EXPLORING AN OPTIMAL SELECTION METHOD OF PHOTOVOLTAIC SYSTEMS FOR UNIVERSITY CAMPUSES

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EXPLORING AN OPTIMAL SELECTION METHOD OF PHOTOVOLTAIC SYSTEMS FOR UNIVERSITY CAMPUSES

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ABSTRACT

OPTIMAL DESIGN OF SOLAR PHOTOVOLTAIC SYSTEMS AT UNIVERSITY CAMPUSES

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The ever-increasing environmental problems associated with the burning of fossil fuels for electrical power generation, together with their availability at acceptable costs difficulties, have led to more and more search for non-polluting, renewable primary sources of such energy, where solar, wind, hydro, geothermal, biomass, ocean energies and others have been considered and studied as alternative sources.

The electrical power needs at university campuses and educational institutions have been increasing by the increasing number of such institutions and their need for electrical power. The nature of their electrical loads consisting mainly of space and water heating, ventilation, air conditioning, lighting, and some other small facilities loads, is almost the same with its heaviest during the day hours and lowest at night, following the site activities. Among the various renewable energy sources, photo-voltaic direct solar radiation conversion to electrical energy has proved to be the most viable in various situations.

The PV systems have been developed through the last years, increasing their efficiencies and lowering their costs, hence increasing their feasibility. Several campuses worldwide have introduced these technologies to generate all or at least part of their electrical energy loads, in what is known as sustainable energy supply,

zero energy application, or green buildings. Some university competitions adopted this issue as one of these competition items. Among the different types, varieties, and manufacturers of PV systems, one may choose what fits his needs. The selection process needs to be considered carefully towards an optimum selection.

In this work, the application of PV systems for university campuses is reviewed and has been found to indicate that building-integrated photovoltaics (BIPV) is an adequate technology for building's electrical power supply, as more and more buildings are being designed and built, particularly in urban areas, realizing several advantages over buildings supplied through conventional grids.

With the technical, economic, architectural, and environmental. social and legal aspects considered; a method is developed to select the optimum PV system for university campus buildings, that gives the maximum energy yield at the lowest cost among the available systems. The method is then demonstrated in a case study, at a typical university campus in Ankara, Turkey, giving reasonable results encouraging further the use of PV systems in such applications with considerable economic saving, particularly when energy conservation ways and means are applied.

For the case study considered here, the annual energy yield was 22,059 MWH, of which 17,905 MWH was from the façade installed PV system, while 4,154 MWH was from on roof positioning system. The unit energy cost was 8.47 Euros per Kwh.

ÖZ

ÜNİVERSİTE KAMPÜSLERİNDEKİ GÜNEŞ PANELLERİNİN OPTİMAL TASARIMI

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Elektrik enerjisi üretimi için fosil yakıtların yakılmasıyla ilgili sürekli artan çevresel sorunlar var. Ayrıca, kabul edilebilir maliyetlerde mevcutturlar. Bu gerçekler, güneş, rüzgar, hidro, jeotermal, biyokütle, okyanus enerjileri ve diğerlerinin alternatif kaynaklar olarak düşünüldüğü ve incelendiği bu tür enerjinin kirletici olmayan, yenilenebilir birincil kaynaklarının giderek daha fazla araştırılmasına yol açmıştır.

Üniversite kampüslerinde ve eğitim kurumlarında ihtiyaç duyulan elektrik enerjisi, bu tür kurumların sayısı ve elektrik enerjisi ihtiyaçları arttıkça sürekli artmaktadır. Ağırlıklı olarak mahal ve su ısıtma, havalandırma, iklimlendirme, aydınlatma ve diğer bazı küçük tesis yüklerinden oluşan elektrik yüklerinin doğası, şantiye faaliyetlerinden sonra gündüz saatlerinde en ağır ve gece en düşük olmak üzere hemen hemen aynıdır. Çeşitli yenilenebilir enerji kaynakları arasında, foto-voltaik doğrudan güneş radyasyonunun elektrik enerjisine dönüştürülmesinin çeşitli durumlarda en uygun olduğu kanıtlanmıştır.

PV sistemleri son yıllarda geliştirilmiş, verimliliklerini artırıp maliyetlerini düşürerek fizibilitelerini artırmıştır. Dünya çapında çeşitli kampüsler, sürdürülebilir enerji kaynağı, sıfır enerji uygulaması veya yeşil binalar olarak bilinen elektrik enerjisi yüklerinin tamamını veya en azından bir kısmını üretmek için bu

teknolojileri tanıttı. Bazı üniversite yarışmaları bu konuyu bu yarışma maddelerinden biri olarak benimsemiştir. PV sistemlerinin farklı türleri, çeşitleri ve üreticileri vardır, bu nedenle ihtiyaçlarına en uygun olanı seçmek mümkündür. Optimum bir seçim için seçim süreci dikkatlice düşünülmelidir.

Bu mevcut çalışma, üniversite kampüsleri için PV sistemlerinin uygulamasını gözden geçirmektedir ve sonuç olarak, binaya entegre fotovoltaiklerin (BIPV), özellikle kentsel alanlarda giderek daha fazla bina tasarlanıp inşa edildiğinden, binanın elektrik güç kaynağı için yeterli bir teknoloji olduğu sonucuna varılmıştır. Konvansiyonel şebekelerle beslenen binalara göre birçok avantajı vardır.

Üniversite kampüs binaları için teknik, ekonomik, mimari, çevresel, sosyal ve yasal yönler dikkate alınarak optimum PV sisteminin seçilmesi için bir yöntem geliştirilmiştir. Bu modelin mevcut sistemler arasında en düşük maliyetle maksimum enerji verimini vermesi beklenmektedir. Yöntem daha sonra bir vaka çalışmasında gösterilir. Bu, Ankara, Türkiye'deki tipik bir üniversite kampüsünde yapıldı ve özellikle enerji tasarrufu yolları ve araçları uygulandığında önemli ölçüde ekonomik tasarruf sağlayan bu tür uygulamalarda PV sistemlerinin kullanımını daha da teşvik eden makul sonuçlar verdi.

Burada ele alınan örnek vaka incelemesinde yıllık enerji verimi 22.059 MWH idi. Bunun 17.905 MWH'si cepheye monte edilen PV sisteminden, 4.154 MWH'si çatı üstü konumlandırma sisteminden elde edildi. Birim enerji maliyeti Kwh başına 8,47 Euro idi.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my parents and my husband for their support and sacrifice for me. Your memories would never shine in my mind. Special thanks to my supervisor Gülsu ULUKAVAK HARPUTLUGİL for the excellent guidance and for providing me with an excellent atmosphere to conduct this research. My special gratitude also goes to the rest of the thesis committee for the encouragement and insightful comments.

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LIST OF SYMBOLS AND ABBREVIATIONS

BIPV	:	Building Integrated Photovoltaics
BIPV	:	Building-Integrated Photovoltaic
BOS	:	Balance of System
EPBD	:	Energy Performance of Buildings Directive
MCDM	:	Multi-Criteria Decision Making
PV	:	Photovoltaic
PVSYST	:	Photovoltaic System Software
STC	:	Standard Test Condition

CHAPTER I

INTRODUCTION

1.1 RESEARCH PROBLEM

Nowadays, relevant parties and organizations all over the world are seeking green energy. The global economy is growing, the population is increasing and people depend on fossil fuels to meet their energy needs. Electrical power is currently produced mostly in unsustainable power plants. These plants burn fossil fuels and emit harmful gases to human health and the environment.

Besides, fossil fuel depletion, its availability in only some countries, and increasing costs problems have led to energy security problems. The accumulation and growth of these problems have resulted in the continuous search for alternative, sustainable, environmentally friendly primary renewable energy sources, such as solar energy, wind energy, biomass, geothermal, hydro, waves, and tide energies.

Photovoltaic technology (PV) converts solar radiation into direct electric current (dc). It uses Silicon cells, modules, and panels. Its system consists of these components, batteries, inverters, and relevant accessories.

According to Kelly Pickerel in his article titled the long history of solar PV (Silicon Power World, Jan. 4, 2018), Bell Telephone Laboratories in the USA developed solar cells in 1954, and the commercial production of crystalline silicon modules began in 1963. With continuous development into polycrystalline, homogeneous, then thin film and other new technologies, as well as attaining higher efficiencies and lower costs.

The produced energy costs through these modules depend on several factors, including the solar energy density at the application site, the system capital costs, the discount rates, the modules cells' efficiency, and surface area, as well as the local variable costs. The PV applications have found feasible life cycle costs in different areas, both as stand-alone and grid-connected systems in supplying electrical power requirements. Universities and schools are suitable applications of such technology, due to their nature of electrical load requirements, and their possible contribution to environmental protection efforts. Their electrical power requirements vary widely, according to their specifics and location, among other relevant factors. These requirements are usually estimated in kW/m^2 of their exposed surface areas, or energy terms, as Kwh per capita per year of their population.

This work tries to study and investigate the application of a PV system at a university campus, to supply at least part of its electrical energy needs, as a typical example to handle, in a comprehensive simple manner, such application, where the different technical, economic, environmental, architectural, social and legal aspects are highlighted and considered, to help in showing such applications, their feasibilities and success, particularly in developing countries. Çankaya University at Ankara, the capital city of Turkey is selected to be the site of the case study here, as an example of a typical leading university, in the country with reasonable solar energy resources, and ongoing economic and social progress, representing several world regions universities. The software was selected to suit the work function, and the calculations are carried out systematically, to determine the optimum system for the application. The other relevant aspects are considered, and the results and conclusions are derived.

1.2 RESEARCH AIM AND OBJECTIVES

The main objective of this research is to develop a method for simple multi-criteria decision-making, in solar PV system application optimization, for university campus buildings. Moreover, the main goals of the proposed method are:

- To identify aspects of the design process, which can be improved, to enable designers to optimize the financial yield of the solar PV system.
- To improve the accuracy of energy yield modeling for PV systems. Furthermore, this improvement in the model accuracy will reduce the financial risk of investment as well as therefore, the cost of capital investment.
- A reduction in the cost of capital will, in turn, also improve the financial return from the PV system. In the same way, the improvement in model accuracy will be achieved by identifying which sub-systems, within a PV system, make the largest contribution to overall system energy losses as well as have the greatest potential for improvements in accuracy.

- To develop an integrated design-decision process model, as well as a decision support system that can provide proactive guidance to facility owners of the project managers in undertaking PV systems of existing buildings.
- At this stage of the work, the decision support for the PV systems is considered. The selected software for PV design, as well as performance, remains tested using some available data to see the operation, input as well as output outcomes, before its application on the project's real information. In addition, the aim as well as, objectives of this stage is then outlined with relevant questions, as well as an analytical hierarchy process model to be applied. The factors that directly influence the design process are identified as
- criteria in the process leading through the various correlations to an optimum design of solar PV system based on these factors.
- To illustrate how to obtain the energy consumption information on campus, as well as assessment of the solar potential identification of the suitable sites for PV integration, taking into account the basic constraints, for example, available area, land utilization, topography, local climate conditions, grid connection characteristics, accessibility, module soiling, etc.
- PV systems design technology selection as well as arrangement, positioning, and electrical configuration at the required building.
- Energy analysis of the selected areas, as well as energy consumption, was the first step throughout the design procedure remained to gather the data related to the energy consumption on the campus.
- To derive as much information as possible, it is needed to check the facility data, for instance, building description, total useful floor area, main heating fuel, annual energy consumption, electricity costs, instantaneous power demand, etc. for future energy requirement and supply.

1.3 THESIS LAYOUT

- The research is structured, as well as developed, through five main chapters, which are introduced here as below:
- Chapter One: Introduction; where a piece of general information about the thesis subject and the motivation for carrying out this work at this level are outlined.

- Chapter two: is devoted to the literature review of the research subject and related issues, briefly mentioning some of the outstanding published papers and some of the main issues they convey. Some of the study gaps, with their handling of the latest on PV systems, their foreseen prospects, calculations, and so on.
- In chapter three: the work methodology, with the definitions, parameters, the case study site, Çankaya University, the software used, for a green campus application, the workflow chart, and the assumptions are considered.
- Chapter four deals with the case study of this work; the application of solar PV system for generating electrical power to supply part or all the needs of the university building chosen, the technical, economical, architectural, environmental, social, and legal aspects considered.
- Finally, chapter five summarizes the work, with the conclusion, notes, and recommendations for further studies.

Figure 1.1 shows the flow chart of this work.

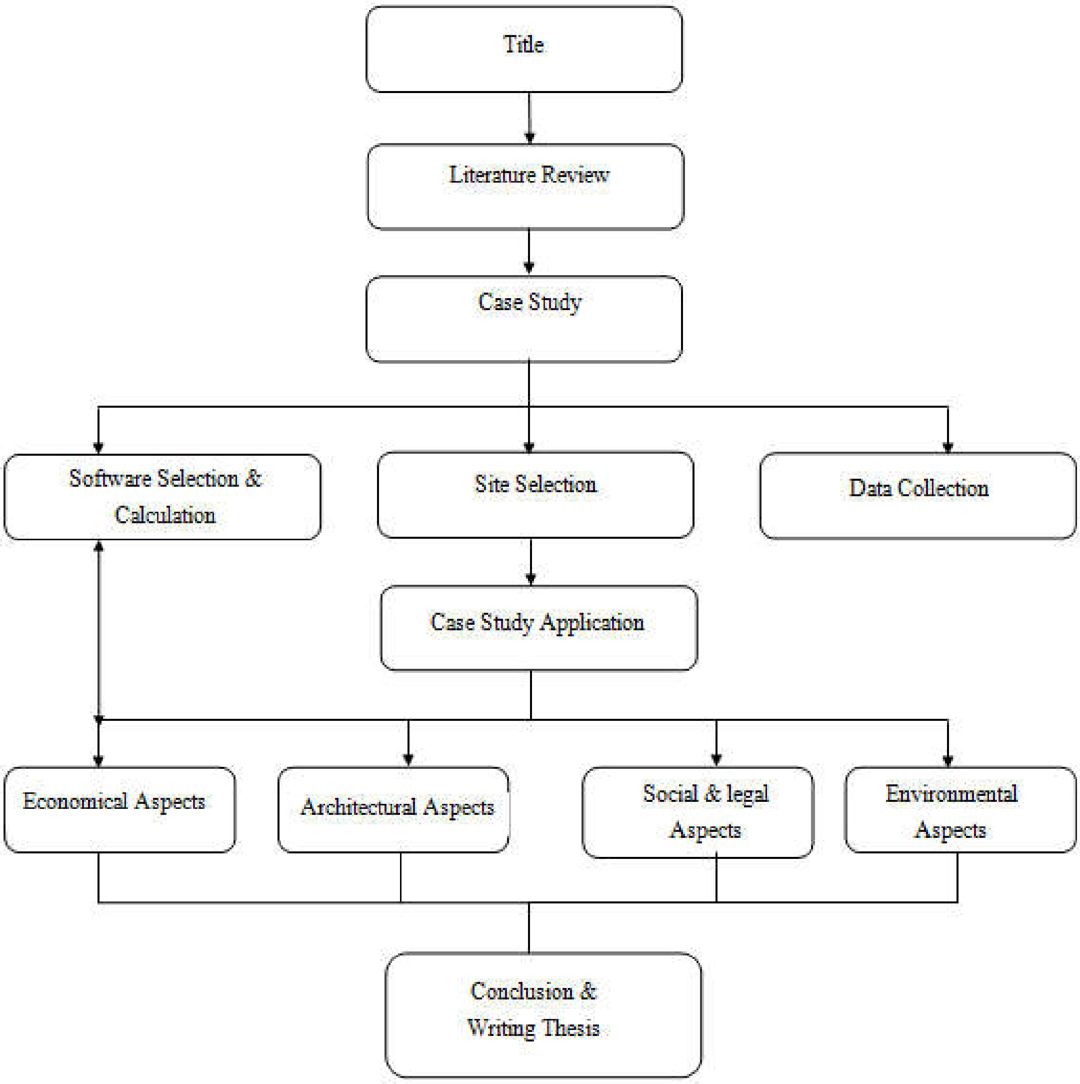


Figure 1.1: The Thesis Flow Chart

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Photovoltaic modules are termed as building-incorporated, on the off chance that they have been planned after the fundamental prerequisites for development works to frame, as well as supplant a development item. If the coordinated PV module is gotten off, it would need to be supplanted by a suitable conventional development item. This chapter reviews the electronic database based on building integrated photovoltaic systems (BIPV), system description, BIPV concept and development, BIPV advantages, BIPV system and components, BIPV systems applications, BIPV for educational institutions, BIPV economies, economic barriers, BIPV and buildings architecture, BIPV soft-wares and PVSYST software. In addition, the research methodology utilized to observe the electronic database based on his research subject has been summarized.

2.2 SOLAR ENERGY OVERVIEW

Solar energy remains radiant light as well as heat generated by the Sun that is associated with harnessed utilizing a range of ever-evolving techies, for instance, solar heating, PVs, solar thermal energy, solar architecture, molten salt power plants as well as artificial photosynthesis PVs[1]. As a source of renewable energy, which is associated with its techies remains broadly characterized as either passive solar [2] as well depending on solar activity on how they either distribute solar energy they have captured or turn it into solar power.. Furthermore, active solar techniques include the utilization of PV frameworks[3] concentrated solar power, as well as solar water heating to harness the energy [2].

Towards the Sun, choosing components with advantageous thermal mass or light-diffusing qualities, and constructing areas with air circulation naturally [4].

The effects of climate change have become burdensome in the 21st-century reality [5][6]. Rapid climate change has an impact on every society and may be observed in the rising sea levels, warming oceans, diminishing ice sheets, and glacial retreat[6]. Additionally, winters are shorter and warmer and summers are longer and hotter [7] [8]. The vast majority of scientists believe that human-induced emissions of heat-trapping gases like CO2 and water vapor (H2O) in the atmosphere are to blame for climate change. [7][9]. Moreover, the consumption of large amounts of non-renewable, fossil-based energy sources has an influence on the environment known as the greenhouse effect. On the off chance that we do not need people in the future to be troubled by the disastrous effect of environmental change, the researchers should act currently to uphold extraordinary change, by the way, acquire and utilizing energy [7][10]. In this manner, going to sustainable power sources; are viewed as inexhaustible because they originate from assets, for example, daylight, wind, sea vitality, hydrogen, waves, as well as geothermal warmth [5][9]. Moreover, sustainable power sources can offer a few advantages that customary sources of power cannot, because they are spotless, as well as ensure source security [8][10]. In this way, it ought to try to replace the traditional plant in the electrical power age with the origins of a sustainable power source. Furthermore, administrative or arrangement trials planned for lessening outflows would likewise influence the power supply system [7].

Over the past 30 years, solar thermal electricity has been used as a proven breakthrough. Its qualities rest in its capacity to make electric limits firm and to time-move power age, for the reason that warm stockpiling[7]. Additionally, low-focus power systems can provide new options with capacity in a wider range of environmental conditions [6], however high fixation power plants, for example, explanatory trough, as well as dish motor systems, can be introduced in desert areas to gather more sun's warmth power [5]. Additionally, the style is to construct working temperatures and to erect skyscrapers with a staggering array of structures connected to applications [7]. Concentrating the sunlight-based beams takes into account higher working temperatures with great productivity at the gatherer level, prompting improved proficiency in the transformation of the warmth into mechanical power [9]. Additionally, perfect proficiency is characterized as the proportion of the distinction in temperatures of the sun’s heat energy [8], isolated by the outright temperature just as a hot source. Likewise, recipient proficiency is an element of the working liquid temperature for different fixation proportions. In addition, the effectiveness of the recipient relies upon the working fluid temperature[9].

With the anticipated growth as well as dynamic complexity of the solar photovoltaic (PV) showcase, alongside the enormous capital expense of PV systems, a requirement for an arranging instrument that will aid the plan of PV systems is wanted [11][9]. Besides, a wide assortment of arranging instruments is at present accessible for breaking down a PV system, where normally these apparatuses are grouped into three classifications: I) feasibility, ii) measuring, and iii) reenactment. A feasibility apparatus decides whether a predetermined application is monetarily plausible while measuring instruments set up the size of the balance of system (BOS) components, furthermore, reenactment devices give a point-by-point examination of the normal power age, by imitating the PV framework [11].

A powerful arranged apparatus doesn't exist that can consider the complex geometry of a housetop for various PV modules, as well as tilt points, while having the option to examine a combination of part databases for the balance of system (BOS), with the end goal that a huge number of sun oriented PV system plans are made [8]. Along these lines, an apparatus that adopts a comprehensive strategy towards breaking down housetop potential that can prompt perfect arrangement structures and financially save building objectives [11]. The reason for the development of solar energy technology, there has been an increase in solar power framework establishment in urban territories [12]. Reliably lower sun-powered board costs have made it conceivable to introduce sun-oriented vitality frameworks in complex territories. Numerous sun-oriented force frameworks are introduced on rooftops, on the ground as well as building facades. Furthermore, mapping of the exact spatial dissemination of sun-powered vitality potential and investigation of shadowing ought to be considered to accomplish expanded effectiveness[8].

The green campus, program gives a critical commitment by elevating maintainable living to the general public [13]. In this way, countless colleges all-inclusive are arranging important ventures, to improve their supportability in the short-and medium-term [9][12][8]. To additionally upgrade this methodology, bolster arrangements have been presented in a few nations, while at times PV vitality age for self-utilization can be productive without appropriations [9]. As of now, most colleges apply sun-based vitality frameworks in part, for example, for road or nursery lighting[14]. Also, the framework applied Off-Grid framework concerning moderately high venture costs Micro-matrix/PV power establishment framework has been a focal point of a few analysts seriously led over the world[13]([14].

In any case, as the sun-powered force age expands, there are elements to think about other than essentially expanding skill. The distinction example of sun-based force supply, as well as force request, requires extra power accumulation [12]. The most agent case is the 'duck curve', which shows net interest, the distinction between the electric burden, and the collection of sun-oriented force. It speaks to the temporary inclination needs of power requests at night [10]like sun-powered force increments. As this abrupt inclining causes trouble in giving a steady power supply, it is important to discover techniques to balance it out. One of the strategies to reduce this unpredictability is to change the direction of the sun-powered board [12]. Besides, power systems have customarily comprised a miniaturized scale structure at the national level, yet as of late, numerous little small-scale matrix structures have been considered [8]. What's more, a small-scale matrix, which is an independent also distributed gathering of intensity systems has numerous potential focal points, for example, low transmission unfortunate case, low net clog, usage of neighboring sustainable assets, and so forth.

2.3 THE SOLAR SELL

A solar cell is a semiconductor gadget, more accurately, a unique kind of diode. Occurrence-free electrons are created by light and isolated by an inward electromagnetic field, as an outcome of the potential contrast [15]. Moreover, crystalline silicon cells are generally produced from silicon wafers. Furthermore, wafers are cut out of single or multi-crystalline silicon ingots. Multi-crystalline silicon is made out of enormous small stone grains [10]. Multi-crystalline silicon cells are less expensive yet have to some degree lower proficiency than single-crystalline. The mono-crystalline silicon PV Module has been chosen for this purpose [8]. In this manner, superior PV modules are made of mono-crystalline silicon sun-oriented cells with a force 250W module[15]. The electrical properties of PV gadgets remain given: at Standard Test Conditions (STC); these are cell temperature 25°C, sun-oriented irradiance 1000W/m^2 as well as sun-powered range air mass 1.5. A dependable guideline is that a square foot of a single PV module region produces ten watts of intensity in brilliant daylight [15], against reflex covering to build light density. Just modules will be conveyed that have the predetermined force or more for high power yield [8]. Furthermore, it is an improved temperature coefficient to diminish power misfortunes at higher temperatures as well as high influence execution even at lower illuminations[15].

2.4 PHOTOVOLTAIC (PVs)

Solar-based cells, which are commonly used in photovoltaic (PV) systems, transform daylight into electrical energy [5][8].The expression "PV system" can truly be interpreted as light power [7][11]. Moreover, straightforward PV systems give the capacity to little PVs which ought to be considered as an essential piece of the general ecological technique of power effective structure plan [16][8], customers' things, for example, adding machines as well as wristwatches [5] [12]. Increasingly muddled systems give the capacity to correspondence satellites, water siphons, lights, apparatuses, and machines in private also business structures. Many street and traffic signals in use today are also powered by PV systems. Sunlight-based photovoltaic (PV) cells are available in a wide variety of shapes and sizes, ranging from those no larger than a postage stamp to those several creeps across[17]. They are regularly associated together to shape PV modules that might be up to a few feet in length, and a couple of feet wide. Likewise, the PV modules, thus, can be arranged and associated with structure PV varieties of shifting sizes also force yields[7][11][12]. In this manner, the modules of the cluster make up the important piece of a PV system, which can likewise include electrical parts, mounting equipment, power-molding gear, and the energy-accumulated systems that store sun-based power for utilization when the daylight isn't easily accessible [7]. The PV system is at present overwhelmed by crystalline silicon-based PV cells [7], PVs will play a significant role in promoting this approach to construction and will help us transition to reduced carbon [16], carbon neutral, and carbon-negative structures [16][11]. Furthermore, silicon is a key component in the current most well-known PV devices[11]. Direct current (DC) flows when the devices are exposed to the sun, as shown in Figure 2.1 below.

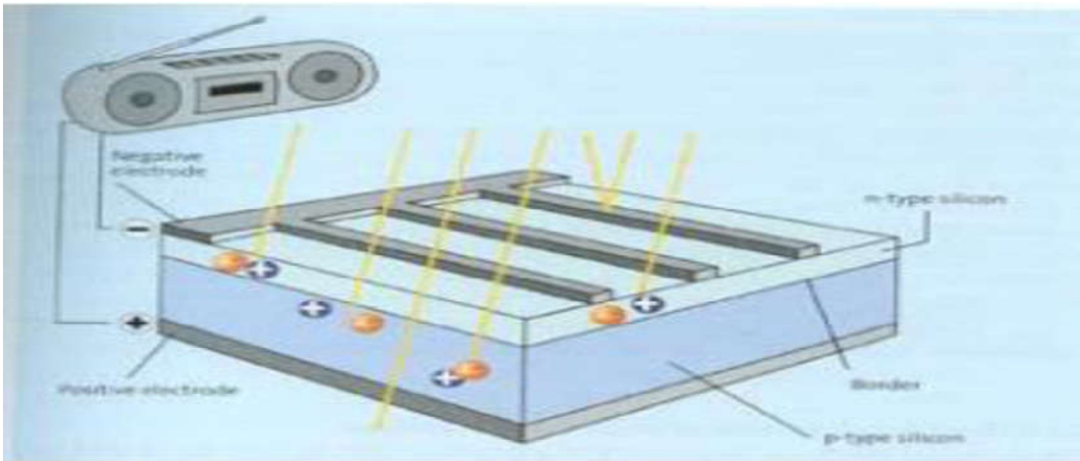


Figure 2.1: Diagram of PV Principles [16]

Furthermore, the PV responds to both the direct and reflected radiation by diffusing the radiation as shown in figure 2.7. The amount of sunshine (irradiance) or solar power, expressed in W/m^2, increases with time [18].

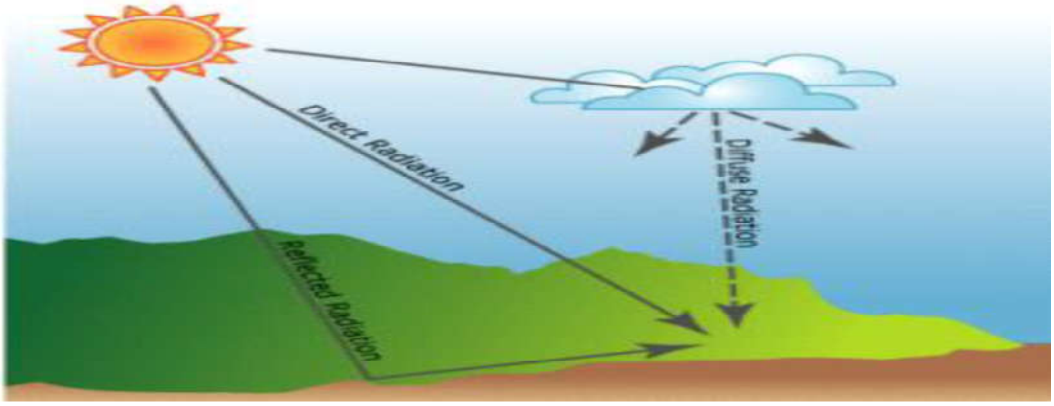


Figure 2.2: Both direct and diffuse radiation [16]

PVs can be seen all over the place. In the same way, the power mini-computers, as well as route floats, structure the wings of satellites and sun-oriented planes, as well as, are starting to show up on vehicles, for example, the Bluecar from Bolloré/Pininfarina [16]. By and large, network-associated PV systems are most proficient, when the cluster encounters uniform conditions [11]. In this manner, this will in general kindness a similar direction, and tilt for all modules, comparable modules, cell types and sizes, uniform temperature conditions, etc. Furthermore, crystalline silicon modules arrive in an assortment of sizes, as well as shapes, however rectangular examples of 0.3 m2 to 1.5 m2 have been generally normal [12] as shown in Figure 2.3 below.

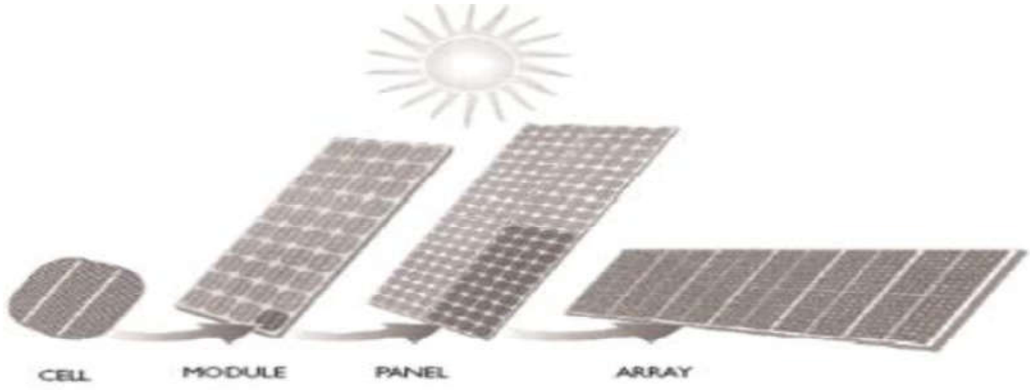


Figure 2.3: Module Cells, Panel, and Array [7]

Furthermore, the power delivered from the sources is transmitted through wires to a force inverter. Combiner boxes are regularly utilized to join the force from the sources onto a single interconnection to solidify wiring [10]. In doing as such, the current from the system is expanded, dependent on the capacity of sources entering/leaving the combiner box [12]. Additionally, an inverter changes over the DC intensity of the modules into AC power, which is then transmitted to the power system [10], or load application. What's more, the important part of a matrix-tied PV system is the inverter which besides managing the voltage, as well as currently obtained from sunlight-based boards, and guarantees that the power supplies in phase with the network power[15].

2.4.1 Photovoltaic Solar Power System

As seen in figure 2.4 below, photovoltaic (PV) cells harness the energy in sunshine to produce electricity. In this manner, the value of power delivered relies upon the nature of the light accessible, also the exposition of the PV cells [7][1]. Moreover, the change proficiency of PV cells is the level of the sun-based power incident on PV cells that are changed over into power [7][11] Figure 2.5 below shows the Levels of the array system.

The research's primary goal is to increase the efficiency of this transformation while also making PV advances more affordable with increasingly common power sources[11][1]. Similar to this, a large portion of the power from sunlight entering a PV cell is wasted before it usually converts to electrical power. What's more, certain qualities of sun-powered cell materials likewise, limit the cell's effectiveness to change over the daylight it gets [1], Figure 2.4 shows how the PV system functions as presented in [7].

