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# Model to Predict Quality of Photovoltaic Panels Considering Customers' Expectations

**Andrzej Pacana * and Dominika Siwiec**

Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, al. Powstancow Warszawy 12, 35-959 Rzeszow, Poland; d.siwiec@prz.edu.pl
* Correspondence: app@prz.edu.pl

**Abstract:** The perspective of reducing negative climate changes in the area of production of electricity is beneficial mainly for photovoltaic panels (PV). In this case, qualitative–ecological interactions arise, which should be verified to properly select PV. It refers to the analysis of customers' expectations of the utility of photovoltaic panels and their impact on the landscape (environments). Therefore, the purpose of the article was to propose a model to predict the quality of photovoltaic panels considering the expectations of the customers. According to the SMART(-ER) method, the purpose of the analysis was determined. Then, using brainstorming (BM), the criteria of PV were determined in groups: technical, utility, and aesthetic. The customer expectations were then obtained by questionnaire with the technique with the method of comparison in pairs and Likert scale. Customer expectations were initially verified using the AHP method, after which the key PV criteria of PV were selected. The relations between these criteria were then determined by the DEMATEL method. According to customer expectations, the quality of PV was calculated. The Weighted Product Model (WPM) was used this purpose. As a result, the best photovoltaic panel was predicted for the best PV for the customer by using the relative state scale. The developed model can be used by any entity for any photovoltaic panel and by individual personalized criteria for the customer and other interested parties. The originality of this model is the integration of selected techniques in such a way as to provide them with the greatest satisfaction after choosing a PV based on customer expectations.

**Keywords:** photovoltaic panels; quality; predict; decision support; quality criteria; DEMATEL; Weighted Product Model; customer expectations; AHP method

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## 1. Introduction

The actions of sustainable development focus on reducing negative climate changes [1–3]. The choice of these actions is based on, e.g., greenhouse gases, which generate approximately 90% anthropogenic climate change [4]. As reported by the energy agency [5], dynamic growth (about 50% to 2040) is the action of implemented renewable energy sources (RES). The energy obtained from the Sun is gaining popularity (increase by about 20% annually) [6]. The use of concentrated solar radiation to produce electricity is used on different scales. There are mainly photovoltaic systems (PV) [3,4,7,8], which are currently important in this area of applications [9]. As shown in Refs. [5,10–13], it is a clean and safe energy and also has potential in the production of electricity. In recent years, there has been a development of photovoltaic systems for generating this energy. According to [14], 102.4 GW of grid-connected solar panels were installed worldwide in 2018. The total global solar power was extended to 500 GW in 2018. Additionally, technologies such as, e.g., photovoltaics, are considered as the main source that supports climate change mitigation, which can be used worldwide. According to [8], photovoltaic systems can be effective in limiting the lack of water by supporting water purification processes. Additionally, as shown in work [15], the energy from PV supports the achievement of decarbonization with a high degree of certification. The actions in this direction are confirmed by data of production solar power, e.g., 633 GW in 2019 (four times more than in 2014) [16]. Moreover, important is mentioned about the main leaders of UE, which propagate and apply PV, i.e., Czech Republic, Germany, Italy, and the Netherlands. The least of this energy is produced, e.g., in Poland, Finland, Austria, and Lithuania [3,10]. The photovoltaic power of UE-28 rose from 11.3 GW (2008) to more than 117 GW (2017), where 130 TWh of electricity was produced from photovoltaic. It is about 5% demand. It resulted, for example, from regulations and funding on the implementation of photovoltaic panels, which is more favourable than in other renewable energy sources [17]. In perspective to 2040, it is predicted that the energy from PV will deliver approximately 7208 TWh (where to 2030 it will be near 3518 TWh). Furthermore, the largest energy resource is achieved by its in households, whereas in roof systems, the cumulative power of PV is greater than 30% globally [15,18–20]. In this view, we observed an increased development to PV in comparison of other RES [21]. Despite the demand and predicted effectives of photovoltaic in limiting negative climate changes, customizing to customer expectations is still a challenge [3,4]. It results mainly from a problem of simultaneously verifying dependents of qualitative–ecological, i.e., achieve expected quality of PV [1], taking care of landscape (aesthetic) of the surrounding, and also including the client's well-being. It also refers to the need for included sustainable criteria, as is shown in the next part of the study.

According to a literature review, instruments of support choice of PV were sought. For example, in articles [22–24], the AHP method (Analytic Hierarchy Process) was used, which in work [24] was also combined with Multiplicative Multi-Objective Ratio Analysis (MULTIMOORA) method. The idea was to choose photovoltaic panels according to different criteria, e.g., economic, technical, and environmental [25]. Additionally, it was tried to process customers' expectations about photovoltaic panels (i.e., qualitative criteria into quantitative criteria). To this aim, the House of Quality (HoQ) integrated with Pythagorean fuzzy Sets (PFS) were used [26]. While it works [27], the Monte Carlo method was tested for photovoltaic power, which included customer satisfaction and localization of PV reserves. The review shows that the Business Model Canvas was used to test to develop PV in business terms [21]. Another approach was presented in article [15], in which the customer was verified customer awareness of the care for the natural environment and the power of photovoltaics. A similar approach was assumed by the authors of work [28], where the motivation of implemented of PV was verified. However, the authors of the work [29] was assessed for PV installed in historic buildings. The verification included aesthetic criteria (landscape), e.g., integration, compatibility, or importance of buildings for society. Furthermore, the authors in works [1,3] test relatively similar approaches, in which mainly differences in methodology and originality of these approaches are shown in Figure 1.

| | Obtaining expectations | Processed expectations | Originality |
|---|---|---|---|
| *Approach 1*<br>Qualitative criteria<br>Quantitative criteria<br>Cost of purchase | Survey with Likert scale | Correlation matrix<br>WSM method<br>AKJ method<br>Relative States Scale | ▪ Correlation of qualitative and environmental criteria<br>▪ Combination of ratings of satisfaction from criteria and its weights to calculate quality of product<br>▪ Combination of product quality with cost of purchase |
| *Approach 2*<br>Quantitative criteria<br>Environmental criteria | Survey with fuzzy Saaty scale | Correlation matrix<br>FAHP method<br>FTOPSIS method | ▪ Correlation of quantitative and environmental criteria<br>▪ Estimating quality of product considering satisfaction and weights for quantitative and environmental criteria by reducing subjectivity (uncertainty) |
| *New approach*<br>Qualitative criteria<br>Quantitative criteria<br>Aesthetic criteria | Survey with Likert scale and the technique of comparison in pairs and also choice of states of criteria | DEMATEL method<br>AHP method<br>WPM method<br>Relative States Scale | ▪ Precise correlated qualitative and aesthetic criteria with quantitative criteria<br>▪ Estimating quality of product for satisfaction and weights for qualitative and aesthetic criteria combined with quantitative criteria |

**Figure 1.** Originality of work in comparison with previous works. Own study based on [1,3].

The models in previous works, i.e., [1,3], included different groups of criteria, e.g., qualitative and quantitative criteria and cost of purchase, and then qualitative and environmental criteria. However, the qualitative, quantitative, and aesthetic (including aspects of environmental) criteria were not integrated in a simultaneously way. Additionally, in previous works, different approaches were used to obtain customers' expectations, e.g., the traditional Likert scale and fuzzy Saaty scale. However, the Likert scale of the technique with comparison in pairs was not used. In addition, in the previous work, the correlations between criteria were created using the matrix of correlation. The methods preferred for that were not used, for example, the DEMATEL method, which allows creating interactions and correlations between criteria. Additionally, previous work included estimating the quality of a product regarding the evaluation of satisfaction and weight for qualitative criteria combined with customer criteria, or evaluation of satisfaction and weights for quantity criteria combined with environmental criteria. Despite that, the quality of the product was not estimated for key criteria, i.e., qualitative and aesthetic criteria correlated (combined) with quantality criteria. Additionally, based on the literature review it was concluded that photovoltaic panels were selected considering different criteria, e.g., technical, aesthetic, and qualitative. However, there is relatively little work on this topic, for example [21–25,27]. Despite that, the quality of photovoltaic panels was not predicted in the context of qualitative–ecological, i.e., by considering achieving the expected quality of PV with simultaneously adherence to the principles of sustainable development and taking care of the landscape and customer well-being. Where, the prediction of PV will be realized considering the expectations of any customer for any PV and for any expected criteria of PV. It was considered that in this context the main difficulty is the combination of customer criteria (subjectively determined as qualitative and aesthetic), and then processed them into technical criteria (quantitative measure). It is still challenging because the quality of the product is mostly determined by including technical criteria. Although previous work included different criteria, these three groups of criteria were not integrated in a sequential, coherent, and sequence way. Additionally, it is problematic to estimate the quality of products according to customer satisfaction from the quality of these three groups of criteria by simultaneously including the weights (importance) of these criteria. It is a complex problem, which is still a challenge, mainly in turn, of dynamical changes of customers' expectations. The motivation of this research was to develop a proposed model which will be of utility to any entity (expert, broker, bidder). This model will allow for the verification of different PVs in terms of quality. It resulted from the fact that the types of photovoltaics are a lot, and their number is still growing. In this approach, quality is determined by qualitative, quantitative, and aesthetic criteria. Therefore, quality is a level of customer satisfaction with the utility of photovoltaic energy and simultaneously with the consideration of the environment. It was assumed that the comparison of different photovoltaics allows the possibility of effectively determining customers' expectations, i.e., according to the comparison of these criteria between each other. As a result, it is possible to predict which PV is the best for customers. In this context, it is an original approach in comparison to the current state of knowledge.

Hence, a need was observed to develop of that model. Therefore, the aim of the considerations was to propose a model to predict of the quality of photovoltaic panels in the context of qualitative–ecological, i.e., by considering achieving the expected quality of photovoltaic panels with simultaneously adherence to the principles of sustainable development and taking care of landscape and customer well-being. During developing this model, two hypotheses were assumed:

**Hypothesis 1.** *It is possible to predict the quality of photovoltaic panels (PV) considering the customer expectations expressed by the following criteria: qualitative (immeasurable, objective), aesthetic (landscape), and quantitative (measurable, technical).*

**Hypothesis 2.** *It is possible to determine qualitative–ecological interactions as part of the sustainable choice of photovoltaic panels, which include customer awareness of the usefulness of PV, impacting these PV on landscape and customer well-being.*

Test of the model was carried out for photovoltaic panels of a key producer in one of the EU countries.

## 2. Model

The universal model of prediction of PV quality was developed. This model includes customer expectation and other interested parties. The concept, conditions of choice methods, assumptions and characteristic of model are shown in the next part of study.

### *2.1. The Concept of Model*

The concept of a model includes the prediction of the quality of photovoltaic panels. Prediction refers to customer expectations of PV criteria. It is achieved by sequential determination qualitative–ecological interactions as part of the sustainable choice of photovoltaic panel. The qualitative and ecological approach is customer awareness of the utility and impact of these photovoltaics on landscape and customer well-being.

The mentioned interactions include customer expectations with respect to PV criteria, i.e.:

- qualitative (immeasurable, subjective),
- aesthetic (landscape),
- quantitative (measurable, technical).

In the model instruments were implemented instruments support this process. The general concept is shown in Figure 2.

