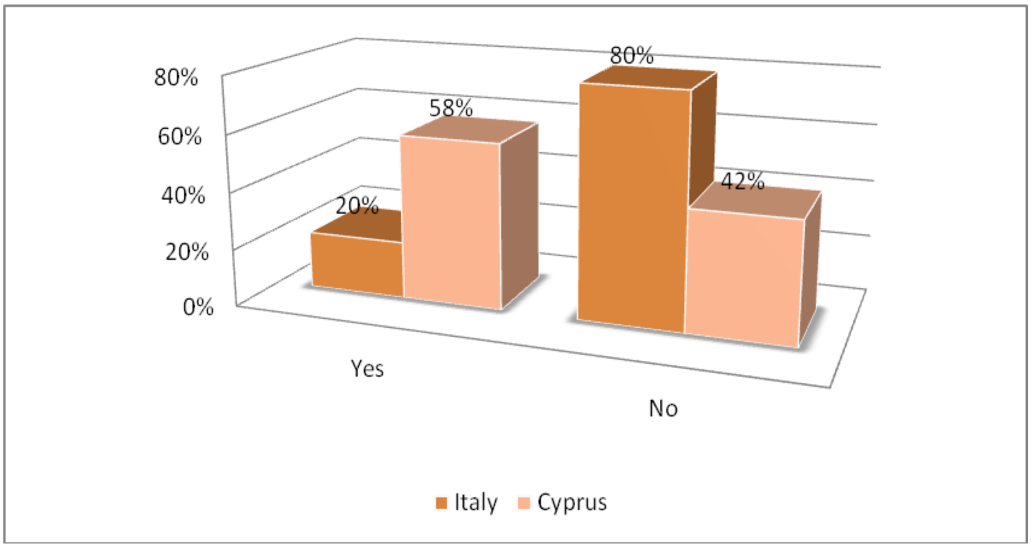
7. Has any extra cost been imposed on you due to unexpected failure or maintenance of the PV system?

☐ Yes
☐ No

8. If yes, please indicate which part of the system has failed to operate.

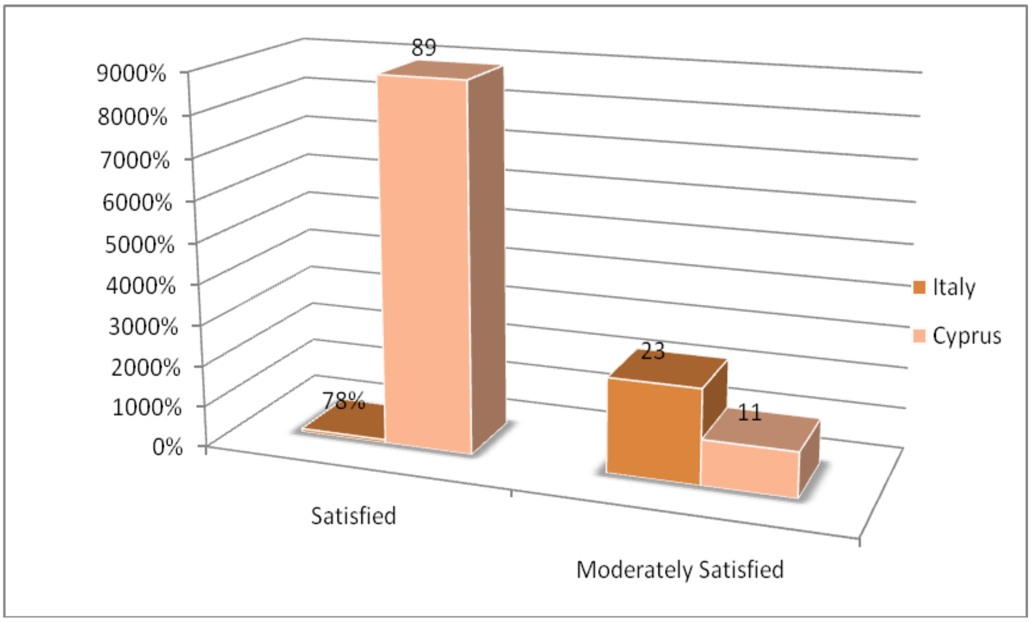
……………………………………………………………………………………………

…………………………………………………………………………………………..