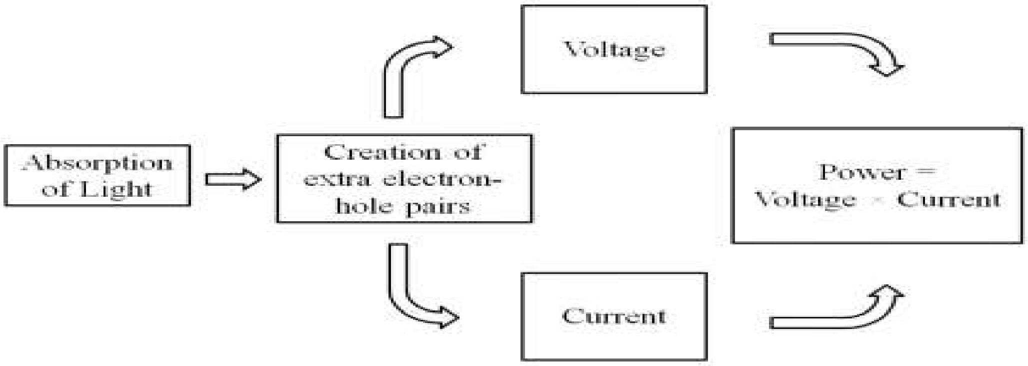


Figure 2.4: Diagram of Photovoltaic Effect [7]


Figure 2.5: Levels of Array System [7]

2.4.2 Photovoltaic Solar Power System Advantages and Disadvantages

Table 2.1: Photovoltaic Solar Power System

Factors	Advantages	Disadvantages	Authors and years
Oriented cells	1. Electricity generated by sun-oriented cells is spotless also quiet since they don't utilize fuel other than daylight. 2. PV systems don't discharge any unsafe air or water contamination into the earth, and exhaust normal assets, just as imperil creatures or human wellbeing.	thin-film technologies but have not yet been used for Perovskite (materials of certain crystal structures) due to some difficulties in the PV market	[19][20][21] [22][23]
Efficiency	PV systems are quiet as well as visually unobtrusive.	Due in part to the expense of making PV devices and in part to the equipment's conversion efficiency, The cost of producing solar energy remains higher than that of conventional energy sources. As conversion efficiencies increase and manufacturing costs decrease, the demand for PV to be cost-competitive with conventional fuels will increase.	[19][1][10] [24][25][23]
Power	Small-scale solar power plants may be able to utilize open space on existing buildings' rooftops.	1. Energy production from solar power is still erratic and dependent on the sun. 2. Sun-powered offices may create no power constantly, which could cause an energy lack if an over-the-top locale's capacity originates from sun-based power.	[25][19][20] [24][10]

Table 2.1 Continued

Cost	1. PV cells were still being developed for use in space, where it is very expensive, if not impossible, to repair things. 2. PV still powers almost all satellites orbiting the globe since it is reliable and requires little to no maintenance over extended periods of time.	1. Expensive 2. longer system life requires higher quality components and hence higher capital costs. 3. The maintenance costs are so high.	[26][10][21] [20][27]
Resource	1. Solar power is still a readily usable renewable resource in the area. 2. It is not necessary to import it from other parts of the world.		[20][22][28] [27][23]
Environmentally	PV decreases the environmental effect that is associated with transportation as well as decreases our dependence on imported oil.	1. In the process of making PV, some hazardous substances are used, including cadmium and arsenic. 2. These minimal environmental effects are easily manageable through recycling and proper disposal.	[25][24][29] [1][20]

Table 2.1 continued

Environmentally	PV decreases the environmental effect that is associated with transportation as well as decreases our dependence on imported oil.	3. Toxic substances including cadmium and arsenic are used in the creation of PV. 4. By recycling and disposing of waste properly, these environmental effects can be easily reduced.	[25][24][29][1][20]
Modules and regularity	1. A PV system can be built to any capacity dependent on power prerequisites. 2. The proprietor of a PV system can be broadened or moved if their power needs to change. 5. Property holders can include modules at regular intervals as their power utilization and monetary assets develop. 6. Farmers can utilize versatile trailer-mounted systems to water steers as the cows are turned to various fields.		[27][19][20][22][28][27][23]

2.5 SITE CONSIDERATIONS

In the same way, More solar radiation is beneficial since it makes the cluster's radiation more uniform. The site's location is crucial because there is less solar power available as one travels further north. In addition, the site's geography needs to be looked at [16]. In this way, the local wind system should be taken into account as a part of the ventilation strategy for the building [30]. Additionally, the problem is uncertain because a microclimate with slow wind speeds is preferred in the winter because it reduces heat misery due of penetration. Mid-year is the best time to have some wind because it can help with cooling in the evenings, increase comfort during the day, support the structure, and enhance PV execution by lowering the temperature of the PV boards, as illustrated in Figure 2.1. What is more, the system ought to accomplish the correct parity [31]. It is alluring to have a site with as meager concealing by slopes, as well as another land, includes as reasonable as this diminishes the electrical yield[18].

In the same way, covering by trees is to be also dodged any place achievable. Shadowing from any source may appear to have an imbalanced impact because of the way PV modules are wired [16][31].The suggestions for the compositional plan are that checks are to be avoided at every possible opportunity [10], regardless of whether they are utility poles, smokestacks, trees, different structures, or significantly different pieces of the exhibit itself [18].

What's more, where concealing is an unavoidable cautious determination of parts and arrangement of the cluster can help limit misfortunes. In urban regions covering different structures is normal[16]. The architectural building's overall energy plan needs to include the use of PVs. Additionally, each project needs to be well thought out because the amount of PV space needed might vary greatly depending on the desired outcome.

2.5.1 PVs Key Factors

- The building on the site needs to have good access, and the location based on the solar radiation at the site is significant [7][27].
- • The quantity of electricity that may be added to the entire electrical demand, for example, storage, as well as stand-alone system and grid-tied system [27], should be sized in order to be optimized in terms of both practicality and economics [10].

- The form, as well as the aesthetics of the community, and the client, will be impacted by the design stage associated with PVs, and the designers must all be happy with the results [27].

2.6 BUILDING INTEGRATED PHOTOVOLTAIC SYSTEMS (BIPV)

In the 1970s, PV applications for structures first appeared. Photovoltaic modules with aluminum borders were attached to or placed on buildings that were often located in remote areas without access to an electric power network. [32] [33] [34][35]. During the 1980s photovoltaic modules, and additional items to rooftops started being illustrated. These PV frameworks were typically introduced on utility-lattice-associated structures in zones with brought-together power stations[33][28][36][35].

During the 1990s BIPV development items uniquely intended to be incorporated into a structure envelope turned out to be industrially accessible.

National Renewable Energy Laboratory recommends that there might be critical specialized difficulties to defeat before the introduced cost of BIPV is competitive with photovoltaic boards [34][35]. Nonetheless, there is a developing agreement that through their far-reaching commercialization [37][38][39][40], BIPV systems will turn into the foundation of the zero energy building (ZEB) European objective for 2020 [41][34][35]. Irrespective of the specialized guarantee, social difficulties to wide use have likewise been distinguished, for example, the traditional culture of the structure business, and high-thickness urban plan [42][32][33], These generators advise employing long-term usage, which probably depends on compelling people to make unusual choices about their arrangements. Even while electricity serves a fundamental purpose in modern civilization, 1.2 billion people worldwide still lack access to energy, most of whom reside in some parts of Africa and Asia. [43][44][45][46][47][48][20].

This fact emphasizes the importance of producing electricity from portable sources in locations with a large supply of renewable energy sources in order to meet local demand. The International Energy Agency claims that, By 2018, the percentage of renewable energy in the power age must increase to 25%[43]. The electricity produced by photovoltaics (PV) is also evaluated twice, with its offer until 2018 and (2011). Additionally, as PV peak is fast compared to other renewable energy sources, numerous analyses into this matter have been conducted[44][45][46][47][48].

As a component of these examinations, Yang and Athienitis, (2016) have declared that building an Integrated Photovoltaic (BIPV) systems assume an important function in producing power[49][44][45][46][47][48][50]. As a result, researchers have studied BIPV systems, but their analyses are either either generic or too narrowly focused on a particular nation or application type, like sun-oriented façades. many possibilities for constructions' energy efficiency were examined in China during period eleven of the five-year plan by [51][44][45][46][47].

In this particular case, Regarding the sponsorships given to BIPV programs and the interview process, they were open. [44][45][46][47][48][50]. Building integrated energy storage and BIPV research was categorized in [7].

In the first decade of the twenty-first century, advancements and research aimed at hiding sun-based façades have been investigated by Zhong et al. (2020), Aguacil Moreno and Rey (2020), Lee et al., (2020), and Borrebaek et al. (2020)[47][52][53][50].

They divided hazy sun-based façades into dynamic and passive façades, respectively. Systems for BIPV/T and BIPV were defined as a component of active solar façades [44][45][46][47][48]. Additionally, they arranged the tests that had been planned up until this point according to their content, "advancement," "achievability," and "application model"Both the BIPV/T and BIPV innovations were thought to be excellent systems. Because the air moving behind PV panels cools them, a significant amount of energy can be delivered more efficiently. In a similar vein, Yang and Athienitis (2016) examined simple, transparent sun-oriented façades with a comparable paper connection. The definition and evaluation of cloudy BIPV and BIPV/T systems as active façade systems followed [49][44][[45][46][47][48][20].

The most recent BIPV technologies have also been examined by Yang and Athienitis (2016) in their study[49]. BIPV systems often keep up with advancements in Pv panels, they initially provided some details on PV technologies and how they are categorized.

Similar to this, a comprehensive review of the crucial advancements of many BIPV/T devices was offered. [37][38][54][39][47][40].

Since their introduction in the mid-1990s, the BIPV/T systems have drawn growing interest as a result of their possibility of assist in the configuration of net-zero energy buildings through increased solar energy utilization[44][45][46][52].

According to Li et al. (2015), a building-integrated photovoltaic system warmly energetic recovery has amazing potential for inclusion into a structure that consumes zero energy, however this invention isn't utilized in the same way[7]. Additionally, the benefits of BIPVT systems are more certain than those of conventional PV systems [41][42][32][33][28][34] [35]. In a BIPV/T system, the movement of a liquid, primarily air, in a channel beneath PV boards offers a method to the successful restoration of a sizable component of sun energy in the form of warmth. From this point forward, Heat can be generated by BIPV/T devices to smoothly and halfway attract interest. [44][45][46][47][48][53][50].

Shi and Chew examined the layout of systems for renewable energy. They also provided models from the up-to-date tests and explained BIPV and BIPVT systems as part of their analysis.

The BIPV advancements, novel materials, and novel models that were addressed [7] were made possible by Li et al(2015) .'s study.

Future BIPV systems were thought to benefit from low production costs, minimal environmental impact, and high efficiency. Retrofitting and relatively easy BIPV installation have been mentioned as being important given the large number of existing structures[45][46][48][53][50].

Additionally, it was stated that legislative funding is necessary to attract investors, and that products for coating solar cells in particular provide excellent opportunities because they provide solar cell-specific concealment, light transmission, and power generation.

PCM technology, which uses materials that change from solid to liquid and vice versa to store and release heat, is another significant advancement. [7] Materials with phase transitions are employed for passive electrical heat regulation and heat storage. Similar to this, all of the PV-PCM each and every Photovoltaic that were examined have the ability to enhance the latent PV's temperature utilizing PCM.

Increasing organic cells' effectiveness, To maintain an organic cell at the ideal temperature for production, it could make sense to use a PCM.

Similar to how Li et al. (2015) introduced advances, approaches, and arrangements associated with BIPV implementations in residences during Solar Decathlon Europe, Li et al.

(2015) reported a few illustrations of BIPV/T systems from publications that were featured in a review combining solar power and warm (PV/T) systems[7][39][47][40].

BIPV is a more minor portion of the solar industry, but it is growing steadily. BIPV's extensive use is prevented by the lack of approved expectation re-enforcement necessary to decide on the specialized financial options. [44][45][46][47][48].

The current reproduction models also require input parameters that depict the electrical exhibition of BIPV boards under various weather situations. In a related article, the authors described how to conduct exploratory tests by setting important boundaries. The heated examination of double skin veneers with BIPV boards was done by Li et al. (2015)[7].

Studies were given hypothetical and published testing, and these investigations are set apart as usually ventilated systems and specifically ventilated with the effects of the outside environment.

The versatility of the system has led scientists to believe that it is more important than ever to explore precisely ventilated façades. Finally, researchers suggested that the major ranges of Reynolds' number be used to relate Nusselt numbers and convective heat transport linkages.

The center to subgroups as indicated by study issue, like is a construction application, reproduction and mathematical investigations, cell module configuration contemplate, lattice incorporation contemplate, and finally strategy and methodologies are examined, are also taken into consideration in the developments of BIPV and BIPV/T area[54][39][47][40].

The description of BIPV systems and their layout is provided in the opening section of the current investigation [44][45][46][47][48][53].

The BIPV/T and bilding integrated phtovoltaic systems described in the publications are then examined from the vivacious, financial, natural, and lively perspectives, their varieties and efficiency measures are provided in an organized format.

Similar to this, market-available BIPV solutions that address a diverse range of needs are finally introduced [49].

2.7 SYSTEM DESCRIPTION

Building-joined PVs (BAPVs) and building-integrated PVs (BIPVs) are the two main groups of PV systems used on structures.

BAPVs are included into the structure but do not immediately affect its capacity. However, buıldıng ıntegrated photovoltaıc systems are considered Photovoltaic panels that may well be combined into the exterior of the building (façade or to the rooftop) by swapping common tiles among other building supplies [55][56][57][58][59][60][61].

As a result, BIPVs affect how useful a structure is and are an essential part of its energy system [37][38][39][47][40]. In addition, numerous parameters need to be considered for the integration of PVs [55][56][57][58][26][59][60] into the building envelope as presented in Figure 2.6. below.

Figure 2.6: Parameters for PV Building Integration[43]

Table 2.1 introduces the information found in the studies. When there was no data, "N/A" was shown.." ". The base value is the number on the left when "-" is used between two integers. However, figures for different systems in related investigations or the effects under of the system consideration under Different situations are distinguished by a ";' indication.

As a result, in such instances, only the realized boundary is stamped, leaving other cells clear. In light of the reviewed articles, it is highly likely that many poetical and experimental considerations have been made up to this point, with a wide range of application to energy age restrictions. On the planet BIPV[54][39][47][40], various researches are also performed. Building application concentrations in Spain, recreation concentrations on the American mainland, cell and module concentrations in South Korea, and matrix, strategy, and technique concentrations in Australia are all more typical, as shown in Figure 2.7 below.

The majority of the systems were also enthusiastically and financially evaluated, with several including including ecological investigations. The parameters for PV building integration are shown in Figure 2.7 below, despite the enthusiastic evaluation of BIPV and BIPVT frameworks[7].

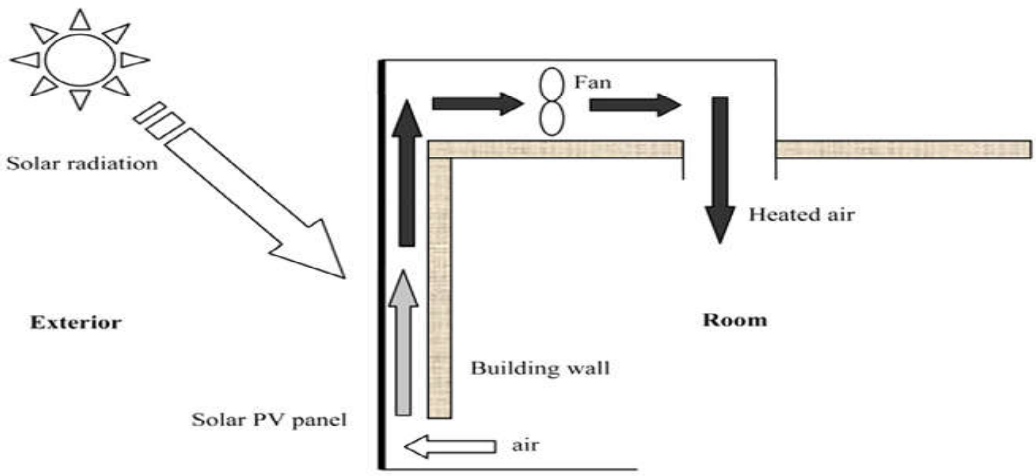


Figure 2.7: Schematic Illustration of a BIPVT System[43]

2.7.1 BIPV Concept and Development

A sizeable portion of power generation is assumed by building integrated photovoltaic (BIPV) systems [39][47][40]. Some audit reviews of BIPV systems have only recently been published, however they either provide a too general picture with insufficient specifics. (2017) about the construction of coordinated energy stockpiling apertures was examined [43].

A hallmark of the twenty-first century are opaque solar façades. They separated passive and active façades, two subgroups of opaque solar façades.

BIPV/T and BIPV systems are a component of active solar façades, which were described. In addition, they divided the previous research into categories based on its substance[62].

BIPV/T as well as BIPV technologies were shown to be advantageous. Biyik et al. (2017) stated that the translucent and transparent solar façades were organized under the same umbrella[43]. In order to better understand and examine BIPV/T and

BIPV systems that are transparent serve as dynamic façade systems [37][38][54][39][47][40] reviewed modern BIPV specialists in their investigation.

BIPV applications often follow advancements in PV cells due to this, they initially provided a few details about existing PV techies [57][58][26][59][60][28]. The BIPV products are on hand and categorized into four divisions, including barriers, tiles, modules, and products with sunlight-based cell coating.

The solar panel's recovered heat is used to cool the panel on the other side, enhancing its ability to produce power. The idea for green power systems was examined by Browne et al. (2015)[62].

Additionally, it was stated that legislative sponsorships are essential to gaining the business's attention and that, in particular, sun-based cell coating products have exceptional opportunities because they provide solar-based concealment, light transmission, and power generation. The creation of PCM is another significant improvement.

If the productivity of natural cells increases, A PCM could be used to keep a natural cell at the proper generation temperature. Similar to how exists a specific Potential of PCM due to the PV's high temperature [55][56][57][58][26][59][60][63].

Examples of BIPV/T frameworks were provided as an element of a summary of photovoltaic/thermal (PV/T) frameworks, along with advances, methods, and fixes for BIPV applications in Solar Decathlon Europe homes.

BIPV is a minor segment of the solar business, according to Li et al. (2015), but it is expanding steadily[7].

The broad use of BIPV is hindered by the absence of verified prediction models needed to make sound economic decisions.

The National Institute of Standards and Techy have compared the estimation of photovoltaic simulation tools to the performance of BIPV panels (NIST). The current simulation models need input parameters that define electrical efficiency of BIPV panels during exposure to varied weather conditions.

A comparable generator has demonstrated how to conduct trial testing by outlining important parameters. When twofold skin veneers with BIPV boards are warmly examined, Browne et al. (2015) can be recognized[62].

2.7.2 BIPV Advantages

- BIPV is more reliable than BIPVT's conventional PV systems[62].
- In the BIPV/T system, thermal energy is recovered from solar radiation by allowing a fluid, such as air, to flow through a canal beneath PV panels[38][54][39][47][40].
- BIPV/T systems can generate heat to partially meet building demand [39][47][40].
- For next BIPV frameworks, low production costs, minimal environmental impact, and high efficiency are crucial considerations.
- Due to the enormous number of buildings that are now in existence, retrofitting and relatively simple installation of BIPVs are crucial.
- BIPVs' effective heat transmission, which is important because temperature affects PV efficiency.

2.7.3 BIPV System and Components

BIPV is an encouraging innovation in the field of renewable energy. Research efforts focus on new plans to build proficiency at the system level as well, for example, new system setups, new cooling strategies, as well as at the PV cell level [55][56][57][58][26][59][60], for example, new photovoltaic materials.

In this work, an exhaustive survey of the current status of the craftsmanship in the BIPV innovation is provided. In a similar vein, BIPV/T systems first appeared in the middle of the 1990s.

This technology, which uses zero energy, acquired a lot of popularity in the middle of the 2000s, but it isn't nowadays because of its higher price when against PV and BIPV [37][38][54][39][47][40]. Due to its great productivity and ability to generate both heat and power, it is a potential breakthrough. Unquestionably, this subject will experience significant breakthroughs in the upcoming years.

Exegetical investigations are few in number and haven't been done significantly in most BIPV execution appraisal initiatives, which are focused on hot views.

With efficiencies ranging from 5% to 18%, the annual electric energy output of BIPV systems can range widely, from a few MWh to more than 100 MWh.

Furthermore, BIPV applications for both the façade and the housetop are commonplace.

In addition, there are important variables such the effect of shadowing, ambient temperature, the building's orientation, to get a higher power output and high productivity in experimental applications, and the slope of the PV.

Investigations were conducted for a variety of situations where at least one of these elements was modified simultaneously [39][47][40[The surrounding temperature condition that significantly impacts efficiency is a common research area for scientists.

Since they are easier and less expensive for system examination and planning, computational investigation and reenactment consider making up a significant portion of the tests in the coming years.

The ability to change the system for different designs is the biggest benefit of simulation reenactment. TRNSYS and Energy Plus programming are the two most frequently used programs for recreation [38][54][39][47][40][64][54] [39][47]. Additionally, one of the key focuses to achieve high efficiency and power output is without a doubt cell/module configuration.

Higher efficiencies have been achieved, according to studies on plans modified with different parts, by achieving.

There are now several different shaded boards to keep the module cool. Additionally, the fashionable positioning of the new BIPV module / cell plans should inform the consumer and then allow for unrestricted transformation.

In the majority of the thorough BIPV exhibitions, PV cells made of silicon have been employed. [37][38][54][39][47][40]. The recent decade has seen an increase in BIPV system revenue in line with general advancements in the photovoltaic cell, which decreased costs and made such BIPV ventures feasible.

A promising answer for BIPV applications is provided by the advancements throughout the dye-sensitized solar cell (Zhong et al. 2020); (Farghaly and Hassan, 2019). Grid integration for renewable energy energy sources works similarly when the BIPV system is considered in its entirety. This method tries to decrease power loss on electronic components, transformers, and long connecting lines by changing the designs of the circulation systems. In a manner similar to this, the range of BIPV combinations that are commercially available results in useful structures.

Experts have thought about concerns including organizing, examining, and providing information for the distribution of the proper use of strategy, as well as information on considerations.

It is typically assumed that the data exchange needs to be increased among partners and creative developments, and that reasons for enlisting financial experts need to be provided on this subject. [37][38][54][39][47][40].

BIPV systems were also categorized into three subgroups as building-integrated energy storage systems: Solar-powered BIPV systems [41] BIPV systems with grid integration and PV-Trombe walls [55][57][58][26] [59][60] [63]. For grid-connected BIPV installations, the grid was seen as a giant, infinite-cycle battery. [62].

2.7.4 BIPV Systems Applications

Currently, BIPV systems only account for a small portion of the PV market, The previous strong incentives were exclusively tied to "utility" products and were not age-appropriate, in addition to the false perception that BIPV mixtures are more expensive than regular rooftop installations, (sun based parks) [41][42][32][33][34][36][35]. As a result, efforts must be made to create and establish the multifunctional BIPV market.

For instance, according to the EU's 2020 goals, 3% of all open structures must be renovated year through that date (Timchenko et al. 2015). In addition, According to a EuroAce estimate, the EU would construct at least 5 million new structures annually over the following 40 years if every existing structure in Europe could get a basic and comprehensive refit until 2050.

There are around 160 million structures in the EU alone, accounting for roughly 40% of all vital energy use and 2/3 of all CO2 emissions.

They coincide in that the bulk of them were designed and put into action without considering passive energy productivity strategies or the combination of RESs for addressing dynamic energy interest, to an uneven energy use that results from the improper use of petroleum derived assets.

A BIPV niche market had so been initiated at that point. The various BIPV configurations will be described[41].

The Multifunctional PV is one of the BIPV options that is more in demand on the development market. It is a creative, productive design that is incredibly useful for providing dynamic, independent benefits to newly constructed or renovated facilities. With this layout, the structure is primarily equipped with the following preferences [41]:

- Distributed generation, a sustainable concept, is implemented in in-situ power generating to reduce energy transit losses.
- Thermal envelope benefits could be realized with energy savings ranging from 15% to 35%, depending on the design and PV glass configuration.
- In addition, heat recovery applications can be used with insulation techniques to provide pre-heating flow all winter long (Zhong et al. 2020; Farghaly and Hassan 2019).
- Daylight entrance directly to the design of semitransparent PV glass in accordance with the lighting requirements of the building.
- The acoustic advantages provided by the behavior of multifunctional façades are equal to those of conventional glass façades from the perspective of meeting the same regulations for construction applications.
- Simple structural and mounting requirements necessitate the use of aluminum staples, brackets, and profiles.
- When silicon technology is incorporated into constructive solutions like ventilated façades or double skins, the aesthetic added value is connected to a pretty visual component that is independent of the silicon technology (Yang and Athienitis, 2016).
- Defense against the effects of dangerous atmospheric conditions.
- The internal structure is less exposed to weather when vented façades or double-skin building techniques are applied.
- However, not all structures can apply this solution. Depending on how several needs are coupled
- When considering the current surroundings, aesthetic considerations directly relate to compatibility in terms of appearance [65].
- Dimensional requirements focused on customizability, separating the multifunctional facade from the existing solid wall, providing space for electrical and storage equipment, and providing the bare minimal amount of space needed for integration (minimum installed power: 1 kW).

There really are currently two basic sorts of workable options for boosting buildings' thermal envelopes or PV facades. Multipurpose Examples include a vented façade and a double skin of [55][56][57][58][26][59] [60][63].

Even though the engineering standard is identical in both cases, Depending on the use, there are significant variations.

The main difference between the two compositional strategies is the distinction between the façade and the current divider.

Similar to this, the hole is between ten and thirty centimeters (cm) to emphasize the latent features of the warm enclosure by giving attention to designs based on the hazy glass.

Double Skin Solutions, on the other hand, are more commonly used than the plan with foggy examples because they are more focused on other qualities like sunshine flow or the ease of doing support work between dividers. These arrangements include separations of between 1 and 1.2 m.

A PV skylight guarantees solar generation is optimized while also providing bioclimatic comfort within the building because the majority of UV and IR rays are absorbed using a silicon-based substance that serves as a sunscreen. Additionally, it is feasible to design and create a two-layer coating in which the outside glass is pv and common light can pass through [57][58][26][59][60][63].

The traditional glass used in building curtain walls can be replaced with photovoltaic glass in PV Curtain Wall applications, improving the envelope performance and enabling neighboring energy age.

In this kind of arrangement, the photovoltaic glass needs to be clear to some extent in order to provide natural light to enter the building. PV Canopy is a practical solution that combines power generation with sunlight-based weather protection capabilities.

The energy produced by the PV system can flexible close surrounding structures or can be infused into the lattice, achieving a significant financial benefit. When planning the covering, important factors including the direction, base incline, measures, wind, and snow must be taken into account. [58][26] [59][60][63].

PV A surprising walkable floor that is now licensed has been made using ONYX. A-Si sunlight-based cells are used to power the building's installation of photovoltaic tiles and triple-covered coating units, which are designed to function as a walking floor. The PV tiles passed the counter slip criteria and supported 400 kg in the point load test.

A photovoltaic parking structure makes up the Photovoltaic parking lot arrangement, and the PV establishment makes sure that there is enough local electricity available to recharge an electric car's batteries as needed.

Similar to the previous arrangement, this one aims for the highest possible energy production and the greatest protection from unfavorable weather conditions[65], such as downpours and wind, by using a securing structure coordinated in the module, shaped through a portable wood board over the external essence of the photovoltaic boards.

New trends in BIPV configurations are focused on PV urban mobility applications like seats, tables, or shades. These creative solutions were developed with the intention of turning common outdoor furniture into charging stations for electronic devices, providing free passages to onlookers where they may charge their gadgets (Phones, Tablets, etc.).

Each of these BIPV solutions guarantee a bright future for distributed energy methods as an energy-productive approximation for upgrading as well as solar options for new structures built in accordance with financial constraints [41].

PV organization is substantially impacted by system costs ($/WP DC). According to an NREL study [65], the added costs of BIPV systems are typically higher than those of PV structures, although the reasons behind these costs are unknown and may involve higher expenses, higher margins, or other factors. According to the analysis from 2011, Potential for c-Si BIPV exists to achieve a less introduced structure cost.

This is revealed by a basic examination of BIPV system components and building costs.

They came to the conclusion that improved PV techniques would result in BIPVs that were more effective and required little effort, that would lead to shorter payment periods.

Yang and Athienitis (2016) conducted a thorough research of the noteworthy developments of various BIPV/T structures, which is given [41].

Since 2000, the BIPV/T systems, that were developed starting in the mid-1990s, have attracted growing interest due to their capacity to assist in the creation of net-zero energy structures employing increased sun-oriented energy utilization. [41][42][32][33][34][36][35].

The BIPV/T system plan and the effects of the BIPV/T structure on the execution of the structure have been the subject of numerous articles reporting testing and mathematical examinations. Air-based systems, water-based systems, focusing systems, and structures with a stage change working medium are among the BIPV/T structures that have been explored [34][35].

A BIPV/T with a heat line or warmth siphon evaporator is another illustration. A building-integrated photovoltaic with thermal energy recovery offers a very good potential for integration into the building that requires zero energy, despite the fact that this technology is not commonly used [65].

Building application describes studies carried out at a research center or on a building. Various analyses of the model or structure were carried out. Module proficiency is typically low in hot environments.

This key topic is the subject of numerous investigations. These investigations show that warmth retention at the PV's back increases productivity [55][56][57][58][26][59][60][63].

In order to achieve higher force yield and efficacy in structural applications, other factors such as the shadowing effect, ambient temperature, the heading of the structure, and the slope of the PV have a significant influence.

The results of two extraordinary BIPV systems' testing have been released by Omer et al. [42][32][33][34][36][35]. The system had a tilt angle of 52 and monocrystalline PV roof slates[41].

The first BIPV (SYS) had an annual system efficiency of 2 percent on average, compared to 3.6 percent for the second system. Additionally, it was determined that neither method was economically viable in 2002, given the cost of electricity at the time.

(Li et al. 2015); ESP-r building energy modeling software was used to computationally model a 260 m2 BIPV system.

With a 250 mm air gap between the modules and the building, they were mounted. This opening enables the heating of the air, which is then used to warm the water.

Yang et al. conducted an experimental investigation on the effectiveness of the first BIPV system put in place. Additionally, there was a space for air between the PVs and the wall to allow for cooling and boost effectiveness.

According to the findings, the roof was where the most electricity was produced [41][33][34][36][35].

However, the concentrating structure's transformation productivity was 6.8 percent compared to the non-concentrating system's 8.6 percent. Additionally, it was explained that the innovative system's typical cell temperature is higher than that of the non-concentrating structure. For the warmth move of a BIPV part, a nonlinear first-request stochastic differential condition was developed.

A PV module made up of 121 polycrystalline Si cells with a 1.44 m2 area was used in a series of meticulously controlled trials to help build the model. Additionally, it was found that the suggested method facilitates the display of nonlinear stochastic warm miracles in BIPV systems. The BIPVT system was examined using three different settings.

The air-based BIPVT system of a solar home was subjected to thermal testing [41]. The BIPVT system was also combined with a vented solid piece (VCS) design to offer dynamic sun-oriented heating [42][32][33] [34][36][35].

More than 3000 kWh of power were reportedly used annually. A dryer, an air-to-water heat exchanger to disperse locally produced high temperature water, and a VCS were also provided as three original solutions for using the warmed air produced by the BIPVT system [41].

