Research Article GU J Sci 36(3): 954-963 (2023) DOI: 10.35378/gujs.1059033

Gazi University

Journal of Science

http://dergipark.gov.tr/gujs

A Simple Selection Method of PV Systems for University Campuses

Mariam BARA[1, *], Gulsu ULUKAVAK HARPUTLUGIL[2]

[1] *Çankaya University, PhD in Design Program, Ankara, Turkey; Libyan Center for Solar Energy and Research and Study, Tripoli, Libya*
[2] *Çankaya University, Faculty of Architecture, Department of Architecture, Ankara, Turkey*

Highlights

- Short cut for designers, engineers and others.
- Method based on MCDM and priority listing.
- A PV selection optimization from software updated list of relevant available systems.
- The highest electrical energy yield at the lowest unit cost.

ArticleInfo

Received: 17 Jan 2022
Accepted:14 June 2022

Keywords

PV systems
University Campus
Optimization
MCDM

Abstract

This paper briefly outlines part of the research work being carried out on the application of the photovoltaic systems to cover universities' electrical energy needs, with due consideration to the technical, architectural, economic, social. and legal aspects and impacts of this application. The paper considers optimizing the PV system selection objectives and methodology with a case study application. at a university campus in Ankara, Turkey. The main objective here is to develop a practical simple method of selecting an optimum PV system that gives the maximum energy yield possible in a certain period of one year, with the minimum specific energy cost per kWh, where a multiple-variable multi-criteria decision-making making method is applied, to help designers and system engineers in selecting the optimum system. The developed method is demonstrated in the example of the typical case, where the recommended PV system was turned out to be at an Azmuth angle of 0 degrees, the PV technology was monocrystelline Silicon, the annual electrical energy yield per 100 m2 of PV modules surface area 22.4 MWH/Year, the specific electrical energy cost was 0.15 Euos/Kwh, as a first merit option, making a difference of around 13% of saving compared with the 10th last option. The work concludes that a viable PV application is feasible, encouraging its application in various campuses provided that comprehensive planning and careful considerations are given to the related aspects.

1. INTRODUCTION

One of the major issues threatening the earth's environment, human health, and life is climate change. Air pollution due to natural phenomena, and human activities results in harmful gas emissions (Carbon Oxides COx, Sulphur oxides Sox, and Nitrogen oxides NOx) in addition to the particulates at energy conversion operations in thermal electrical power plants, industries, and transportation sectors that burn fossil fuels. This has encouraged the search for non-polluting, environment-friendly primary energy resources to replace fossil fuel sources. Attention and work have shifted to renewable energy sources such as solar, and wind energy, originating from the sun as a non-depleting energy source, available in different degrees everywhere, giving energy and light that can be converted through thermal or photovoltaic technologies into electrical power. Several researchers have dealt with energy sources selection, advantages and disadvantages of each, and comparisons among them such as D. Streimikiene and others [1], where they stated that economic, technological, social, and political developments stressed the need for shifts in the energy mix. Therefore, it is important to provide a rationale for sustainable decision-making in energy policy [2]. As factors influence the energy technology selection from one region to another, different studies have been carried out to consider these factors and effects on this choice, for example, M. Amer and T. U. Daim in their paper [3] explored some renewable energy options for electricity generation in Pakistan from

*Corresponding author, e-mail: m76bara@yahoo.com

multiple perspectives comprising technical, economic, social, environmental, and political aspects. Other researchers have considered different aspects of energy source selection and renewable solar energy applications [4-6].

The aim of this paper is to develop a multi-criteria decision support framework for choosing the most sustainable electricity production technologies; renewable energy in particular, solar energy using photovoltaic (PV) technology for its conversion to electrical power, with no GHG (greenhouse gas) emissions. Where the PV system that gives the highest electrical energy yield in kWh per year for a specific PV module exposed area and the lowest specific energy produced cost in Euros per kW can be determined.It is expected that using PV systems with their inherent advantages and applying the optimization method will have a reasonable share of the electrical energy supply for university campuses and other educational facilities in both rural and urban communities. In this paper, a simple optimization procedure is developed to contribute to the ongoing work towards reducing the PV electric energy costs relative to that of the grid energy, with the mentioned PV advantages, and its application to university campuses. The proposed method will help the designers and engineers to select the most suitable PV system for their specific conditions.