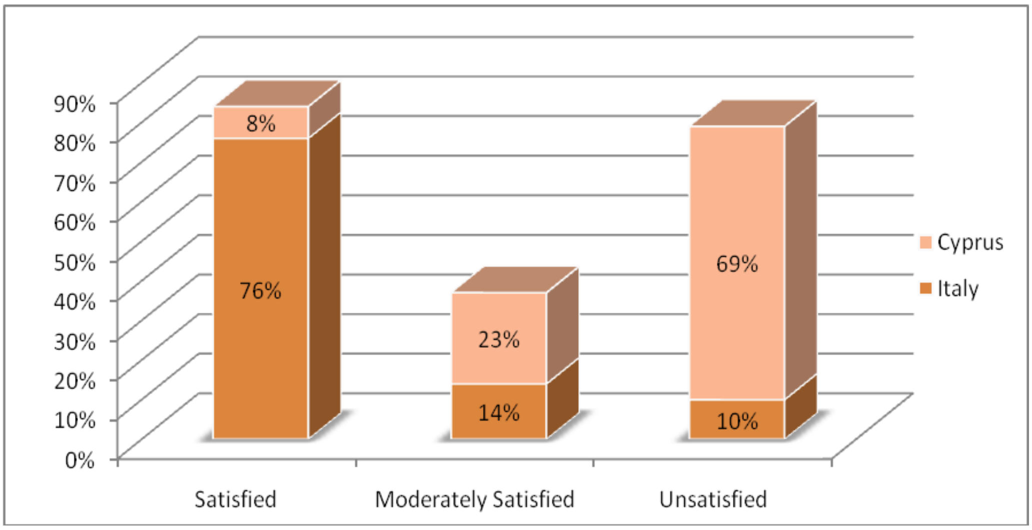
9. Have any batteries being used in the structure of your PV system?

☐ Yes
☐ No



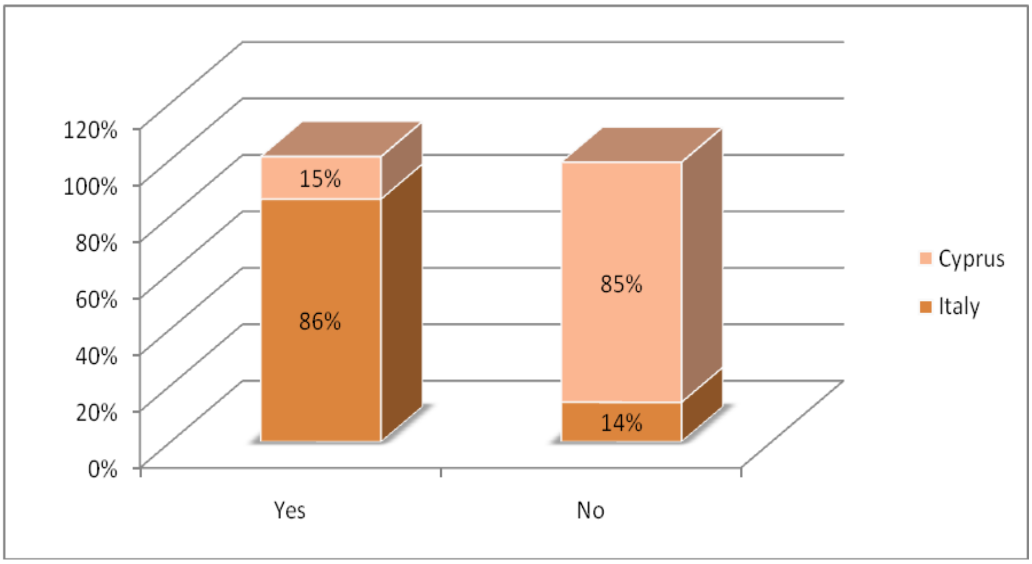
10. In case your response to question 10 is ‘Yes’, how satisfied are you with the quality of the batteries?