Additionally, a semi-two-dimensional control volume that is in line with state theory was created.

Additionally, it was claimed that the model might be used to compare systems and control wind streams. The findings indicated that while lowering total PV working temperatures, the BIPVT system may greatly increase warm energy generation.

The temperature rise of the air flowing through the gatherer at a 250 L/s stream rate on a sunny day is discovered to be between (30-25) 0C.

Additionally, this rise in temperature corresponds to an increase in warm energy of (8.5–10) kW. In contrast to earlier work, a 3D control volume, explicit finite difference thermal model was developed for the VCS system. How the VCS framework from (Li et al., 2015) was created was explained.

The VCS structure was also sized for a typical bright Canadian winter day, assuming a 4-hour air temperature of 400 C and a flow rate of (250) L/s.

Experimental analysis of the VCS system's performance revealed that it can store between 9 and 12 kWh of thermal energy in six hours.

Li et al. (2015) claim that the application of the BIPVT system was investigated. A continuous mass flow of 1.2 kg/s was delivered through the ducts by a 0.12 kWp air blower that was also part of the system[41].

With a typical overall warm efficacy of 53.7%, the system's electrical and thermal exergies were found to be 16,209 kWh/y and 1531 kWh/y, respectively. Additionally, it was expected that an equal blend would present optimally for constant airspeed and would perform better for constant air mass flow rate than an arrangement-related structure.

The structure was thermally shown and dissected in Srinagar and Bangalore under the appropriate local environmental conditions in a comparable experiment [65]. It investigated a BIPVT structure that was affixed to the housetop of a research facility building to find out the temperatures of the sun-oriented cell, channel air, and room air [41].

The system's PV modules are displayed in [7]. (Li et al. 2015). Six 12W fans were used to move the air through the conduits.

According to the findings, the recommended system performs admirably for both moderate and cold atmospheres in terms of annual electrical energy and exergy creation sums when compared to a conventional BIPV system.

The electrical efficiencies were determined to be between 12.5% and 16%, whereas the thermal efficiencies ranged from 50% to 54%. A scientific assessment of the presentation of hazy and murky BIPVT systems for rooftops and façades was done [7], in contrast to the previous two investigations, and two choices were taken into consideration[41]:

- The BIPVT system, both when it has an air duct and when it doesn't.
- For the systems utilizing air ducts, the air mass flow rate was set between 0.85 and 10 kg/s.
- The semitransparent and opaque BIPVT systems with an air duct were found to differ from the systems without an air duct by 9.80^0C.
- The semitransparent BIPVT framework lacked an air duct and the ambient air temperature was 4.4^0C.

2.7.5 BIPV Educational Institutions

BIPV techy represents the opportunity for a triple advantage in building design. It bridles solar-powered energy [42][32][33][34][36][35], addresses a few impediments of utility-scale PV, and converts the structure from an energy buyer to an energy maker as a multi-utilitarian part [41][66]. In tackling solar-powered energy, it uses environmentally friendly power from the sun which gives more energy in one hour than all individuals on earth need for an entire year [38][66].

It additionally gives decentralized nearby energy directly close to the point of use, subsequently, decreasing transmission and change misfortunes, just as subordinate costs constraints with utility-scale PV (Attoye et al. 2018). Likewise, it fills in as a multifunctional energy-delivering building part used for material, cladding, coating, or concealing (Attoye et al. 2018). The worldwide BIPV market saw a 35 percent development between (2014 &2015) from an expected 1.5 (GW) to 2.3 (GW) [41].

In any case, the commitment of BIPV to the energy limit added through Solar PV in 2016 was 1 percent - being about 3.4GW of the complete from Solar PV about 303GW[41][66].

Thus, though BIPV technology has different advantages and has been in open spaces throughout the previous thirty years, its reception rate in the fabricated climate is restricted [66].

Likewise, BIPV Barriers from the discoveries of a few investigations expressed before, six general classifications of boundaries have been distinguished.

Every one of these boundaries typifies a novel arrangement of difficulties to BIPV appropriation; further clarification of every boundary class is introduced as recorded underneath.

2.7.6 Educational Barriers

- Lack of sufficient technical knowledge via architect [41].
- Few certified BIPV contractors available [41].
- Poor public understanding and cost perceptions of BIPV [41].
- Lack of appropriate products for architects [41].

2.7.7 BIPV Economies

Economic barriers:

- High Price of BIPV systems, Expected Pay Back Time (EPBT), and Maintenance costs for modules [41].
- Lack of governmental incentives [66].
- Low government support as well as developers' reluctance[67].

2.7.8 BIPV and Buildings Architecture

Building-integrated photovoltaics (BIPV) are photovoltaic materials used to replace conventional building materials in certain areas of the structure envelope, such as the roof, observation windows, or exteriors. [68][44][52][41][69]. Additionally, they are increasingly being incorporated into the creation of new structures as a primary or secondary source of electrical power, even though older facilities may be retrofitted with a comparable geek [44][52] [41]. Additionally, the advantage of integrated photovoltaics over more conventional non-incorporated frameworks is that the initial cost can be offset by reducing the amount spent on labor and building supplies that would typically be required to develop the portion of the structure that the BIPV modules replace [44][52][41][69]. BIPV is moreover one of the photovoltaic manufacturing industry's fastest-growing industries [44][41][69] due to these areas of emphasis. The architectural design elements of BIPV frameworks, including how to plan BIPV structures, the longevity of such systems, and whether to select BIPV or BAPV, were given careful consideration. [42][32][33][34][36][35]. Similarly, the innovative mounting system resolves problems with PV part maintenance and replacement. Furthermore, it was considered that needs other than high blend were higher in terms of labour, money, nerd, and style. Additionally, Since PVs have a shorter lifespan than structures—50 years—

simple maintenance as well as the replacement of PV modules are essential, it was said.

Research was done on the force age ratios of the two systems. The primary structure also had a 3.072 kWp BIPV system [42][32][33][34][36][35]. Additionally, the brief film a-Si geek was employed, and 24 flexible modules were used (128Wp each). Additionally, the resulting system was a twisted, 12 kWp PV structure consisting of 88 flexible sheets and thin film a-Si overlays.

The results also revealed that the primary system produced 1265 kWh/kWp annually, which was greater than the subsequent structure's (1110 kWh/kWp), which is roughly 88 percent of the primary systems. Additionally, the bending structure's yield was slightly higher in the late spring period.

They concluded that the ensuing system achieved a good balance between structure and capacity in this way. Additionally, a BIPV system's X" In [7]transient thermal analysis was carried out experimentally [41]. The experimental setup also included a Plexiglas panel and a PV panel. A canopy was also constructed on the frame's exit, and two distinct axial fans were used, each with a different capacity. Nevertheless, there were three stages to the experimentation.

No fan was used in the first mode, whereas fans were used in the second and third modes at flow rates of 110 m3/h and 190 m3/h, respectively.

Additionally, the findings indicated that higher airflow rates boosted overall heat transfer and cooling, which led to larger fan capabilities. Li et al.

(2015) investigated the first BIPV use in practice experimentally. [7][42][32][33][34][36][35]. The windows were also equipped with translucent thin-film a-Si cells, as shown in Figure 2.5 BIPV Hierarchy of Form Source, which is displayed in Figure 2.8 below.

The PV arrays were also linked eight times in parallel and six times in series.

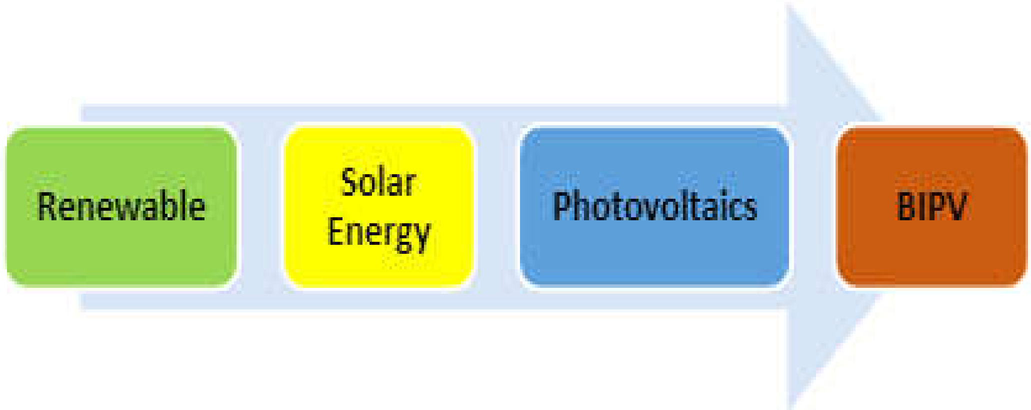


Figure 2.8: BIPV Hierarchy of Form Source[38]

Li et al. (2015) studied the system for two years and computed the system's monthly energy output. A total of 580.5 kWh/kWp of power were reported to be produced annually[7]. Additionally, simulations showed that the azimuth and shading effects, together with the BIPV/BAPV systems for the existing 496 single-family residential buildings, may be altered to improve the amount of electricity produced by the system by up to forty-seven percent. Furthermore, the results showed that 87 percent of PV packs would be able to generate 95 percent of the highest possible potential, but only 3 percent of the structures would be able to provide 85 percent of the highest hypothetical yield.

The packs would also have the ability to generate 40% of the personal annual energy consumption of the structures, it was further implied. A BIPV structure's effects on power generation, cooling, and energy conservation were also evaluated. But the delicate film a-Si triple junction solar cells that made up the structure were [41]. Additionally, with the installation of the BIPV, the solar absorptance of the roof dropped from 0.75 to 0.38 [42][32][33][34][36][35].

The system's daily energy production range, according to the results, was 0.15 kWh/m2 in the winter and -0.4 kWh/m2 in the summer. Additionally, the system's average efficiency for the full assessment period was found to be 4.6 percent. Even though the repairs to the HVAC system made it impossible to quantify the impact on HVAC energy consumption.

The structure's envelope was compromised by the electrical and thermal efficiency of a PV system inserted as cladding segments. Additionally, a test reference climate was used for the tests (TRE). The glass-Tedlar PV module also performed electrically better than a standard glass PV module. The information obtained after that was put to use for the subsequent course of events and acceptance of a numerical model. A twofold skin BIPV structure was additionally shown. Similar to this, exploratory work was conducted in the Lleida test reference climate (TRE-L) [42][32][33][34][36][35]. The TRE-L was also a highly protected wooden box that could be shaped anyway the user desired.

Over the course of a half-year, the examinations for two unique inclinations (vertical and 300) and seven flow rates were accomplished. Additionally, the Continuous-Time Stochastic Modeling (CTSM) programming language was utilized for the demonstration cycle, and the Dim box model was used as the stochastic approach. Furthermore, it was deduced that the two-state dim box model accurately represented the structure's components. Additionally, a Test Reference Environment (TRE) was established, allowing the evaluation of test data for the electrical and warm execution appraisal of double-skinned BIPV structures. The specifications of a typical TRE, problems related to the geometry, instruments, experimentation method, and calibration, were also detailed using the expertise obtained throughout the creation of various European research programs over a ten-year period. Additionally, it was determined that although IEC standards describe the examination of electrical performance data, BIPV systems are not included. Additionally, it was suggested that the study's outdoor test environment serve as the standard TRE for assessing the electrical and thermal efficiency of BIPV applications[41].

2.7.9 BIPV Software

Calculation software's used in this case to save time in arriving at the required results in a very short time, with the needed reasonable accuracy. Furthermore, several PV application software has been developed over the last few years. Moreover, a search has been carried out here to obtain suitable software for this study's calculation purpose. What's more, the software availability was the most important factor in this selection, as well as its adequacy to carry out the needed calculations. Likewise, with flexibility, functionality, and ease of operation, upon this process, the PVSYST software has been chosen. In addition, it was developed by the energy group (CUEPE) at the University of Geneva, Switzerland, to be suitable for grid-connected, stand-alone, pumping as well as a dc-grid public transport system.

This software handles the calculations and helps in the design of the photovoltaic generation of electrical power particularly for building-mounted PV systems, at the different stages of the projects, including the assessment, planning, design phases calculation, and so on. Furthermore, through its stored design database and tools. Additionally, the user has to specify the geological location of the site to be served, and hence the meteorological data of the same. Besides, other details are worked out such as the basic system variables, the orientation of the PV system modules, as well as the required power or the allocated area, and the rest of the system components' choice details; the battery, the inverter, and the wiring system. Additionally, with all of these details, the software calculates and proposes a system configuration for the given and found data. In addition, the proposal given through the software may be modified to care for the user requirements as well as conditions.

Table 2.2: Software used in the Simulation Studies

Software	Purpose	Authors and years
BIPV	Analysis and Simulation	[46][42][32][33][34][36][35]
PVsyst	Examination of the data and PV modeling	[45][47][48][49][50][51]
ESP-r	Calculating the photovoltaic system's power output	[45][47][48][49][50][51]
PHEON_ICS	BIPV Simulation and Analysis	[46][52]
EnergyPlus	BIPV Simulation and Analysis	[7][52]
Green Building XML BIPV	Simulation and Analysis	[7][52]
PHEON_ICS	BIPV Simulation and Analysis	[46][52]
EnergyPlus	BIPV Simulation and Analysis	[7][52]

2.8 UNIVERSITY RANKING SYSTEM

An "organizational report card" that gives clear ranking criteria for institutions is called a university ranking [77]. Rankings demand accountability from the general population and offer feedback to service providers. Organizational report cards are well-known strategic tools, given their growing importance in consumer decisions and the politicians' growing irritability with instances of poor quality and exorbitantly expensive social service delivery [77]. Ranking systems are unavoidable from the perspective of public policy since stakeholders want to know how money spent in institutions is managed [78The university ranking system is used by prestigious universities in the US and the UK. They are able to enhance their international brands and advance their academic standing as a result. As a result, these nations could draw in young, gifted students and increase revenue for their universities and the country at large [79].

2.8.1. Importance and Implication of University Rankings

University rating processes have had both positive and negative effects on universities. In general, universities have significantly aided a nation's transition to sustained economic growth [80].

The study also found that engineering and natural sciences contributed more in terms of nation-building, compared with the humanities fields. [81] Levin argued that a few countries in East Asia, such as Japan, Singapore, South Korea, Taiwan, and Hong Kong, recognized the importance of educated human resources to national economic growth. Therefore, investment in education had reaped the rewards in these countries, particularly China and India, which are seeking to gain control of the regional economy by 2050. In the chase to elevate their rankings, universities have been under constant pressure to perform their very best [82] . This includes increasing the volume of publications in reputable academic journals indexed in leading bibliometric databases, such as Web of Science and Scopus [83]. Governments and university administrations both want to see their institutions' rankings rise. This is accomplished by enhancing the available facilities and human resources, which serve as leading indications in university rating processes [84]. These initiatives have resulted in enormous costs, which, if mismanaged, could cause a significant drop in a university's advancement. Some prominent colleges prefer to spend money on other areas that fit with their vision for the institution in terms of beliefs, socioeconomics, and culture - areas that are not prioritized in university ranking systems. In other instances, inefficient utilization of the limited finances prevents universities from making purchases. Even though a university spends in certain situations, its rating does not rise.

Individual universities experience pressure as a result of the rankings because it has an impact on their operations. Some people might succumb to the temptation by using previous data to "overshadow" their standing in an effort to "create narratives that modify their ranks to showcase their strengths" [85]. Academic communities may become competitive as a result of university rankings. Greater compensation structure disparities were found among research-oriented institutions than teaching-oriented universities, according to a study on salaries and rankings

[86]. The consequences of university rankings seemed to be the cause of the discrimination. The majority of a university's academics may feel more confident as a result of its high ranking, yet there is a possibility of academic corruption.

CHAPTER III

METHODOLOGY

In this chapter, the methodology of this work is considered. Furthermore, the software used in the calculations is selected and described, and the parameters of these calculations are introduced. Moreover, calculations are carried out using the selected software, and the site region parameters for different cases, to get the output at different sets of parameters, and hence through analyzing these results proposing the most suitable set of these parameters.

3.1 THE METHOD

This study tries to optimize the selection of the most economically suitable PV system variables, using PVSYST Software and Multi-Criteria Decision Making (MCDM). This forms a multi-variable system optimization through a direct and simple method that may be applied when choosing the best system, among others. The variables concerned are shown in Table 3.1.

Table 3.1: The Variables Concerned in The Study

Mono-crystalline, poly-crystalline, or thin film	PV modules
The angle the modules make with the horizontal plane is usually manually adjusted	Tilt angle
The horizontal angle measured clockwise from a north line	Azimuth angle

Calculating through each case of the system, the outcomes are; energy yield in kWh per year, the system cost, the produced energy cost per year, and the specific energy cost of the system in monetary units per kWh. The constant parameters are the area of the PV system which is considered here as 100 square meters and the case site, which is Ankara, Turkey, with its climatic conditions, including a yearly .

average solar radiation of 3.6 KWh/(m2 day)m) and, a total yearly insulation period of approximately 2460 hr. Yielding around 1825 KWh/m2 [20].

It is assumed here that the university is considering using PV systems to supply the electrical power needs of some of its campus buildings. At this stage of planning for such an undertaking, the university has several options of choices of different PV systems. The method introduced here may be used to optimize the university PV system selection. For determining the best option, on comparing the available ones, the same site information and the typical 100 square meters PV surface exposed area will be used.

The optimization method is carried out in two stages, first the energy yield and the specific energy yield cost are calculated for each possible case of the systems mentioned with all variables. From these calculations, the highest energy yield is considered as a base, with all the other cases' energy yields relative to this base per unit. Next, the lowest specific energy cost in Euros per kWh is taken as a base, with the rest cases' costs as relative values per unit. Each of these two merits; the annual energy yield and the generated energy cost per kWh are considered of equal weight and each is hence multiplied by 0.5 as a relative weight. and are added together to give the total merit of each case, these are then arranged in descending order to give a priority list of the best PV system selection.

The soft-wares used in the performance calculations have databases that are automatically market updated giving the available PV systems, batteries, inverters, protection and control systems, together with their capital costs, and estimated operation and maintenance costs as a percentage of their capital.

The software calculates the energy yield per year, using the solar radiation level at the site, the total module exposed surface area, and the module's efficiency. The useful life of the systems, as well as the annual interest rate (rate of return) in percent per annum, are also given for calculating the total specific produced energy cost by adding the capital (constant) cost and the running (variable) costs, each per year, and then calculating the energy produced costs as shown in Table 2.

This gives the optimum system from the points of view of the highest energy yield and the lowest specific energy cost, under the given conditions and information. In the typical case study conducted applying this procedure, the site gives its average solar energy density in kWh per square meter per year. The calculations are then carried out in steps using the help of the software PVSYST [87] selected here for its availability, simplicity of operation, and, giving of straightforward results.

3.2 PVSYST SOFTWARE

Calculation soft wares are used in this case to save time in arriving at the required results in a very short time, with the needed reasonable accuracy. Furthermore, several PV application software has been developed over the last years. Moreover, a search has been carried out here to obtain suitable software for this study's calculation purpose. What's more, the software availability was the most important factor in this selection, as well as its adequacy to carry out the needed calculations. Additionally, with flexibility, functionality, and ease of operation, upon this process, the PVSYST software has been chosen.

A full software suite for researching, sizing, simulating, and evaluating PV systems is called PVSYST. Additionally, this software is a fantastic instructional tool and is created for usage by academics, architects, and engineers. The software also has a thorough text-based help menu that provides an accessible technique for project development and explains the concepts and methodologies employed. PVSYST may import both private information and meteorological data from other sources. It was created by Michel Veloz, an electrical engineer, and Swiss scientist Andre Mermoud. Furthermore, this program is regarded as the benchmark for PV design and simulation systems globally.

Rapid estimation of production at the project planning stage, detailed study, sizing, hourly estimation, and reporting are key features of this program. Likewise, it allows a high level of control over various factors. In addition, the features and Specifications of this software can be summarized as follows [88]:

- Decide on the region or power source that is available.
- From the internal database, choose the PV module.
- From the internal database, choose the inverter.
- Offer a system and array setup for the first simulation.
- Display the PV array's I/V curve, inverted MPPT range, and restrictions on voltage, power, and current.
- Display the annual power distribution matrix.
- Offer specific instruments to evaluate system unavailability, thermal behavior resulting from mechanical installation, unit incompatibilities, and wiring damage (as well as other losses like unit quality).

• Total annual energy output measured in megawatt-hours to determine the PV system's financial viability.

• kWh/kWp output index based on radiation availability; specific energy (location and orientation).

• Display the simulation's main power and any gains or losses.

• A potent tool for quick system behavior analysis and future design enhancements.

• Direct location search on Google Maps.

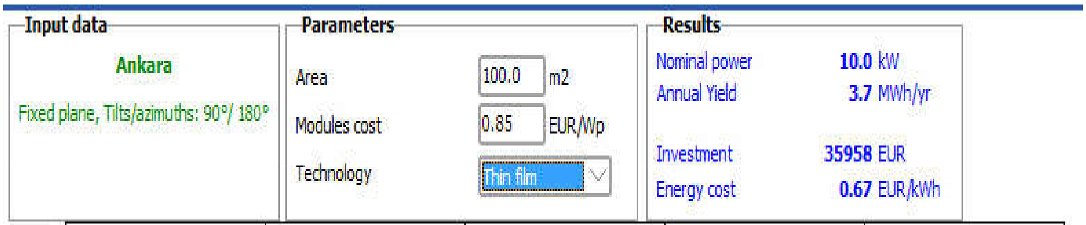
• Determine each inverter's input electrical circuit.

• Better control over project parameters, copy, and form.

• Resources for enhancing parameter values.

The library of the PVSYST software contains detailed data on the most common PV modules, inverters, and whatever is required for a PV system project. Moreover, it accounts for losses due to the partial shadowing effects, mismatches between connected PV modules, wiring losses, inverter losses, and the effect of the ambient temperature variations on its electrical output power N calculation [89]

This software handles the photovoltaic generation of electrical power particularly for buildings, including assessment, planning, design, calculations …etc. through design, database, and tools. Furthermore, the user has to specify the geological location of the site to be served, and hence the meteorological data of the same. Moreover, the other details have to be worked out such as the basic system variables, the orientation of the PV system modules, as well as the required power or the allocated area, and the rest of the system components details choice; the battery, the inverter, the wiring system …etc. What's more, with all of these details, the software calculates and proposes a system configuration for the given and found data. Besides, the proposal given through the software may be modified to care for the user requirements or conditions. In addition, details of PVSYST and its use are provided in its user manual and publications, while Figure. 3.2. Figure 3.3 show the software interfaces as well as Ankara parameters.



	Horizontal global kWh/m²/day	Coll. plane kWh/m²/day	System output kWh/day	System output kWh
Jan.	1.67	0.56	4.79	149
Feb.	2.36	0.76	6.41	180
Mar.	3.15	1.02	8.67	269
Apr.	4.65	1.41	12.00	360
May	5.29	1.79	15.16	470
June	6.40	2.03	17.25	517
July	6.49	2.06	17.47	541
Aug.	5.68	1.53	12.96	402
Sep.	4.23	1.16	9.88	296
Oct.	2.87	0.88	7.47	232
Nov.	2.18	0.70	5.93	178
Dec.	1.77	0.56	4.76	148
Year	3.90	1.21	10.25	3741

Figure 3.1: Software Interfaces as Well as Ankara Parameters

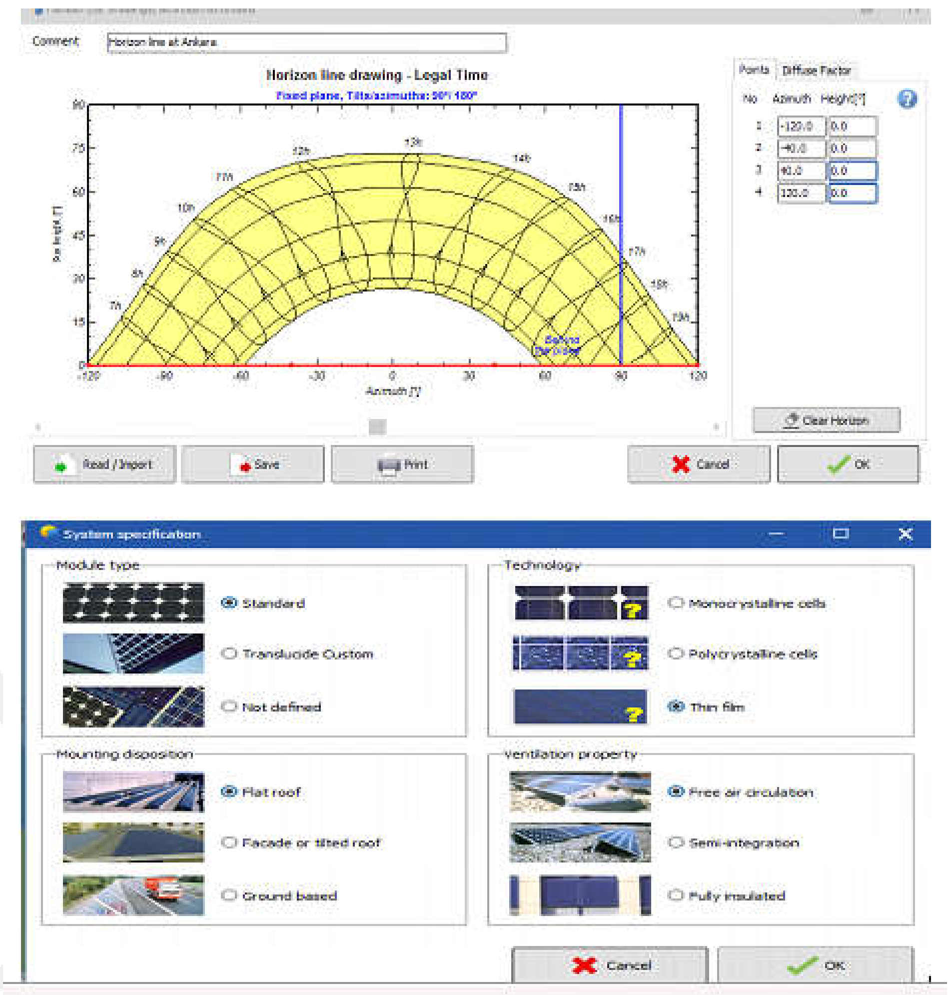


Figure 3.2: The Software Interfaces as Well as (Ankara) Parameters

3.3 SYSTEM PARAMETERS

The calculations carried out here through the selected application software PVSYST are carried out using a solar module area of 100 square meters at various relevant parameters, mainly the following:

The tilt angle: it is the angle of the solar PV module inclination from the horizontal axes. Here it is taken as the main variable against the generation costs at different sets of the other parameters. The angles considered are 0°, 45°, 30°, 90°, 120°, and 180° degrees, while Figure. 3.4. Figure 3.5 shows the tilt angles used,

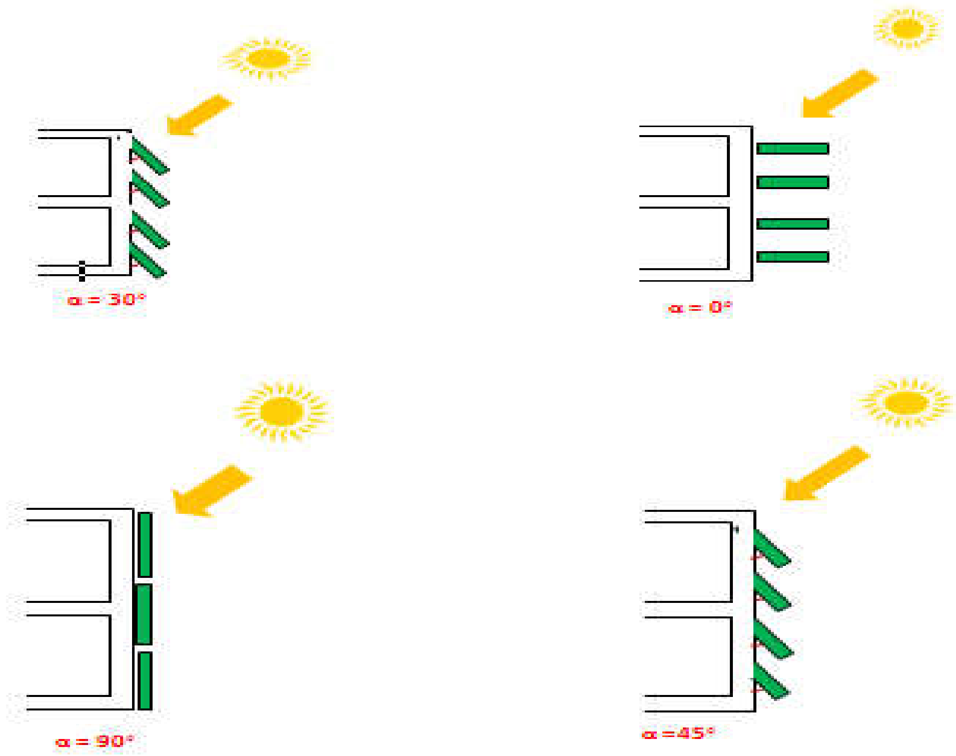


Figure 3.3: The Tilt Angles Used for Façade

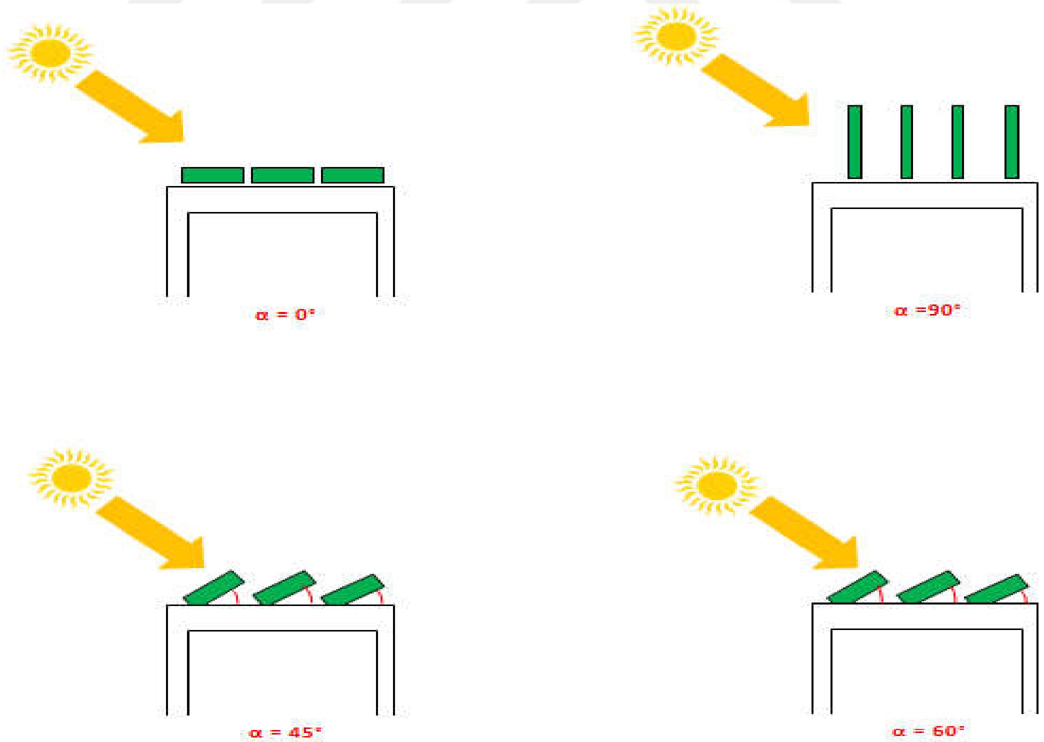


Figure 3.4: The Tilt Angles used for the Roof

- The azimuth: here it is the angle between the sun and the north direction measured clockwise at the observation point level

- The mounting disposition: The method of the solar module, either on a flat roof or on a façade of a building.
- The PV technology: monocrystalline, polycrystalline, depending on the number of Silicon crystals in each of the module cells; either one crystal for the monocrystalline, or many crystals for the polycrystalline, or thin film
- The annual yield: the energy generated per year, in MWH/Year.
- The total yearly cost: the cost of the generated energy per year in Euros/year at the assumed cost rates
- The energy cost: the generated energy cost per year in Euros/KWH at the assumed rates.