2. LITERATURE REVIEW

2.1. PV Systems Applications

Since its introduction, back in the late fifties of the last century, photovoltaic technology has found its applications in various situations, making use of its advantages over conventional primary energy sources, which include its being renewable, environment-friendly, providing energy security and self-dependence [7,8]. However, its main problems are its relatively high primary capital costs as compared to the conventional electrical energy systems, as well as its much lower overall system efficiency, its being a site and weather variations dependent, and land-use [9,10]. The continuous worldwide research and development through the last years, as well as the experience gained in its applications, have effectively helped in overcoming most of the disadvantages of PV technology applications for producing electrical power. These include the continuous decrease in the system capital costs and the rising system efficiency, which have opened a wide range of applications and markets for PV systems [10].The PV system consists mainly of the solar modules, storage batteries and their charging systems, DC to AC inverters, protection and control systems and wirings as sketched in Figure 1, which shows the main system components, to be sized and chosen to meet the system load, and the solar radiation level. The of modules solar cells convert the incident solar radiation into direct current electricity, the wiring system collects the contribution of each cell connected in series/parallel to give the required voltage and the terminals of the modules, and this output charges the battery (for night and cloudy days supplies) and feeds the inverter which converts the generated direct current into the commonly used alternating current, to feed the loads. The control system controls the battery charging, and the flow of the current, while the protection system protects the system from possible faults.

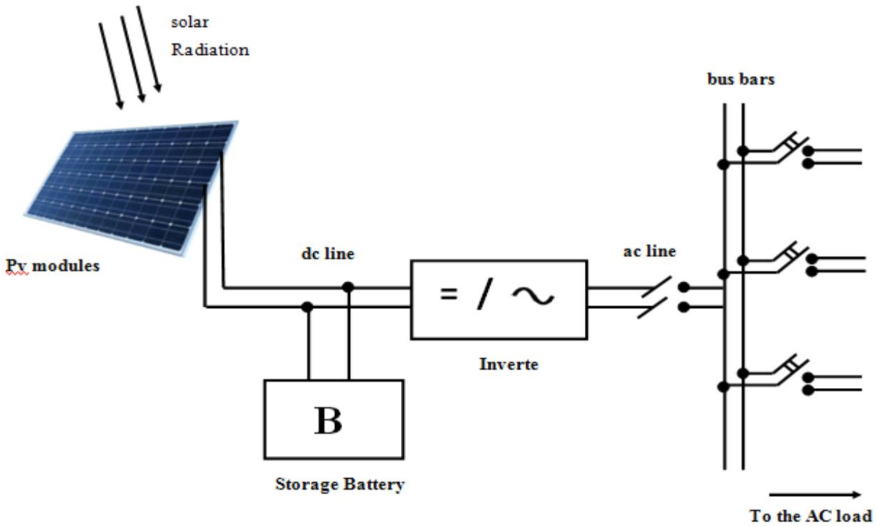

Figure 1. *Typical PV System Components*

For further details about PV systems, reviews in many references such as in [11-17], which site some typical useful samples of some of such material, may be consulted. The first five listed references deal with the multiple-criteria application in this connection, [1-5], while a typical application is considered by Amer and Daim [3], with Georgopoulou and Papagiannakis [18] giving a review of some PV systems applications at university campuses. PV systems have been introduced both for new and old buildings innovation by Aguacil and Rey in [11,8], with variable levels of social acceptance and adoption given by Attoyeet and others [16].

2.2. Application of PV Systems at University Campuses

University campuses and other similar educational facilities are typical examples of PV system applications for producing totally or partially the electrical power consumed by these institutions, which usually constitute considerable energy consumption by their number and type. Campus load varies with the day's hours reflecting the user activities that need electrical energy for their load, which is mostly daytime load with less consumption during the night. With the solar power available during the sunshine hours, this will require smaller capacity energy storage devices such as batteries, for the usually smaller night loads, and energy consumption on cloudy days.