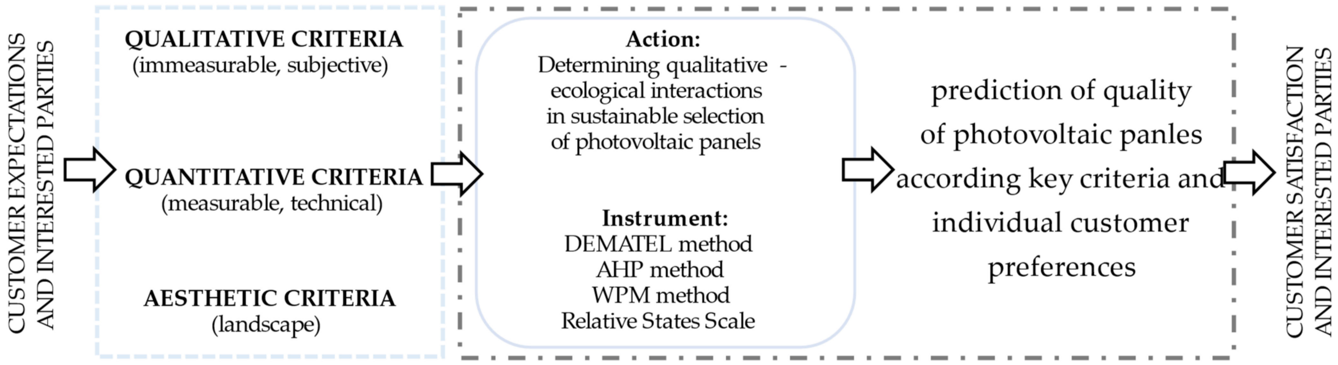


**Figure 2.** General concept of model. Own study.

Initially, the purpose of the analysis is determined according to the SMART(-ER) method (Specific, Measurable, Achievable, Relevant, Time-bound, Exciting Recorded) [30,31]. Then, according to adequately prepared questionnaires (with the method of comparison in pairs), customer expectations are obtained. The questionnaires were developed to determine customer expectations about the qualitative and aesthetic criteria of PV. Then, the mutual influence (intensity) of customer criteria (qualitative and aesthetic) and quantity criteria is determined. The DEMATEL method (Decision Making Trial and evaluation laboratory) is used for this [32–35]. As a result, the key criteria of PV are determined. Then, the weights (importance) of these criteria are calculated. This is done in accordance with the dependencies determined dependencies of the criteria, and the evaluation of the weight of the criteria obtained using the pairwise comparison technique [36]. The weights are calculated using the AHP (Analytic Hierarchy Process) method [37–39]. Then, photovoltaic panels are assessed using the Likert scale [40,41]. It is an initial assessment of the satisfaction of customer expectations from photovoltaic panels. Based on this assessment and the weights of criteria, the quality level of PV is estimated. The Weighted Product Model (WMP) is used for that [36,37,42]. The last stage of the model is the prediction of customer satisfaction from the choice of photovoltaic panel. This prediction is realized on relative states scale according to the quality levels of PV.

### 2.2. Conditions of Choice Instruments Implemented in Model

In the model instruments, i.e.: SMART(-ER) method, brainstorming (BM), technique for comparison in pairs, DEMATEL method, AHP method, and WPM method. The choice and combinations of these instruments resulted from the benefits of these techniques, i.e.,

- SMART(-ER) method [30,31]—a method to assist in the precise determination of the purpose of the analysis, which allows for any adaptation of the purpose due to the nature of the analysis;
- brainstorming (BM) [43,44]—a teamwork technique that conditions the effectiveness of analysis, creative thinking and increases the possibility of achieving the goal;
- pairwise comparison technique [36]—increases the precision of obtaining customer requirements (expectations), streamlines the process of criteria verification by comparing all criteria in an orderly and limited manner, that is, only two criteria at the same time;
- DEMATEL method [32–35]—a method to support decisions in determining the interdependencies between complex elements and reflecting the complex connections between them; additionally, it provides verification of any number and type of criteria;
- AHP method [37–39]—a decision support method that allows for the determination of, e.g., weights (importance) of criteria according to the principle of pairwise comparison; it is uncomplicated and commonly used to estimate the weights of criteria and check the consistency of the client's (decision-maker) preferences;
- The WPM method [36,37,42] provides an estimate of the level of product quality according to the quality ratings of the criteria and their validity; additionally, it is a dimensionless method, so it is not necessary to standardize the measurement measures of the verified criteria;
- Relative states scale [1,4,40]—a scale that supports (and predicts) satisfaction with making a decision; effective in determining customer satisfaction in terms of product quality.

The characteristics and way of application of these instruments in the proposed model are shown in the next chapters of the study.

### 2.3. Assumptions and Characteristics of the Model

The model was developed for its universal application. After the literature review [1,32,35–37,39,42,43], we assumed that:

- the model can be used by any entity (expert, broker, bidder);
- possibility to verify any customers expectations, also customers who do not have knowledge about PV;
- the model allows for the verification of any photovoltaic panels;
- the model is designed for individual photovoltaic panel selection, i.e., by an individual customer;
- the model allows the analysis of three groups of PV criteria, i.e.: qualitative (subjective, immeasurable), aesthetic (landscape), and quantitively (technical, measurable);
- the model supports the prediction of the quality of PV resulting from customer preferences and other interested parties, e.g., an entity who offered photovoltaic panels.

The assumptions adopted determine the universality of the proposed model to predict the quality of photovoltaic panel considering customer expectations. The model is presented in Figures 3 and 4.

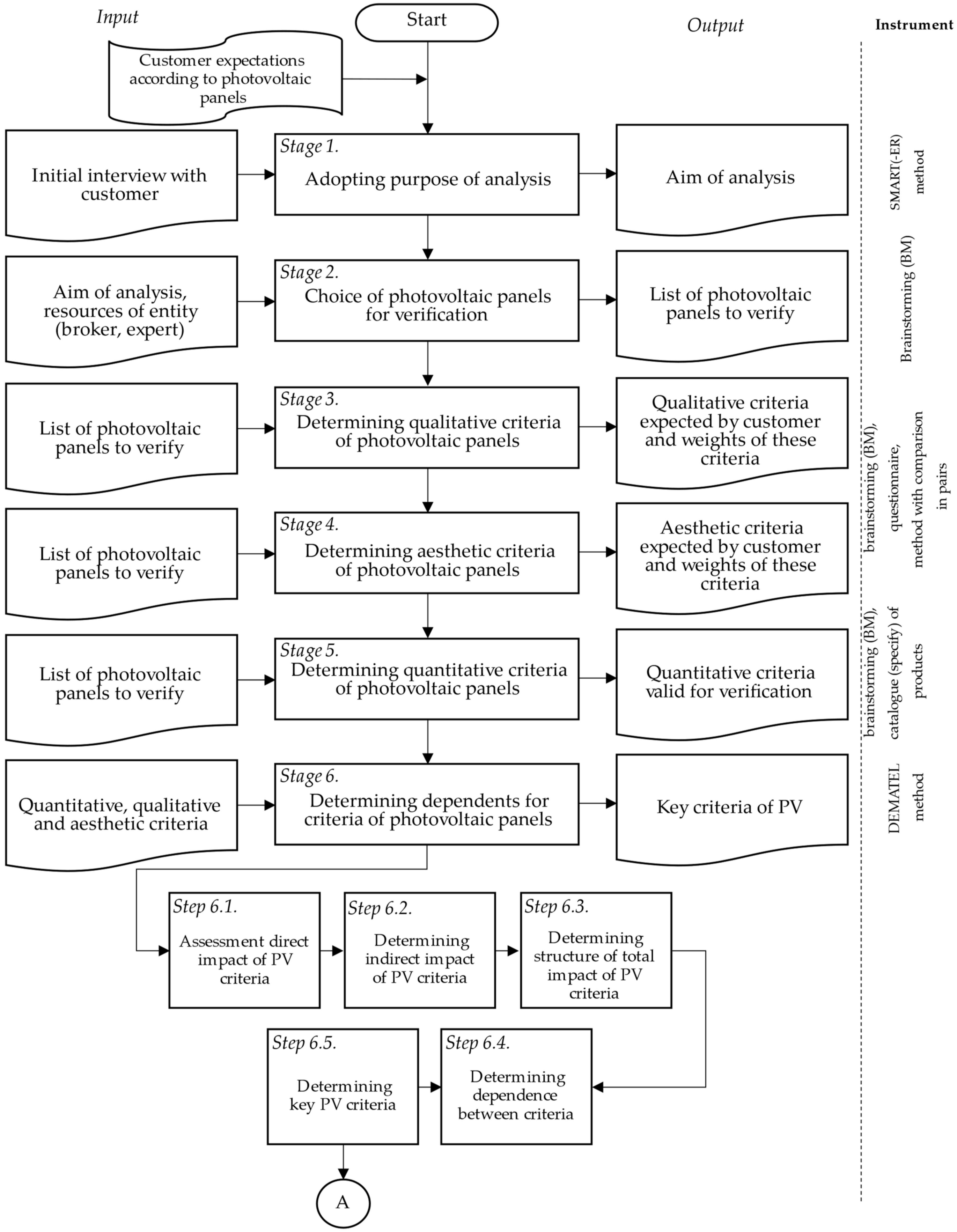


**Figure 3.** Model of prediction of quality photovoltaic panels—part 1. Own study.

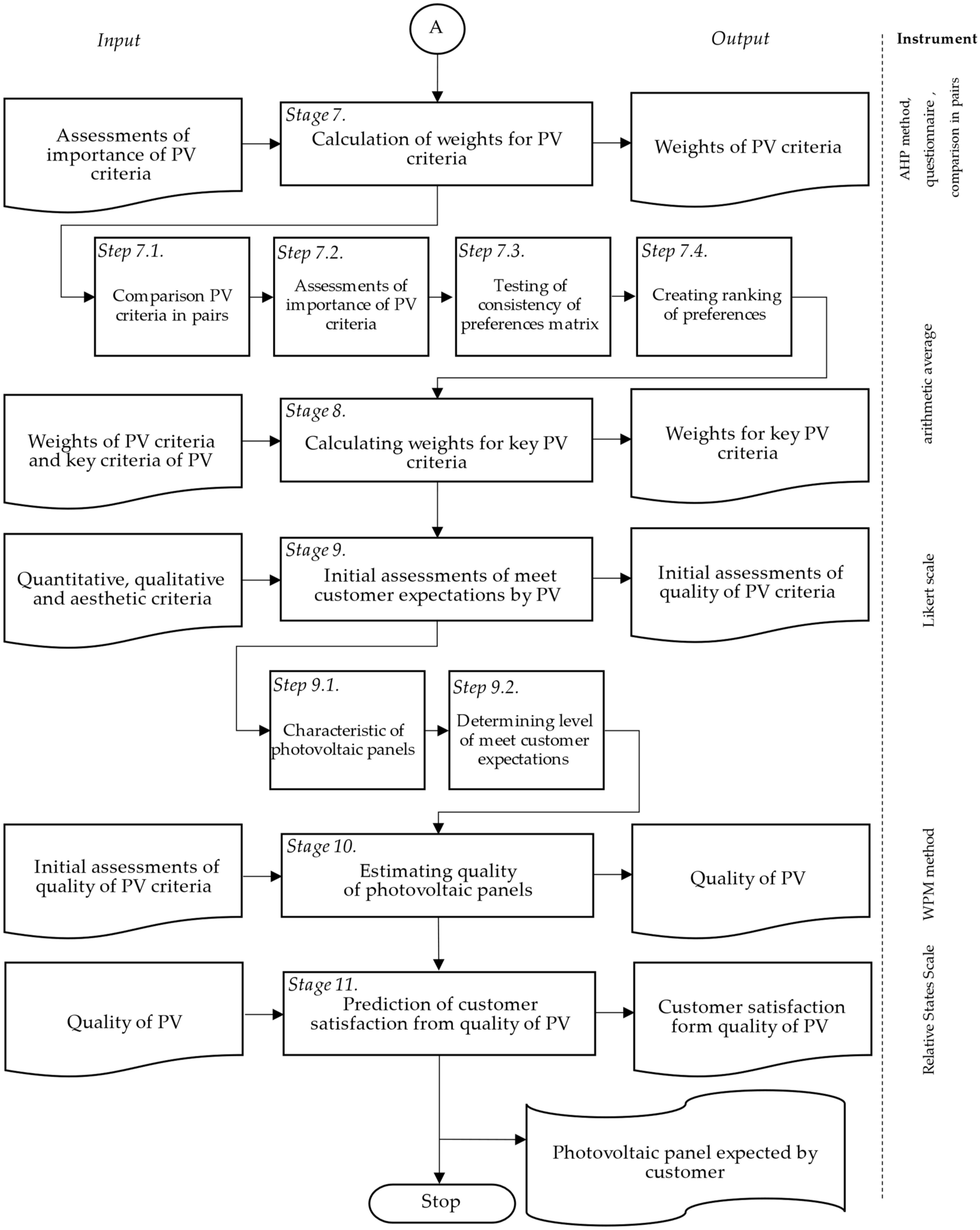


**Figure 4.** Model of prediction of quality photovoltaic panels—part 2. Own study.

The characteristic of stages of the model is presented in the next part of the study.