The following tables represent the software output for different possible cases. Furthermore, these will be made use of in the upcoming chapter on a case study application.

3.3.1. Electrical Energy Production of PV Panels at a Tilt of 30° and Changing the Other Parameters

3.3.1.1 Electrical Energy Production of PV Panels at a Tilt of 30° and Azimuth 0°

Based on this part with a tilt of 30°, the changes will be only in PV technology, fixing the other parameters, Azimuth 0° as presented in Table 3.2 and figure 3.5 below

Table 3.2: Electrical Energy Production of PV Panels at a Tilt of 30°, Fixing Azimuth of 0°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr.	Energy cost EUR/kWh
30	0	Monocrystalline	22.4	0.15
30	0	polycrystalline	21	0.15
30	0	Thin film	14	0.18

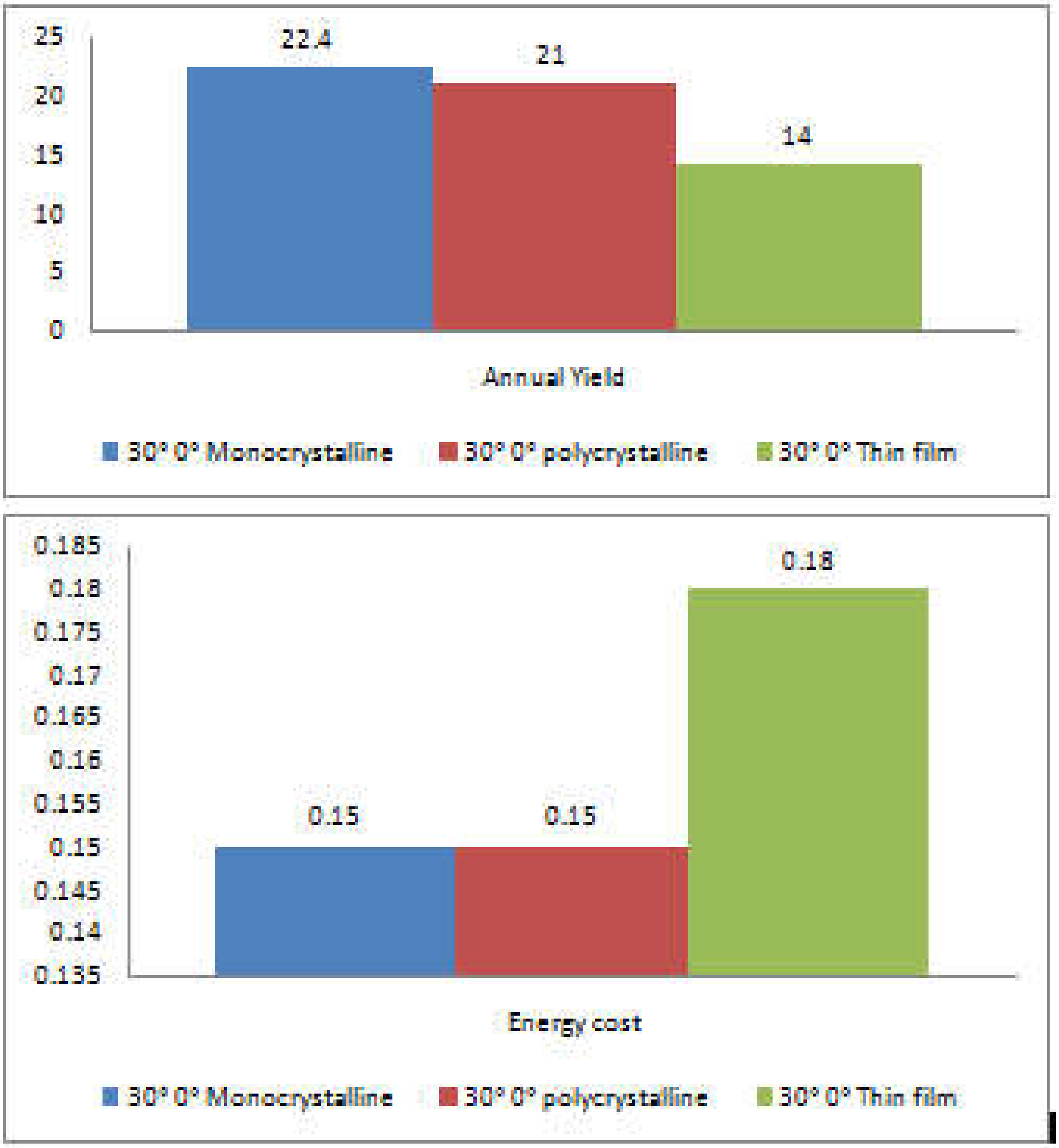


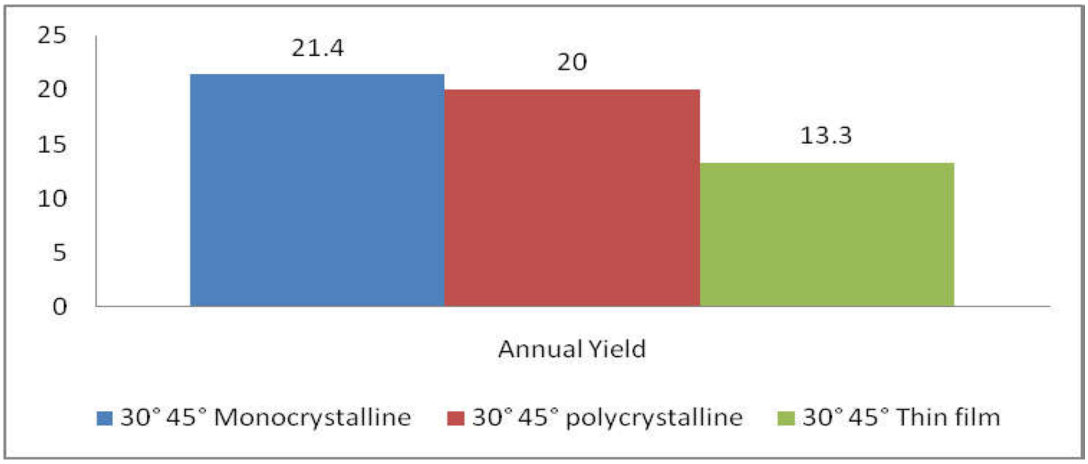
Figure 3.5: Annual Yield and Energy Cost of PV Panels at a Tilt of 30°, Fixing Azimuth at 0°

3.3.1.2 Electrical Energy Production of PV Panels at a Tilt of 30 and Azimuth 45°

In this part the change will be only in PV technology fixing the tilt at 30°, Azimuth 45°as presented in Table 3.3 and Figure 3.6 below.

Table 3.3: Electrical Energy Production of PV Panels at a Tilt of 30°, Fixing Azimuth of 45°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr.	Energy cost EUR/kWh
30	45	Monocrystalline	21.4	0.16
30	45	polycrystalline	20	0.16
30	45	Thin film	13.3	0.19



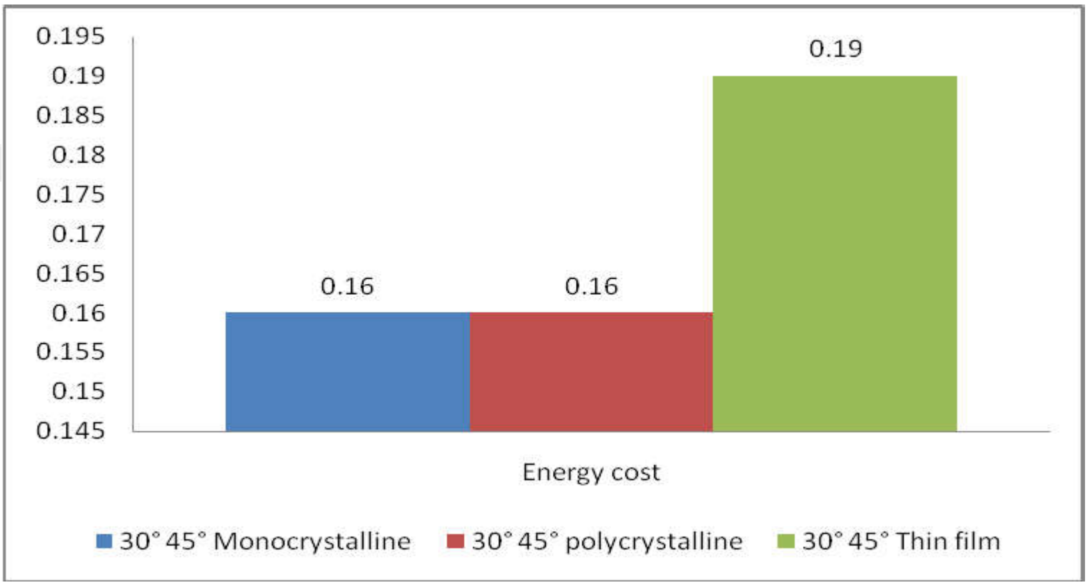


Figure 3.6: Annual Yield and Energy Cost of PV Panels at a Tilt of 30°, Fixing Azimuth at 45°

3.3.1.3 Electrical Energy Production of PV Panels at a Tilt 30° Fixing Azimuth at 120°

In this part, the change will be only in PV technology fixing the tilt 30°, Azimuth 120° as presented in Table 3.4 and Figure 3.7 below.

Table 3.4: Electrical Energy Production of PV Panels at a Tilt of 30°, Fixing Azimuth at 120°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
30	120	Monocrystalline	16.3	0.21
30	120	polycrystalline	15.3	0.21
30	120	Thin film	10.2	0.24

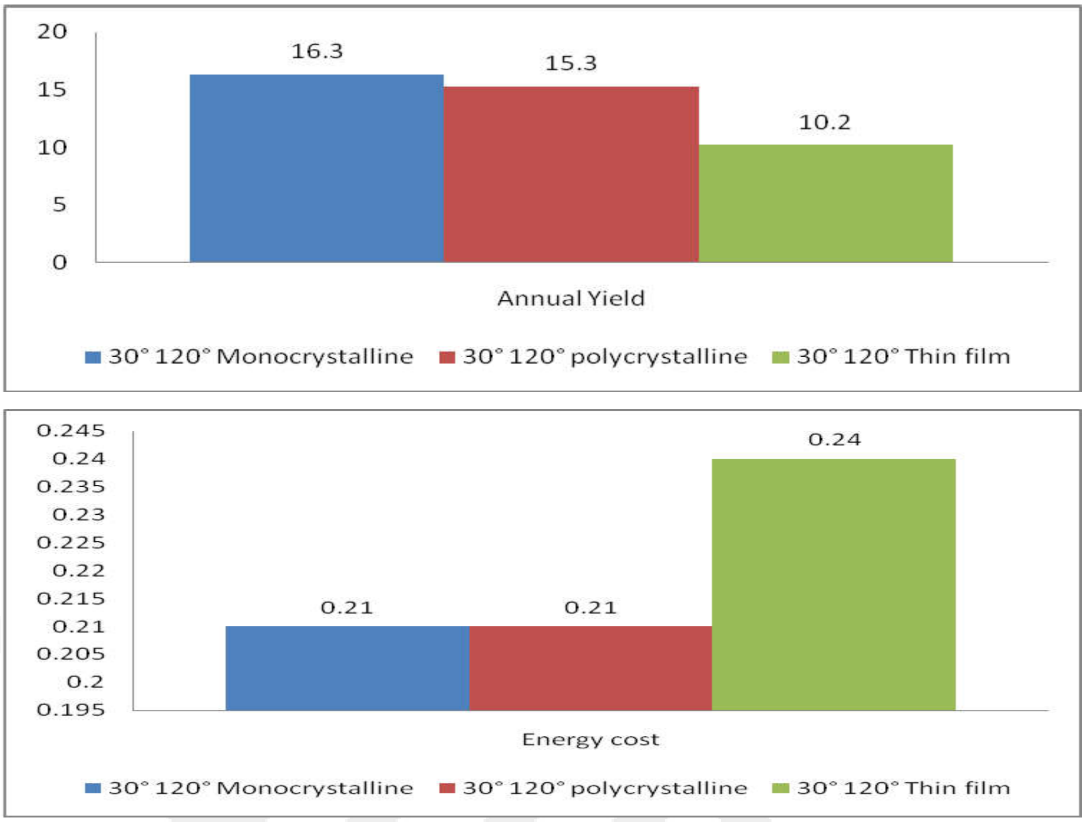


Figure 3.7: Annual Yield and Energy Cost of PV Panels, at a Tilt of 30°, Fixing Azimuth at 120°

3.3.1.4 Electrical Energy Production of PV Panels at a Tilt of 30° and Azimuth of 90°

In this part, the change will be only in PV technology fixing the tilt at 30°, Azimuth 90° as presented in Table 3.5 and Figure 3.8 below.

Table 3.5: Electrical Energy Production of the PV Panels at a Tilt of 30°, Fixing Azimuth of 90°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
30	90	Monocrystalline	18.6	0.18
30	90	polycrystalline	17.4	0.18
30	90	Thin film	11.6	0.21

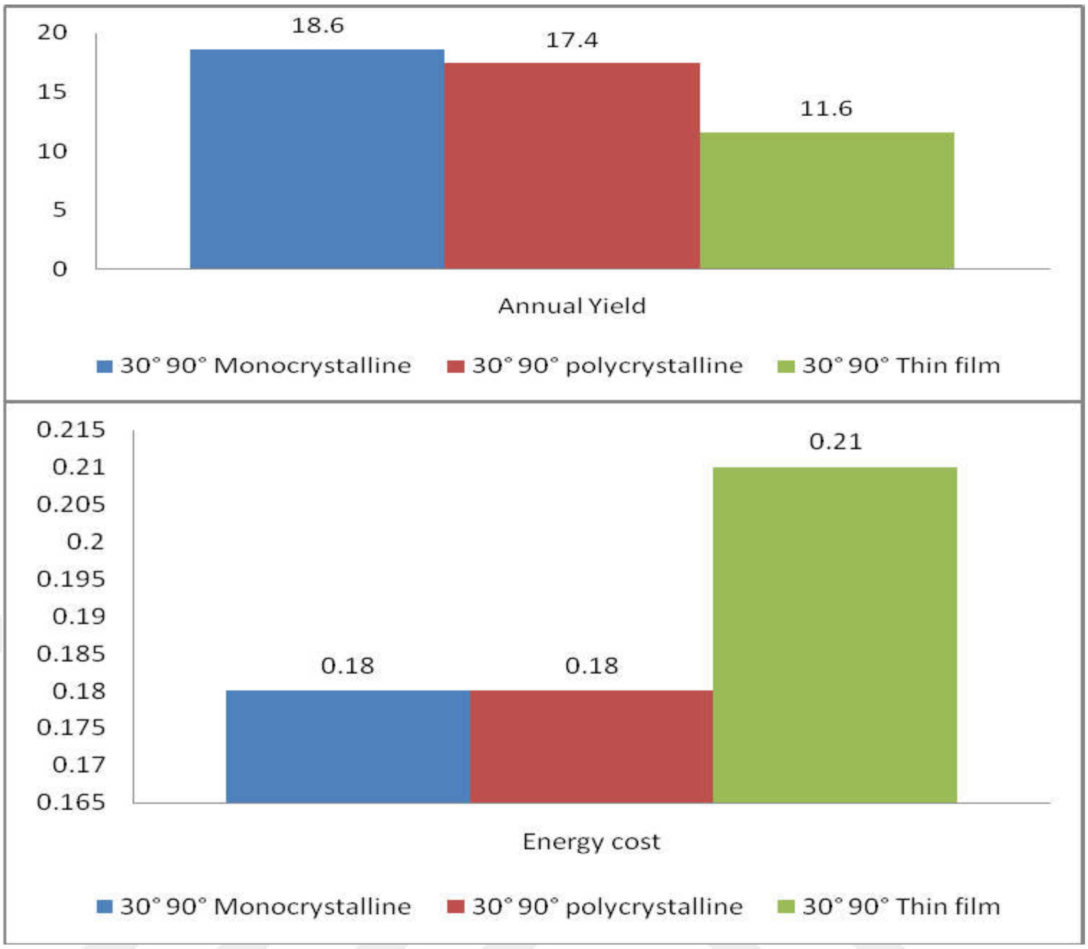


Figure 3.8: Annual Yield and Energy Cost of PV Panels, at a Tilt of 30°, Fixing Azimuth at 90°

3.3.1.5 Electrical Energy Production of PV Panels at a Tilt of 30° and Azimuth of 180°

In this part, the change will be only in PV technology fixing the tilt 30°, Azimuth180° as presented in Table 3.6 and Figure 3.9 Below.

Table 3.6: Electrical Energy Production of PV Panels at a Tilt of 30°, Fixing Azimuth of 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
30	180	Monocrystalline	15.8	0.21
30	180	polycrystalline	14.8	0.22
30	180	Thin film	9.9	0.25

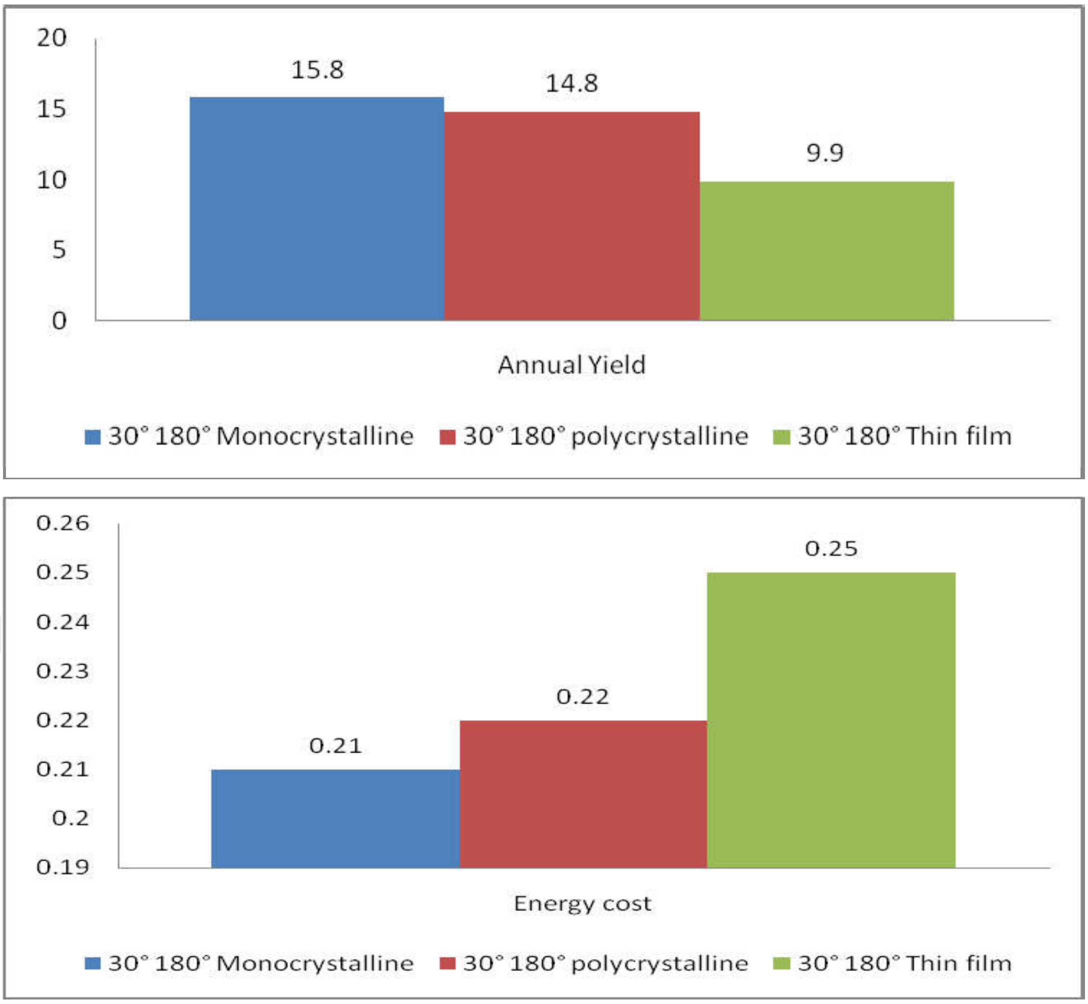


Figure 3.9: Annual Yield and Energy Cost of PV Panels, at a Tilt of 30°, Fixing Azimuth at180°

Table 3.7 Gives Summary of the Calculations Results

Table 3.7: Electrical Production of PV Panels at a Tilt of 30° and Azimuth of 0°, 45°, 120°, 90° and 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
30	0	Monocrystalline	22.4	0.15
30	0	polycrystalline	21	0.15
30	0	Thin film	14	0.18
30	45	Monocrystalline	21.4	0.16
30	45	polycrystalline	20	0.16
30	45	Thin film	13.3	0.19
30	120	Monocrystalline	16.3	0.21
30	120	polycrystalline	15.3	0.21
30	120	Thin film	10.2	0.24
30	90	Monocrystalline	18.6	0.18
30	90	polycrystalline	17.4	0.18

Table 3.7 Continued

30	90	Thin film	11.6	0.21
30	180	Monocrystalline	15.8	0.21
30	180	polycrystalline	14.8	0.22
30	180	Thin film	9.9	0.25

3.3.2. Electrical Energy Production of PV Panels at a Tilt of 45° and Changing of the Other Parameters

3.3.2.1 Electrical Energy Production of PV Panels at a tilt of 45 and Changing the Azimuth to 0°

In this part with a tilt of 45°, the changes will be only in the PV technology and fixed other parameters Azimuth 0° as presented in Table 3.8 and Figure 3.10 below.

Table 3.8: Electrical Energy Production of PV Panels at a Tilt of 45°, Fixing Azimuth of 0°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
45	0	Monocrystalline	22.1	0.15
45	0	polycrystalline	20.7	0.16
45	0	Thin film	13.8	0.18

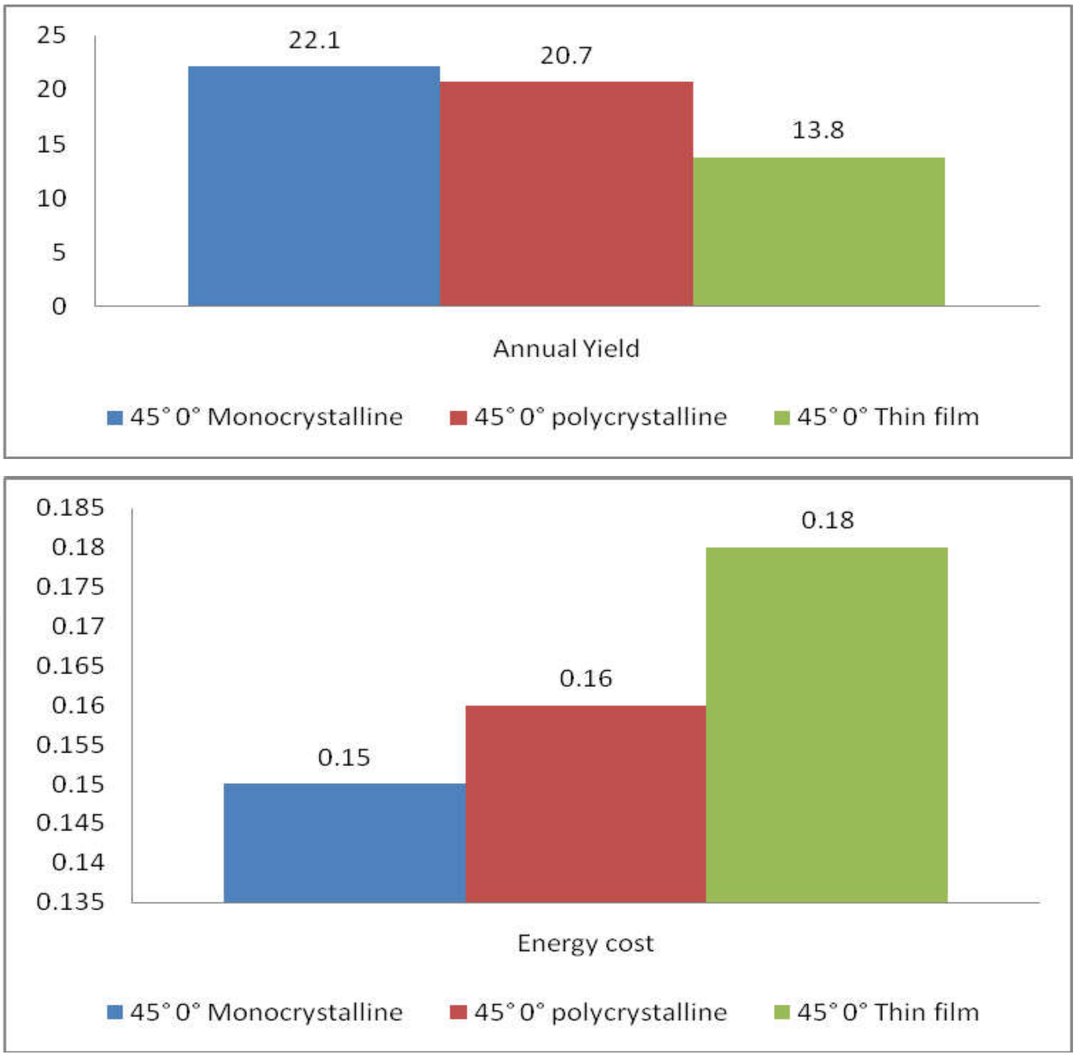


Figure 3.10: Annual Yield and Energy Cost of PV Panels, at a Tilt of 45°, Fixing Azimuth at 0°

3.3.2.2 Electrical energy Production of PV Panels on the, Tilt 45° and Change Azimuth 45°

In this part, the change will be only in PV technology and fixed the tilt 45°, Azimuth 45° as presented in Table 3.9 and Figure 3.11 below.

Table 3.9: Electrical Energy Production of PV Panels at Tilt of 45°, Fixing Azimuth of 45°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
45	45	Monocrystalline	21	0.16
45	45	polycrystalline	19.6	0.16
45	45	Thin film	13.1	0.19

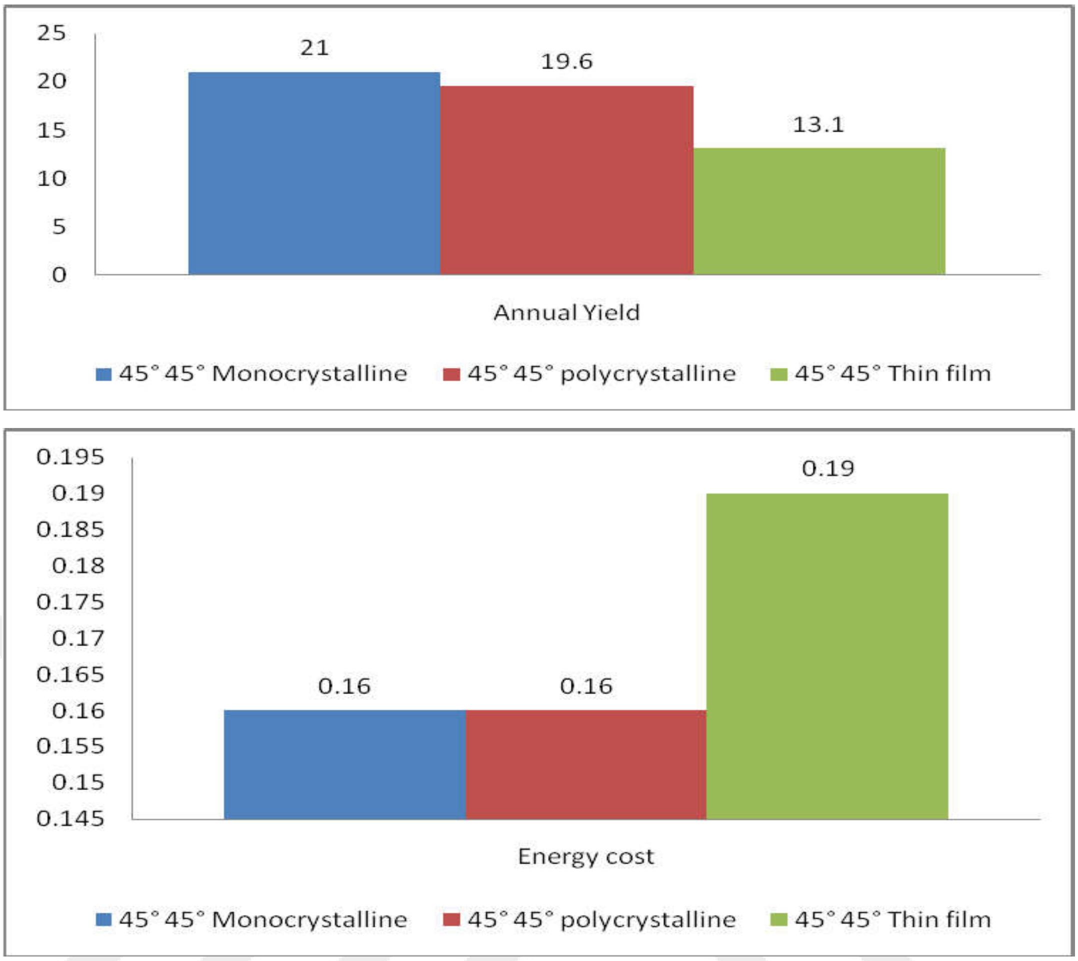


Figure 3.11: Annual Yield and Energy Cost of PV Panels, at a Tilt of 45°, Fixing Azimuth at 45°

3.3.2.3 Electrical Energy Production of PV Panels at a Tilt of 45° and Changing the Azimuth to 120°

In this part, the change will be only in PV technology and fixed the tilt 45°, Azimuth 120° as presented in Table 3.10 and Figure 3.12 below.