Several publications, such as the National Renewable Energy Laboratory (NREL), USA report [6] and others have given examples of the PV applications at universities and schools campuses, green campuses, zero energy campuses and sustainable campuses worldwide, where PV systems, energy conservation, high efficiency, load control and environmental protection measures are applied, such as in Butte college, California, which in 2011, was the first college campus in the USA to become grid positive, where it generates more electrical power than it needs. With 25,000 solar panels; saving since 2005 over $100m in 30 years. Arizona State University in 2016 had the most solar energy production among the USA universities, with half of its daytime peak demand covered by solar energy. The University of Washington has its life science building supplied by its own generated electrical power the rooftop PV panels producing 5,000 kWh/yr. and building integrated PV on its glass fins on the southern façade producing 110,000 kWh/yr. Harvard University in the USA has PV solar panels system on 8 of its buildings and a wind turbine on one of the others. They also purchase electrical energy from renewable primary sources to have around 17% their energy consumption from renewable energy sources and many others.Beside the technical and economic considerations of the PV systems in these application, the environmental, architectural, social, and legal aspects of the PV application have to be considered and handled for achieving successful projects.

- Environmental Aspects

The replacement of grid electricity with PV generated one will result in avoiding the emitted harmful gases, particularly CO_2, which can be estimated in gm/kWh produced and can be converted to equivalent into monetary units when referred to the carbon market. It is estimated that during fuel combusion, coal fired power plants may produce around 900 g. CO_2 for each kwh it generates, while an electric power PV generation system may produc only 100 – 200 g CO_2 once during its manufacturing [19]. In addition, the PV system will not need fuel, its handling and storage, and maintenanance and repair works disturbing the nearby environmentm togather with large water use. For land use, the PV system requires relatively large modules exposed area, but for buildings, it is the case with university campuses, the roofs, and the facades can be used for installing the solar modules. The PV system components and accessories, other than the modules need much less land area than the equivalent conventional power plants. The PV system operation is quite, with no noise pollution, as there are no moving parts.

- The Architectural Aspects

The PV building-mounted system may be designed as building attached (BAPV), where the PV has the sole function of power production or, as building integrated (BIPV), where, in addition to Power generation function, the solar PV modules form parts of the building structure. In both cases the modules may be designed to suit the building architecture and enhance its aesthetics. PV modules sizes, forms and pieces are available to help preserve and even enhance the building view, while providing the technical data required in the total calculated effective solar cells exposed surface area and the system efficiency. Another option is also available, where thermal space heating or cooling functions can be performed as well, through the PV pannels, by selecting the (BIPV/T) option of these systems, at additional costs. All of these are open options for the designer and owner to choose from to suit their needs and requirements.

- Social and Legal Aspects

The social aspects include the social acceptance of the application by the customers and their reactions towards the same, as well as their cooperation together, and with the manufacturers, suppliers and technicians, and their attitudes. Particularly, for the educational campuses, PV systems are one of the learning/awareness areas of the renewable systems benefits for social acceptability.

The legal aspects concern the permissions, forms, transactions that may be required by the relevant authorities to assure the legality of erecting and using the system, and to solve any rising dispute. These processes need to be well defined and conveniently followed. Related regulations and energy laws should determine the legal frame of the applications.

3. METHOD

The conducted study for this paper tries to optimize the selection of the most economically suitable PV system variables, using Multi Criteria Decision Making (MCDM), outlined in Figure 2.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 as shown in Table 1.

Table 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, usually manually adjusted	Tilt angle
The horizontal angle measured clockwise from a north line	Azimuth angle

