Solar Photovoltaic Panel Evaluation

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The use of solar photovoltaic (PV) panels is one of the most promising ways to generate electricity. However, the complex technical parameters associated with them make the choice between different PV panels a complicated task.

solar energy photovoltaic panels multi-criteria decision-making

1. Introduction

Energy is of great importance for the economic development of every country in the world. Its sources include both fossil fuels: coal, gas, and crude oil; and renewable energy: sun, wind, water, biomass, hydrogen, and geothermal energy [1][2]. Fossil fuel deposits are limited. They have a negative impact on the environment and climate change. All this makes it very necessary to increase the degree of use of renewable energy sources (RES) [3]. More than 75% of the source of greenhouse gases emitted in the European Union (EU) is the production and use of energy. Reducing or completely excluding CO_2 production from the EU energy system is important for achieving the climate goals for 2030. To reduce greenhouse gas emissions by at least 55% by 2030, the share of renewable energy should be increased and energy efficiency improved. It is also extremely important in the longer term, as a stage on the path leading to climate neutrality by 2050 [4].

Existing technological innovations enable the replacement of fossil fuels with low-emission solutions. This leads to an energy balance characterized by an adequacy between the generation and use of energy. The operation of a sustainable energy system is within the limits of environmental tolerance, which means that it has little or no negative impact on the environment. Moreover, it enables conducting normal economic and social activity in the country [5].

The use of RESs is currently enjoying great interest. However, the complex issues involved make the choice between different proposals for the use of RESs a complicated task. There are institutional, legal, political, technical, socio-economic, and environmental barriers to be overcome [3]. One of the more promising ways of supplying and generating electricity is the use of solar energy [6].

Solar energy can be converted into heat or electricity. Depending on the type of energy obtained, solar panels and photovoltaic (PV) panels are distinguishable. Solar panels are primarily used to heat water [7][8][9]. On the other hand, PV panels directly transform the sun rays falling on their surface into electricity [10][11][12]. The electricity generated in this way can be used to power all electrical equipment, including, for example, a heat pump.

Currently, several types of solar PV panel manufacturing technologies are available. They differ in the elements that are used to produce the cells that make up the panel. The elements used determine the color, structure, and efficiency of the cell. The following basic types of cells are distinguished [6][10][13][14][15][16][17][18]:

- Monocrystalline silicon—are made of melted silica sand with the addition of boron; cells produced on their basis are characterized by the highest efficiency, but also the highest price;
- Polycrystalline silicon—they are made of ground silicon, which is melted and cast in the form of a block composed of non-homogenous crystals with a diameter of several millimeters to several centimeters; the distances between the crystals weaken the efficiency of the cell compared to monocrystalline cells;
- Cadmium telluride—they are created in the process of applying a thin layer of cadmium telluride to glass or other substrate; the entire photovoltaic module is usually made of one cell;
- Copper indium gallium selenide—they can absorb more solar radiation than other cells, which is why they work well in poorer insolation;
- Amorphous silicon—they are created in the process of applying a thin layer of allotropic silicon to glass or another substrate; due to the small amount of semiconductor used and low energy consumption in the production process, their production is quick and cheap, but their efficiency is worse than other types of cells.

Monocrystalline and polycrystalline cells belong to the group of crystalline silicon cells, while amorphous silicon, cadmium telluride, and copper indium gallium selenide cells belong to the thin-film group, while amorphous cells are thin film Si, and the others belong to thin film non-Si. Thin-film cells have much worse efficiency than crystalline silicon cells. In terms of market share, there is a huge advantage for crystalline silicon cells, which have an approx. 98% share in the global market of PV panels [19].

One of the basic decision problems in the field of solar energy is the selection of the appropriate solar PV panel. In order to find the best solar PV panel, the properties of each panel should be examined, taking into account carefully selected criteria [18]. It should be noted that many of the criteria for evaluating solar PV panels are uncertain and imprecise. One of the main causes of uncertainty is the testing of PV panels under benchmark conditions. As a result of such tests, the technical characteristics of solar PV panels describe their performance in standard test conditions. Meanwhile, in the real working environment, solar PV panels obtain diametrically different values of the generated power and current–voltage characteristics. Unfortunately, articles on the selection of solar PV panels do not usually take into account the uncertainty and imprecision of PV panel operating parameters. Therefore, a research gap is visible, consisting of the need to include uncertain criteria describing the parameters of the operation of solar PV panels.

Consideration of a decision problem from the perspective of many uncertain and often contradictory criteria is possible with the use of fuzzy multi-criteria decision-making (MCDM) methods. They give the opportunity to take into account the multidimensionality of the problem under consideration and enable a comparative analysis of the assessed solar PV panels according to the considered criteria. The MCDM approach supports rational decision-making that takes into account the decision-maker's priorities, resulting in a pareto-optimal solution combining all the decision-maker's goals [20][21]. In other words, the MCDM methods are suitable for evaluating the available alternatives, taking into account many attributes and selecting the most advantageous of them. A relatively new method of this kind is new easy approach to fuzzy preference ranking organization method for enrichment evaluation (NEAT F-PROMETHEE). This method eliminates the basic disadvantages of other fuzzy variants of the PROMETHEE method [22], and its applicability in decision problems related to RES has been confirmed in previous studies [22][23][24][25][26].