Table 3.10: Electrical Energy Production of PV Panels at a Tilt of 45° Fixing Azimuth of 120°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
45	120	Monocrystalline	14.5	0.23
45	120	polycrystalline	13.6	0.24
45	120	Thin film	9.1	0.27

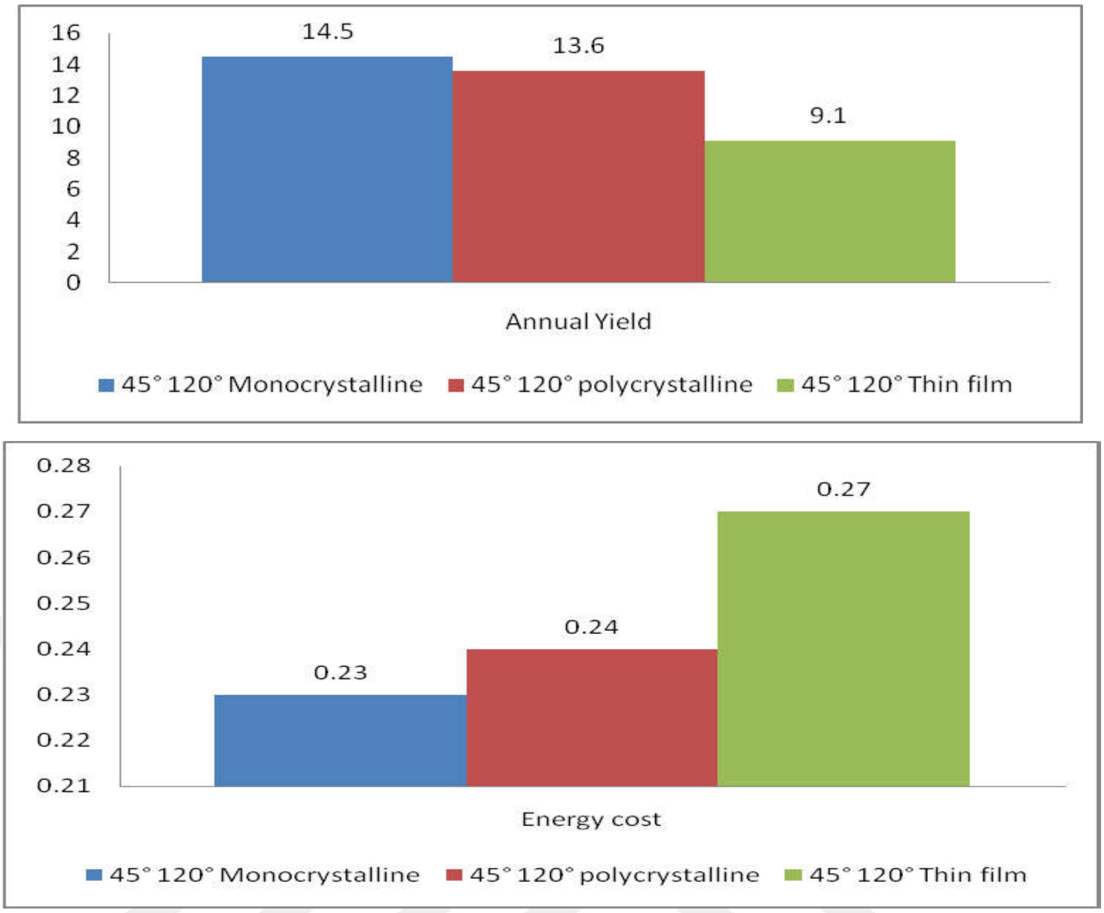


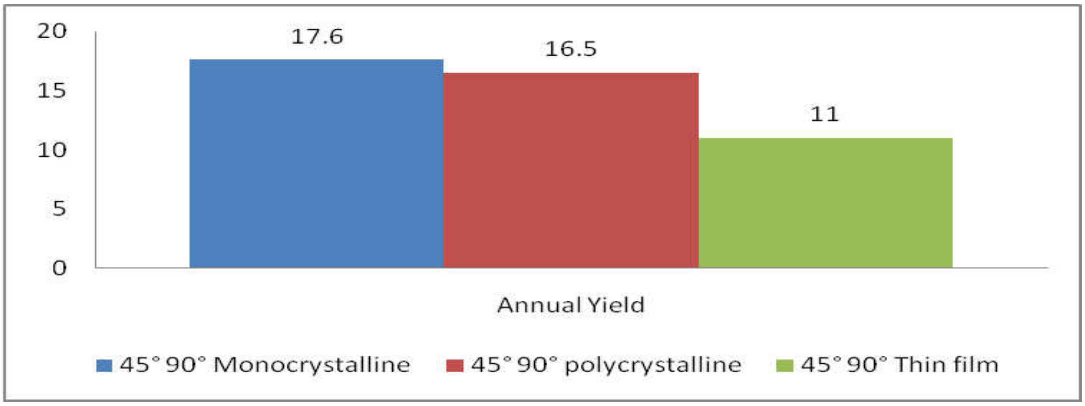
Figure 3.12: Annual Yield and Energy Cost of PV Panels, at a Tilt of 45°, Fixing Azimuth at 120°

3.3.2.4 Electrical Energy Production of PV Panels at a Tilt 45° and changing the Azimuth to 90°

In this part, the change will be only in PV technology and fixed the tilt 45°, Azimuth 90° as presented in Table 3.11 and Figure 3.13 below.

Table 3.11: Electrical Energy production of PV Panels at a Tilt of 45° Fixing Azimuth of 90°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
45	90	Monocrystalline	17.6	0.19
45	90	polycrystalline	16.5	0.2
45	90	Thin film	11	0.23



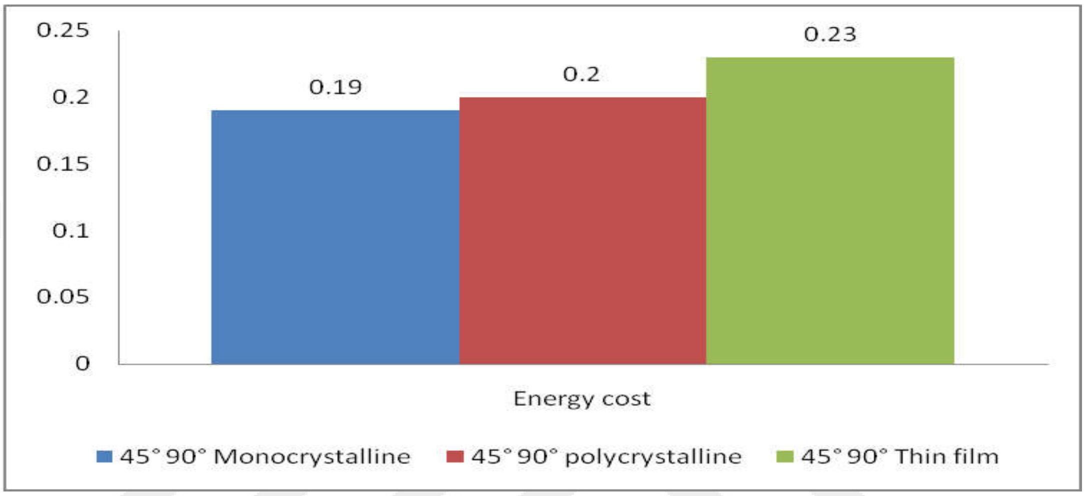


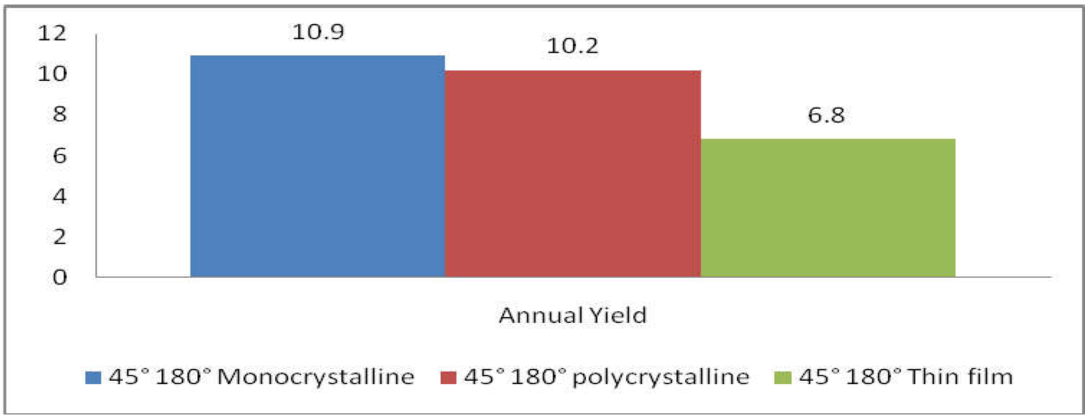
Figure 3.13: Annual Yield and Energy Cost of PV Panels, at a Tilt of 45°, Fixing Azimuth at 90°

3.3.2.5 Electrical Energy Production of PV Panels at a Tilt 45° and changing the Azimuth to 180°

In this part, the change will be only in PV technology and fixed tilt 30°, Azimuth180° as presented in Table 3.12 and Figure 3.14 below.

Table 3.12: Electrical Energy production of PV Panels at a Tilt of 45° and Fixing Azimuth of 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
45	180	Monocrystalline	10.9	0.31
45	180	polycrystalline	10.2	0.32
45	180	Thin film	6.8	0.37



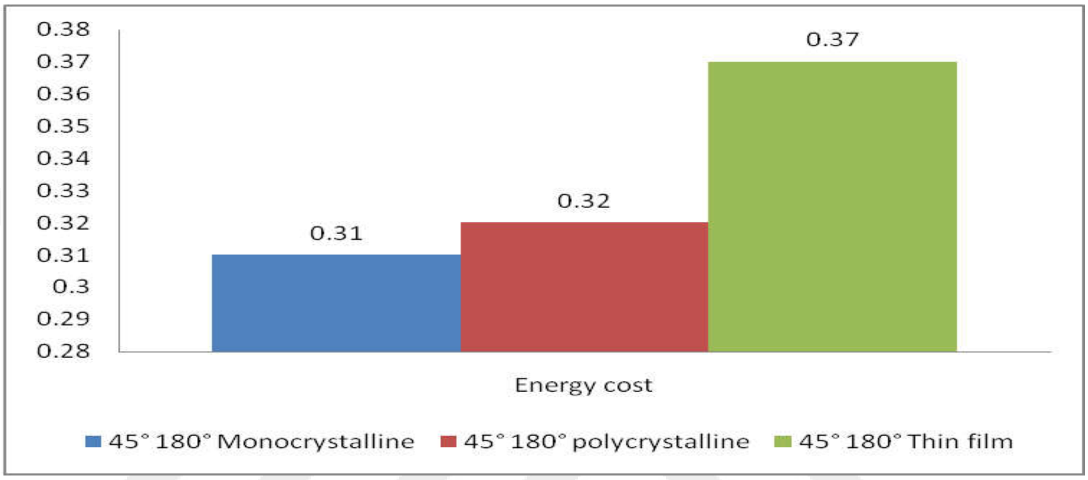


Figure 3.14: Annual Yield and Energy Cost of PV Panels, at a Tilt of 45°, Fixing Azimuth at 180°

Table 3.13 Gives Summary of the Calculations Results

Table 3.13: Electrical Energy Production of PV Panels at a Tilt of 45° and Changing the Azimuth to 0°, 45°, 120°, 90° and 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
45	0	Monocrystalline	22.1	0.15
45	0	polycrystalline	20.7	0.16
45	0	Thin film	13.8	0.18
45	45	Monocrystalline	21	0.16
45	45	polycrystalline	19.6	0.16
45	45	Thin film	13.1	0.19
45	120	Monocrystalline	14.5	0.23
45	120	polycrystalline	13.6	0.24
45	120	Thin film	9.1	0.27
45	90	Monocrystalline	17.6	0.19
45	90	polycrystalline	16.5	0.2
45	90	Thin film	11	0.23
45	180	Monocrystalline	10.9	0.31
45	180	polycrystalline	10.2	0.32
45	180	Thin film	6.8	0.37

3.3.3 Electrical Energy Production of PV Panels at a Tilt of 60 and Changing of the Other Parameters

3.3.3.1 Electrical Energy Production of PV Panels at a Tilt 60 and changing the Azimuth to 0°

In this part with tilt 60°, the changes will be only in PV technology, fixing the other parameters Azimuth 0° as presented in Table 3.14 and Figure 3.15 below

Table 3.14: Electrical Energy production of PV Panels at a Tilt of60° and Fixing Azimuth of 0°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr.	Energy cost EUR/kwh
60	0	Monocrystalline	20.7	0.16
60	0	polycrystalline	19.4	0.17
60	0	Thin film	13	0.19

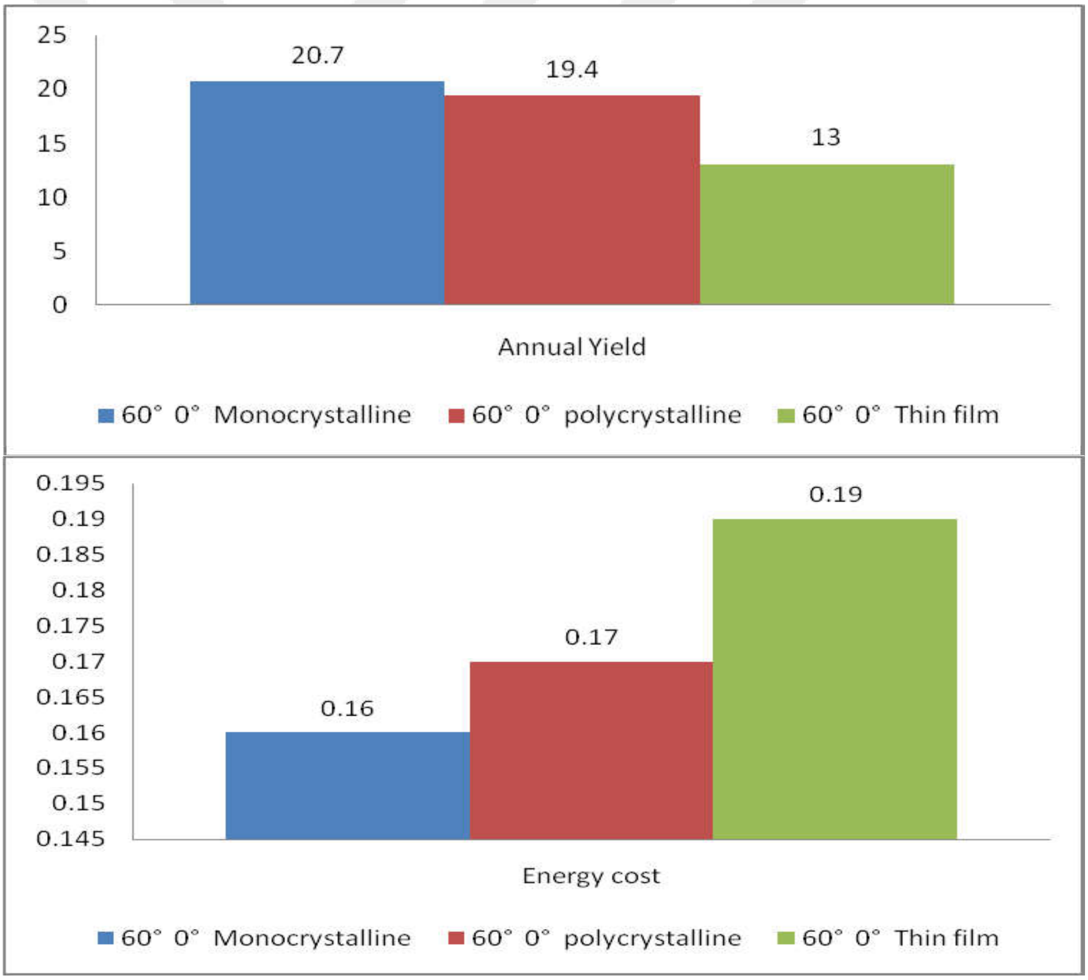


Figure 3.15: Annual Yield and Energy Cost of PV Panels, at a Tilt of 60°, Fixing Azimuth at 0°

3.3.3.2 Electrical Energy Production of PV Panels at a Tilt of 60° and changing the Azimuth 45°

In this part with a tilt of 60°, the changes will be only in PV technology and fixed other parameters Azimuth 45° as presented in Table 3.15 and Figure 3.16 below.

Table 3.15: Electrical Energy production of PV Panels at a Tilt of 60°, Fixing Azimuth of 45°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
60	45	Monocrystalline	19.6	0.17
60	45	polycrystalline	18.4	0.18
60	45	Thin film	12.3	0.2

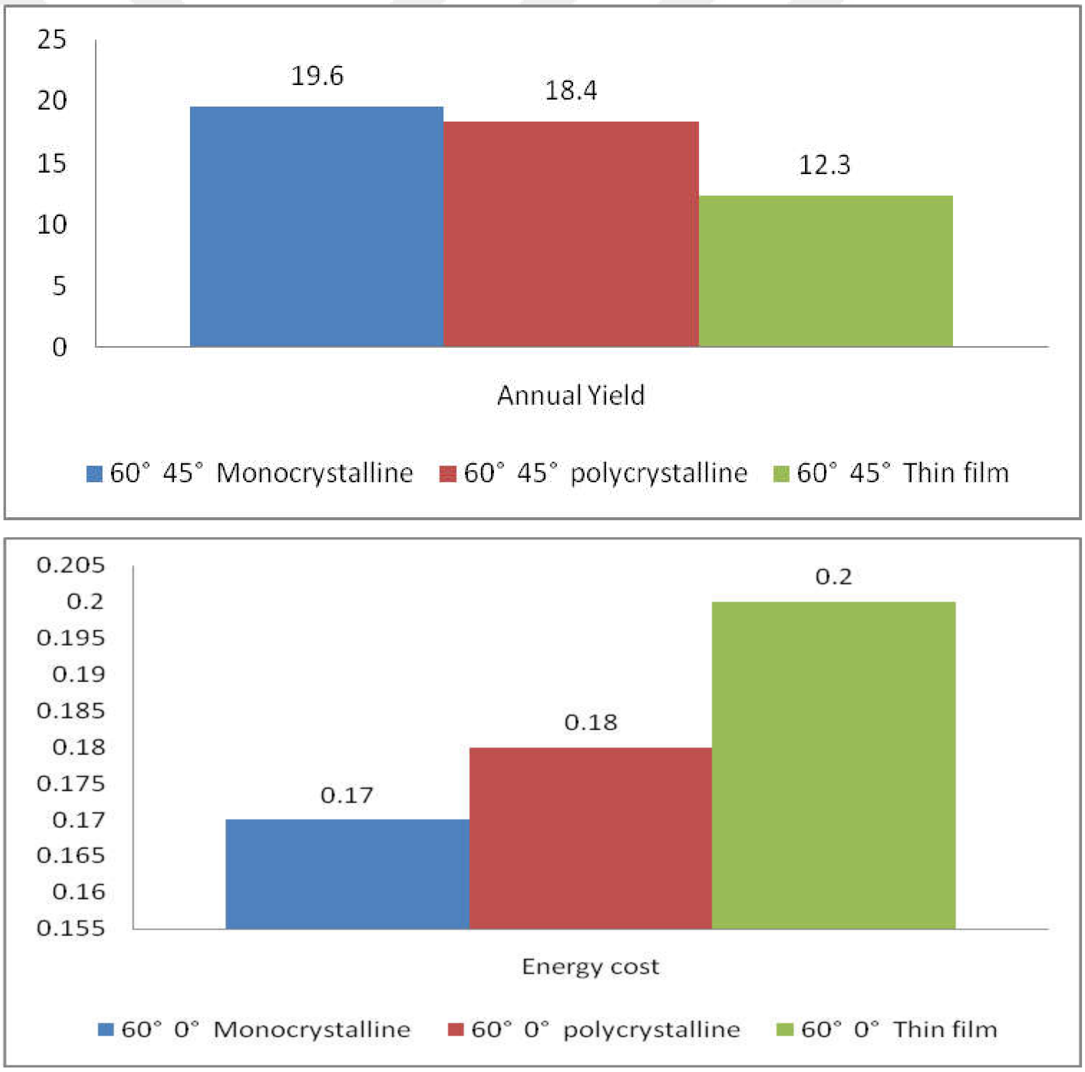


Figure 3.16: Annual Yield and Energy Cost of PV Panels, at a Tilt of 60°, Fixing Azimuth at 45°

3.3.3.3 Electrical Energy Production of PV Panels at a Tilt 60° and Changing Azimuth to 120°

In this part, the change will be only in PV technology and fixing the tilt 60°, Azimuth 120° as presented in Table. 3.16 and Figure 3.17 below

Table 3.16: Electrical Energy production of PV Panels at a Tilt of 60°, Fixing Azimuth of 120°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kwh
60	120	Monocrystalline	12.9	0.26
60	120	polycrystalline	12.1	0.27
60	120	Thin film	8	0.31

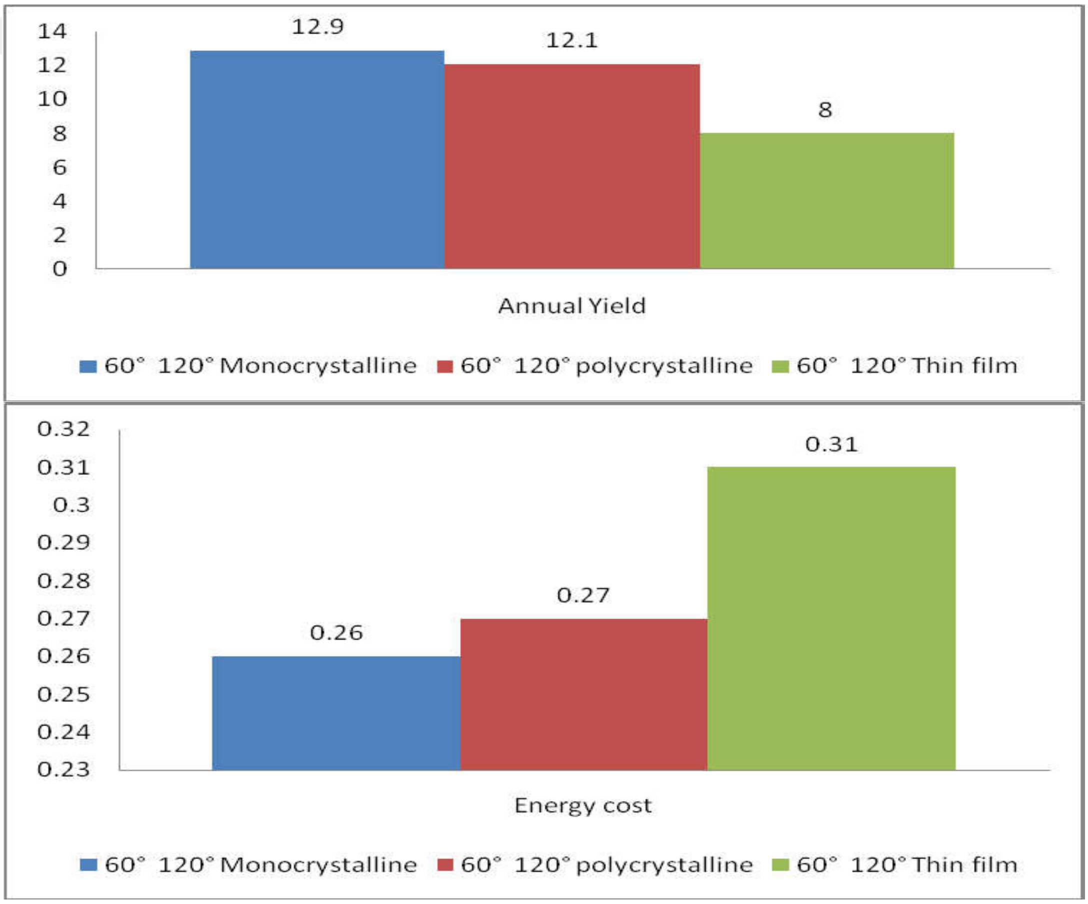


Figure 3.17: Annual Yield and Energy Cost of PV Panels, at a Tilt of 60°, Fixing Azimuth at 120°

3.3.3.4 Electrical Energy Production of PV Panels at a Tilt 60° and Changing Azimuth to 90°

In this part, the change will be only in PV technology and fixing tilt 60°, Azimuth 90° as presented in Table 3.17 and Figure 3.18 below

Table 3.17: Electrical Energy production of PV Panels at a Tilt of 60°, Fixing Azimuth of 120°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
60	90	Monocrystalline	16.2	0.21
60	90	polycrystalline	15.1	0.21
60	90	Thin film	10.1	0.25

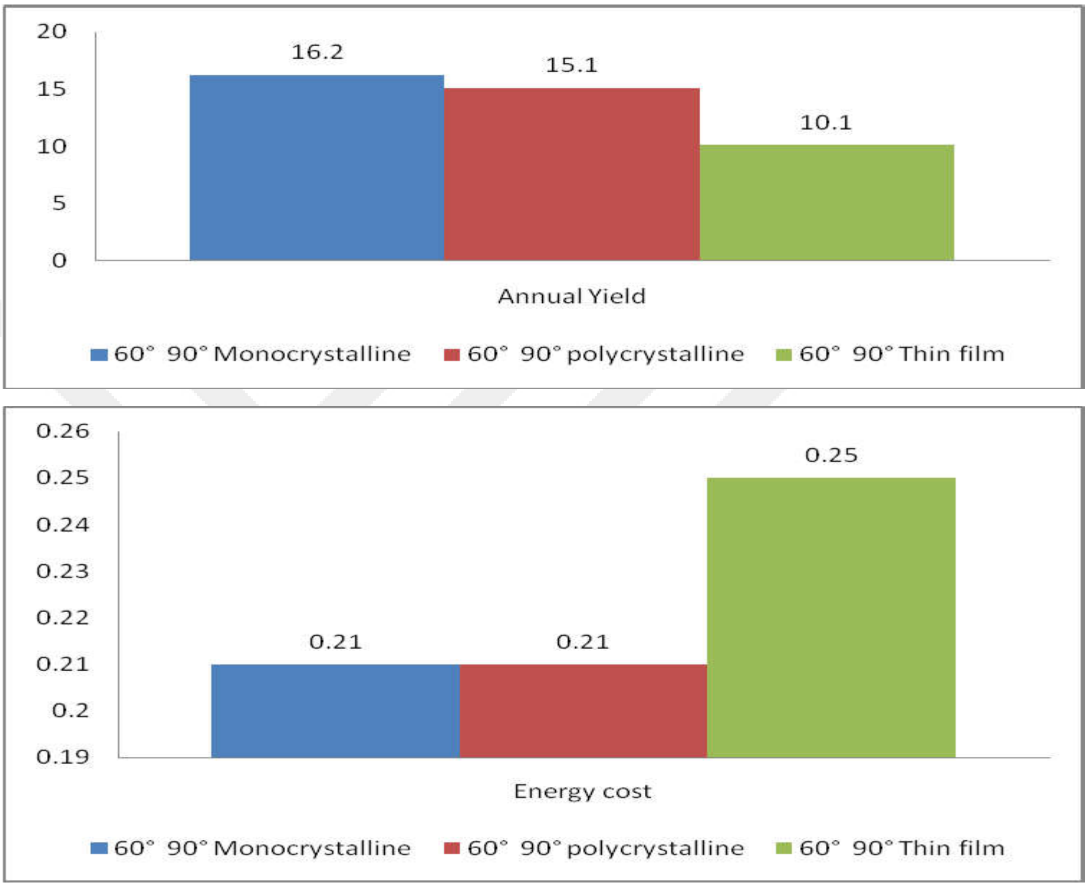


Figure 3.18: Annual Yield and Energy Cost of PV Panels, at a Tilt of 60°, Fixing Azimuth at 90°

3.3.3.5 Electrical Energy Production of PV Panels at a Tilt of 60° and Changing the Azimuth to 180°

In this part, the change will be only in PV technology and fixing the tilt 60°, Azimuth 180° as presented in Table 3.18 and Figure 3.19 below

Table 3.18: Electrical Energy production of PV Panels at a Tilt of 60°, Fixing Azimuth of 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
60	180	Monocrystalline	8.4	0.4
60	180	polycrystalline	7.8	0.41

Table 3.18 Continued

60	180	Thin film	5.2	0.48

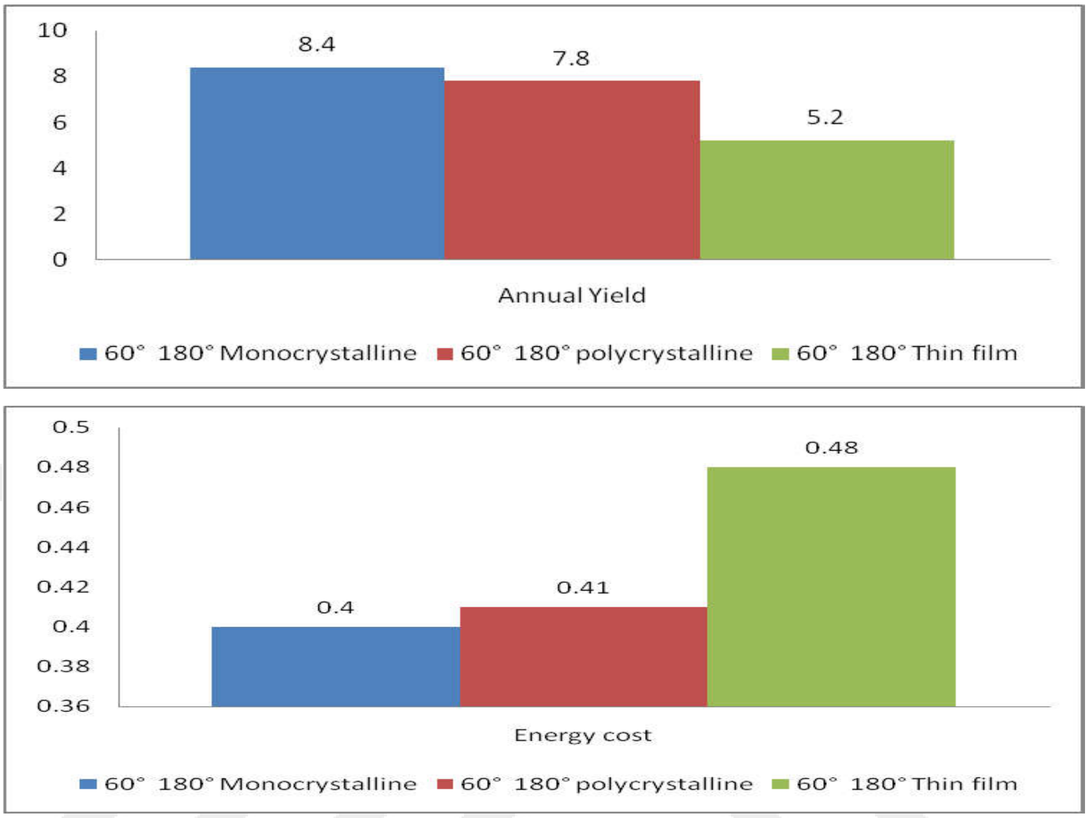


Figure 3. 19: Annual Yield and Energy Cost of PV Panels, at a Tilt of 60°, Fixing Azimuth at 90

Table 3.19 Gives Summary of the Calculations Results

Table 3.19: Electrical Energy Production of PV Panels at a Tilt of 45° and Changing the Azimuth to 0°, 45°, 120°, 90° and 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
60	0	Monocrystalline	20.7	0.16
60	0	polycrystalline	19.4	0.17
60	0	Thin film	13	0.19
60	45	Monocrystalline	19.6	0.17
60	45	polycrystalline	18.4	0.18
60	45	Thin film	12.3	0.2
60	120	Monocrystalline	12.9	0.26
60	120	polycrystalline	12.1	0.27
60	120	Thin film	8	0.31
60	90	Monocrystalline	16.2	0.21
60	90	polycrystalline	15.1	0.21
60	90	Thin film	10.1	0.25

Table 3.19 Continued

60	180	Monocrystalline	8.4	0.4
60	180	polycrystalline	7.8	0.41
60	180	Thin film	5.2	0.48

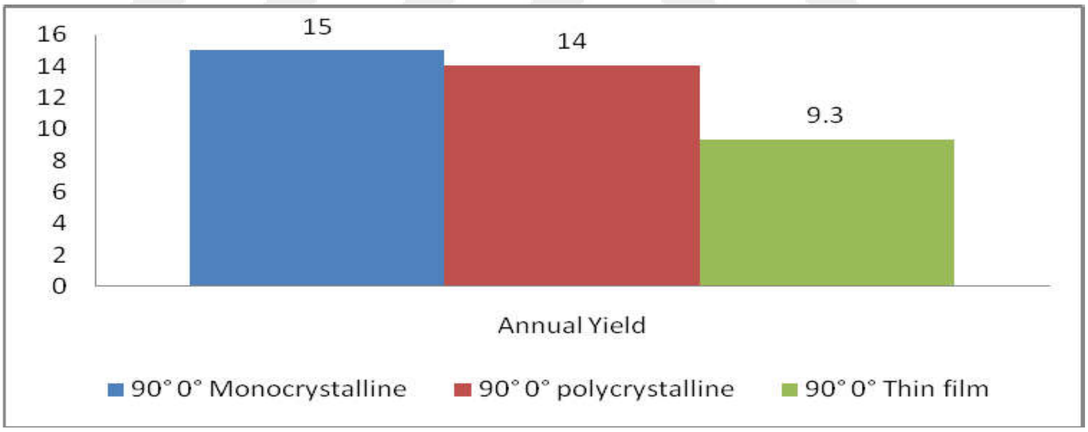
3.3.4 Electrical Energy Production of PV Panels at a Tilt of 90° and Changing of the Other Parameters