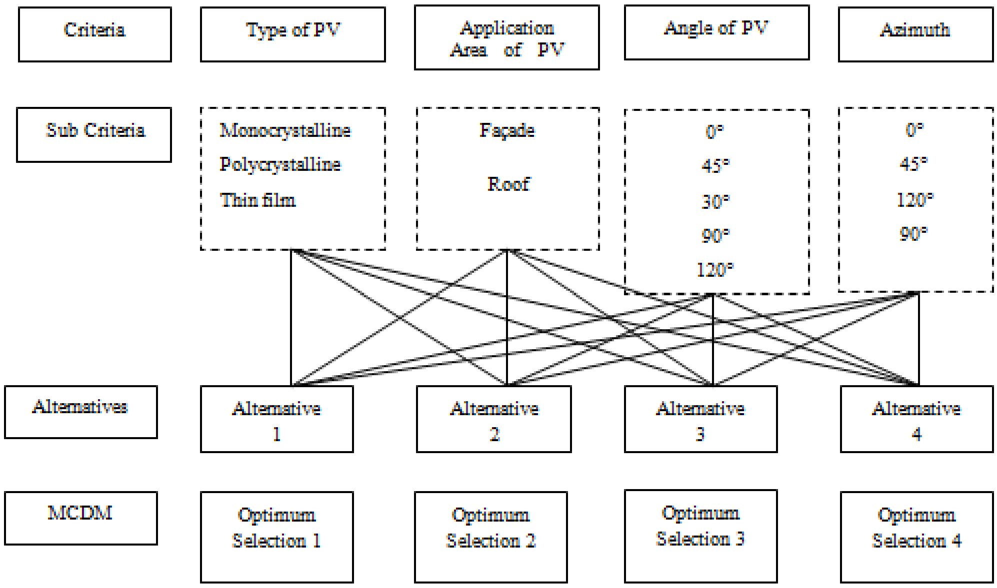

Figure 2. *Multi Criteria Decision Making (MCDM) process of the study*

Calculating through each case of the system 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 unit per kWh, The constant parameters are the area of 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/(m^2 day)m) and, a total yearly insulation period of approximately 2460 hr. Yielding around 1825 KWh/m^2 [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 as relative to this base in 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 in 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 types of the available PV systems, batteries, inverters, protection and control systems and wirings with their capital costs are given by the software used. from its updated stored data, as well as the annual operation and maintenance costs, which are calculated by the software as a percentage of say 5% of the capital costs. The software calculates the energy yield per year, using the solar radiation level at the site, the total modules exposed surface area and the modules efficiency. The useful life of the systems, as well as the annual interest rate (rate of return) in per cent 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. in Euros per Kwhs.

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 software PVSYST selected here for its availability, simplicity in operation, and, its giving of straightforward results.

3.1. PVSYST Software

Calculation software is used in this case to save time in arriving at the required results in a very short time, with the needed reasonable accuracy.Several PV application soft-wares have been developed through the last few years. A search has been carried out here to obtain suitable software for this study's calculations purpose. The software availability was the most important factor in this selection, as well as its adequacy to carry out the needed calculations, with flexibility, functionality, and ease of operation, upon this process, the PVSYST software has been chosen. It was developed by the energy group (CUEPE) at the University of Geneva, Switzerland, to be suitable for grid connected, stand alone, pumping and 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, through its stored design data base and tools. The user has to specify the geographical location of the site to be served, and hence the meteorological data of the same. Other details are 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 choice details, the battery, the inverter, the wiring system. With all of these details, the software calculates and proposes a system configuration for the given and found data. The proposal given through the software may be modified to care for the user requirements or conditions.Details of PVSYST and its use are provided in its user manual and publications such as those in [21-26] of the references.

The site selected gives the solar energy intensity in kWh per square meter per year, as the input to the software.

3.2. 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*:* 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, 30, 45, 60, and 120 degrees, The modules inclination from the horizontal at 90 degrees, is considered verticle and is represented by facad (building walls) mounted modules.

- The azimuth is the angle between the sun and the north direction measured clockwise at the observation point level. It takes the values of 0, 45, 90, 120, and 180 degrees.

- The PV technology: refers to the way the PV cells are manufactured, depending on the number of crystals on the cell; monocrystalline for one crystal per cell, polycrystalline with numerous crystals, or thin film of crystals technology.

The outcome of the calculations is represented by the parameters listed below:

- The annual yield is the energy generated per year, in MWH/Year.

- The total yearly cost is the cost of the generated energy per year in Euros/year at the assumed cost rates.

- The energy cost is the generated energy cost per year in Euros/KWH at the assumed rates.

3.3. Mathematical Model

In this paper Multi-Criteria Decision Making (MCDM) method and SAW the weighted Sum Method have been used:

- SAW method requires a process of normalizing the decision matrix (X) to a scale that can be compared with all the ratings of existing alternatives

$$r_{ij} = \frac{x_{ii}}{\text{Max}\ (x_{ij})} \tag{1}$$

$$r_{ij} = r_{ij} = \frac{Min(x_{ij})}{(x_{ij})}. \tag{2}$$

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

$$w = \frac{c_1}{c_1 + \cdots + c_n} \times 100\% \tag{3}$$

$$V_i = \sum_{j-1}^{n} = 1\ w_j r_{ij}. \tag{4}$$

With the area assumed as 100 m^2, 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. For example, the total points of merit for the first option is 22.4 + 0.15 = 22.55 which is the base case here. The next option scores 22.1 + 0.15 = 22.25, which is 22.25 / 22.55 = 0.99 as shown in the table and so on for the other cases. The results for the selected typical case are summarized as shown in Table 2.