*Stage 1. Adopting purpose of analysis*

The purpose of the analysis is determined by the entity using the proposed model (bidder, expert broker). The determined purpose should include rules of the SMART(-ER) method (Specific, Measurable, Achievable, Relevant, Time-bound, Exciting, Recorded) [30,31]. As part of the proposed model, it can be assumed that the purpose is the prediction of quality of photovoltaic panels considering sustainable criteria, i.e.: qualitative (immeasurable, determined by the customer), quantity (measurable, technical-base criteria of the utility of product), aesthetic (landscape). To determine the purpose, it is recommended to realize an initial interview with the customer, i.e., individual customer (household), small and medium companies, or others.

*Stage 2. Choice of photovoltaic panels for verification*

The choice of PV for verification is made by the entity. The choice results from the availability of products that can be offered for the customer. At this stage, it is necessary to determine the photovoltaic panels initially expected. It is preferred to inform the customer about possibilities using BIPV panels (i.e., integrated with building) [7,45,46], or BAPV panels (not integrated with the building) [47–49]. The customer can then initially indicate the type of solar panels expected. On the basis of initial customer preference, it is possible to choose photovoltaic panels for the next analysis. The number and type of verified photovoltaic panels are not limited and depend on the entity.

*Stage 3. Determining qualitative criteria of photovoltaic panels*

The qualitative criteria for photovoltaic panels are immeasurable criteria. In the proposed approach, assumed that these criteria are general (subjective) determined of quantitative (technical, measurable) criteria. Additionally, it was assumed that at this stage, qualitative criteria should not be not aesthetic criteria of the product. It results from the concept of the proposed model, where all criteria will be integrated sequentially. Examples of qualitative criteria are shown in Figure 4. At this stage, the purpose is to obtain the so-called Voice of Customer (VoC) about the important (preferred) criteria of PV. To obtain customer expectations, the questionnaire is used with the proposed qualitative criteria. The idea is to support the customer in determining their expectations. Additionally, the customer should be able to point out his own criteria. According to the literature review, for example [1,3,12,14,40,50], the customer is able to simultaneously assess simultaneously from 5 to 9 criteria. Therefore, the summary number of all criteria (proposed and individually determined by the customer) should be equal to $7 \pm 2$ [9,14,50]. Then, the weights of these criteria are determined by the customer. According to a review of the literature [36–39], it is preferred to use the approach of comparison in pairs, which increases the precision of the results. The popular Likert scale (five-point) is used for comparison of criteria weights, which according to Refs. [51,52] is effective in obtaining customer expectations. The matrix of comparisons in pair is created by the entity (broker, expert) based on the qualitative criteria determined by the customer. An example of the questionnaire with proposed qualitative criteria is shown in Figure 5. These proposed qualitative criteria are correlated with quantitative criteria. These quantitative criteria were the following.

- high power—It relates to the high-power potential value of electrical energy, i.e., available power;
- high performance—high efficiency (usability);
- light weight—relatively low overall weight of PV;
- small size—small size determined by the length, width, and thickness of PV;
- easy to assemble—possibility of uncomplicated assembly, i.e., integrated assembly, non-integrated assembly, the possibility of self-assembly;
- high corrosion resistance—relates to corrosion resistance; therefore, it includes additional specifications used to protect the PV coating;
- minimal energy loses;

- high-temperature resistance—concerns the criteria of maximum PV power and efficiency.

The worksheet indicates the criteria selected as a result of preliminary research conducted with installers. These were the criteria that clients most frequently articulated.

**QUESTIONNAIRE**

From the proposed criteria please mark by X only these criteria which are important (expected) for you. It is possible to propose your own qualitative criteria (without aesthetic criteria). Please mark not more than 9 criteria. Then, determine the importance (weight) of these criteria in a matrix with comparison in pairs.

**STAGE 1.** Determine expected criteria (maximum 9 criteria)

| | *proposed criteria* | *other criteria* |
|---|---|---|
| ☐ | high power | …………………………………………………… |
| ☐ | high performance | …………………………………………………… |
| ☐ | light weight | …………………………………………………… |
| ☐ | small size | …………………………………………………… |
| ☐ | easy to assemble | …………………………………………………… |
| ☐ | high corrosion resistance | …………………………………………………… |
| ☐ | minimal energy losses | |
| ☐ | high temperature resistance | |

**STAGE 2.** Determine the importance of expected criteria

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| criteria | absolutely more important | much more important | more important | a little more important | equally important | a little more important | more important | much more important | absolutely more important | criteria |
| | ← | | | | ● | | | | → | |
| criterion 1 | | | | | | | | | | criterion 2 |
| criterion 1 | | | | | | | | | | criterion 3 |
| criterion 1 | | | | | | | | | | criterion 4 |
| criterion n | | | | | | | | | | criterion n |

where: n - number of expected criteria (criteria determined by customer as expected/preferred)

**Figure 5.** Example of questionnaire to obtain customer expectations. Own study.

In the questionnaire, it is possible to include any qualitative criteria, e.g., basic criteria and innovative criteria, which are not popular and perhaps not known by customers.

*Stage 4. Determining the aesthetic criteria of photovoltaic panels*

The aesthetic criteria of PV are criteria that determine landscape values, i.e., the satisfaction of the customer from landscape caused by the product [53,54]. The purpose is to select the expected criteria as part of achieving customer satisfaction from the landscape. Additionally, the concept of a model includes the integration of aesthetic criteria with qualitative and quantitative criteria. It refers to the simultaneous achievement of satisfaction from the landscape and quality of the photovoltaic in terms of its utility. It is realized in the next part of the model.

After reviewing the literature, it is proposed to include aesthetic criteria (landscape), i.e., [53–57]:

- visibility—It is possible to observed PV by the customer and other interested parties, where the higher the visibility, the higher negative the impact of this criterion on the quality level; the visibility is measured by geographic information systems (GIS) or as the percentage of surface occupied by PV to the total (seen) surface of landscape; against this criterion it is necessary to determine visibility from areas with important impact on viewing values for the client and interested parties, e.g., from a distance of 5 to 10 km distance from nature and history, historic buildings, recreation areas, or

landscaping sites that the customer does not want to be disturbed by PV installation; a certain difficulty in determining visibility in a precise manner is the need to take into account the customer's point of view;
- degree of integration—it determines degree of combination of PV with landscape and simultaneously refers to the visibility criterion; in this context, it is necessary to include the attributes of BIPV and BAPV; according to experts, a high level of integration is preferred, which to some extent reduces its visibility, i.e., non-integrated, partially integrated or integrated panels;
- colour (hue, saturation, brightness)—determines the color values of PV, e.g., panel frame and values of the landscape in which PV is installed;
- light reflection—determines the reflection of light (sunlight or artificially induced light) from the photovoltaic panel; not controlled light reflection has an impact on customer satisfaction, e.g., by decreased visual performance, dazzle, and a need for frequent blinking or looking away, discomfort or headache;
- pattern (texture)—it is the appearance of surface that is consisting of its complexity and similarity to nearby elements due to density/porosity or transparency;
- fractality—visual image that includes repeating elements at different scales.

The final choice of aesthetic criteria lies with the entity using the proposed model. It results from the possibilities of adjusting groups of aesthetic criteria to the initial determined customer expectations in the case of BIPV or BAPV panels (from stage 2). According to the literature [1,3,12,14,40,50], the number of criteria should be equal to 5 to 9 criteria. Also, it results from the concept of model, where the aesthetic criteria will be a comparison in pairs. Additionally, aesthetic criteria are immeasurable criteria (like qualitative criteria). Therefore, its precise definition is problematic [39,40]. In turn of that, it is proposed to obtain customer expectations based on possible modification (alternatives) of these criteria. It will be helpful for the customer to determine its preferences. For this purpose, the questionnaire is used. Therefore, the questionnaire should allow for the determination of the expected states (modifications) of the criteria. These states are determined by the entity (expert, bidder, broker). Additionally, the questionnaire should include the stage of determining the weights of criteria. To this aim, the approach with comparison in pairs is used. The example of a questionnaire is shown in Figure 6.

**QUESTIONNAIRE**

From the proposed criteria please mark by X only these criteria which are important (expected) for you. Then, determine the importance (weight) of these criteria in a matrix with comparison in pairs.

**STAGE 1.** Determine expected state for each aesthetic criterion

| | | | | | | |
|---|---|---|---|---|---|---|
| **visibility** | ☐ | practically invisible | ☐ | partially invisible | ☐ | visible |
| **degree of integrated** | ☐ | not integrated | ☐ | partially integrated | ☐ | integrated |
| **colour** | ☐ | standing out from the landscape | ☐ | close to the landscape | ☐ | fully integrated into the landscape |
| **light reflection** | ☐ | small | ☐ | medium | ☐ | large |
| **pattern** | ☐ | transparent | ☐ | porous | ☐ | plain |
| **fractality** | ☐ | small | ☐ | medium | ☐ | large |

**STAGE 2.** Determine the importance of aesthetic criteria

| | **5** | **4** | **3** | **2** | **1** | **2** | **3** | **4** | **5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| criteria | **absolutely more important** | **much more important** | **more important** | **a little more important** | **equally important** | **a little more important** | **more important** | **much more important** | **absolutely more important** | criteria |
| criterion 1 | | | | | | | | | | criterion 2 |
| criterion 1 | | | | | | | | | | criterion 3 |
| criterion 1 | | | | | | | | | | criterion 4 |
| criterion n | | | | | | | | | | criterion n |

where: n - number of expected criteria (criteria determined by customer as expected/preferred)

**Figure 6.** Example of questionnaire to obtain customer expectations about aesthetic criteria. Own study.

After obtaining customer expectations from aesthetic criteria, it is necessary to determine the quantity criteria.

*Stage 5. Determining quantitative criteria of photovoltaics*

The quantitative criteria of PV are measurable criteria, so technical criteria. These criteria for the use are based on the criteria of using PV, which refer to its utility. These criteria are determined to process the customer criteria (qualitative and aesthetic) into measurable criteria. It is achieved by determining the relations between these criteria, as is shown in the next stage of the proposed model. Qualitative criteria are selected by an entity or group of experts. These criteria are determined during brainstorming (BM) [58–63]. Also, the product catalogue is used for that.

Based on the literature review determined quantity criteria of PV, that is, [3,6,16,53–56]:

- rated power (installed) (Wp) refers to the value of the potential value of electric energy, i.e., available power;
- short-circuit current (current at maximum load) (A)—this is the intensity of the current flowing when the cell is short-circuited;
- maximum (output) current (A)—the current supplying photovoltaic panel to the load;
- open-circuit voltage (no load, open circuit) (V)—voltage generated without connecting the module to the load;
- maximum (critical) voltage (V)—voltage at the maximum power point, i.e., during PV operation in Standard Test Conditions;
- efficiency (efficiency) (%)—the efficiency of changing the power of solar radiation into electricity, where the higher the value, the better;
- maximum system voltage (VDC)—voltage in the PV installation circuit limits the number of panels connected in one series/string;
- maximum power (MPP)—the power achieved by the cell, it is the power available under standard test conditions and the main output parameter in PV selection;
- panel efficiency (%)—PV efficiency to convert solar energy into electricity, where the efficiency of the entire module is lower than that of a single cell and depends on the method of connecting the cells;
- weight (kg)—this is the total weight of the photovoltaic panel;
- warranty—period covered by the possibility of no costly repair or replacement of PV;
- kinematics—PV inclination angle adjustment;
- dimensions (mm)—overall dimensions of PV, i.e., length, width, thickness;
- single-cell efficiency (Solar Cell Efficiency) (%)—efficiency of one cell included in the entire PV module.