3.3.4.1 Electrical Energy Production of PV Panels at a Tilt of 90° and Changing the Azimuth to 0°

In this part with tilt 90°, the changes will be only in PV technology and fixing the other parameters Azimuth 0° as presented in Table. 3.20. and Figure 3.20 below

Table 3.20: Electrical Energy Production of PV Panels at a Tilt of 90°, Fixing Azimuth of 0°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
90	0	Monocrystalline	15	0.22
90	0	polycrystalline	14	0.23
90	0	Thin film	9.3	0.27



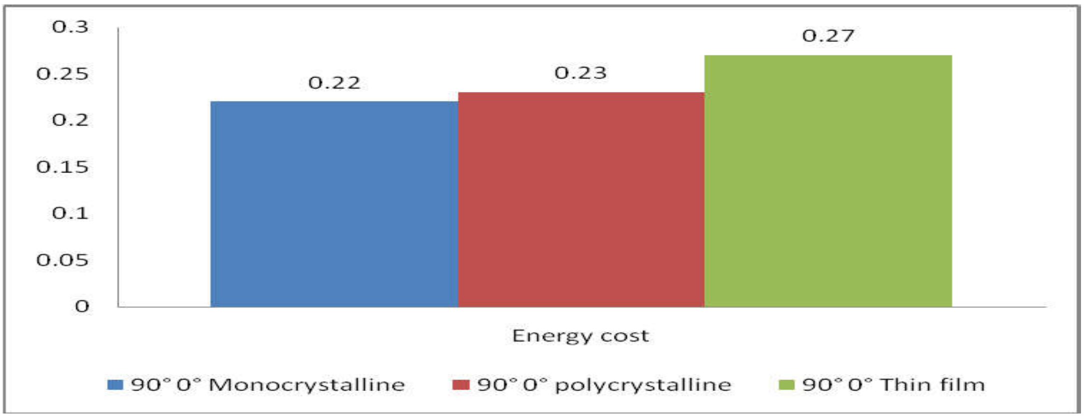


Figure 3.20: Annual Yield and Energy Cost of PV Panels, at a Tilt of 90°, Fixing Azimuth at 0°

3.3.4.2 Electrical Energy Production of PV Panels at a Tilt 90° and Changing the Azimuth to 45°

In this part, the change will be only in PV technology and fixing the tilt 90°, Azimuth 45° as presented in Table. 3.21 and Figure 3.21 below

Table 3.21: Electrical Energy Production of PV Panels at a Tilt of 90°, Fixing Azimuth of 45°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
90	45	Monocrystalline	14.8	0.23
90	45	polycrystalline	13.9	0.23
90	45	Thin film	9.3	0.27

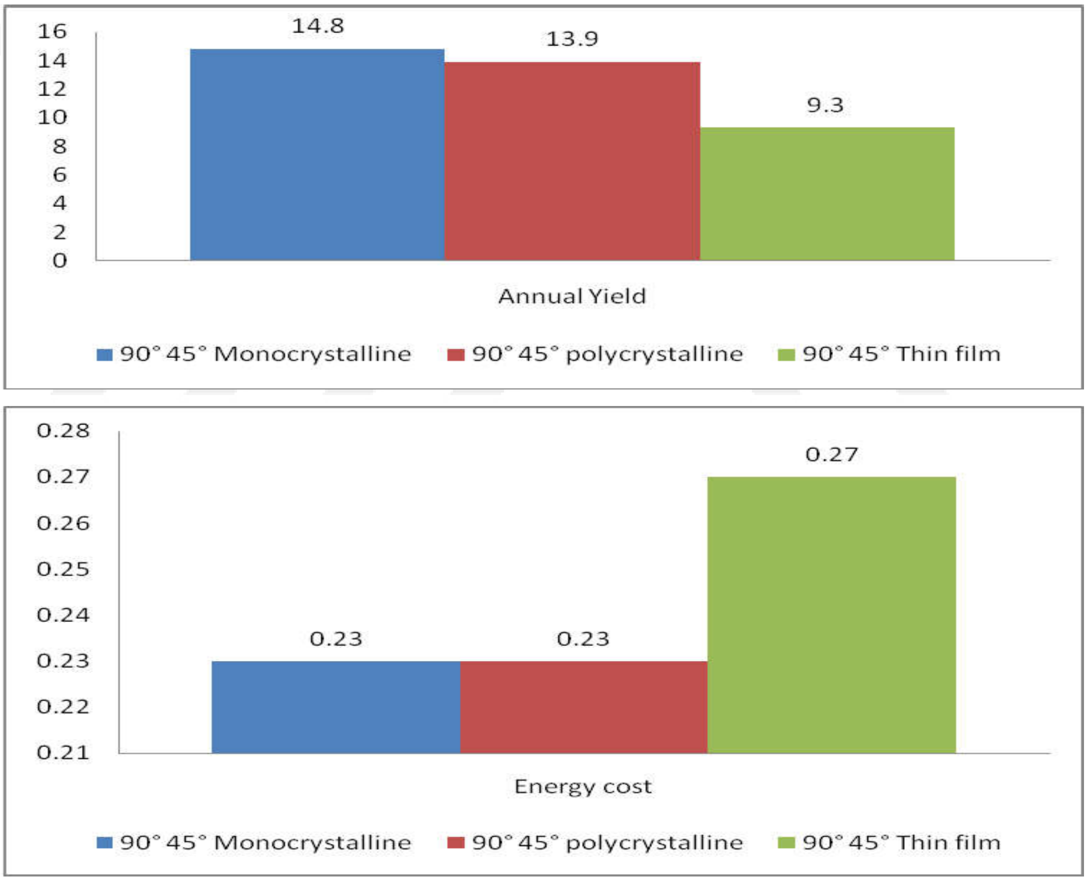


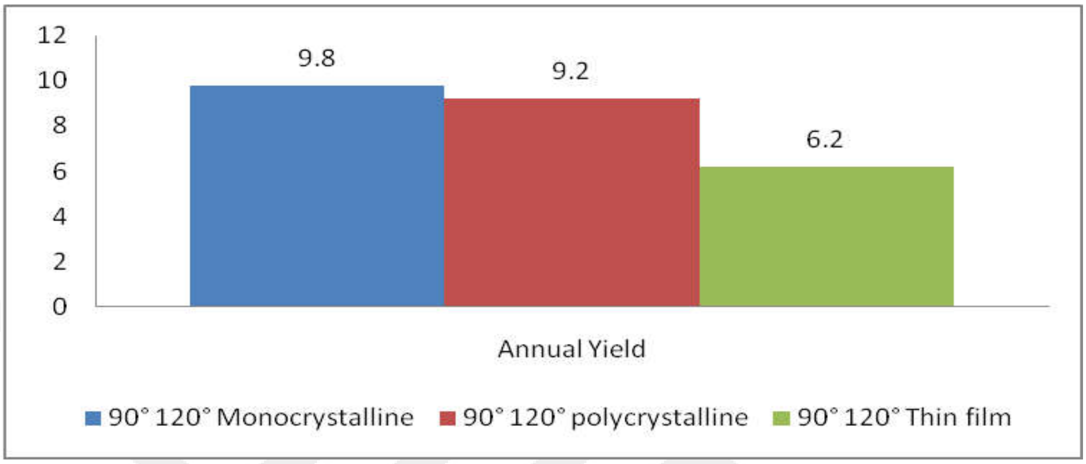
Figure 3.21: Annual Yield and Energy Cost of PV Panels, at a Tilt of 90°, Fixing Azimuth at 45°

3.3.4.3 Electrical Energy Production of PV Panels at a Tilt of 90° and Changing the Azimuth to 120°

In this part, the change will be only in PV technology and fixing the tilt 90°, Azimuth 120° as presented in Table 3.22 and Figure 3.22 below

Table 3.22: Electrical Energy Production of PV Panels at a Tilt of 90°, Fixing Azimuth of 120°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
90	120	Monocrystalline	9.8	0.34
90	120	polycrystalline	9.2	0.35
90	120	Thin film	6.2	0.41



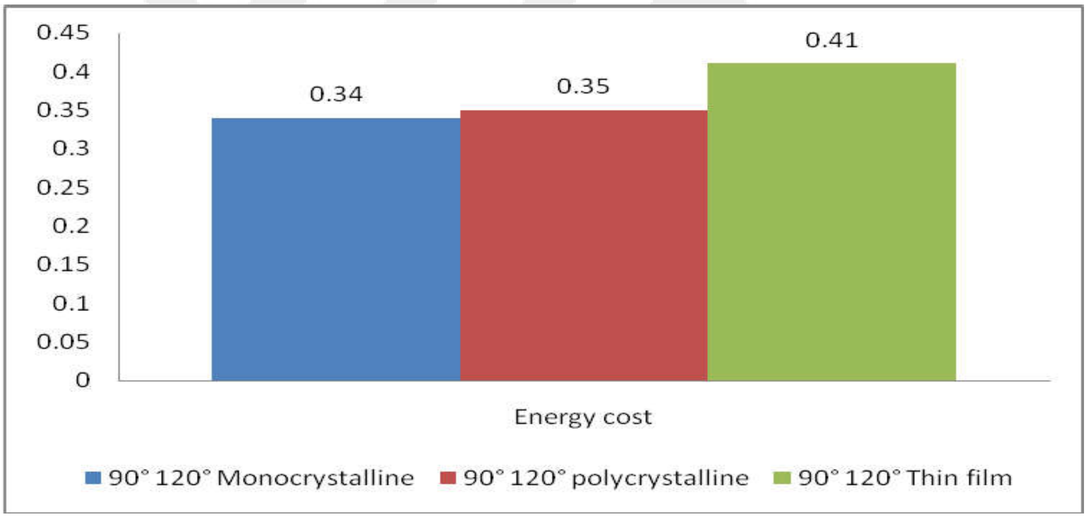


Figure 3.22: Annual Yield and Energy Cost of PV Panels, at a Tilt of 90°, Fixing Azimuth at 120°

3.3.4.4 Electrical Energy Production of PV Panels at a Tilt 90° and Changing Azimuth to 90°

In this part, the changes will be only in PV technology and fixed tilt 90°, Azimuth 90° as presented in Table 3.23 and Figure 3.23 below.

Table 3.23: Electrical Energy Production of PV Panels at a Tilt of 90, Fixing Azimuth of 90°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
90	90	Monocrystalline	12.5	0.27
90	90	polycrystalline	11.7	0.28
90	90	Thin film	7.8	0.32

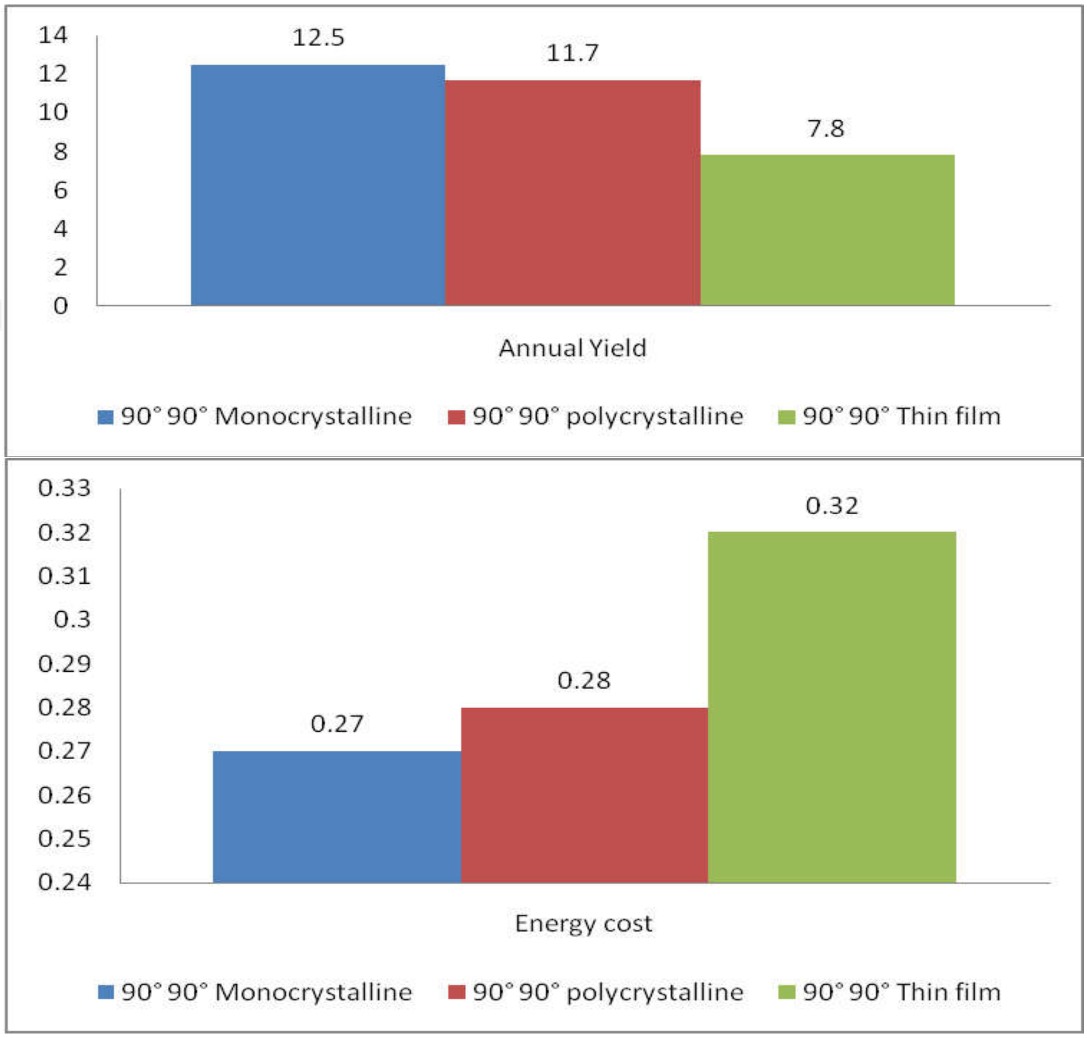


Figure 3.23: Annual Yield and Energy Cost of PV Panels, at a Tilt of 90°, Fixing Azimuth at 90°

3.3.4.5 Electrical Energy Production of PV Panels at a Tilt of 90° and Changing the Azimuth to 180°.

In this part, the change will be only in PV technology and fixed the tilt 90°, Azimuth180° as presented in Table 3.24 and Figure 3.24below.

Table 3.24: Electrical Energy production of PV Panels at a Tilt of 90°, Fixing Azimuth of 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
90	180	Monocrystalline	6	0.56
90	180	polycrystalline	5.6	0.57
90	180	Thin film	3.7	0.67

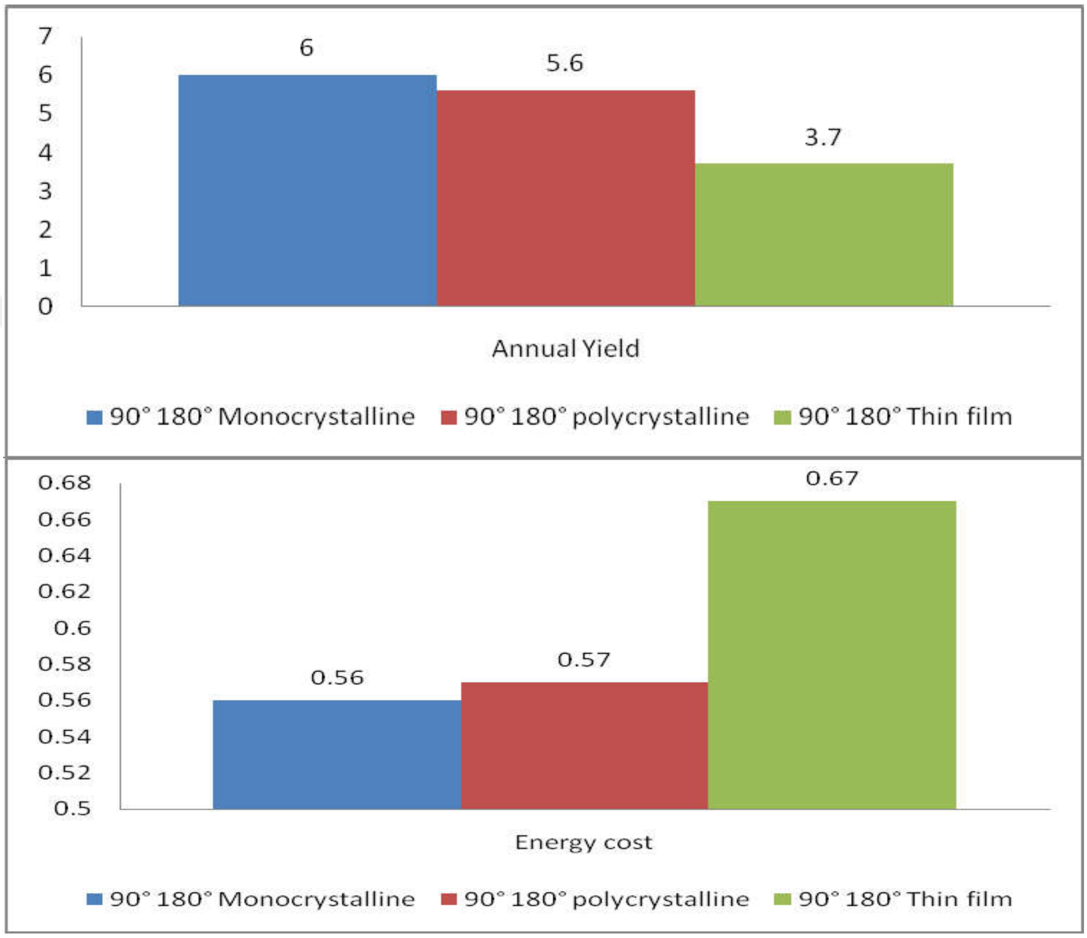


Figure 3.24: Annual Yield and Energy Cost of PV Panels, at a Tilt of 90°, Fixing Azimuth at 180°

Table 3.25 Gives Summary of the Calculations Results

Table 3.25: Electrical Energy Production of PV Panels at a Tilt of 90° and Changing the Azimuth to 0°, 45°, 120°, 90° and 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
90	0	Monocrystalline	15	0.22
90	0	polycrystalline	14	0.23
90	0	Thin film	9.3	0.27
90	45	Monocrystalline	14.8	0.23
90	45	polycrystalline	13.9	0.23
90	45	Thin film	9.3	0.27

Table 3.25: Continued

90	120	Monocrystalline	9.8	0.34
90	120	polycrystalline	9.2	0.35
90	120	Thin film	6.2	0.41
90	90	Monocrystalline	12.5	0.27
90	90	polycrystalline	11.7	0.28
90	90	Thin film	7.8	0.32
90	180	Monocrystalline	6	0.56
90	180	polycrystalline	5.6	0.57
90	180	Thin film	3.7	0.67

3.3.5 Electrical Energy Production of PV Panels at a tilt of 0° and changing of the Other Parameters

3.3.5.1 Electrical energy Production of PV Panels at a Tilt of 0° and Changing the Azimuth to 0°

In this part, the change will be only in PV technology and fixed the tilt 0°, Azimuth 0° as presented in Table 3.26 and Figure 3.25 below.

Table 3.26: Electrical Energy production of PV Panels at a Tilt of 0°, Fixing Azimuth of 0°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
0	0	Monocrystalline	19.4	0.17
0	0	polycrystalline	18.1	0.18
0	0	Thin film	12.1	0.21

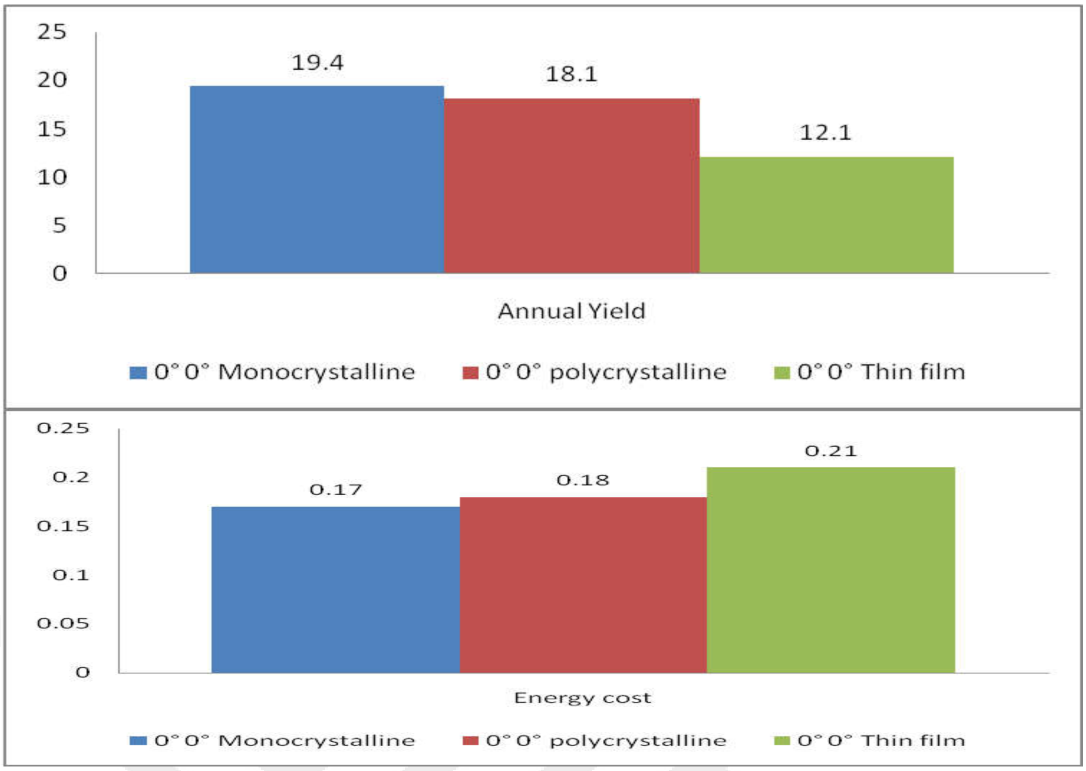


Figure 3.25: Annual Yield and Energy Cost of PV Panels, at a Tilt of 0°, Fixing Azimuth at 0°

3.3.5.2 Electrical Energy Production of PV Panels at a Tilt 0° and Changing the Azimuth to 45°

In this part, the change will be only in PV technology and fixed the tilt 0°, Azimuth 0° as presented in Table 3.27 and Figure 3.26 below.

Table 3.27: Electrical Energy production of PV Panels at a Tilt of 0°, Fixing Azimuth of 45°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
0	45	Monocrystalline	19.4	0.17
0	45	polycrystalline	18.1	0.18
0	45	Thin film	12.1	0.21

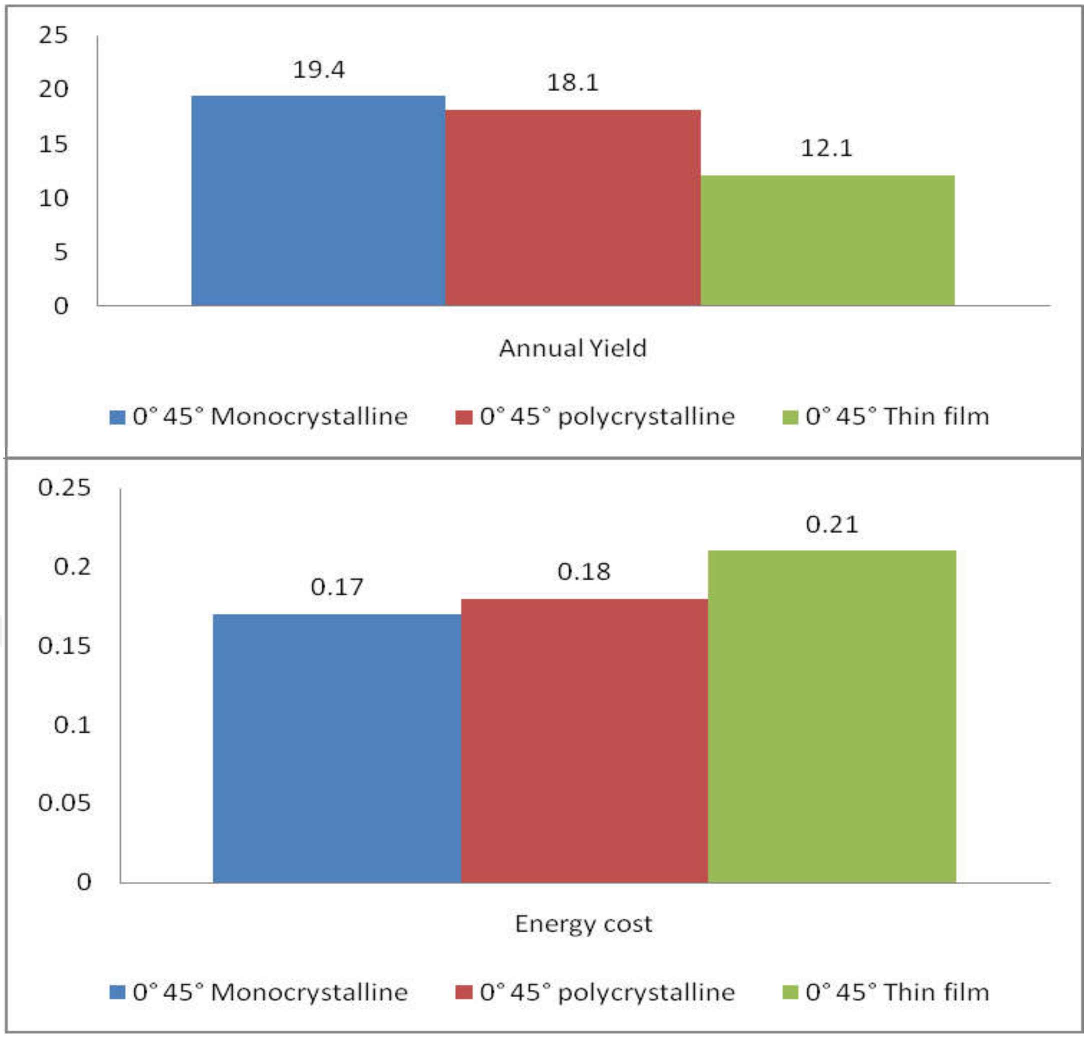


Figure 3.26: Annual Yield and Energy Cost of PV Panels, at a Tilt of 0°, Fixing Azimuth at 45°

3.3.5.3 Electrical Energy Production of PV Panels at a Tilt 0° and Changing the Azimuth to 120°

In this part, the change will be only in PV technology and fixed the tilt 0°, Azimuth 0° as presented in Table 3.28 and Figure 3.27 below.

Table 3.28: Electrical Energy production of PV Panels at a Tilt of 0°, Fixing Azimuth of 120°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
0	120	Monocrystalline	19.4	0.17
0	120	polycrystalline	18.1	0.18
0	120	Thin film	12.1	0.21

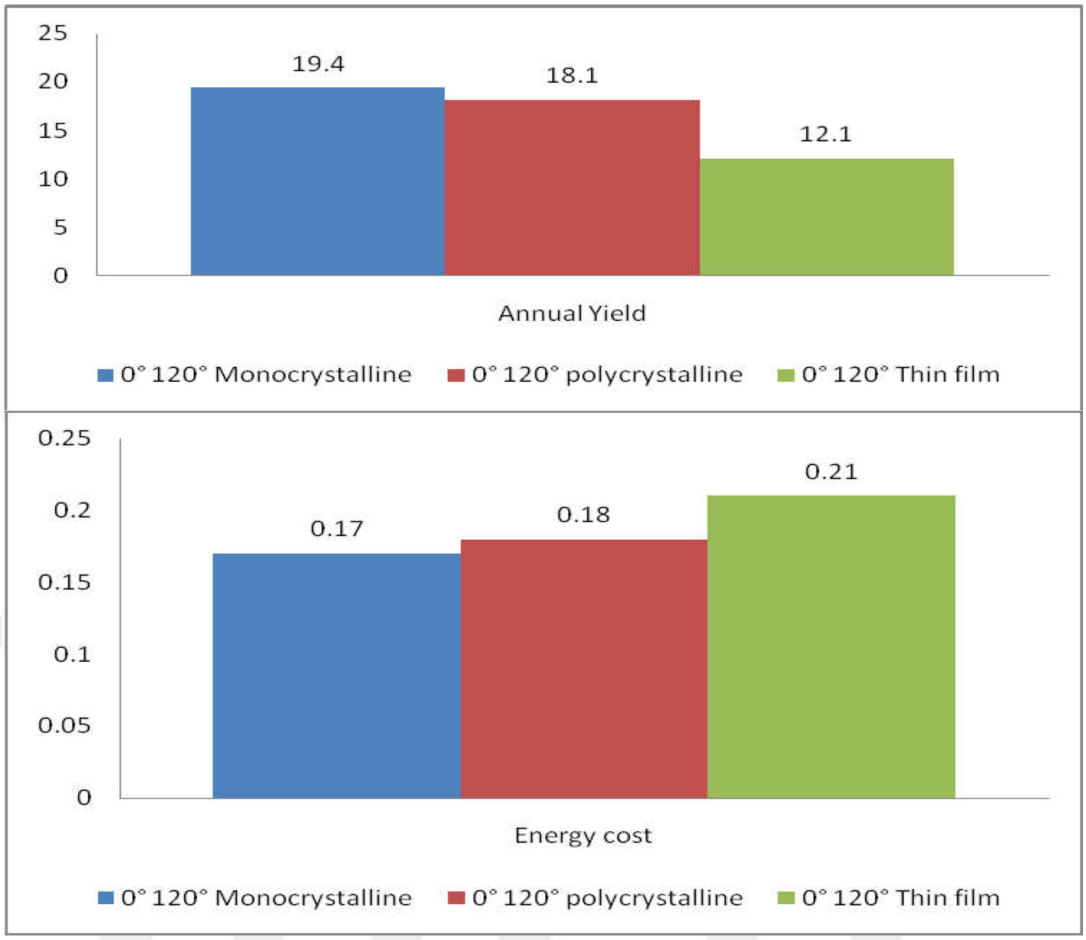


Figure 3.27: Annual Yield and Energy Cost of PV Panels, at a Tilt of 0°, Fixing Azimuth at 120°

3.3.5.4 Electrical Energy Production of PV Panels at a Tilt 0° and changing the Azimuth to 90°

In this part, the change will be only in PV technology and fixed the tilt 0°, Azimuth 90° as presented in Table 3.29 and Figure 3.28 below.