Table 2. *Calculations and Results*

Tilt	Azimuth	PV technology	Annual Yield merit	Energy cost merit	**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

4. DISCUSSION

The case study results shown in Table 2, reflects a simple straight forward 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 a descending order of 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 2, 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 implies 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.
It may be noted from the table that:

- The first rank goes to the case where the tilt angle is 30 degrees, and the azimuth at zero, with the monocrystalline type of PV, which generally agrees, as in the literature, with the results of other studies at other locations, while the lowest score is for zero (flat position) tilt, with zero azimuth, and with the same type of PV; the monocrystalline type.

- For the 10 ranks considered here, using the suggested method, the difference between the highest score and the lowest one is 13%, which is worth consideration, as the variations take place among three variables; the PV type, the tilt angle, and the azimuth, at the simple steps introduced by the method.

- In comparing between the first and the second rank and between the fourth and the fifth rank, it is noted that a change of 15 degrees of the tilt angle, keeping the other two variables; the azimuth and the PV type the same in each of these two comparisons change the score by only 0.01 and the rank by just one step.

- In going from the fifth to the eighth rank, that is changing from monocrystalline to polycrystalline PV types, while keeping the other two variables the same, lowers the score from 0.94 to 0.91 and hence the rank from 5 to 8. This emphasizes the large effect of varying the PV type.

- The above notes and similar ones that can be drawn from the table results, give the designer ample room for selecting his choice based on the differences among the different cases according to his desire.

5. CONCLUSION

The paper has dealt with introducing solar photovoltaic technology as a viable source of electrical power supply for university campuses and has come up with a simple method for optimizing the selection of the PV systems most suitable for such applications to help the designers and engineers in their planning to apply such systems to best fit the local conditions, and to encourage applying PV systems with their economical, technical architectural, environmental, and social advantages as energy supplies to these educational institutions when compared with the conventional energy sources. The proposed method of optimizing the PV system selection creteria, lies in selecting, among the available systems, the ones that give the highest energy yield per unit exposed solar cells surface areas and, the least electrical energy cost per Kwh. A typical case study was carried out here to illustrate how to select the best PV system for supplying electrical power to a university campus, where a priority list of the considered systems was generated, as indicated in Table 2. The best system is that which gives the largest electrical energy output with the least specific unit cost.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] Streimikiene, D., Balezentis, T., Krisciukaitienė, I., Balezentis, A., "Prioritizing Sustainable Electricity Production Technologies: MCDM Approach", Renewable and Sustainable Energy Reviews, 16(5): 3302-3311, (2012).

[2] Zhong, B., Hei, Y., Jiao, L., Luo, H., Tang, J., "Technology Frontiers of Building-Integrated Photovoltaics (BIPV): A Patent Co-citation Analysis", International Journal of Low-Carbon Technologies, 15(2): 241-252, (2020).

[3] Amer, M., Daim, T. U.,"Selection of Renewable Energy Technologies for a Developing County: A Case of Pakistan", Energy for Sustainable Development, 15(4): 420-435, (2011).

[4] Lu, Y., Chang, R., Shabunko, V., Yee, A. T. L.,"The Implementation of Building-Integrated Photovoltaics in Singapore: Drivers Versus Barriers", Energy, 168: 400-408, (2019).

[5] Rosa, F.,"Building-Integrated Photovoltaics (BIPV) in Historical Buildings: Opportunities and Constraints", Energies, 13(14): 3628, (2020).

[6] Samir, H., Ali, N. A.,"Applying Building-Integrated Photovoltaics (Bıpv) in Existing Buildings, Opportunities and Constrains in Egypt", Procedia Environmental Sciences, 37: 614-625, (2017).

[7] Bhutto, Y. A., Mahar, M. A., Larik, A. S., Bhellar, S. H., Khuwahar, A.,"Analysis of Photovoltaic System at Various Sites of Pakistan Using Retscreen Software", Engineering Science and Technology International Research Journal, 2: 7-13, (2018).

[8] Goh, K. C., Goh, H. H., Yap, A. B. K., Masrom, M. A. N., Mohamed, S., "Barriers and Drivers of Malaysian BIPV Application: Perspective of Developers", Procedia Engineering, 180: 1585-1595, (2017).

[9] Al Garni, H. Z., Awasthi, A., "A Monte Carlo Approach Applied to Sensitivity Analysis of Criteria Impacts on Solar PV Site Selection", Handbook of Probabilistic Models, edited by P. Samui Dieu, Tien Bus...Ravish C. Defo, Butterworth-Heinemann,489-504, (2020).