☐ Satisfied
☐ Moderately Satisfied
☐ Unsatisfied



11. In case there is a blackout or electric grid failure, can your system produce electricity?

☐ Yes
☐ No



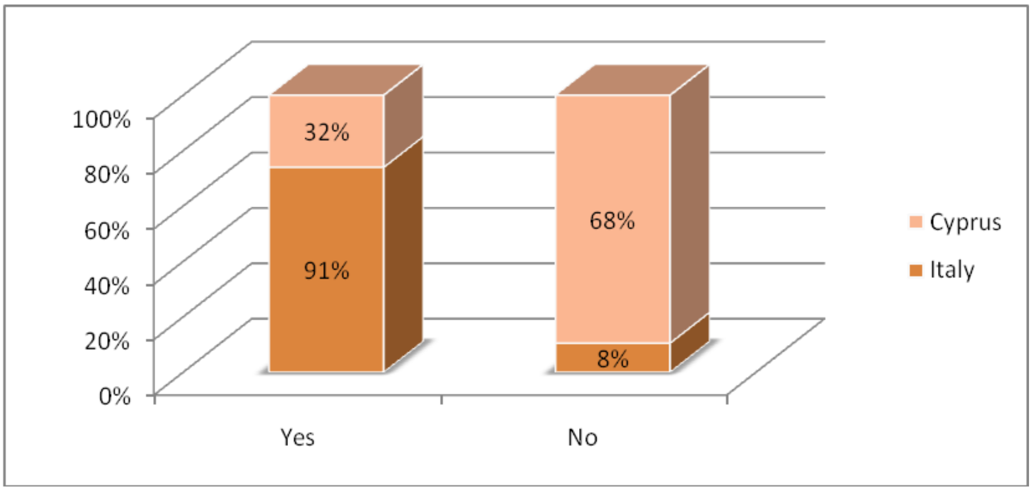
12. Please indicate the amount of the monthly electricity bills before and after utilizing PV systems:

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Before												
After												

13. Do you use the PV system to generate required power for ectrical systems?

□ Yes

□ No



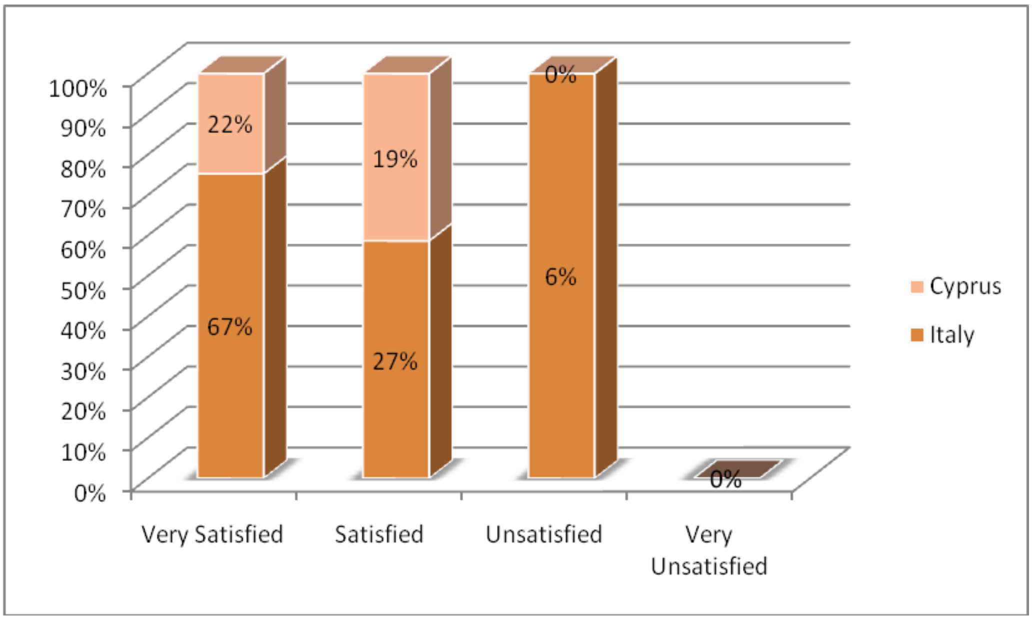
14. If your response to question 14 is ‘Yes’, please indicate the level of your satisfaction regarding the provided thermal comfort:

□ Very Satisfied

☐ Satisfied

☐ Unsatisfied

☐VeryUnsatisfied

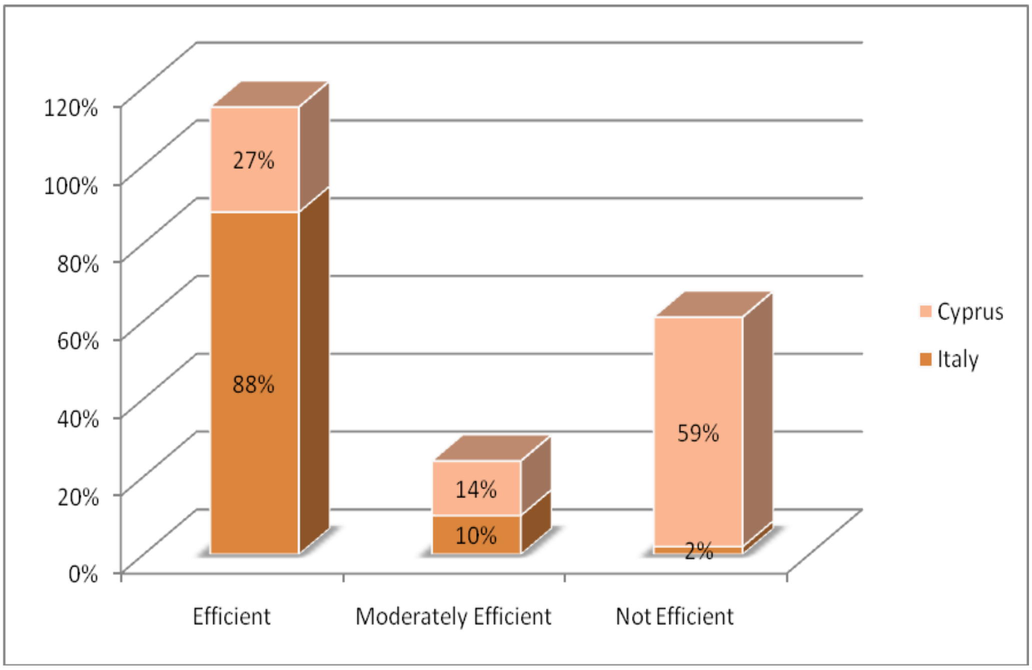


15. How has PV system been economically efficient in terms of reducing your household electricity expense?

☐ Efficient

☐ Moderately Efficient

☐ Not Efficient


120%
100%
80%
60%
40%
20%
0%
27%
88%
14%
10%
59%
2%
Efficient
Moderately Efficient
Not Efficient
Cyprus
Italy

2.6 Discussion

Data collected from participants (residential PV users) will be analyzed and discussed descriptively. Since the survey was conducted both in North Cyprus and Italy, the collected data from the two contexts will be compared. Following you can see the descriptive analysis of a number of selected questions from the questionnaire.

In general, the results show that the majority of the participants in Cyprus have installed PV systems on the buildings they are currently living in; however, in Italy nearly half of the participants had bought their houses equipped with PV systems by the previous owners or builders. The use of PV systems in Italy dates back to more than 5 years ago, while in North Cyprus it can be considered as a new phenomenon which has become more prevalent mainly in the last 4 years.

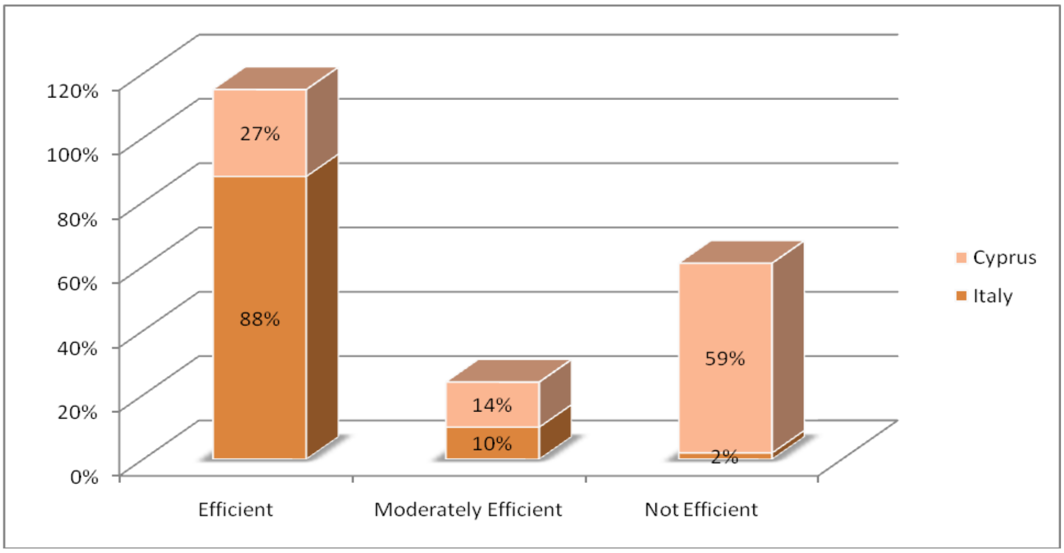
Unlike the majority of Italians who obtained information about PV systems via advertisements and promotional programs offered by their government, Cypriot participants sought and got information through internet. Although in both cases the degree of satisfaction with the performance of their PV systems is more than 50%, the Italians seem to be more satisfied with them. Moreover, less Italians have encountered unexpected failure of the system and paid less maintenance expenses.