According to [64–66] the most frequently are selected from 14 to 25 criteria. The different number of quantitative criteria and customer criteria (qualitative and aesthetic criteria, i.e., ($7 \pm 2$)), resulted from the assumptions of model, i.e., a lack of need to compare quantitative criteria simultaneously. Therefore, the number of criteria may be greater but large enough to maintain the precision of the assessment of these criteria.

*Stage 6. Determining Dependencies for criteria of Photovoltaic Panels*

At this stage, the dependents between qualitative and quantitative criteria are determined. It refers to the determination of mutual influence (correlations) for these criteria. The purpose is to process the expected qualitative criteria (immeasurable) into quantitative criteria (measurable). The idea is to identify which technical (quantitative) criteria should be included in estimating the quality of photovoltaics. The DEMATEL method (Decision Making Trial And Evaluation Laboratory) is used for that. The choice of the DEMATEL method was caused by supporting decisions in determining the interdependencies between PV criteria and reflecting the complex connections between them. Additionally, this method provides verification of any number and type of criteria, therefore being used for that [32–35]. How to apply this method is presented in five steps.

Step 6.1. Assessment direct impact of PV criteria

This assessment is done for qualitative and quantitative criteria. The assessment is carried out by expert (entity) on an ordinal scale using the DEMATEL method. It is scaled from 0 to 4, where 0—no impact, 1—low impact, 2—clear impact, 3—high impact, 4—extreme impact. Based on the assigned assessments of the influence of given elements on each other, a direct influence matrix is created, where there are zero values on the diagonal (no influence of identical elements on each other) (1) [33,35]:

$$z_{ij} = \frac{1}{l}\sum_{k=1}^{l} z_{ij}^{k}, \quad i, j = 1, 2, \ldots, n \ , \tag{1}$$

where $z_{ij}^{k}$—assessment, l—expert opinion.

Based on the direct impact matrix, it is possible to create a network of connections (interactions) of these elements. This is called the structure of direct influence, as shown in [35].

Step 6.2. Determining indirect impact of photovoltaic criteria

It is realized on the basis of direct impact of PV criteria. For this purpose, the impact matrix on the PV criteria is created. It is the normalized matrix of indirect impact of PV criteria $\left(X = [x_{ij}]_{n\times n}\right)$, as shown Formula (2) [32,34]:

$$X = \frac{Z}{s} \quad \text{where}: \ s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}, \ \max_{1\le i\le n}\sum_{i=1}^{n} z_{ij}\right) \ , \tag{2}$$

where all elements of the X matrix included in range $0 \le x_{ij} \le 1$, $0 \le \sum_{j=1}^{n} x_{ij} \le 1$, and the last element i is shown as $\sum_{j=1}^{n} z_{ij} \le s$.

Step 6.3. Determining Structure of Total Impact of PV criteria

Next, the structure of total impact is created, and in this structure is included the simultaneously direct and indirect impact of PV criteria. It is sum all direct effects and all indirect effects for verified criteria, i.e., (3) [32,34,35]:

$$T = X + X^2 + X^3 + \ldots + X^h = X(I - X)^{-1}, \quad \text{when } h \to \infty, \tag{3}$$

where: X—normalized matrix of indirect impact, I—identical matrix.

Step 6.4. Determining Dependence Between Criteria

According to the structure of total impact, it is possible to determine cause-and-effect dependencies, which, in the proposed concept are dependencies between quantitative, aesthetic, and qualitative criteria. It refers to the determination of the mutual correlation (impact) between these criteria. For this purpose, the map of impact relations is created (4) [33,34]:

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \quad C = [c_j]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n}^{T} \ , \tag{4}$$

where R—sum of values in the rows of matrix of total impact, C—sum of values in the columns of matrix of total impact, r—sum of the i-th row in T matrix and determines the sum of direct and indirect effects not included among the verified elements, c—sum of the j-th column in T matrix and determines the sum of direct and indirect effects not included among the verified elements.

Step 6.5. Determining Key PV Criteria

Based on quantitative and qualitative dependencies, it is possible to determine key PV criteria, i.e., strongly correlated quantitative (technical) criteria (from stage 5) with qualitative criteria (from stage 3). The purpose is to identify quantitative criteria on which the quality of photovoltaic panels will be estimated. As part of the DEMATEL method, it refers to determining the average value ($\alpha$) from all values of the total impact (T) (5) [32,33]:

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N}, \tag{5}$$

where as in Formula (3).

The values of the T matrix that are above average ($\alpha$) mean important the mutual impact of qualitative and quantitative criteria. Criteria that have values above average are key PV criteria. Key criteria for solar panels are included in the further analysis.

*Stage 7. Calculation of Weights for PV criteria*

The weights of the PV criteria are estimated based on customer assessments obtained from stage 3 and stage 4. The weights of PV criteria are estimated based on customer assessments obtained from stage 3 and stage 4. Therefore, to calculate the weights of PV criteria, the AHP method was used, because the methodology of AHP method includes a rule of comparison in pairs to determine the weights of criteria [37–39]. The use of the AHP method is shown in four steps. The process is realized double, i.e., for qualitative criteria (from stage 3), and for aesthetic criteria (from stage 4). At this stage, the quantity criteria not correlated (result of stage 6) are not included in this analysis.

Step 7.1. Comparison of photovoltaic criteria in pairs

The comparison of PV criteria in pairs is performed according to the evaluations of criteria in the Likert scale. For this purpose, the dominate matrix ($S_{ij}$) is created, where i, j = 1, 2, . . . , k; with proportion of $i_{th}$ weights for $j_{th}$ criteria. It is a square matrix ($n \times n$), where n is the number of criteria (6–7) [37]:

$$S_{ij} \approx \frac{w_i}{w_j}, \text{ where } i, j = 1, 2, \ldots, k, \tag{6}$$

$$S_{ij} = \frac{1}{S_{ij}}, \text{ where } i, j = 1, 2, \ldots, k, \tag{7}$$

In this matrix, the diagonal values are valued equal to 1, which proves that the criteria are equivalent. In turn, above the diagonal is the value from the comparison of two different criteria and below the diagonal, the reciprocal values of these comparisons.

Step 7.2. Assessments of Importance of PV criteria

Assessment of PV criteria refers to the calculation of the geometric average of rows of the dominance geometric matrix and its normalization (8) [38,39]:

$$w_i = \frac{\left[\prod_{j=1}^{k} S_{ij}\right]^{\frac{1}{k}}}{\sum_{i=1}^{k}\left[\prod_{j=1}^{k} S_{ij}\right]^{\frac{1}{k}}}, \text{ dla } i \ldots 1, \ldots. k, \tag{8}$$

The sum of all assessments of importance (weights) should be equal to 1. Proves the correctness of the calculations performed. To check whether the ratings were given consistently, it is necessary to check that the results do not violate the principle of stability of preferences.

Step 7.3. Testing of the consistency of preferences matrix

To determine the correctness of the customer ratings, the consistency of the preferences matrix should be examined. It refers to the calculation of the consistency factor ($\lambda_{max}$) (9), the compatibility coefficient of the comparison matrix (CI) (10), and the compatibility ratio (CR) (11) [37,39]:

$$\lambda_{max} = \frac{1}{w_i} \sum_{j=1}^{k} w_{ij} w_j, \tag{9}$$

$$CI = \frac{\lambda_{max} - n}{r(n-1)}, \tag{10}$$

$$CR = \frac{CI}{r}, \tag{11}$$

where:

$\lambda_{max}$—consistency factor,
n—number of criteria,
r—mean value of the random index for n according to Saaty [37,38].

Achieved $\lambda_{max}$ = n, CI = 0, CR = 0, determine the full correctness of the results. Also, it is acceptable to achieve $\lambda_{max}$ near to n, for CI < 0.1 and CR < 0.1 [37–39]. If results are not correct, it is necessary to repeat the calculations starting from step 1.

Step 7.4. Creating a ranking of preferences

The weights of the criteria should be ordered in a ranking. It relies on segregating values of weights from maximum to minimum. The maximum value is the first position in the ranking, so it is the most preferred (the most important criterion). The minimum value is the last position in the ranking, so the least preferred (the least important criterion). After calculating the weights for qualitative criteria, it is necessary to calculate the weights for aesthetic criteria. To achieve this, the process is repeated from step 1 to step 4. Then, it is possible to calculate the weights of the key PV criteria, as is shown in the next stage of the model.

*Stage 8. Calculating Weights for Key PV criteria*

In this stage, it is necessary to calculate the weights only for key PV criteria, so for criteria that generate the quality of PV an important degree. The key criteria are quantitative criteria (measurable, technical) correlated with criteria expected by the customer (qualitative). The set of these criteria was determined in Step 6.5 of model. To determine the weights of the key PV criteria, it is necessary to based on the weights of qualitative criteria (from stage 7). The quantitative criteria can be integrated with the different numbers of qualitative criteria (Figure 7).

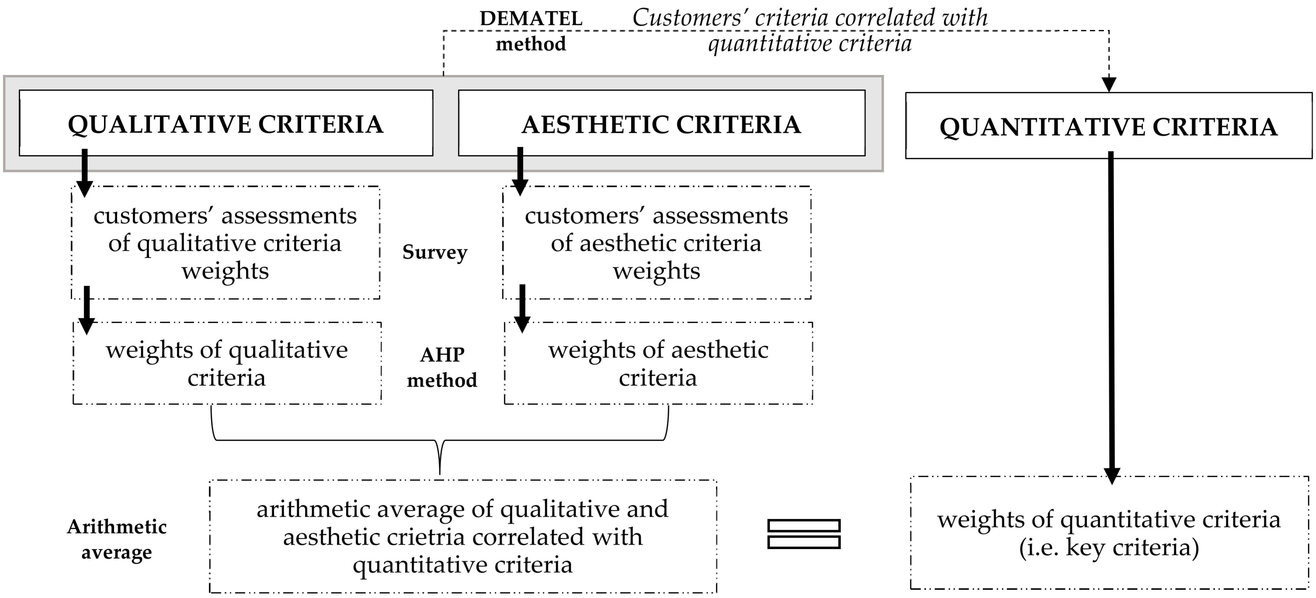


**Figure 7.** Relations between PV criteria and way to calculate its weights. Own study.

Therefore, the weights of the key criteria are calculated as the arithmetic average of these weights (12) [67]:

$$\overline{w}_i^k = \frac{\sum_{i=1}^{n} w_i^q}{n}, \tag{12}$$

where $w^k$—weights of $i_{th}$ key criteria, n—number of customer criteria correlated with $i_{th}$ quantitative criterion $w^q$—weights of $i_{th}$ qualitative criteria, i—criterion of PV expected by the customer.