[10] Brand, B., Missaoui, R., "Multi-Criteria Analysis of Electricity Generation Mix Scenarios in Tunisia", Renewable and Sustainable Energy Reviews, 39: 251-261, (2014).

[11] Aguacil Moreno, S., Rey, E., "Active Renovation Strategies with Building-Integrated Photovoltaics (BIPV). Application on an Early 20thCentury Multi-family Building", Proceedings of the 8th Euro-American Congress. Rehabend. Construction Pathology, Rehabilitation Technology and Heritage Management, Granada, Spain, (2020).

[12] Kuhn, T. E., Erban, C., Heinrich, M., Eisenlohr, J., Ensslen, F., Neuhaus, D. H., "Review of Technological Design Options for Building Integrated Photovoltaics (BIPV)", Energy and Buildings, 231: 110381, (2020).

[13] Farghaly, Y., Hassan, F., "A Simulated Study of Building Integrated Photovoltaics (BIPV) as an Approach for Energy Retrofit in Buildings", Energies, 12(20): 3946, (2019).

[14] Chianese, D., Cereghetti, N., Rezzonico, S., Travaglini, G., "Types of PV Modules Under the Lens", Sixteenth European Photovoltaic Solar Energy Conference 2418-2421, Routledge, (2020).

[15] Guacil, S., Lufkin, S., Rey, E.,“Active Surfaces Selection Method For Building-Integrated Photovoltaics (BIPV) in Renovation Projects Based on Self-Consumption and Self-Sufficiency”, Energy and Buildings, 193: 15-28, (2019).

[16] Attoye, D. E., Adekunle, T. O., Tabet Aoul, K. A., Hassan, A., Attoye, S. O., “A Conceptual Framework for a Building Integrated Photovoltaics (BIPV) Educative-Communication Approach”, Sustainability, 10(10): 3781, (2018).

[17] Biyik, E., Araz, M., Hepbasli, A., Shahrestani, M., Yao, R., Shao, L., Atlı, Y. B., “A Key Review of Building Integrated Photovoltaic (BIPV) Systems”, Engineering Science and Technology, an International Journal, 20(3): 833-858, (2017).

[18] Georgopoulou, E., Lalas, D., Papagiannakis, L., “A Multicriteria Decision Aid Approach for Energy Planning Problems: The Case of Renewable Energy Option”, European Journal of Operational Research, 103(1): 38-54, (1997).

[19] Dermaut, J., Greoraent, “A Better Understanding of Green Gas Emission for Different Energy Vectors and Applications”, WEC Conference 17, Houston, Texas, 13-18 September, (1998).

[20] Balat, H., “Solar Energy Potential in Turkey”, Energy Exploration & Exploitation, 23(1): 61-69, (2005).

[21] Streimikiene, D., Balezentis, T., Krisciukaitienė, I., Balezentis, A., “Prioritizing Sustainable Electricity Production Technologies: MCDM Approach”, Renewable and Sustainable Energy Reviews, 16(5): 3302-3311, (2012).

[22] Van Geet, O. D., Polly, B. J., Pless, S., Heeter, J. S., Shepherd, R.,“Zero Energy University Campuses: A 2018 Progress Update on Reaching Campus Energy Goals”, (No. NREL/CP-7A40-71822), National Renewable Energy Lab.(NREL), Golden, CO (United States), (2018).

[23] Gholami, H., Røstvik, H. N., Müller-Eie, D., “Holistic Economic Analysis of Building Integrated Photovoltaics (BIPV) System: Case Studies Evaluation”, Energy and Buildings, 203: 109461, (2019).

[24] Gholami, H., Røstvik, H. N., Kumar, N. M., Chopra, S. S., “Lifecycle Cost Analysis (LCCA) of Tailor-Made Building Integrated Photovoltaics (BIPV) Façade: Solsmaragden Case Study in Norway”, Solar Energy, 211: 488-502, (2020).

[25] Carrington, G., Stephenson, J., “The Politics of Energy Scenarios: Are International Energy Agency and Other Conservative Projections Hampering the Renewable Energy Transition?”, Energy Research and Social Science, 46: 103-113, (2018).

[26] Mermoud, A., Wittmer, B., “Bifacial Shed Simulation with PVSyst”, Bifacial Workshop, Germany, 25-26, (2017).