Table 3.29: Electrical Energy production of PV Panels at a Tilt of 0° , Fixing Azimuth of 90°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
0	90	Monocrystalline	19.4	0.17
0	90	polycrystalline	18.1	0.18
0	90	Thin film	12.1	0.21

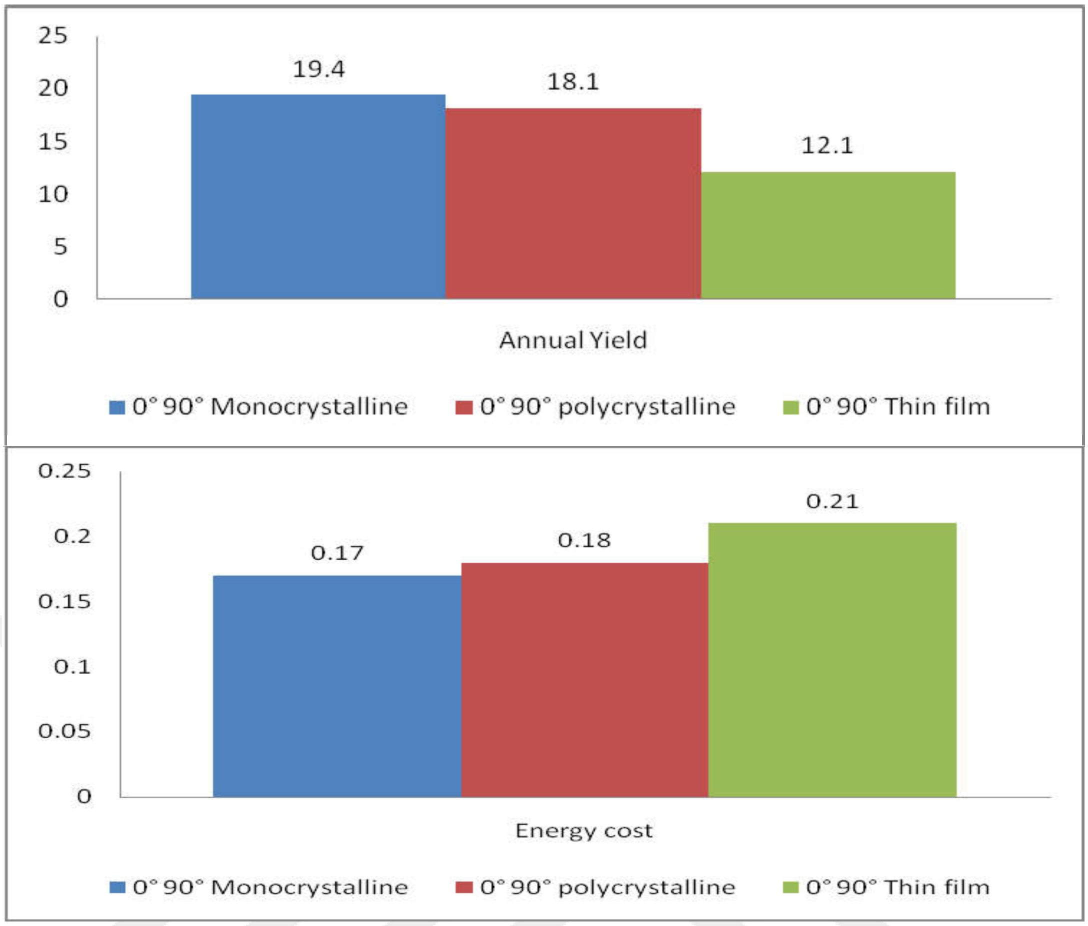


Figure 3.28: Annual Yield and Energy Cost of PV Panels, at a Tilt of 0°, Fixing Azimuth at 90°

3.3.5.5 Electrical Energy Production of PV Panels at a Tilt 0 and Changing the Azimuth to 180

In this part, the change will be only in PV technology and fixed the tilt 0°, Azimuth 180° as presented in Table 3.30 and Figure 3.29 below.

Table 3.30: Electrical Energy production of PV Panels at a Tilt of 0°, Fixing Azimuth of 180°

Tilt	Azimuth	PV technology	Annual Yield MWh/yr	Energy cost EUR/kWh
0	180	Monocrystalline	19.4	0.17
0	180	polycrystalline	18.1	0.18
0	180	Thin film	12.1	0.21

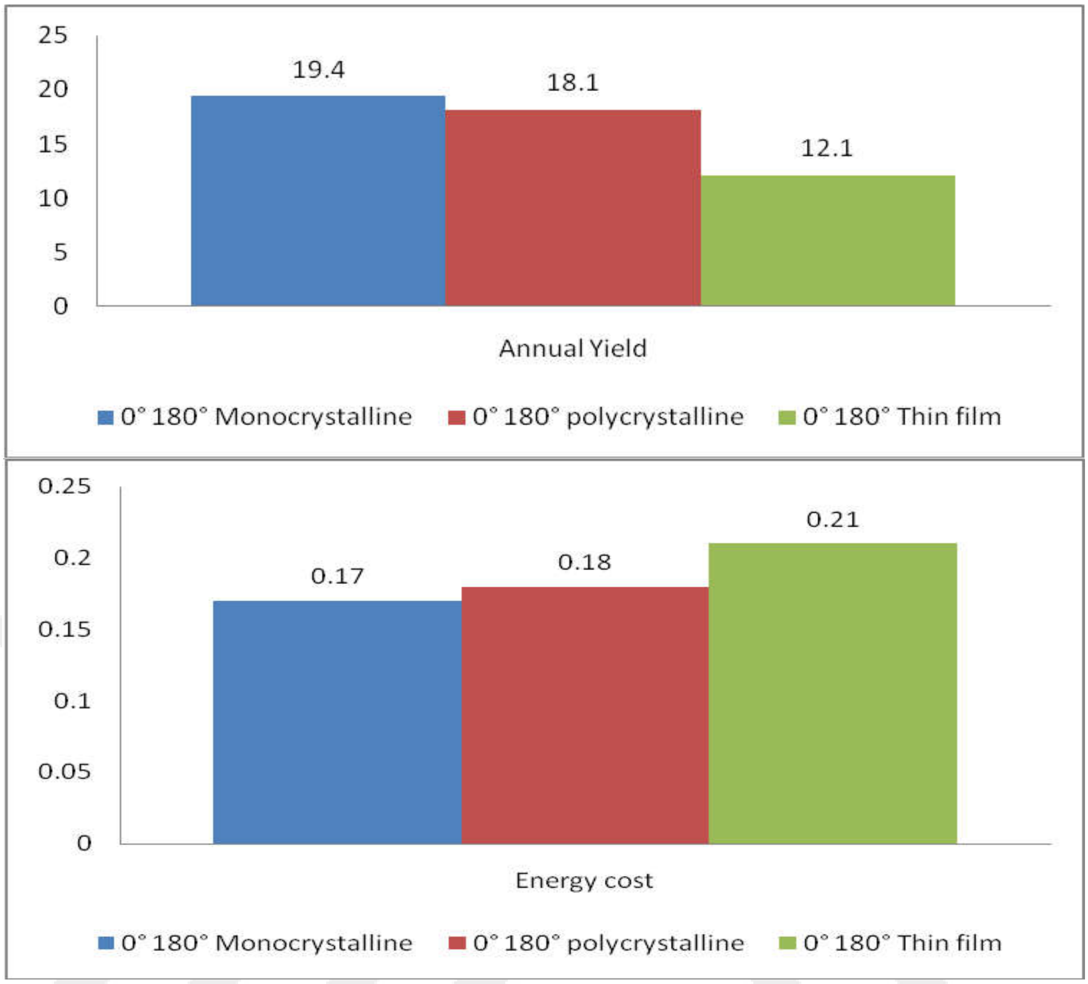


Figure 3.29: Annual Yield and Energy Cost of PV Panels, at a Tilt of 0° Fixing Azimuth at 180°

Table 3.31 Gives Summary of the Calculations Results

Table 3.31: Calculations and Results From PVSYST

Tilt	Azimuth	PV technology	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)
0	0	Monocrystalline	19.4	0.17
0	0	polycrystalline	18.1	0.18
0	0	Thin film	12.1	0.21
0	45	Monocrystalline	19.4	0.17
0	45	polycrystalline	18.1	0.18
0	45	Thin film	12.1	0.21
0	120	Monocrystalline	19.4	0.17
0	120	polycrystalline	18.1	0.18
0	120	Thin film	12.1	0.21
0	90	Monocrystalline	19.4	0.17
0	90	polycrystalline	18.1	0.18

Table 3.31: Continued

0	90	Thin film	12.1	0.21
0	180	Monocrystalline	19.4	0.17
0	180	polycrystalline	18.1	0.18
0	180	Thin film	12.1	0.21
30	0	Monocrystalline	22.4	0.15
30	0	polycrystalline	21	0.15
30	0	Thin film	14	0.18
30	45	Monocrystalline	21.4	0.16
30	45	polycrystalline	20	0.16
30	45	Thin film	13.3	0.19
30	120	Monocrystalline	16.3	0.21
30	120	polycrystalline	15.3	0.21
30	120	Thin film	10.2	0.24
30	90	Monocrystalline	18.6	0.18
30	90	polycrystalline	17.4	0.18
30	90	Thin film	11.6	0.21
30	180	Monocrystalline	15.8	0.21
30	180	polycrystalline	14.8	0.22
30	180	Thin film	9.9	0.25
45	0	Monocrystalline	22.1	0.15
45	0	polycrystalline	20.7	0.16
45	0	Thin film	13.8	0.18
45	45	Monocrystalline	21	0.16
45	45	polycrystalline	19.6	0.16
45	45	Thin film	13.1	0.19
45	120	Monocrystalline	14.5	0.23
45	120	polycrystalline	13.6	0.24
45	120	Thin film	9.1	0.27
45	90	Monocrystalline	17.6	0.19
45	90	polycrystalline	16.5	0.2
45	90	Thin film	11	0.23
45	180	Monocrystalline	10.9	0.31
45	180	polycrystalline	10.2	0.32
45	180	Thin film	6.8	0.37
60	0	Monocrystalline	20.7	0.16
60	0	polycrystalline	19.4	0.17
60	0	Thin film	13	0.19
60	45	Monocrystalline	19.6	0.17
60	45	polycrystalline	18.4	0.18
60	45	Thin film	12.3	0.2
60	120	Monocrystalline	12.9	0.26
60	120	polycrystalline	12.1	0.27

Table 3.31:Continued

60	120	Thin film	8	0.31
60	90	Monocrystalline	16.2	0.21
60	90	polycrystalline	15.1	0.21
60	90	Thin film	10.1	0.25
60	180	Monocrystalline	8.4	0.4
60	180	polycrystalline	7.8	0.41
60	180	Thin film	5.2	0.48
90	0	Monocrystalline	15	0.22
90	0	polycrystalline	14	0.23
90	0	Thin film	9.3	0.27
90	45	Monocrystalline	14.8	0.23
90	45	polycrystalline	13.9	0.23
90	45	Thin film	9.3	0.27
90	120	Monocrystalline	9.8	0.34
90	120	polycrystalline	9.2	0.35
90	120	Thin film	6.2	0.41
90	90	Monocrystalline	12.5	0.27
90	90	polycrystalline	11.7	0.28
90	90	Thin film	7.8	0.32
90	180	Monocrystalline	6	0.56
90	180	polycrystalline	5.6	0.57
90	180	Thin film	3.7	0.67

3.4 MULTI CRITERIA DECISION MAKING (MCDM) METHOD

MCDM is a technique that combines qualitative and quantitative results with an alternate option to create a small solution. Numerous issues that arise in businesses and in our daily lives can be solved using these strategies. MCDM is a decision-making method that has been used for many years to evaluate many options, including policy, strategy, and choice, in order to find solutions to issues. MCDM has a long history, but it really took off in the 1940s and 1950s. In 1944, Von Neumann and Morgenstern proposed the utility theory, which has since grown to be a significant procedural stream in contemporary decision science. The task keeps progressing even after goal programming [90The MCDA is currently being used to solve a genuine issue[91]. The researcher's contributions pave the way for the advancement of computing and the creation of a user-friendly decision-making support system. There are several issues in the world, and MCDM is the tool to find the best answer. To make the concepts and associated processes easier to understand, many books on MCDM have been written[92][93].

Not all of the MCDM techniques presented here are recommended for the solution of multi-criteria decision issues. Both qualitative and quantitative data are used in MCDM, but some approaches exclusively utilize quantitative data, while others only use qualitative data. The weighted technique provides quantitative data and results presented in ranking order. The evaluation's usage of visuals provides qualitative and quantitative data as well as results that are presented visually. The outranking approaches also present quantitative data and provide rankings of the outcomes. However, occasionally it shows incomplete data. The analytical hierarchy process (AHP) produces findings in ranking form while displaying qualitative data in a low-transparency manner. Additionally, permutation techniques present qualitative data with little transparency and offer results in the form of rankings [94]. Additionally, it has been shown that there are numerous different kinds of information, such as information on standards and alternative approaches, that are being categorized and displaying the categorization depending on input data [95][96].

The MCDM method offers a clear, organized way to increase objectivity and produces data that can be applied to analysis [97]. In addition, the MCDM has a lot of components, which can be summed up as follows:

- **Aggregation algorithms:** Many MCDM procedures produce a large number of outcomes that can be combined to arrive at a solution that can be regarded as the best possible outcome[54][98]. However, choosing the best strategy is not always easy.
- **Compensatory methods:** Complete accumulation systems that permit trade-offs between good and poor performance on several criteria, for example, poor performance on water quality may be offset by good performance on investment costs Additionally, these issues are covered and other performance standards are included [54]. Additionally, the mathematical MCDM computations yield excellent results for one standard and subpar results for another. Additionally, this is a requirement.
- **Elicitation process:** Some methods rely on idiosyncratic information, such as weights and preferences, which are not insignificant and are likely to have an impact on the results [54].

- **Alternatives with low incomparability:** The aim of all MCDM is to reduce options with low incomparability and to reduce the problems to single-criteria problems for which an optimal solution happens completely. This led to selecting the best option with a value, for example, A is superior to B by 0.45 value[99].
- **Scaling effects:** certain MCDM techniques operate on a scale that produces an unacceptable[100] assessment.
- **Problem structuring:** In some circumstances, findings may be used by omitting or adding a specific connected standard or choice.
- **Additional data that is required:** Some MCDM techniques require more data in order to produce better results.
- **Uncertainty:** If the number of decimals entered is increased or lowered, the results could change.

The study that was undertaken for this research uses Multi-Criteria Decision Making (MCDM), as shown in Figure 3.31 below, to try to optimize the selection of the PV system characteristics that are the most economically viable. Additionally, by using a straightforward way, this creates a multi-variable system optimization that can be used, among other things, to select the optimal system.

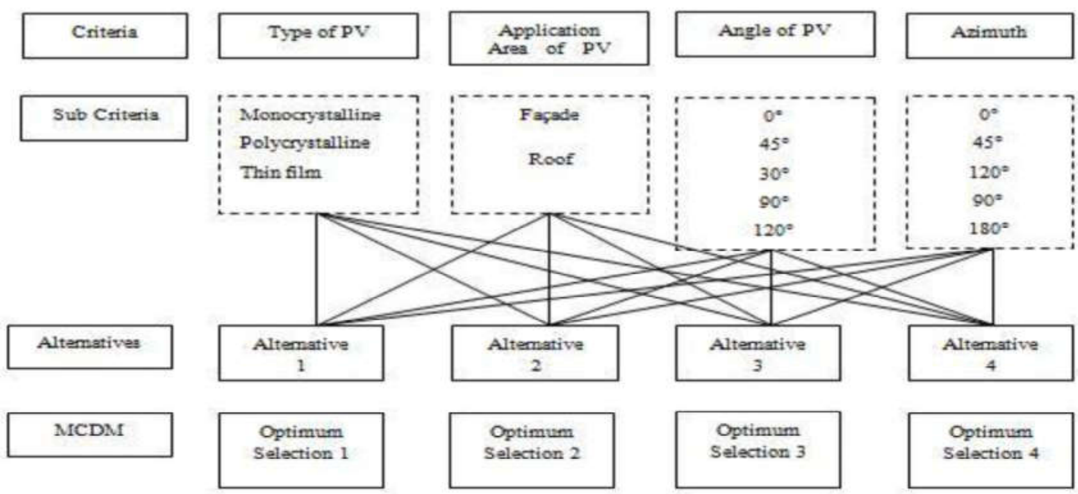


Figure 3.30: Multi Criteria Decision Making (MCDM) Method

The conducted study for this work tries to optimize the selection of the most economically suitable PV system variables, using Multi-Criteria Decision Making (MCDM)[101]. For optimization, the optimum case from all the available ones is selected here using the Multi-Criteria Decision Making (MCDM) method such as Analytic Hierarchy Process (AHP), Weighted Sum Method (WSM), Weighted Product Method(WPM), AHP Combined Method, Group Evaluations Method[102].

Fuzzy AHP, Fuzzy AHP Combined, and Fuzzy AHP Group[102] [103]. Figure 3.31 shows methods for grouping decision-making based on Multi-Criteria Decision Making (MCDM).

In decision-making problems, the Weighted Sum Model or Method (WSM) (Fishburn et.al.,1967) has been used by this research which is the simplest known multi-criteria decision-making (MCDM) method for evaluating several alternatives in terms of several decision criteria[89]. Also, Applicable only when all the data are in the same unit.

- Sum Model or Method (WSM)[91] requires a process of normalizing the decision matrix (X) to a scale that can be compared with all the ratings of existing alternatives.

$$r_{ij} = \frac{x_{ij}}{Max(x_{ij})} \quad (3.1)$$

$$r_{ij} = \frac{Min(x_{ij})}{(x_{ij})} \quad (3.2)$$

- If j is an attribute benefit, then use the formula number one. If the attribute j cost, then using the formula number two:

$$w = \frac{c_1}{c_1 + \cdots + c_n} \times 100\% \quad (3.3)$$

$$V_i = \sum_{j-1}^{n} = 1 w_j r_{ij} \quad (3.4)$$

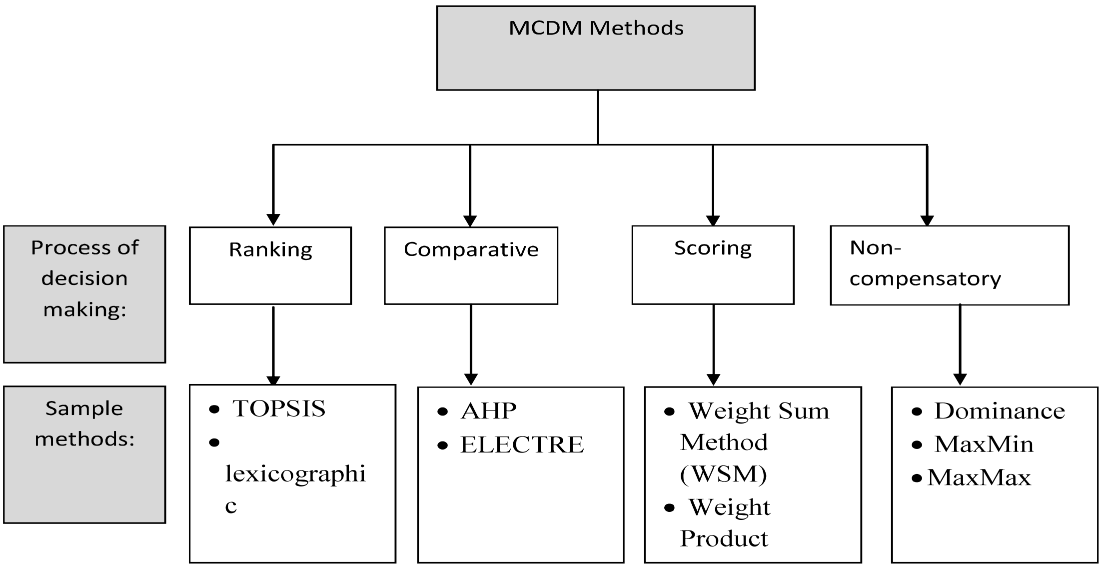


Figure 3.31: Methods for Grouping Decision Making Based on Multi-Criteria Decision Making (MCDM) Method Adapted From [103][98]

For optimization, the optimum case from all the available ones is selected here using the Multi-Criteria Decision Making (MCDM) method as follows:

- From the calculations for all the different cases, the highest energy yield is considered as a base with all the other cases' results relative to this base per unit.
- Next, the lowest specific energy cost is taken as a base, with the rest cases' costs as relative values per unit.
- The systems considered are then arranged as the highest energy yield and the lowest specific energy cost consideration.
- With the area assumed as 100 m2, for the sake of comparing the different available PV systems, the software then calculates the electrical energy yield in Kwh/year, its cost in Euros, and the specific electrical energy cost in Euros /Kwh for each available PV system selected at all possible tilt and azimuth angles. In addition, results for the selected typical case are summarized as shown in Tables 3.32 as well as Table. 3.33.

Table 3.32: Electrical Energy Production of PV Panels and the Specific Electrical Energy Cost in Euros /Kwh

Tilt	Azimuth	PV technology	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	A	B	Score =A+B
							Annual Yield*0.5	Energy cost*0.5	
0	0	Monocrystalline	19.4	0.17	0.87	0.88	0.43	0.44	0.87
0	0	polycrystalline	18.1	0.18	0.81	0.83	0.40	0.42	0.82
0	0	Thin film	12.1	0.21	0.54	0.71	0.27	0.36	0.63
0	45	Monocrystalline	19.4	0.17	0.87	0.88	0.43	0.44	0.87
0	45	polycrystalline	18.1	0.18	0.81	0.83	0.40	0.42	0.82
0	45	Thin film	12.1	0.21	0.54	0.71	0.27	0.36	0.63
0	120	Monocrystalline	19.4	0.17	0.87	0.88	0.43	0.44	0.87
0	120	polycrystalline	18.1	0.18	0.81	0.83	0.40	0.42	0.82
0	120	Thin film	12.1	0.21	0.54	0.71	0.27	0.36	0.63
0	90	Monocrystalline	19.4	0.17	0.87	0.88	0.43	0.44	0.87
0	90	polycrystalline	18.1	0.18	0.81	0.83	0.40	0.42	0.82
0	90	Thin film	12.1	0.21	0.54	0.71	0.27	0.36	0.63
0	180	Monocrystalline	19.4	0.17	0.87	0.88	0.43	0.44	0.87
0	180	polycrystalline	18.1	0.18	0.81	0.83	0.40	0.42	0.82
0	180	Thin film	12.1	0.21	0.54	0.71	0.27	0.36	0.63
30	0	Monocrystalline	22.4	0.15	1.00	1.00	0.5	0.5	1
30	0	polycrystalline	21	0.15	0.94	1.00	0.47	0.50	0.97
30	0	Thin film	14	0.18	0.63	0.83	0.31	0.42	0.73
30	45	Monocrystalline	21.4	0.16	0.96	0.94	0.48	0.47	0.95
30	45	polycrystalline	20	0.16	0.89	0.94	0.45	0.47	0.92
30	45	Thin film	13.3	0.19	0.59	0.79	0.30	0.39	0.69

Table 3.32: Continued

30	120	Monocrystalline	16.3	0.21	0.73	0.71	0.36	0.36	0.72
30	120	polycrystalline	15.3	0.21	0.68	0.71	0.34	0.36	0.70
30	120	Thin film	10.2	0.24	0.46	0.63	0.23	0.31	0.54
30	90	Monocrystalline	18.6	0.18	0.83	0.83	0.42	0.42	0.83
30	90	polycrystalline	17.4	0.18	0.78	0.83	0.39	0.42	0.81
30	90	Thin film	11.6	0.21	0.52	0.71	0.26	0.36	0.62
30	180	Monocrystalline	15.8	0.21	0.71	0.71	0.35	0.36	0.71
30	180	polycrystalline	14.8	0.22	0.66	0.68	0.33	0.34	0.67
30	180	Thin film	9.9	0.25	0.44	0.60	0.22	0.3	0.52
45	0	Monocrystalline	22.1	0.15	0.99	1.00	0.49	0.5	0.99
45	0	polycrystalline	20.7	0.16	0.92	0.94	0.46	0.47	0.93
45	0	Thin film	13.8	0.18	0.62	0.83	0.31	0.42	0.72
45	45	Monocrystalline	21	0.16	0.94	0.94	0.47	0.47	0.94
45	45	polycrystalline	19.6	0.16	0.88	0.94	0.44	0.47	0.91
45	45	Thin film	13.1	0.19	0.58	0.79	0.29	0.39	0.69
45	120	Monocrystalline	14.5	0.23	0.65	0.65	0.32	0.33	0.65
45	120	polycrystalline	13.6	0.24	0.61	0.63	0.30	0.31	0.62
45	120	Thin film	9.1	0.27	0.41	0.56	0.20	0.28	0.48
45	90	Monocrystalline	17.6	0.19	0.79	0.79	0.39	0.39	0.79
45	90	polycrystalline	16.5	0.2	0.74	0.75	0.37	0.38	0.74
45	90	Thin film	11	0.23	0.49	0.65	0.25	0.33	0.57
45	180	Monocrystalline	10.9	0.31	0.49	0.48	0.24	0.24	0.49
45	180	polycrystalline	10.2	0.32	0.46	0.47	0.23	0.23	0.46
45	180	Thin film	6.8	0.37	0.30	0.41	0.15	0.20	0.35
60	0	Monocrystalline	20.7	0.16	0.92	0.94	0.46	0.47	0.93

Table 3.32: Continued

60	0	polycrystalline	19.4	0.17	0.87	0.88	0.43	0.44	0.87
60	0	Thin film	13	0.19	0.58	0.79	0.29	0.39	0.68
60	45	Monocrystalline	19.6	0.17	0.88	0.88	0.44	0.44	0.88
60	45	polycrystalline	18.4	0.18	0.82	0.83	0.41	0.42	0.83
60	45	Thin film	12.3	0.2	0.55	0.75	0.27	0.38	0.65
60	120	Monocrystalline	12.9	0.26	0.58	0.58	0.29	0.29	0.58
60	120	polycrystalline	12.1	0.27	0.54	0.56	0.27	0.28	0.55
60	120	Thin film	8	0.31	0.36	0.48	0.18	0.24	0.42
60	90	Monocrystalline	16.2	0.21	0.72	0.71	0.36	0.36	0.72
60	90	polycrystalline	15.1	0.21	0.67	0.71	0.34	0.36	0.69
60	90	Thin film	10.1	0.25	0.45	0.60	0.23	0.30	0.53
60	180	Monocrystalline	8.4	0.4	0.38	0.38	0.19	0.19	0.38
60	180	polycrystalline	7.8	0.41	0.35	0.37	0.17	0.18	0.36
60	180	Thin film	5.2	0.48	0.23	0.31	0.12	0.16	0.27
90	0	Monocrystalline	15	0.22	0.67	0.68	0.33	0.34	0.68
90	0	polycrystalline	14	0.23	0.63	0.65	0.31	0.33	0.64
90	0	Thin film	9.3	0.27	0.42	0.56	0.21	0.28	0.49
90	45	Monocrystalline	14.8	0.23	0.66	0.65	0.33	0.33	0.66
90	45	polycrystalline	13.9	0.23	0.62	0.65	0.31	0.33	0.64
90	45	Thin film	9.3	0.27	0.42	0.56	0.21	0.28	0.49
90	120	Monocrystalline	9.8	0.34	0.44	0.44	0.22	0.22	0.44
90	120	polycrystalline	9.2	0.35	0.41	0.43	0.21	0.21	0.42
90	120	Thin film	6.2	0.41	0.28	0.37	0.14	0.18	0.32
90	90	Monocrystalline	12.5	0.27	0.56	0.56	0.28	0.28	0.56
90	90	polycrystalline	11.7	0.28	0.52	0.54	0.26	0.27	0.53

Table 3.32:Continued

90	90	Thin film	7.8	0.32	0.35	0.47	0.17	0.23	0.41
90	180	Monocrystalline	6	0.56	0.27	0.27	0.13	0.13	0.27
90	180	polycrystalline	5.6	0.57	0.25	0.26	0.13	0.13	0.26
90	180	Thin film	3.7	0.67	0.17	0.22	0.08	0.11	0.19
			MAX =22.4	MIN = 0.15					

Table 3.33: An Electrical Production of PV Panels and The Scores and Rank

Tilt	Azimuth	PV technology	Annual Yield	Energy cost	score	Rank
30	0	Monocrystalline	22.4	0.15	1	1
45	0	Monocrystalline	22.1	0.15	0.99	2
30	0	polycrystalline	21	0.15	0.97	3
30	45	Monocrystalline	21.4	0.16	0.95	4
45	45	Monocrystalline	21	0.16	0.94	5
45	0	polycrystalline	20.7	0.16	0.93	6
60	0	Monocrystalline	20.7	0.16	0.93	6
30	45	polycrystalline	20	0.16	0.92	7
45	45	polycrystalline	19.6	0.16	0.91	8
60	45	Monocrystalline	19.6	0.17	0.88	9
0	0	Monocrystalline	19.4	0.17	0.87	10
0	45	Monocrystalline	19.4	0.17	0.87	10
0	120	Monocrystalline	19.4	0.17	0.87	10
0	90	Monocrystalline	19.4	0.17	0.87	10
0	180	Monocrystalline	19.4	0.17	0.87	10
60	0	polycrystalline	19.4	0.17	0.87	10
30	90	Monocrystalline	18.6	0.18	0.83	11
60	45	polycrystalline	18.4	0.18	0.83	11
0	0	polycrystalline	18.1	0.18	0.82	12
0	45	polycrystalline	18.1	0.18	0.82	12
0	120	polycrystalline	18.1	0.18	0.82	12
0	90	polycrystalline	18.1	0.18	0.82	12
0	180	polycrystalline	18.1	0.18	0.82	12
30	90	polycrystalline	17.4	0.18	0.81	13
45	90	Monocrystalline	17.6	0.19	0.79	14
45	90	polycrystalline	16.5	0.2	0.74	15
30	0	Thin film	14	0.18	0.73	16
30	120	Monocrystalline	16.3	0.21	0.72	17
45	0	Thin film	13.8	0.18	0.72	17
60	90	Monocrystalline	16.2	0.21	0.72	17
30	180	Monocrystalline	15.8	0.21	0.71	18
30	120	polycrystalline	15.3	0.21	0.7	19
30	45	Thin film	13.3	0.19	0.69	20
45	45	Thin film	13.1	0.19	0.69	20
60	90	polycrystalline	15.1	0.21	0.69	20
60	0	Thin film	13	0.19	0.68	23
90	0	Monocrystalline	15	0.22	0.68	23
30	180	polycrystalline	14.8	0.22	0.67	24
90	45	Monocrystalline	14.8	0.23	0.66	25
45	120	Monocrystalline	14.5	0.23	0.65	26
60	45	Thin film	12.3	0.2	0.65	26
90	0	polycrystalline	14	0.23	0.64	27

Table 3.33: Continued

90	45	polycrystalline	13.9	0.23	0.64	27
0	0	Thin film	12.1	0.21	0.63	28
0	45	Thin film	12.1	0.21	0.63	28
0	120	Thin film	12.1	0.21	0.63	28
0	90	Thin film	12.1	0.21	0.63	28
0	180	Thin film	12.1	0.21	0.63	28
30	90	Thin film	11.6	0.21	0.62	28
45	120	polycrystalline	13.6	0.24	0.62	28
60	120	Monocrystalline	12.9	0.26	0.58	29
45	90	Thin film	11	0.23	0.57	30
90	90	Monocrystalline	12.5	0.27	0.56	31
60	120	polycrystalline	12.1	0.27	0.55	32
30	120	Thin film	10.2	0.24	0.54	33
60	90	Thin film	10.1	0.25	0.53	34
90	90	polycrystalline	11.7	0.28	0.53	34
30	180	Thin film	9.9	0.25	0.52	35
45	180	Monocrystalline	10.9	0.31	0.49	36
90	0	Thin film	9.3	0.27	0.49	36
90	45	Thin film	9.3	0.27	0.49	36
45	120	Thin film	9.1	0.27	0.48	37
45	180	polycrystalline	10.2	0.32	0.46	38
90	120	Monocrystalline	9.8	0.34	0.44	39
60	120	Thin film	8	0.31	0.42	40
90	120	polycrystalline	9.2	0.35	0.42	40
90	90	Thin film	7.8	0.32	0.41	41
60	180	Monocrystalline	8.4	0.4	0.38	42
60	180	polycrystalline	7.8	0.41	0.36	43
45	180	Thin film	6.8	0.37	0.35	44
90	120	Thin film	6.2	0.41	0.32	45
60	180	Thin film	5.2	0.48	0.27	46
90	180	Monocrystalline	6	0.56	0.27	46
90	180	polycrystalline	5.6	0.57	0.26	48
90	180	Thin film	3.7	0.67	0.19	49

3.5 DISCUSSION

The shown case study results are in Table. 3.27, Table. 3.28.Table. 3.29,Table. 3.30 as well as Table. 3.31, gives a simple straightforward method for selecting the optimum PV system for any application requirements. For each case, the site location, and the assumed costs are entered into the software which performs the calculations according to the described method, giving the results as the optimum PV system with the highest electrical energy output and the lowest possible cost, arranging the other systems options according to descending order merit based on the same said criteria.