Note that weights have also been set for the aesthetic criteria (in step 7). The weights of the key PV criteria and the weights of the aesthetic criteria will be considered in stage 10 of the model to determine the quality of the PV panels.

*Stage 9. Initial assessment of meet customer expectations by PV*

The evaluations of meeting customer expectations are evaluations of the quality of key PV criteria in terms of customer expectations. Assessments are carried out by expert (broker, bidder) based on key PV criteria (stage 6) for all photovoltaic panels (stage 2). This is achieved in two steps.

Step 9.1. Characteristic of Photovoltaic Panels

The entity applying this model characterizes all photovoltaic panels (from stage 2) according to key criteria. For each key criterion, it is necessary to determine, e.g., the value (parameter) or a range of values. The catalogue (specification) of PV is used for that. The characteristic can be realized in the table.

Step 9.2. Determining the level to meet customer expectations

The level of satisfaction of customer expectations from PV criteria is realized based on the characteristic of these criteria. Assessments are performed by entity (expert) according to the Likert scale (1–5, where 1—the lowest quality of criterion, 5 is the highest quality of criterion) [40,41]. The entity (expert) is based on customer expectations obtained from questionnaires, i.e., questionnaire for qualitative criteria (stage 3) and the questionnaire for aesthetic criteria (stage 4). The assessments are used to estimate the quality of the photovoltaic panels, which is shown in the next stage of the model.

*Stage 10. Estimation of the quality of photovoltaic panels*

The estimation of the quality of photovoltaic panels refers to determining the so-called level of customer satisfaction with the quality of photovoltaic panels. The quality of PV is calculated considering weights of key criteria (i.e., quantitative correlated with qualitative) and the weights of aesthetic criteria. Moreover, it is necessary to include assessments to meet customer expectations (from stage 9). For this purpose, the Weighted Product Model (WPM) is used [36,37,42]. In this method, there is no need to standardize the measurement units for the verified criteria. Therefore, there is no need to standardize expert ratings for the various key PV criteria. Using the WPM refers to calculating the quotient of the weights of PV criteria and assessments of meeting customer expectations for the verified PV (13) [36,37,42]:

$$P^*_{WPM} = \max_{m \geq i \geq 1} \prod_{j=1}^{n} a_{ij}^{w_j}, \tag{13}$$

where a—evaluations to meet customer expectations for $i_{th}$ PV in case of $j_{th}$ criterion, W—weight of $j_{th}$ criterion, i, j = 1, 2, . . . , n.

It is necessary to remember that the sum of weights should be equal to 1. Otherwise, the normalization of the criteria weights must be done by Formula (14) [67]:

$$w_i^{kn} = \frac{\overline{w}_i^k}{\max\limits_{i=1} \overline{w}_i^k}, \tag{14}$$

where $w^{kn}$—normalized weight of $i_{th}$ key criterion, $\overline{w}_i^t$—arithmetic average from weights of $i_{th}$ key criteria, i—criterion expected by the customer.

In the WPM it is possible to eliminate all measure values. Therefore, the quality of PV is estimated as dimensionless. Then, a ranking of quality of PV is created. The maximum value (first position in the ranking) is the photovoltaic panel with the most satisfaction for the customer (meet his expectations to the highest degree). In turn, to predict satisfaction from the quality of PV, the relative state scale is used, as is shown in the next stage of the model.

*Stage 11. Prediction of customer satisfaction with the quality of PV*

This stage refers to verifying the quality levels of the photovoltaic panels according to the universal scale of relative states [1,40] (Figure 8). For this purpose, it is necessary to analyze the quality of PV that was estimated using the WPM method (from stage 10).


**Figure 8.** Relative scale of states of customer satisfaction. Own study based on [1,4,40].

In addition, the choice of the final solar panel may be influenced, for example, the cost of its purchase. Therefore, the entity (bidder, broker, expert) should offer the customer the most advantageous PV in terms of quality and then indicate the cost of its purchase. Then the customer can decide which photovoltaic is expected.

## 3. Results

The model was verified for photovoltaic panels from a key producer from UE countries. However, any entity (bidder, expert, broker) can use this model to predict the quality of PV considering customer expectations.

*Stage 1. Adopting the purpose of analysis*

The purpose was to predict the quality of photovoltaic panels for the home. It was assumed that prediction includes sustainable criteria, i.e.: qualitative (immeasurable, determined by customers), quantity (measurable, technical-based criteria of the utility of products), aesthetic (landscape).

*Stage 2. Choice of photovoltaic panels for verification*

Based on the possibilities of the entity (expert), twelve photovoltaic panels were verified. These were panels of key UE producers. After the initial interview with the customer, no special expectations for BIPV or BAPV were determined. As part of the test of the model, these panels were determined from PV1 to PV12.

*Stage 3. Determining Qualitative Criteria of photovoltaic panels*

The questionnaire was used to obtain customer expectations about the preferred qualitative criteria. The results are shown in Figure 9.

Among the proposed criteria, the customer pointed that these are important for him: high power, high performance, light weight, high corrosion resistance, minimal energy loss, and high temperature resistance. Moreover, the customer pointed out his own criteria, i.e., high efficiency and ability to change the settings. Additionally, the customer determined the importance of these criteria on the Likert scale. The questionnaire with the method of comparison in pairs was used for that. These results were analyzed in the next stages of the model.

**QUESTIONNAIRE**

From the proposed criteria please mark by X only these criteria which are important (expected) for you. It is possible to propose your own qualitative criteria (without aesthetic criteria). Please mark not more than 9 criteria. Then, determine the importance (weight) of these criteria in a matrix with comparison in pairs.

**STAGE 1.** Determine expected criteria (maximum 9 criteria)

| | *proposed criteria* | *other criteria* |
|---|---|---|
| ☒ | high power | high efficiency |
| ☒ | high performance | ability to change the settings |
| ☒ | light weight | ........................................................................... |
| ☐ | small size | ........................................................................... |
| ☐ | easy to assemble | ........................................................................... |
| ☒ | high corrosion resistance | ........................................................................... |
| ☒ | minimal energy losses | |
| ☒ | high temperature resistance | ........................................................................... |

**STAGE 2.** Determine the importance of expected criteria

| criteria | 5 absolutely more important | 4 much more important | 3 more important | 2 a little more important | 1 equally important | 2 a little more important | 3 more important | 4 much more important | 5 absolutely more important | criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| high power | | | | | | X | | | | high performance |
| high power | | X | | | | | | | | light weight |
| high power | | | | X | | | | | | high corrosion resistance |
| high power | | | | X | | | | | | minimal energy losses |
| high power | | | | | X | | | | | high temperature resistance |
| high power | | | | | X | | | | | high efficiency |
| high power | | X | | | | | | | | ability to change the settings |
| high performance | | X | | | | | | | | light weight |
| high performance | | | X | | | | | | | high corrosion resistance |
| high performance | | | | X | | | | | | minimal energy losses |
| high performance | | | | X | | | | | | high temperature resistance |
| high performance | | | | | X | | | | | high efficiency |
| high performance | X | | | | | | | | | ability to change the settings |
| light weight | | | | | | X | | | | high corrosion resistance |
| light weight | | | | | | | | X | | minimal energy losses |
| light weight | | | | | | | X | | | high temperature resistance |
| light weight | | | | | | | | X | | high efficiency |
| light weight | | | | | | X | | | | ability to change the settings |
| high corrosion resistance | | | | | | X | | | | minimal energy losses |
| high corrosion resistance | | | | | X | | | | | high temperature resistance |
| high corrosion resistance | | | | | | | X | | | high efficiency |
| high corrosion resistance | | | | X | | | | | | ability to change the settings |
| minimal energy losses | | | X | | | | | | | high temperature resistance |
| minimal energy losses | | | | | X | | | | | high efficiency |
| minimal energy losses | | X | | | | | | | | ability to change the settings |
| high temperature resistance | | | | | | | | X | | high efficiency |
| high temperature resistance | | | X | | | | | | | ability to change the settings |
| high efficiency | X | | | | | | | | | ability to change the settings |

**Figure 9.** Results from a questionnaire about customer expectations for qualitative criteria. Own study.

*Stage 4. Determining the aesthetic criteria of photovoltaic panels*

At this stage, the expected aesthetic criteria of photovoltaic energy were determined. The customer did not have a special preference for BIPV and BAPV. Therefore, the basic aesthetic criteria were verified. The proposed questionnaire was used to obtain customer expectations (Figure 10).

**QUESTIONNAIRE**

From the proposed criteria please mark by X only these criteria which are important (expected) for you. Then, determine the importance (weight) of these criteria in a matrix with comparison in pairs.

**STAGE 1.** Determine expected state for each aesthetic criterion

| | | | |
|---|---|---|---|
| **visibility** | ☐ practically invisible | ☐ partially invisible | ☐ visible |
| **degree of integrated** | ☐ not integrated | ☐ partially integrated | ☐ integrated |
| **colour** | ☐ standing out from the landscape | ☐ close to the landscape | ☐ fully integrated into the landscape |
| **light reflection** | ☐ small | ☐ medium | ☐ large |
| **pattern** | ☐ transparent | ☐ porous | ☐ plain |
| **fractality** | ☐ small | ☐ medium | ☐ large |

**STAGE 2.** Determine the importance of aesthetic criteria

| | **5** | **4** | **3** | **2** | **1** | **2** | **3** | **4** | **5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| criteria | **absolutely more important** | **much more important** | **more important** | **a little more important** | **equally important** | **a little more important** | **more important** | **much more important** | **absolutely more important** | criteria |
| visibility | | | | | X | | | | | degree of integrated |
| visibility | | | | | X | | | | | colour |
| visibility | | | X | | | | | | | light reflection |
| visibility | | X | | | | | | | | pattern |
| visibility | | X | | | | | | | | fractality |
| degree of integrated | | | | | X | | | | | colour |
| degree of integrated | | | X | | | | | | | light reflection |
| degree of integrated | | X | | | | | | | | pattern |
| degree of integrated | | X | | | | | | | | fractality |
| colour | | | | X | | | | | | light reflection |
| colour | | | X | | | | | | | pattern |
| colour | | X | | | | | | | | fractality |
| light reflection | | | | X | | | | | | pattern |
| light reflection | | | | X | | | | | | fractality |
| pattern | | | | | X | | | | | fractality |

**Figure 10.** Results of questionnaire for customer expectations for aesthetic criteria of PV. Own study.

The customer determines the preferred states of the criteria. It was determined that the client expects a photovoltaic panel that will be practically invisible, partially integrated, fully integrated with the landscape (surroundings), smooth, with low light reflection, and low fractality. Then the customer determined the importance of all verified aesthetic criteria. For this, he used a personalized pairwise comparison questionnaire. The results were analyzed in the subsequent stages of the model.

*Stage 5. Determining quantitative criteria of photovoltaics*

To process customer expectations (qualitative criteria) into technical criteria of photovoltaic, quantitative criteria were determined. After brainstorming, the entity determined 14 basis quantity criteria for the selected photovoltaic panels. These criteria were determined according to the public catalogues (specification) of these products. These criteria were: rated power, short-circuit current, maximum current, no-load voltage, temperature, current factor, efficiency (efficiency), temperature, voltage factor, temperature power, factor, panel efficiency, weight, warranty, kinematics, dimensions, efficiency of a single cell. The characteristics of these criteria are presented in Chapter 2 of the article.