2. Solar Photovoltaic Panel Evaluation

In the contemporary literature, there are many studies on the use of renewable energy sources, including solar energy. MCDM methods have been used by the authors of scientific publications, among others, to assess PV technology as a potential alternative for future energy generation and consumption of fossil fuels [27][28][29]. In each of the cited studies, the authors used the analytic hierarchy process (AHP) method. The study by Garni et al. [28] presents a case study of Saudi Arabia. The obtained results show that PV panels are the most advantageous technologies. Next came the concentrated solar power. Ahmad and Tahar [29] set out to review the potential of various RESs for electricity generation in Malaysia. They characterized the power system as a social, technical, and institutional complex. They used an AHP method to rank renewable sources. The ranking was to serve the decision-makers in developing a strategy for the development of a sustainable electricity generation system. Also in this ranking, solar energy was indicated as the most promising RES. In turn, Seddiki and Bennadji [27] used the integrated Delphi–fuzzy AHP–fuzzy preference ranking organization method for enrichment evaluation (PROMETHEE) methodology. The authors studied the selection of the best available RES alternatives for generating electricity in a residential building. To this end, the researchers used the Delphi method, which was also used to define an initial set of criteria (environmental, social, economic, etc.). A questionnaire was used to examine the preferences of the building's residents regarding the potential use of alternative renewable energy sources. The fuzzy AHP method was used to obtain the weights of the criteria, taking into account the uncertainty in the expert assessments. Finally, using the FPROMETHEE method, a ranking of alternative renewable energy solutions was developed, taking into account the uncertainties associated with the assessments of the alternatives. As in the previously cited studies, here various variants of PV technology also turned out to be dominant over other solutions.

The MCDM methods were also used in scientific research to indicate effective criteria for the location of solar power plants and their construction technology [30][31][32][33][34][35][36]. Chen et al. [34] examined the interdependence and influence of weights between the selection criteria for the location of solar PV farms. They used a hybrid MCDM model using decision-making trial and evaluation laboratory (DEMATEL) and DEMATEL-based analytic network process (DANP) methods based on a geographic information system (GIS). Watson and Hudson [33] used the GIS–MCDM approach in their work to assess the impact of wind and solar PV farms on the development of the region and compared the results with the existing degree of development in the study area. They used the AHP method to weigh the variables and validated them through consultation with experts who were professionals in the field of renewable energy localization. Kereush and Perovych [32] also used the AHP method in their work. They proposed a way of defining and classifying individual criteria taken into account when choosing the location of a solar PV farm. The credibility of the criteria helping decision-makers in planning new investments in solar PV power plants has been tested and proven in the pilot area (the Zastavna district within the Chernivtsi region). In turn, in the study by Vafaeipour et al. [36], a hybrid MCDM approach was applied and priorities were set for 25 dispersed cities across the country where future investments in solar PV power plants should be implemented. Stepwise weight assessment ratio analysis (SWARA) was performed to rank the identified criteria, and the weighted aggregates sum product assessment (WASPAS) method was then used for evaluation and prioritization. In the work of Sánchez-Lozano et al. [35], GIS and a combination of fuzzy AHP and fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) methods were used. The fuzzy AHP method was used to weight the criteria, while the fuzzy TOPSIS method was used to rank alternative locations. In order to compare the results obtained with fuzzy TOPSIS, the elimination and choice translating reality (ELECTRE-TRI) method was additionally used. GIS was also used in the study by Kengpol et al. [30]. The aim of the study was to develop a decision support system that served for the optimal selection of a place for a solar power plant in Thailand. The study sought a location that would meet all the expectations of the decision-makers, i.e., avoiding the effects of flooding, reducing costs, time, and reducing environmental impact. Qualitative and quantitative variables based on the fuzzy AHP and TOPSIS models were integrated in the work. Fuzzy AHP was used to model linguistic ambiguity, vagueness, and incomplete knowledge. The TOPSIS method was used to rank locations based on overall performance. In a study by Mokarram et al. [31], an innovative solution was proposed to select locations for the construction of PV farms in the Fars province in Iran. In the first stage of the research, a fuzzy system was used to homogenize data from various inputs. Then, the fuzzy output data was fed into the AHP and Dempster–Shafer (DS) systems. Finally, maps were generated using fuzzy AHP (no confidence level) and fuzzy DS (at 95%, 99%, and 99.5% confidence levels), and the capabilities of both methods were compared and evaluated.

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