The developed method provides the largest possible energy production at the lowest possible cost when selecting the suggested system, under the used assumptions at the selected site, as indicated in the score column of Table 3.31 above with the shown set variable of the PV system selected.

The reliability of the method results depends on the reliabilities of the used data and assumptions, which imply that these have to be as accurate as possible. For that purpose, and as they may change with time, they have to be checked and updated with the most correct ones.

CHAPTER IV

CASE STUDY APPLICATION

4.1 INTRODUCTION

In the previous chapters, several relevant aspects have been dealt with in relation to the proposed method of optimizing the selection of the PV system for supplying university campuses with all or at least part of their electrical energy needs.

A real-life application example of the introduced method, at a typical university campus is outlined here, to demonstrate the simplicity of the method and, its usefulness in selecting the PV system, with the highest annual electrical energy yield at the lowest unit electrical energy cost.

It is to be stressed here, that with a still relatively low overall efficiency and, high cost of the PV-generated energy, ways, and means of optimizing the possible available energy from this source and its conservation is always worthwhile.

The comprehensive treatment of using PV solar renewable energy sources requires the consideration of the other related aspects besides the technical and economic ones, such as the environmental, architectural, legal, and social aspects, which are outlined here, for detailed considerations at each specific case.

Another issue raised here has to do with the university's competition and, the ranking systems, which have started to include their energy supply, use, efficiency, as well as their use of clean, renewable energy sources.

It is hoped that considering all of these issues in this work and the introduced brief review of the PV systems and their applications will lead to useful conclusions and recommendations discussed in the next chapter.

4.2 CASE STUDY: APPLICATION at CANKAYA UNIVERSITY

As has been mentioned, this work was intended to study the application of PV at Çankaya University, Ankara, Turkey. The university is founded in 1997, to become by 2020 the highest-ranked university in Turkey among all the country's public and private universities [104]. It has 5 faculties and 21 departments, as well as 2 institutes and 2 vocational schools with three programs. The university, besides its undergraduate programs, runs 12 master's and 6 Ph.D. programs. Almost all of its programs are conducted in the English language. Its new central campus occupies 440,000 m2. , figure 4.1 and figure 4.2.

Figure 4.1: Çankaya University View [94]

Figure 4.2: Çankaya University Map

The solar PV system is proposed here for some of the university buildings, to cover part or all of their electrical power needs. The proposed system is based on the previous calculation method using the PVSYS computer software for both roof and façade positioning and the previously calculated best option. The calculation results are as shown in the following cases tables:

4.2.1 On Roof Positioning

On applying the on-roof positioning, around 15% of the total roof area is left free for the handling of tools and equipment and personnel movement, this gives different areas options as shown in table (3.31) for consideration, details of these areas including, the optimum option; area 1.

Table 4.1: The Three Selected Cases

Cases	Tilt	Azimuth	PV technology
Case 1	30	0	Monocrystalline
Case 2	45	45	polycrystalline
Case 3	60	0	Thin film

From the previous calculations, the best on-roof position option is as shown in table 4.2 and table 4.3:

Table 4.2: Case 1

Tilt	Azimuth	PV technology	score	Rank
30	0	Monocrystalline	1	1

Table 4.3: On Roof Positioning Case 1

No	Building Name	Area m^2	85 % Area	Annual Yield (MWh/yr.)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	680	580	125	0.14	267851
2	Faculty of Architecture	1652	1400	303	0.12	582667
3	Faculty Of Low	1314	1120	242	0.13	471868
4	Faculty structure	511	435	94	0.14	204336
5	Faculty of Arts and Sciences	872	740	160	0.13	319272
6	Social Facilities Classrooms laboratories	1453	1240	268	0.13	519494
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheatres laboratories	1917	1630	352	0.12	672911
8	Faculty structure	1430	1200	259	0.13	503644
9	Faculty of Engineering 2	944	800	173	0.13	343581
10	Faculty of Engineering 1	718	610	132	0.14	280886
11	Faculty of Economics and Administrative	810	690	149	0.13	298939
12	Libraries and Information Centers	888	750	162	0.13	323330
13	Rectorate Blok A	480	400	86.5	0.14	188854
14	Rectorate Blok A	338	290	62.7	0.15	139696

Table 4.3 Continued

16	Preparatory school Blok A & C	1127	950	205	0.13	403976
17	Congress Centre	1963	1700	368	0.12	700260
18	Sport Centre	1418	1200	259	0.13	503644
19	Male Dormitory	920	780	169	0.13	335489
20	Girl Dormitory	920	780	169	0.13	335489
Total		17905	3870.2	2.64	7677073	Total

Another roof position option is given in table 4.4 and table 4.5.

Table 4.4: Case 2

Tilt	Azimuth	PV technology	score	Rank
45	45	polycrystalline	0.91	8

Table 4.5: On Roof Positioning Case 2

No	Building Name	Area m^2	85 % Area	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	680	580	113	0.15	257856
2	Faculty of Architecture	1652	1400	272	0.13	562163
3	Faculty Of Low	1314	1120	218	0.14	455176
4	Faculty structure	511	435	84.5	0.15	196666
5	Faculty of Arts and Sciences	872	740	114	0.14	307866
6	Social Facilities Classrooms laboratories	1453	1240	241	0.13	501162
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheaters laboratories	1917	1630	317	0.13	649314
8	Faculty structure	1430	1200	233	0.13	485857
9	Faculty of Engineering 2	944	800	155	0.14	331330
10	Faculty of Engineering 1	718	610	119	0.15	270415
11	Faculty of Economics and Administrative	810	690	134	0.14	288241
12	Libraries and Information Centers	888	750	146	0.14	311783
13	Rectorate Blok A	480	400	77.7	0.15	181753
14	Rectorate Blok A	338	290	56.4	0.16	134408

Table 4.5 Continued

15	Preparatory school Blok B	718	610	119	0.15	270415
16	Preparatory school Blok A & C	1127	950	185	0.14	389630
17	Congress Centre	1963	1700	330	0.13	675728
18	Sport Centre	1418	1200	233	0.13	485857
19	Males Dormitory	920	780	152	0.14	323519
20	Girls Dormitory	920	780	152	0.14	323519
Total			17905	3451.6	2.81	7402658

The last selected roof option is shown in table 4.6 and Table 4.7.

Table 4.6: Case 3

Tilt	**Azimuth**	**PV technology**	**score**	**Rank**
60	0	Thin film	0.68	23

Table 4.7: On Roof Positioning Case 3

No	Building Name	Area m^2	85 % Area	Annual Yield (MWh/yr.)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	680	580	74.1	0.18	206988
2	Faculty of Architecture	1652	1400	1794	0.16	57842
3	Faculty of Law	1314	1120	143	0.16	370211
4	Faculty structure	511	435	55.6	0.18	157608
5	Faculty of Arts and Sciences	872	740	94.5	0.17	260855
6	Social Facilities Classrooms laboratories	1453	1240	158	0.16	407864
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheaters laboratories	1917	1630	208	0.16	529297
8	Faculty structure	1430	1200	153	0.16	395330
9	Faculty of Engineering 2	944	800	102	0.17	289022
10	Faculty of Engineering 1	718	610	77.9	0.18	217132
11	Faculty of Economics and Administrative	810	690	88.2	0.18	244080
12	Libraries and Information Centers	888	750	95.8	0.17	264204
13	Rectorate Blok A	480	400	52.1	0.18	145585
14	Rectorate Blok A	338	290	31	0.19	107456
15	Preparatory school Blok B	718	610	77.9	0.18	217132
16	Preparatory school Blok A & C	1127	950	121	0.17	330830
17	Congress Centre	1963	1700	217	0.16	550963

Table 4.7 Continued

18	Sport Centre	1418	1200	153	0.16	395330
19	Males Dormitory	920	780	99.6	0.17	274240
20	Girls Dormitory	920	780	99.6	0.17	99.6
Total			17905	3205.1	2.58	3870606

4.2.2 On Façade Positioning

as in the on-roof positioning, this section gives the corresponding tables for the façade positioning., Table 4.8 gives the details of three selected cases of these

Table 4.8: The Three Selected Cases

Cases	Tilt	Azimuth	PV technology
Case 1	90	0	Monocrystalline
Case 2	60	0	Thin film
Case 3	45	90	Monocrystalline

Here the same procedure is applied with the PV panels positioned on the south side of each building. The case is detailed as before in table 4.9 and table 4.10 for the best option.

Table 4.9: Case 1

Tilt	Azimuth	PV technology	score	Rank
60	0	Monocrystalline	0.93	6

Table 4.10: Façade positioning case 1

No	Building Name	Area m^2	50% Area	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	23.100	11.55	1.7	0.34	7904
2	Faculty of Architecture	78	39	5.6	0.29	22994
3	Faculty of Law	48	24	3.4	0.31	14904
4	Faculty structure	42	21	3	0.32	13185
5	Faculty of Arts and Sciences	96	48	6.9	0.28	27852
6	Social Facilities Classrooms laboratories	60	30	4.3	0.30	18299
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheaters laboratories	60	30	4.3	0.30	18299
8	Faculty structure	56	28	4	0.30	17173
9	Faculty of Engineering 2	94.5	47	6.7	0.28	27316
10	Faculty of Engineering 1	147	73	10.6	0.28	39314
11	Faculty of Economics and Administrative	126	63	9	0.27	34310

Table 4.10 Continued

12	Libraries and Information Centers	42	21	3	0.32	13185
13	Rectorate Blok A	70	35	5	0.29	20812
14	Rectorate Blok A	21	10	1.6	0.34	6694
15	Preparatory school Blok B	42	21	3	0.32	13185
16	Preparatory school Blok A & C	98	49	7.2	0.28	28388
17	Congress Centre	6870	3435	493	0.17	1366290
18	Sport Centre	112	56	8	0.28	32120
19	Males Dormitory	112	56	8	0.28	32120
20	Girls Dormitory	112	56	8	0.28	32120
Total			4154	1192.6	11.66	1786464

Another façade positioning case is as detailed in table 4.11 and table 4.12

Table 4.11: Case 2

Tilt	Azimuth	PV technology	score	Rank
60	0	Thin film	0.68	23

Table 4.12: Façade positioning case 2

No	Building Name	Area m^2	50% Area	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	23.100	11.55	1.5	0.27	5875
2	Faculty of Architecture	78	39	5	0.24	17458
3	Faculty of Law	48	24	3.1	0.25	11129
4	Faculty structure	42	21	2.7	0.26	9837
5	Faculty of Arts and Sciences	96	48	6.1	0.24	21179
6	Social Facilities Classrooms laboratories	60	30	3.8	0.25	13684
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheaters laboratories	60	30	3.8	0.25	13684
8	Faculty structure	56	28	3.6	0.25	12836
9	Faculty of Engineering 2	94.5	47	6	0.24	20768
10	Faculty of Engineering 1	147	73	9.3	0.22	30957
11	Faculty of Economics and Administrative	126	63	8	0.23	26978
12	Libraries and Information Centers	42	21	2.7	0.26	9837
13	Rectorate Blok A	70	35	4.5	0.24	15788
14	Rectorate Blok A	21	10	1.3	0.28	4970
15	Preparatory school Blok B	42	21	2.7	0.26	9837

Table 4.12 Continued

16	Preparatory school Blok A & C	98	49	6.3	0.24	21590
17	Congress Centre	6870	3435	439	0.15	1079869
18	Sport Centre	112	56	7.2	0.23	24172
19	Males Dormitory	112	56	7.2	0.23	24172
20	Girls Dormitory	112	56	7.2	0.23	24172
Total			4154	531	4.82	1398792

The last faced selected positioning case is shown in Tables 4.13 and 4.14

Table 4.13: Case 3

Tilt	Azimuth	PV technology	score	Rank
45	90	Monocrystalline	0.79	14

Table 4.14: Façade positioning Case 3

No	Building Name	Area m^2	50% Area	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	23.100	11.55	2.1	0.28	7904
2	Faculty of Architecture	78	39	6.8	0.24	22994
3	Faculty of Law	48	24	4.2	0.25	14904
4	Faculty structure	42	21	3.7	0.26	13185
5	Faculty of Arts and Sciences	96	48	8.4	0.23	27852
6	Social Facilities Classrooms laboratories	60	30	5.3	0.25	18299
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheaters laboratories	60	30	5.3	0.25	18299
8	Faculty structure	56	28	4.9	0.25	17173
9	Faculty of Engineering 2	94.5	47	8.2	0.23	27316
10	Faculty of Engineering 1	147	73	12.8	0.22	39314
11	Faculty of Economics and Administrative	126	63	11	0.22	34310
12	Libraries and Information Centers	42	21	3.7	0.26	13185
13	Rectorate Blok A	70	35	6.1	0.24	20812
14	Rectorate Blok A	21	10	1.8	0.28	6694
15	Preparatory school Blok B	42	21	3.7	0.26	13185
16	Preparatory school Blok A & C	98	49	8.6	0.23	28388
17	Congress Centre	6870	3435	602	0.14	1366290
18	Sport Centre	112	56	9.8	0.23	32120

Table 4.14 Continued

19	Males Dormitory	112	56	9.8	0.23	32120
20	Girls Dormitory	112	56	9.8	0.23	32120
Total			4154	728	4.78	1786464

4.2.3 On Roof and Façade Positioning

In this last case, the positioning of the PV panels is made up of a combination of on-roof and façade positioning of 50% each, and the calculations are carried out as before, as shown in Table 4.15.

Table 4.15: Roof and Façade case

No	Building Name	Area m^2	Annual Yield (MWh/yr)	Energy cost (EUR/kWh)	Investment (EUR)
1	Heat Centre	592	126.7	0.48	275755
2	Faculty of Architecture	1439	308.6	0.41	605661
3	Faculty of Law	1144	245.4	0.44	486772
4	Faculty structure	456	97	0.46	217521
5	Faculty of Arts and Sciences	788	166.9	0.41	347124
6	Social Facilities Classrooms laboratories	1270	272.3	0.43	537793
7	Social Facilities Facilities Dining Hall Cafeteria Amphitheaters laboratories	1660	356.3	0.42	691210
8	Faculty structure	1228	263	0.43	520817
9	Faculty of Engineering 2	847	179.7	0.41	370897
10	Faculty of Engineering 1	683	142.6	0.42	320200
11	Faculty of Economics and Administrative	753	158	0.4	333249
12	Libraries and Information Centers	771	165	0.45	336515
13	Rectorate Blok A	435	91.5	0.43	209666
14	Rectorate Blok A	300	64.3	0.49	146390
15	Preparatory school Blok B	631	135	0.46	294071
16	Preparatory school Blok A & C	999	212.2	0.41	432364
17	Congress Centre	5135	861	0.29	2066550
18	Sport Centre	1256	267	0.41	535764
19	Males Dormitory	836	177	0.41	367609
20	Girls Dormitory	836	177	0.41	367609
Total		22059	4466.5	8.47	9463537

As of this work, the calculations of the proposed PV system for Çankaya university buildings, using on roof, façade and a combination of the two PV panels positioning have shown the following:

- The areas available with the on-roof positioning for the PV panels (3,870 m^2), are much larger than that with the façade construction (1,193 m^2), noting that in the first one 15% of the roof areas were allowed for spacing and movement, while only 50% of the façade areas was used to allow for windows and other construction openings.
- The combination case was with the largest available areas (4,467 m2) as it includes both roof and façade areas.
- The annual energy yield in MWh/yr. was at its largest (22,059 MWh/yr.) with the combination case, at its least value (4,154 MWh/yr.) with the façade and a larger value with on-roof positioning relative to the façade one (17,905 MWh/yr.).
- The energy cost in Euros/Kwh was the largest with the façade positioning at (11.66 Euros/Kwh), the least cost was for the on the roof and a medium cost for the combination case at (8.47 Euros/Kwh).
- The above conclusion gives the designer choices to select from according to his desire and needs

It must be mentioned that this project can be applied not only to the determined university (Çankaya University), but, it can be used in other buildings in the same region according to the geographical information that this research has entered and, it is related to the city of Ankara, Turkey. In the same way, in this section, some closer information about the university case is tried, by using some analysis and relevant references. It has been found through this work when considering 100 m2 of module surface area, that the electrical energy yield with the chosen technology at the university site is 16.1 MWh per year. The information received will aid in the design of the entire PV system components required to power the university campus and other related studies. In each case, the electrical load has to be determined to design the system components and determine its costs.

It should be noted that such systems necessitate the implementation of feasible energy conservation measures, such as the use of high-efficiency lighting, like LED lighting, and high-efficiency motors, as well as the reduction of unnecessary use, energy conservation, system efficiency as well as management.

Universities across the country are on one hand working to make their students smarter, on the other hand, to make their campuses smarter and more energy efficient. Furthermore, a solar photovoltaic (PV) system is a large undertaking these colleges are accomplishing. The beautiful open spaces, as well as the solar photovoltaic (PV) systems, produce a sculpture park feel, while visual effects with the panels' reflective properties emphasize the installation's magnitude. Furthermore, for example, the university invites students from all over the state to come to learn about clean, renewable energy as well as be inspired by how beautiful sustainability can be by using solar photovoltaic (PV) systems. Furthermore, solar photovoltaic (PV) systems energy is becoming one of the most promising sources for producing power for residential, commercial, as well as industrial applications in any building and domain. In the same way, energy production based on solar photovoltaic (PV) systems has gained much attention from researchers and practitioners recently due to its desirable characteristics. However, the main difficulty in solar energy production is the volatility intermittent of photovoltaic system power generation, which is sometimes mainly due to weather conditions. Furthermore, this modern system is considered an economic and environmentally friendly system all over the world. Moreover, this research presented the possibility of installing this system in the building of Çankaya University, and the possibility of linking and installing it to include all university buildings, so that the university becomes one of the largest and most prestigious universities in Turkey, which is characterized by its use of the solar panel system. The disadvantages of using city electricity are now increasing. Additionally, the use of solar panels would raise the production capacity of the university and, raise the efficiency at the university level by making all departments of the university work throughout the day and meet all the requirements of students and visitors. Also, to cover the wishes of professors and doctors in all the university departments, the provision of green energy would raise the efficiency of the university laboratories, as this energy saves effort and time and, reduces costs during the work of these laboratories, which makes them high-level. Thus, based on this research, the usage of the proposed and implemented system has obtained a speedy increase in the number of research resulting from this university, which leads to raising the level of the university locally in Ankara and internationally for the

Turkish state in all respects to reach a high level based on rating system selection guidance and world university green campus ranking, in contrast with the international level, similar to the major international universities.

Based on the rating system selection guidance and, world university green campus ranking, as well as the green metric program, to enhance Çankaya University's ranking rate, according to the described method, giving the results as the optimum PV system with the highest electrical energy output and, the lowest possible cost, arranging the other systems options according to descending order merit, based on the same said criteria. Furthermore, the developed method provides the largest possible energy production at the lowest possible cost when selecting the suggested system, under the used assumptions at the selected site.

Environmental issues, solar photovoltaic (PV) systems independence and the high costs of fossil fuels have motivated the use and development of renewable as well as sustainable energy technologies. Furthermore, the implementation of integrated solar photovoltaic (PV) systems, according to international standards, shows the potential offered by these types of technological solutions for the energy mix. Moreover, these solutions comply with the regulations and guidelines established by the Turkish Government, Regulation photovoltaic energy in buildings at Çankaya University. Additionally, the results have motivated other university campuses to get involved in the concept of the smart campus, achieving joint strategies for monitoring and evaluating the performance of these systems, installed as laboratories in Çankaya University where there are different climatic conditions and options for installation, as well as where the government will in future increase it is renewable energy capacity for the more beneficial system.

The use of PV technology provides many benefits and, it may raise the rank of the university where the advantages of using this technology can be summarized as follows:

- No polluting emissions whatsoever;
- Saving in fossil fuels;
- Increased system reliability, since there are no moving parts;
- Minimal running costs and maintenance;
- Use of high-efficiency lighting, such as LED lighting
- Modular system, power remains increasing, simply by adding more modules.

- To decrease incomparability
- To decrease the problems based on single-criterion problems for which an ideal solution occurs entirely.

4.3 ÇANKAYA UNIVERSITY RANKING IMPROVEMENT AND THE PROPOSED SOLAR PV SYSTEM

University ranking systems have been in existence for several years, recording, displaying, and documenting the relative overall classification of universities based on several criteria in different activities reflecting the university's relative merits and stand nationally, regionally, or internationally.

The objectives of university rankings include showing those interested in where each university stands relative to the others. The ranking bodies usually issue a ranking update each year showing the latest status of the ranking.

Several items are included for universities to indicate their stand for the ranking organizers to evaluate each university's rank. These items include the university research, teaching, activities, teaching staff, students, contributions … etc.

Universities around the world try their best to secure high-ranking levels and improve them year by year in competition with other universities.

Some ranking systems immerse in recent years concentrating on green university campuses, and sustainability, including such items as renewable clean sources of energy, pollution reduction, and the environment, where universities are classified based on their activities and achievements in these areas.

One of these internationally recognized ranking systems is the UI Green Metric World University Ranking, run by SRM Institute of Science and Technology, the University of Indonesia, based broadly on environment, economy, and equity on campus sustainability, with categories on setting and infrastructure (15%), energy and climate change (21%), waste (15%), water (10%), transportation (18%) and, education (18%). The energy and climate change items include:

- Energy-efficient appliances usage
- Smart building implementation
- Renewable energy usage
- The ratio of total electricity usage towards the campus population
- The ratio of renewable energy produced to energy usage

- Elements of green building implementation
- Greenhouse gas emission reduction program
- The ratio of total carbon footprint toward campus population

It is noted that most of these items are included in the solar PV system proposed here, and hence its implementation will introduce Çankaya University to this program and will give it, together with its programs in the other categories mentioned above adequate classification.

The proposed project of introducing buildings solar PV electrical energy supply system at the Çankaya University campus in Ankara, Turkey will help raise the university's rank among other universities as it will provide site generation of electrical energy needs of the university without harmful gases emission, in a sustainable, clean, environmentally friendly process that turns out to be sustainable and economically feasible.

4.4 DISCUSSION

Upon carrying out the study, the following points may be outlined:

- The reviewed information indicates that building-integrated photovoltaics (BIPV) is an adequate technology for buildings' electrical power supply, as more and more buildings are being designed and built, particularly in urban areas.
- The BIPV technology is being improved and developed based on the experience gained from the already-built examples, making use of the learned lessons.
- Together with improving the technology, standards and market specifications are also improving as the market is expanding, with more and more competitors.
- The costs of applying the BIPV technology are expected to decrease and compete with those of conventional electrical power supplies. The solar modules' efficiency is also increasing.
- For PV technology's wider application in developing counties, the costs have to be reduced, perhaps through market demand expansion.
- Further work is needed to lower the costs for this technology to compete with conventional power generation supplies.

- Automatic solar tracking and concentrated PV techniques to raise the site solar radiation received and hence increase the yield and reduce the output electrical energy costs need to be improved at lower costs to be feasible.
- Ways and means need to be looked for to further reduce the technologies modules' costs for reduced competitive energy output.
- Batteries and inverters need also to be further developed and their costs reduced to contribute to reducing the output energy costs.
- Universities to better cope with and benefit from the PV technology application need to apply energy conservation measures, and load management and use efficient load components such as using high-efficiency motors and LED (Light Emitting Diodes) lighting systems.
- The PV technology applications provide less cost and time effort to the university, as well as anywhere where it can be implemented.
- Maintenance costs of the PV system are relatively easy and contribute only by a small portion to the energy costs, which makes room for enhancing such works to expand the system life with relatively little increase in the cost
- Selection among the BIPV, BAPV, and BIPV/T is related to the customer requirements, associated costs, and the project conditions, it is not possible to generalize a rule for making such a choice, but this is left to be considered as a case.
- The social technology acceptance of all stakeholders does not seem to form much of a problem for university campuses, provided that all the legal requirements are well met and followed.
- It is recommended in PV systems applications to document the system performance for the benefit of system follow-up, improvement, and relevant future studies.

CHAPTER V

CONCLUSION

The purpose of carrying out this thesis is to consider the various aspects related to the introduction of photovoltaic technology to generate clean sustainable energy for the needs of university campuses buildings, trying to optimize this process. The following points are set as the main objectives of this study:

- To review the application of photovoltaic technology as direct conversion of solar energy to electrical energy.
- Select and use suitable software to study the different factors affecting this application.
- To consider the different relevant parameters of the application, and to optimize the system's main parameters selection and values in a simple example to demonstrate how a proposed method can help the designers of such projects.
- To consider the technical, economic, architectural, environmental, social, and legal aspects of this undertaking.
- To document notes and recommendations for such project designers.

The main hypothesis here is that PV technology, when optimized, can provide a reliable source of energy for university campuses buildings, and that this study contributes positively to realizing this optimization.

The methodology here is meant to be simple, practical, and fruitful; The market’s available PV systems are compared in the specific energy yield and the generated unit energy cost, giving equal weight to these two criteria and hence arranging the available systems in order of merits.

The proposed method may be applied to any set of PV systems at any location to serve as a guide to planners, designers, engineers, and relevant others. It is tried in this work for a typical university campus giving reasonable results as detailed in the study.

The following notes are worth mentioning here:

- It was the intention here to collect relevant specific information and data about the university campus, but due to the widespread coronavirus movement restrictions, it becomes not possible to carry out the needed contacts.
- The study was carried out using the geographical information and data of Ankara city, considering a typical 100 m2 PV modules surface area
- No design details are considered here, but the intention is to set guidelines that may help the designers of specific buildings in the region and other areas.
- The reviewed information indicates that building-integrated photovoltaics (BIPV) is an adequate technology for building's electrical power supply, as more and more buildings are being designed and built, particularly in urban areas, realizing several advantages over buildings supplied through conventional grids.
- As can be seen from the literature review, the BIPV technology is being improved and developed based on the experience gained from the already-built examples, making use of the learned lessons.
- Together with improving the technology, standards and market specifications are also improving as the market is expanding, with more and more competitors, and offers
- The costs of applying the BIPV technology are expected to continue decreasing and compete with those of conventional electrical power supplies. The solar module's efficiency is also increasing.
- For PV technology's wider application in developing counties, the costs have to be reduced further, perhaps through market demand expansion and improved systems economics.
- Further work is needed to lower the costs for this technology to favorably compete with conventional power generation supplies.
- Automatic solar tracking and concentrated PV techniques to raise the site solar radiation received and, hence increase the yield and, reduce the output electrical energy costs need to be improved at lower costs to be more feasible.

- Ways and means need to be looked for to further reduce the technology module's costs for reduced competitive energy output.
- Batteries and inverters need also to be further developed and their costs reduced to contribute to reducing the output energy costs.
- Universities to better cope with and benefit from the PV technology application have to apply energy conservation measures, load management, and use efficient load components such as using high-efficiency motors and LED (Light Emitting Diodes) lighting systems.
- The PV technology applications provide less cost and time effort to the university, as well as anywhere where it can be implemented.
- Maintenance of the PV system is usually relatively easy and contributes only by a small portion to the produced energy costs, which makes room for enhancing such works to expand the system life with relatively little increase in the cost
- Selection among the Building Integrated PV (BIPV), Building Attached PV (BAPV), and Thermal Building Integrated PV (BIPV/T) are related to the customer requirements, associated costs, and the project conditions, it is not possible to generalize a rule for making such a choice, but this is left to be considered as case by case.
- The social technology acceptance of all stakeholders does not seem to form much of a problem for university campuses, provided that all the legal requirements are well met and followed.
- As for the architectural impacts of positioning the PV panels on the roof or faÇad of the building, without inversely affecting the prevailed building's external profile architecture, there generally seems to be not much of a problem, as shown by the existing cases, with clever interference and touches of the concerned architects.

The worldwide interest and trend to replace the non-sustainable, conventional primary energy sources of fossil fuels to generate electrical energy because burning these fuels in such a thermal process, results in several pollutants that are harmful to human health, animal and sea life, soil, air and the ecosystem at large, to replace these sources by non-pollutant, environment-friendly, sustainable alternative primary sources, such as solar, wind, hydro, biomass, geothermal and wave primary energy sources.

The availability of convenient, solar energy sources and technologies to convert them directly to electrical energy in photovoltaic processes that do not pollute the environment

The need to outline and emphasize the importance of other aspects besides the technical and economical ones in PV application, such as the environmental, architectural, social, and legal aspects that work in favor of PV systems power generation and supply versus the traditional technologies.

- The need to contribute to the studies investigating the application of solar photovoltaic technology, for meeting the university campuses' electrical energy needs, at different world regions sites with variable conditions.
- The fact that Çankaya University, Ankara is a known accredited modern educational institution of higher education in a region of relatively high solar radiation density of an average of about 500-600 watts/m^2
- The intention and work of the university are to be, a typical green campus in this region, and a focal point of research work in the area.

The wide spread of university campuses and educational schools, particularly in large cities, and their growing needs for electrical power and hence their contribution to the resulting pollution. The future work to be suggested here may lead to further conclusions, it is hoped, that this will enhance and, update this study results based on possible upcoming developments and, hence keep the research ideas and concepts up to date.

Carrying out the suggested and related future works, particularly in different world regions, under different conditions and circumstances, it is expected to globalize the concept further, for more fruitful results for the benefit of man and his environment in this area.

- It is recommended in PV systems applications to document the system performance for the benefit of system follow-up, improvement, and relevant future studies PV systems and their applications in university campuses and educational institutions give a wide range of possible research work and study consideration:

- As for the components of the system, updating the recent development in system components; modules, inverters, batteries and protection, control sub-systems, module materials, and their performance are suggested areas of study.

- The building system's environmental performance is worth studying, taking into consideration the monetary value of the saved CO_2 emissions as estimated at the carbon market.
- The system's energy and efficient performance should be moving towards saving money, cost as well as time.
- A comprehensive detailed sensitivity analysis of the BIPV may be carried out to study the percentage resulting variations of the energy output and its costs, with certain variations in the effective variables in its calculations, such as the interest rate, the system life, and capital and running costs.
- The system energy, thermal and optical performance experience is also worth studying.
- The system's economic performance and its development through the life cycle are worthwhile, as well as comparative studies of such performance among different applications.
- The reliability of PV systems at university campuses is worth studying
- Stakeholders' views on the systems from another area of study.

Upon carrying out the study, the following points may be outlined:

- The BIPV technology is being improved and developed based on the experience gained from the already-built examples, making use of the learned lessons.
- The electrical energy-specific consumption of university campuses comprising mainly of heating, ventilation, air conditioning (HVAC), and lighting varies widely from one institution to another and, from one country/region to another country as well as regions. Furthermore, such a framework should be carefully estimated for better economic projects

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