*Stage 6. Determining Dependencies for criteria of Photovoltaic Panels*

As part of the sixth stage of the model, the mutual impact (correlations) of qualitative and quantitative criteria were determined. This stage was completed by the expert (broker). The DEMATEL method was used for that. It was assumed that the quantitative criterion determines the quality of PV. These criteria are included by an entity to calculate the quality of a product. Because qualitative criteria in a measured way determine the utility of photovoltaics. In turn, the qualitative and aesthetic criteria are determined by customers subjectively. Therefore, the DEMATEL method was used to process the customer criteria (qualitative and aesthetic) into technical criteria (quantitative). In the proposed approach, it was assumed that qualitative and aesthetic criteria are a group of subjective criteria that are answers to quantitative criteria. These qualitative and aesthetic criteria are determined in a simpler way by the customers. By using the DEMATEL method, it is possible to determine the relations and interactions between technical criteria and customers' criteria.

Step 6.1. Assessment direct impact of PV criteria

The expert assessed the direct impact of verified PV criteria. The assessments were done on a scale from 0 to 4. According to Formula (1) the evaluation was realized in the matrix of direct impact (Table 1).

**Table 1.** Matrix of the direct impact of PV criteria. Own study.

| Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 4 | 4 | 0 | 1 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| T2 | 3 | 2 | 0 | 0 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 3 | 3 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 2 | 3 | 0 | 0 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 3 | 3 | 0 | 0 | 2 | 1 | 3 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| T6 | 3 | 4 | 0 | 1 | 3 | 3 | 4 | 2 | 2 | 2 | 2 | 3 | 2 | 2 |
| T7 | 2 | 2 | 0 | 0 | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| T8 | 4 | 3 | 0 | 0 | 3 | 2 | 4 | 1 | 0 | 0 | 1 | 2 | 3 | 1 |
| T9 | 4 | 4 | 2 | 3 | 4 | 4 | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| T10 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| T11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T12 | 0 | 0 | 3 | 0 | 1 | 1 | 3 | 4 | 1 | 1 | 0 | 2 | 0 | 0 |
| T13 | 1 | 2 | 4 | 0 | 1 | 0 | 0 | 1 | 4 | 4 | 0 | 3 | 0 | 1 |
| T14 | 3 | 3 | 1 | 1 | 2 | 1 | 4 | 3 | 1 | 1 | 0 | 1 | 0 | 0 |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T11—warranty, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Then, the next step of the model was realized.

Step 6.2. Determining indirect impact of photovoltaic criteria

On the basis of the matrix of direct impact of PV, it was determined indirect impact of these criteria. According to Formula (2), the normalization of the matrix of direct impact was carried out. As a result, the matrix of indirect impact of PV criteria was achieved, as is shown in Table 2.

All PV criteria from the matrix of direct impact matrix (x) were in the range $0 \leq x_{ij} \leq 1$, $0 \leq \sum_{j=1}^{n} x_{ij} \leq 1$. Therefore, the indirect matrix was well prepared.

**Table 2.** Matrix of indirect impact of PV criteria. Own study.

| Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.11 | 0.11 | 0.00 | 0.03 | 0.06 | 0.03 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 |
| T2 | 0.09 | 0.06 | 0.00 | 0.00 | 0.03 | 0.03 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T3 | 0.09 | 0.09 | 0.00 | 0.00 | 0.03 | 0.03 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T4 | 0.06 | 0.09 | 0.00 | 0.00 | 0.03 | 0.03 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T5 | 0.09 | 0.09 | 0.00 | 0.00 | 0.06 | 0.03 | 0.09 | 0.00 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| T6 | 0.09 | 0.11 | 0.00 | 0.03 | 0.09 | 0.09 | 0.11 | 0.06 | 0.06 | 0.06 | 0.06 | 0.09 | 0.06 | 0.06 |
| T7 | 0.06 | 0.06 | 0.00 | 0.00 | 0.06 | 0.09 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |
| T8 | 0.11 | 0.09 | 0.00 | 0.00 | 0.09 | 0.06 | 0.11 | 0.03 | 0.00 | 0.00 | 0.03 | 0.06 | 0.09 | 0.03 |
| T9 | 0.11 | 0.11 | 0.06 | 0.09 | 0.11 | 0.11 | 0.11 | 0.11 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| T10 | 0.00 | 0.00 | 0.11 | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 |
| T11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T12 | 0.00 | 0.00 | 0.09 | 0.00 | 0.03 | 0.03 | 0.09 | 0.11 | 0.03 | 0.03 | 0.00 | 0.06 | 0.00 | 0.00 |
| T13 | 0.03 | 0.06 | 0.11 | 0.00 | 0.03 | 0.00 | 0.00 | 0.03 | 0.11 | 0.11 | 0.00 | 0.09 | 0.00 | 0.03 |
| T14 | 0.09 | 0.09 | 0.03 | 0.03 | 0.06 | 0.03 | 0.11 | 0.09 | 0.03 | 0.03 | 0.00 | 0.03 | 0.00 | 0.00 |

Where: quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T11—warranty, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Step 6.3. Determining Structure of Total Impact of PV criteria

Then, the structure of the total impact of PV criteria was created. According to Formula (3), the simultaneous direct and indirect impact of these criteria was included. The results are shown in Table 3.

**Table 3.** Matrix of the total impact of PV criteria. Own study.

| Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.18 | 0.18 | 0.01 | 0.04 | 0.10 | 0.07 | 0.13 | 0.02 | 0.01 | 0.01 | 0.00 | 0.05 | 0.04 | 0.04 |
| T2 | 0.13 | 0.10 | 0.00 | 0.01 | 0.06 | 0.05 | 0.13 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| T3 | 0.13 | 0.13 | 0.00 | 0.01 | 0.06 | 0.05 | 0.10 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| T4 | 0.10 | 0.13 | 0.00 | 0.01 | 0.06 | 0.05 | 0.13 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| T5 | 0.15 | 0.14 | 0.01 | 0.01 | 0.10 | 0.06 | 0.15 | 0.01 | 0.04 | 0.04 | 0.01 | 0.02 | 0.01 | 0.01 |
| T6 | 0.21 | 0.24 | 0.04 | 0.05 | 0.18 | 0.17 | 0.26 | 0.11 | 0.09 | 0.09 | 0.07 | 0.14 | 0.09 | 0.08 |
| T7 | 0.11 | 0.11 | 0.01 | 0.01 | 0.10 | 0.12 | 0.15 | 0.02 | 0.01 | 0.01 | 0.01 | 0.05 | 0.01 | 0.01 |
| T8 | 0.21 | 0.18 | 0.03 | 0.01 | 0.15 | 0.11 | 0.21 | 0.06 | 0.03 | 0.03 | 0.04 | 0.10 | 0.10 | 0.05 |
| T9 | 0.26 | 0.26 | 0.08 | 0.11 | 0.21 | 0.20 | 0.27 | 0.16 | 0.06 | 0.06 | 0.05 | 0.08 | 0.06 | 0.06 |
| T10 | 0.04 | 0.04 | 0.13 | 0.01 | 0.03 | 0.02 | 0.07 | 0.04 | 0.04 | 0.04 | 0.00 | 0.01 | 0.04 | 0.04 |
| T11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T12 | 0.07 | 0.06 | 0.10 | 0.01 | 0.08 | 0.07 | 0.16 | 0.14 | 0.04 | 0.04 | 0.01 | 0.09 | 0.02 | 0.01 |
| T13 | 0.11 | 0.14 | 0.15 | 0.02 | 0.09 | 0.05 | 0.09 | 0.07 | 0.13 | 0.13 | 0.01 | 0.11 | 0.02 | 0.04 |
| T14 | 0.17 | 0.17 | 0.04 | 0.04 | 0.12 | 0.08 | 0.21 | 0.11 | 0.04 | 0.04 | 0.01 | 0.06 | 0.02 | 0.02 |

Where: quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T11—warranty, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Then, the next step of the model was realized.

Step 6.4. Determining Dependence Between Criteria

Based on the structure of total impact, the dependence between quantitative, aesthetic, and qualitative criteria was determined. It is a cause-and-effect analysis. In the proposed approach, the mutual impact of these criteria was determined by Formula (4). The created matrix of relations is shown in Table 4.

**Table 4.** Matrix of the total impact of PV criteria. Own study.

| Qualitative Criteria | R | Customer′ Criteria | C | R + C | R − C | Result |
|---|---|---|---|---|---|---|
| T1 | 0.89 | Q1 | 1.88 | 2.77 | −0.99 | effect |
| T2 | 0.53 | Q2 | 1.89 | 2.42 | −1.36 | effect |
| T3 | 0.52 | Q3 | 0.62 | 1.14 | −0.09 | effect |
| T4 | 0.52 | Q4 | 0.31 | 0.83 | 0.21 | cause |
| T5 | 0.75 | Q5 | 1.31 | 2.07 | −0.56 | effect |
| T6 | 1.83 | Q6 | 1.12 | 2.95 | 0.70 | cause |
| T7 | 0.74 | Q7 | 2.05 | 2.79 | −1.30 | effect |
| T8 | 1.31 | Q8 | 0.75 | 2.06 | 0.56 | cause |
| T9 | 1.93 | A1 | 0.53 | 2.46 | 1.40 | cause |
| T10 | 0.54 | A2 | 0.53 | 1.07 | 0.01 | cause |
| T11 | 0.00 | A3 | 0.21 | 0.21 | −0.21 | effect |
| T12 | 0.91 | A4 | 0.76 | 1.67 | 0.15 | cause |
| T13 | 1.17 | A5 | 0.44 | 1.61 | 0.73 | cause |
| T14 | 1.14 | A6 | 0.38 | 1.52 | 0.76 | cause |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T11—warranty, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer′ criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer′ criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Qualitative (technical) criteria that have important impact on quality of photovoltaic power were shown to be: rated power (T1), short-circuit current (T2), maximum current (T3), temperature current factor (T5), temperature voltage factor (T7), and warranty (T11).

Step 6.5. Determining Key PV Criteria

In this step, the key photovoltaic panels' criteria were determined, i.e., quantitative criteria based on which quality of PV will be calculated considering customer expectations. According to Formula (5), the mean value was calculated and it was equal to $\alpha = 0.07$. The criteria, whose values from the matrix of total impact matrix were above $\alpha$ were considered key PV criteria. The results are shown in Table 5.

It was shown that criterion T11 (warranty) was not integrated with other customer criteria (i.e., value equal to 0.00). Therefore, this criterion was not considered in the next analysis.