As to the motivating factors to install and use PV systems electricity costs, power production, and concerns about fossil fuels ranked the highest for both participating groups. However, the data demonstrates that Italians are more concerned with environmental and health issues.

Since the focus of the study is on the economic efficiency and thermal comfort aspects of PV systems, the related questions will be discussed here in more details. Question 15 addresses the level of satisfaction with the provided thermal comfort for those who deployed PV systems to supply the required electricity.

Among these users, 27% of Cypriots and 88% of Italians were 'very satisfied' with the provided thermal comfort. Only a low percentage of participants declared their dissatisfaction with the provided thermal comfort.

One of the main objectives of this study is to explore the economic efficiency of PV systems. Question 16 addresses this issue as regards the reduction of each household's electricity expenses.



Majority of the Cypriot group (59%) contend that PV systems have not been economically efficient; on the contrary, Italian users declared the efficiency of PVs by 88%.

Chapter 3

CONCLUSION AND RECOMMENDATION

The inexhaustible source of energy known as solar has the privilege to be available and used in the majority of regions across the world. The potential of this renewable energy exceeds the energy required for primary consumptions. Therefore, to benefit from advantages of this abundant source of energy in different economic, environmental, and social dimensions, solar technologies should be developed.

PV system as a well-established solar technology has been the focus of attention of scholars, government authorities, and public worldwide. Economically speaking, the growing demand of PVs has led into an intensive competition in PV markets which consequently has ended up in constant reduction of the cost of PV.

Solar energy seems to be an acceptable remedy to address global social and environmental concerns. They would serve a broad range of purposes such as rising the level of comfort and living standard of the residents, enhancing the sustainability of buildings, decreasing use of fossil fuels and consequently reducing pollution.

Recently, many countries have initiated taking measures to promote the use of PV systems in buildings and have achieved different levels of success. North Cyprus is among the countries which have faced energy crisis due to lack of reliable resources of energy. To face this problem utilizing PV technology is suggested as an alternative and a means of achieving environmental, social, and economic sustainability. Utilizing this technology in North Cyprus has many advantages such as increasing comfort level and standards of living, and creating job opportunities both at local and foreign levels. The data analysis showed that the majority of PV users are satisfied with the application of the system in terms of its economic efficiency and thermal comfort provided. Moreover, PV panels can be introduced and utilized as one of the most efficient technologies on the way towards achieving sustainability.

Although preliminary steps towards utilizing renewable sources have been taken and the use of photovoltaic has been introduced as an efficient way of generating energy, the economic issues and high costs of photovoltaic seem to be an obstacle.

Yet there is a potential of growth in the PV market in North Cyprus provided that it is supported by the government. Non-integrated PV systems have been observed to be used in a number of buildings in North Cyprus; they are mainly of monocrystalline cell type which is cheaper and more durable. Therefore, if the government provides supportive offers to the residential in order to utilize PV systems, it will considerably contribute into the comfort level of the residents and saving energy.

Resorting to PV seems necessary in North Cyprus because of several reasons and factors. There is a considerable power shortage on the island and there are regions where grid has not been implemented. Therefore, to provide everyone with electricity power requires deployment of another resource of energy, that is solar, through usage of PV technology. North Cyprus enjoys the sunshine in almost all regions and all the yearlong; hence, PV would appear to be best option to obtain environmental sustainability. The government can encourage owners to integrate PV into their buildings and promote sustainable living in North Cyprus by offering loans and subsidies. People in North Cyprus should become aware of the global environmental concerns and take steps towards producing less greenhouse gases and CO_2. Moreover, utilization of PV on the island would create opportunities of employment for a large number of people.