**Table 5.** Key PV criteria. Own study.

| Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.18 | 0.18 | 0.01 | 0.04 | 0.10 | 0.07 | 0.13 | 0.02 | 0.01 | 0.01 | 0.00 | 0.05 | 0.04 | 0.04 |
| T2 | 0.13 | 0.10 | 0.00 | 0.01 | 0.06 | 0.05 | 0.13 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| T3 | 0.13 | 0.13 | 0.00 | 0.01 | 0.06 | 0.05 | 0.10 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| T4 | 0.10 | 0.13 | 0.00 | 0.01 | 0.06 | 0.05 | 0.13 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| T5 | 0.15 | 0.14 | 0.01 | 0.01 | 0.10 | 0.06 | 0.15 | 0.01 | 0.04 | 0.04 | 0.01 | 0.02 | 0.01 | 0.01 |
| T6 | 0.21 | 0.24 | 0.04 | 0.05 | 0.18 | 0.17 | 0.26 | 0.11 | 0.09 | 0.09 | 0.07 | 0.14 | 0.09 | 0.08 |
| T7 | 0.11 | 0.11 | 0.01 | 0.01 | 0.10 | 0.12 | 0.15 | 0.02 | 0.01 | 0.01 | 0.01 | 0.05 | 0.01 | 0.01 |
| T8 | 0.21 | 0.18 | 0.03 | 0.01 | 0.15 | 0.11 | 0.21 | 0.06 | 0.03 | 0.03 | 0.04 | 0.10 | 0.10 | 0.05 |
| T9 | 0.26 | 0.26 | 0.08 | 0.11 | 0.21 | 0.20 | 0.27 | 0.16 | 0.06 | 0.06 | 0.05 | 0.08 | 0.06 | 0.06 |
| T10 | 0.04 | 0.04 | 0.13 | 0.01 | 0.03 | 0.02 | 0.07 | 0.04 | 0.04 | 0.04 | 0.00 | 0.01 | 0.04 | 0.04 |
| T11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T12 | 0.07 | 0.06 | 0.10 | 0.01 | 0.08 | 0.07 | 0.16 | 0.14 | 0.04 | 0.04 | 0.01 | 0.09 | 0.02 | 0.01 |
| T13 | 0.11 | 0.14 | 0.15 | 0.02 | 0.09 | 0.05 | 0.09 | 0.07 | 0.13 | 0.13 | 0.01 | 0.11 | 0.02 | 0.04 |
| T14 | 0.17 | 0.17 | 0.04 | 0.04 | 0.12 | 0.08 | 0.21 | 0.11 | 0.04 | 0.04 | 0.01 | 0.06 | 0.02 | 0.02 |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T11—warranty, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

*Stage 7. Calculation of Weights for PV criteria*

The weights of the PV criteria were calculated according to the expectations of the customer expectations (obtained from the questionnaire). In this purpose, the AHP method was used for separately calculated weights separately for qualitative and aesthetic criteria. The evaluations of the weights of qualitative and aesthetic criteria are determined by the customer. According to these assessments, the weights of these criteria are calculated by using the AHP method. In turn, the weights of quantitative criteria are calculated based on the weights of qualitative and aesthetic criteria (which were correlated according to the DEMATEL method). These quantitative criteria correlated with qualitative and aesthetic criteria were named as key criteria of photovoltaics, i.e., necessary to calculate the quality of photovoltaics.

Step 7.1. Comparison of photovoltaic criteria in pairs

Two domination matrices were created based on weight assessment for qualitative and aesthetic criteria. Formulas (6) and (7) were used for that. These matrices are shown in Tables 6 and 7.

**Table 6.** Domination matrix of qualitative criteria of PV. Own study.

| Qualitative Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|
| Q1 | 1.00 | 0.50 | 4.00 | 2.00 | 2.00 | 1.00 | 1.00 | 4.00 |
| Q2 | 2.00 | 1.00 | 4.00 | 3.00 | 2.00 | 2.00 | 1.00 | 5.00 |
| Q3 | 0.25 | 0.25 | 1.00 | 0.50 | 0.25 | 0.33 | 0.25 | 0.50 |
| Q4 | 0.50 | 0.33 | 2.00 | 1.00 | 0.50 | 1.00 | 0.33 | 2.00 |
| Q5 | 0.50 | 0.50 | 4.00 | 2.00 | 1.00 | 3.00 | 1.00 | 4.00 |
| Q6 | 1.00 | 0.50 | 3.00 | 1.00 | 0.33 | 1.00 | 0.25 | 3.00 |
| Q7 | 1.00 | 1.00 | 4.00 | 3.00 | 1.00 | 4.00 | 1.00 | 5.00 |
| Q8 | 0.25 | 0.20 | 2.00 | 0.50 | 0.25 | 0.33 | 0.20 | 1.00 |

Where qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings.

**Table 7.** Domination matrix of aesthetic criteria of PV. Own study.

| Aesthetic Criteria | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|
| A1 | 1.00 | 1.00 | 1.00 | 3.00 | 4.00 | 4.00 |
| A2 | 1.00 | 1.00 | 1.00 | 3.00 | 4.00 | 4.00 |
| A3 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 4.00 |
| A4 | 0.33 | 0.33 | 0.50 | 1.00 | 2.00 | 2.00 |
| A5 | 0.25 | 0.25 | 0.33 | 0.50 | 1.00 | 1.00 |
| A6 | 0.25 | 0.25 | 0.25 | 0.50 | 1.00 | 1.00 |

Where aesthetic criteria (customer′ criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Then, the importance of these criteria was calculated according to step 7.2 of model.

Step 7.2. Assessments of Importance of PV criteria

According to the geometric average order of the dominance geometric matrix and their normalization, the validity of the PV criteria was determined. Formula (8) was used for that. Assessments were carried out for qualitative and aesthetic criteria. The results are shown in Tables 8 and 9.

**Table 8.** Weights of qualitative criteria of PV. Own study.

| Qualitative Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Weight ($W_i$) |
|---|---|---|---|---|---|---|---|---|---|
| Q1 | 0.15 | 0.12 | 0.17 | 0.15 | 0.27 | 0.08 | 0.20 | 0.16 | 0.16 |
| Q2 | 0.31 | 0.23 | 0.17 | 0.23 | 0.27 | 0.16 | 0.20 | 0.20 | 0.22 |
| Q3 | 0.04 | 0.06 | 0.04 | 0.04 | 0.03 | 0.03 | 0.05 | 0.02 | 0.04 |
| Q4 | 0.08 | 0.08 | 0.08 | 0.08 | 0.07 | 0.08 | 0.07 | 0.08 | 0.08 |
| Q5 | 0.08 | 0.12 | 0.17 | 0.15 | 0.14 | 0.24 | 0.20 | 0.16 | 0.16 |
| Q6 | 0.15 | 0.12 | 0.13 | 0.08 | 0.05 | 0.08 | 0.05 | 0.12 | 0.10 |
| Q7 | 0.15 | 0.23 | 0.17 | 0.23 | 0.14 | 0.32 | 0.20 | 0.20 | 0.20 |
| Q8 | 0.04 | 0.05 | 0.08 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 |

Where qualitative criteria (customer′ criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings.

**Table 9.** Weights of aesthetic criteria of PV. Own study.

| Aesthetic Criteria | A1 | A2 | A3 | A4 | A5 | A6 | Weight ($W_i$) |
|---|---|---|---|---|---|---|---|
| A1 | 1.00 | 1.00 | 1.00 | 3.00 | 4.00 | 4.00 | 0.26 |
| A2 | 1.00 | 1.00 | 1.00 | 3.00 | 4.00 | 4.00 | 0.26 |
| A3 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 4.00 | 0.24 |
| A4 | 0.33 | 0.33 | 0.50 | 1.00 | 2.00 | 2.00 | 0.11 |
| A5 | 0.25 | 0.25 | 0.33 | 0.50 | 1.00 | 1.00 | 0.07 |
| A6 | 0.25 | 0.25 | 0.25 | 0.50 | 1.00 | 1.00 | 0.06 |

Where aesthetic criteria (customer′ criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

The sum of weights was equal to 1. This means that the calculations were correct.

Step 7.3. Testing of the consistency of preferences matrix

The consistency matrix of preferences was created as part of the determination of the correctness of the ratings granted by the customers. According to Formulas (9)–(11), using these matrices were created these matrixes for qualitative and aesthetic criteria, as shown in Tables 10 and 11.

**Table 10.** Weights for qualitative criteria of PV. Own study.

| Qualitative Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | $\sum_{j=1}^{k} w_{ij}$ | Weight (Wi) | $\sum_{j=1}^{k} w_{ij} w_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Q1 | 0.16 | 0.11 | 0.15 | 0.15 | 0.31 | 0.10 | 0.20 | 0.17 | 1.37 | 0.16 | 8.38 |
| Q2 | 0.33 | 0.22 | 0.15 | 0.23 | 0.31 | 0.19 | 0.20 | 0.22 | 1.86 | 0.22 | 8.38 |
| Q3 | 0.04 | 0.06 | 0.04 | 0.04 | 0.04 | 0.03 | 0.05 | 0.02 | 0.32 | 0.04 | 8.24 |
| Q4 | 0.08 | 0.07 | 0.08 | 0.08 | 0.08 | 0.10 | 0.07 | 0.09 | 0.64 | 0.08 | 8.37 |
| Q5 | 0.08 | 0.11 | 0.15 | 0.15 | 0.16 | 0.29 | 0.20 | 0.17 | 1.32 | 0.16 | 8.47 |
| Q6 | 0.16 | 0.11 | 0.12 | 0.08 | 0.05 | 0.10 | 0.05 | 0.13 | 0.80 | 0.10 | 8.27 |
| Q7 | 0.16 | 0.22 | 0.15 | 0.23 | 0.16 | 0.38 | 0.20 | 0.22 | 1.73 | 0.20 | 8.44 |
| Q8 | 0.04 | 0.04 | 0.08 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 | 0.36 | 0.04 | 8.18 |
| $\lambda_{max} = 8.34, \quad CI = 0.05, \quad CR = 0.03, \quad where: \ r = 1.45$ | | | | | | | | | | | |

Where qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings.

**Table 11.** Weights for aesthetic criteria of PV. Own study.

| Aesthetic Criteria | A1 | A2 | A3 | A4 | A5 | A6 | $\sum_{j=1}^{k} w_{ij}$ | Weight ($W_i$) | $\sum_{j=1}^{k} w_{ij} w_i$ |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.26 | 0.26 | 0.24 | 0.33 | 0.26 | 0.25 | 1.60 | 0.26 | 6.06 |
| A2 | 0.26 | 0.26 | 0.24 | 0.33 | 0.26 | 0.25 | 1.60 | 0.26 | 6.06 |
| A3 | 0.26 | 0.26 | 0.24 | 0.22 | 0.20 | 0.25 | 1.42 | 0.24 | 6.04 |
| A4 | 0.09 | 0.09 | 0.12 | 0.11 | 0.13 | 0.12 | 0.66 | 0.11 | 6.02 |
| A5 | 0.07 | 0.07 | 0.08 | 0.05 | 0.07 | 0.06 | 0.39 | 0.07 | 6.01 |
| A6 | 0.07 | 0.07 | 0.06 | 0.05 | 0.07 | 0.06 | 0.37 | 0.06 | 6.03 |
| $\lambda_{max} = 6.04, \quad CI = 0.01, \quad CR = 0.01, \quad \text{where}: \ r = 1.24$ | | | | | | | | | |

Where aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Analysis of the consistency of preferences showed that the weights were calculated in the right way.

Step 7.4. Creating a ranking of preferences

At this step of the model, the ranking of preferences was created. This ranking presents the importance of qualitative and aesthetic criteria. This ranking was created based on the weights from step 7.2. of the model. The result is shown in Table 12.

**Table 12.** Ranking of qualitative and aesthetic criteria. Own study.

| Qualitative Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|
| Weight | 0.16 | 0.22 | 0.04 | 0.08 | 0.16 | 0.10 | 0.20 | 0.04 |
| Ranking | 3 | 1 | 6 | 5 | 3 | 4 | 2 | 6 |
| **Aesthetic Criteria** | **A1** | **A2** | **A3** | **A4** | **A5** | **A6** | | |
| Weight | 0.26 | 0.26 | 0.24 | 0.11 | 0.07 | 0.06 | | |
| Ranking | 1 | 1 | 2 | 3 | 4 | 5 | | |

Where qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

The most important qualitative criterion was the high efficiency (Q2 = 0.22), and the least important was the ability to change the settings (Q8 = 0.04). Whereas, the most important aesthetic criteria were visibility and the degree of integration (i.e., A1 and A2 equal to 0.26). The least important was the fractality (A6 = 0.06). These weights were included in stage eight of the model.