In sum, based on the data collected from people using PV systems in North Cyprus, it can be concluded that people have started noticing the advantages of PV technology particularly in terms of economic benefits it offers. In response to questions addressing satisfaction of PV owners with its economical efficiency, a majority of the owners reported a good level of satisfaction. Another significant advantage of PV system is providing thermal comfort in the building. According to the responses of PV users in North Cyprus, photovoltaic system has been functioning successfully regarding provision of thermal comfort.

Overall, it can be concluded that PV has the potential to meet the energy demands of the people in North Cyprus and contribute to sustainability in all its three components, that is, social, environmental, and economic.

To fully benefit from the privileges of PV systems substantial measures should be taken by the government. Similar to developed European countries which are widely using PV technology, the government of North Cyprus is supposed to make efforts to raise awareness of people towards necessity of PV utilization to achieve sustainability. Government needs to promote and advertise encouraging the public to take steps towards sustainable economy, environment, and society. The government is required to support people in the path towards use of renewable energies, modern solar technologies through policies and regulation which facilitate access to and implementation of PVs.

Recommendations:

One of the major obstacles on the way of PV utilization nationwide is resistance of the public. Therefore, the authorities and all contributing stakeholders should offer strategies and plan policies which remove this obstacle. Following are some recommendations:

- Authorization and licensing processes for PV projects should be facilitated;
- A communication strategy should be adopted to target both private and public sectors to reduce the level of resistance;
- Training courses, programs, or workshops should be offered to engineers, architects, installers, and all those who are involved in the process of PV utilization;
- Insurance related issues should be clarified and offers need to be provided
- Financial supports such as long-term bank loans should be given to interested sectors and individuals;
- Informative programs should be offered through TV, radio, internet, etc.

Definitely there are many other techniques and strategies to promote use of PV systems, reduce resistance of the public and raise their consciousness but the ones mentioned above seem to be the most feasible ones.

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APPENDIX

Appendix A: Questionnaire

1. Which of the options below describes the situation of the PV system in your building?

☐ a) PV is installed on the building I currently live in based on my own decision
☐ b) PV was installed by the previous owner/ builder when I bought this house

2. How long have you been using your PV system?

☐ a) Around 1 year
☐ b) 1 year to 4 years
☐ c) 4 years to 5 years
☐ d) More than 5 years

3. How do you evaluate the following factors as contributing to your decision to install a PV system?

Factors	**Very Important**	**Moderately Important**	**Not Very Important**	**Not Important At All**	**Unsure**
Current electricity cost reduction					
Future electricity cost reduction					
Producing one's own electricity					
Reducing fossil fuels' consumption					

Environmental issues e.g. Global warming					
Health issues					

4. How important were the following factors before you decide to install the PV system?

	Very Important	**Moderately Important**	**Not Very Important**	**Not Important At All**	**Unsure**
Initial Cost					
Quality of the PVs					
Maintenance					

5. How did you find information about PV systems?

☐ Internet

☐ Government's advertisements

☐ Private Companies' advertisements

Other: ………………………………………………..

6. The degree of your satisfaction with the performance of your PV system:

☐ Very Satisfied
☐ Satisfied
☐ Unsatisfied
☐ Very Unsatisfied

7. Has any extra cost been imposed on you due to unexpected failure or maintenance of the PV system?

☐ Yes
☐ No

8. If yes, please indicate which part of the system has failed to operate.

……………………………………………………………………………………………
…………………………………………………………………………………………..

9. Have any batteries being used in the structure of your PV system?

☐ Yes
☐ No

10. In case your response to question 10 is ‘Yes’, how satisfied are you with the quality of the batteries?

☐ Satisfied
☐ Moderately Satisfied
☐ Unsatisfied

11. In case there is a blackout or electric grid failure, can your system produce electricity?

☐ Yes
☐ No

12. Please indicate the amount of the monthly electricity bills before and after utilizing PV systems:

	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Before												
After												

13. Do you use the PV system to provide required electricity for cooling/ heating systems?

☐ Yes
☐ No

14. If your response to question 14 is 'Yes', please indicate the level of your satisfaction regarding the provided thermal comfort:

☐ Very Satisfied
☐ Satisfied
☐ Unsatisfied
☐ VeryUnsatisfied

15. How has PV system been economically efficient in terms of reducing your household electricity expense?

☐ Efficient
☐ Moderately Efficient
☐ Not Efficient