*Stage 8. Calculating Weights for Key PV criteria*

At this stage weights were calculated for key criteria of PV. It was based on the important relations between quantitative criteria and customer criteria (qualitative and aesthetic), which were determined on stage 6, i.e., in step 6.5. of the model.

The matrix with these relations was supplemented with the weights of qualitative and aesthetic criteria (from step 7.2). According to Formula (12) the weights for key PV criteria of PV were estimated. The result is shown in Table 13.

**Table 13.** Weights for key criteria of PV. Own study.

| Criteria | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | A1 | A2 | A3 | A4 | A5 | A6 | $\overline{w}_i^k$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.16 | 0.22 | | | 0.16 | | 0.20 | | | | | | | | 0.15 |
| T2 | 0.16 | 0.22 | | | | | 0.20 | | | | | | | | 0.12 |
| T3 | 0.16 | 0.22 | | | | | 0.20 | | | | | | | | 0.12 |
| T4 | 0.16 | 0.22 | | | | | 0.20 | | | | | | | | 0.12 |
| T5 | 0.16 | 0.22 | | | 0.16 | | 0.20 | | | | | | | | 0.13 |
| T6 | 0.16 | 0.22 | | | 0.16 | 0.10 | 0.20 | 0.11 | 0.26 | 0.26 | 0.24 | 0.11 | 0.07 | 0.06 | 0.14 |
| T7 | 0.16 | 0.22 | | | 0.16 | 0.10 | 0.20 | | | | | | | | 0.12 |
| T8 | 0.16 | 0.22 | | | 0.16 | 0.10 | 0.20 | | | | | 0.11 | 0.07 | | 0.15 |
| T9 | 0.16 | 0.22 | 0.04 | 0.08 | 0.16 | 0.10 | 0.20 | 0.11 | | | | 0.11 | | | 0.18 |
| T10 | | | 0.04 | | | | | | | | | | | | 0.13 |
| T12 | | | 0.04 | | 0.16 | 0.10 | 0.20 | 0.11 | | | | 0.11 | | | 0.11 |
| T13 | 0.16 | 0.22 | 0.04 | | 0.16 | | 0.20 | | 0.26 | 0.26 | | 0.11 | | | 0.12 |
| T14 | 0.16 | 0.22 | | | 0.16 | 0.10 | 0.20 | 0.11 | | | | | | | 0.14 |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

The weights for key criteria were included in the 10 stages of the model. Subsequently, the fulfilment of customer expectations was preliminarily assessed, as illustrated in stage 9 of the model.

*Stage 9. Initial assessment of meet customer expectations by PV*

At this stage, the expert (entity broker) assessed the meet of customer expectations by photovoltaic panels. The assessment was carried out using quantitative criteria. This process was performed in two steps.

Step 9.1. Characteristic of Photovoltaic Panels

The entity applied model has characterized all photovoltaic panels (from stage 2) according to all key PV criteria of PV (from stage 6). The photovoltaic panels were described according to the catalogue (specification) of these products. The result is shown in Table 14.

After PV was characterized, the assessments of its properties were done, as is shown in the next step of the model.

**Table 14.** Characteristic of selected photovoltaic panels according to key criteria. Own study.

| Criteria | PV1 | PV2 | PV3 | PV4 | PV5 | PV6 | PV7 | PV8 | PV9 | PV10 | PV11 | PV12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 5 | 10 | 20 | 30 | 100 | 130 | 170 | 180 | 80 | 365 | 325 | 470 |
| T2 | 0.32 | 0.58 | 1.19 | 1.8 | 5.85 | 8.67 | 9.31 | 9.67 | 4.79 | 9.44 | 9.99 | 11.53 |
| T3 | 0.28 | 0.54 | 1.08 | 1.63 | 5.47 | 7.17 | 8.93 | 9.36 | 4.67 | 10.75 | 9.57 | 11.01 |
| T4 | 17.9 | 18 | 18.82 | 18 | 18.29 | 18.13 | 19.04 | 19.2 | 17.14 | 11.3 | 40.99 | 50.31 |
| T5 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 |
| T6 | 17.22 | 18.21 | 19.43 | 19.21 | 20.31 | 20.04 | 20.59 | 20.3 | 18.39 | 19.5 | 19.43 | 21.2 |
| T7 | −0.27 | −0.27 | −0.27 | −0.27 | −0.27 | −0.27 | −0.27 | −0.27 | −0.47 | −0.27 | −0.27 | −0.27 |
| T8 | −0.35 | −0.35 | −0.35 | −0.35 | −0.35 | −0.35 | −0.35 | −0.35 | −0.35 | −0.35 | −0.36 | −0.35 |
| T9 | high | high | high | high | high | high | high | high | high | high | high | high |
| T10 | 0.7 | 1.2 | 2 | 3 | 8 | 10.4 | 10.6 | 10.6 | 6.8 | 20.7 | 9 | 10 |
| T12 | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| T13 | 250 × 190 × 25 | 430 × 190 × 25 | 430 × 345 × 25 | 545 × 345 × 25 | 910 × 670 × 35 | 1130 × 670 × 35 | 1480 × 670 × 35 | 1480 × 670 × 35 | 770 × 668 × 30 | 250 × 190 × 25 | 1665 × 1005 × 40 | 2112 × 1053 × 36 |
| T14 | high | high | high | high | high | high | high | high | high | high | high | high |
| A1 | visible | visible | visible | partially visible | visible | visible | visible | visible | visible | partially visible | visible | partially visible |
| A2 | integrated | integrated | integrated | integrated | integrated | integrated | integrated | integrated | integrated | integrated | integrated | integrated |
| A3 | black | black | black | black | white | white | white | white | white | black | black | silver |
| A4 | medium | medium | medium | medium | small | small | small | small | small | medium | medium | medium |
| A5 | porous | porous | porous | plain | porous | plain | plain | porous | plain | porous | porous | porous |
| A6 | small | small | small | small | small | medium | small | medium | small | small | small | small |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

Step 9.2. Determining the level to meet customer expectations

Experts evaluated photovoltaic panels according to customer expectations. According to the assumptions of the model, these assessments were performed on the Likert scale. The expert based on the customer expectations determined by questionnaires. The result is shown in Table 15.

**Table 15.** Initial evaluation of the quality of PV criteria. Own study.

| P | PV1 | PV2 | PV3 | PV4 | PV5 | PV6 | PV7 | PV8 | PV9 | PV10 | PV11 | PV12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 80 | 5 | 4 | 5 |
| T2 | 1 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 3 | 5 | 5 | 5 |
| T3 | 1 | 1 | 2 | 2 | 3 | 4 | 4 | 4 | 3 | 5 | 5 | 5 |
| T4 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 2 | 1 | 5 | 5 |
| T5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 |
| T6 | 2 | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 3 | 4 | 4 | 5 |
| T7 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| T8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| T9 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| T10 | 4 | 4 | 5 | 5 | 5 | 3 | 3 | 3 | 5 | 2 | 4 | 4 |
| T12 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| T13 | 5 | 5 | 4 | 4 | 2 | 2 | 2 | 2 | 3 | 4 | 3 | 1 |
| T14 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| A1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 3 |
| A2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| A3 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 5 | 5 | 2 |
| A4 | 3 | 3 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 3 |
| A5 | 1 | 1 | 1 | 5 | 1 | 5 | 5 | 1 | 5 | 1 | 1 | 1 |
| A6 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 3 | 5 | 5 | 5 | 5 |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

The initial assessments were used to calculate the quality of the photovoltaic panels, as is shown in the next stage of the model.

*Stage 10. Estimation of the quality of photovoltaic panels*

At the tenth stage, the quality of photovoltaic panels was estimated. It refers to the calculation of the level of customer satisfaction with photovoltaic panels. The WPM method was used for that. Therefore, Formulas (13) and (14) were used (Table 16).

After using the WPM method, it was concluded that the most satisfying is panel PV4, which quality was estimated at 0.82. A relatively similar quality level was estimated for PV10 (that is, 0.81). Therefore, the relative state scale was used to predict the satisfaction from the quality of the photovoltaic.

**Table 16.** PV quality according to the WPM method. Own study.

| Criteria | Weight ($w_i^{kn}$) | PV1 | PV2 | PV3 | PV4 | PV5 | PV6 | PV7 | PV8 | PV9 | PV10 | PV11 | PV12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.05 | 0.92 | 0.92 | 0.95 | 0.95 | 0.97 | 0.97 | 0.97 | 0.97 | 1.00 | 1.00 | 0.99 | 1.00 |
| T2 | 0.04 | 0.93 | 0.93 | 0.96 | 0.96 | 0.98 | 0.99 | 1.00 | 1.00 | 0.98 | 1.00 | 1.00 | 1.00 |
| T3 | 0.04 | 0.93 | 0.93 | 0.96 | 0.96 | 0.98 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 | 1.00 | 1.00 |
| T4 | 0.04 | 0.96 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 | 0.99 | 0.96 | 0.93 | 1.00 | 1.00 |
| T5 | 0.05 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 |
| T6 | 0.05 | 0.95 | 0.97 | 0.99 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 0.99 | 0.99 | 1.00 |
| T7 | 0.04 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| T8 | 0.05 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| T9 | 0.07 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| T10 | 0.05 | 0.99 | 0.99 | 1.00 | 1.00 | 1.00 | 0.98 | 0.98 | 0.98 | 1.00 | 0.96 | 0.99 | 0.99 |
| T12 | 0.04 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| T13 | 0.04 | 1.00 | 1.00 | 0.99 | 0.99 | 0.96 | 0.96 | 0.96 | 0.96 | 0.98 | 0.99 | 0.98 | 0.93 |
| T14 | 0.05 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| A1 | 0.10 | 0.90 | 0.90 | 0.90 | 1.00 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 1.00 | 0.90 | 1.00 |
| A2 | 0.10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| A3 | 0.09 | 1.00 | 1.00 | 1.00 | 1.00 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 1.00 | 1.00 | 0.92 |
| A4 | 0.04 | 0.98 | 0.98 | 0.98 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.98 | 0.98 |
| A5 | 0.03 | 0.96 | 0.96 | 0.96 | 1.00 | 0.96 | 1.00 | 1.00 | 0.96 | 1.00 | 0.96 | 0.96 | 0.96 |
| A6 | 0.02 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 1.00 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |
| $P^*_{WPM}$ | | 0.61 | 0.63 | 0.71 | 0.82 | 0.66 | 0.68 | 0.70 | 0.66 | 0.68 | 0.81 | 0.79 | 0.79 |
| Ranking | | 9 | 8 | 5 | 1 | 7 | 6 | 4 | 7 | 6 | 2 | 3 | 3 |

Where quantitative criteria (technical, measurable): T1—rated power, T2—short-circuit current, T3—maximum current, T4—no-load voltage, T5—temperature current factor, T6—efficiency (efficiency), T7—temperature voltage factor, T8—temperature power factor, T9—panel efficiency, T10—weight, T12—kinematics, T13—dimensions, T14—efficiency of a single cells; qualitative criteria (customer' criteria, immeasurable): Q1—high power, Q2—high performance, Q3—light weight, Q4—high corrosion resistance, Q5—minimal energy losses, Q6—high temperature resistance, Q7—high efficiency, Q8—ability to change the settings; aesthetic criteria (customer' criteria, immeasurable): A1—visibility, A2—degree of integration, A3—colour, A4—light reflection, A5—pattern (texture), A6—fractality.

*Stage 11. Prediction of customer satisfaction with the quality of PV*

To predict customer satisfaction from the quality of PV, the universal relative state scale was used. By this scale, the quality of photovoltaic was analyzed which was estimated by the WPM method (Figure 11).

It was predicted that the favourable option is to choose panels marked PV4 or PV10. The differences between PV were relatively small. Therefore, the final choice of photovoltaic was influenced by the cost of purchase. Therefore, the panel marked PV4 was the choice. However, in this approach, the final decision can be different and depend on the individual preference of the customer.

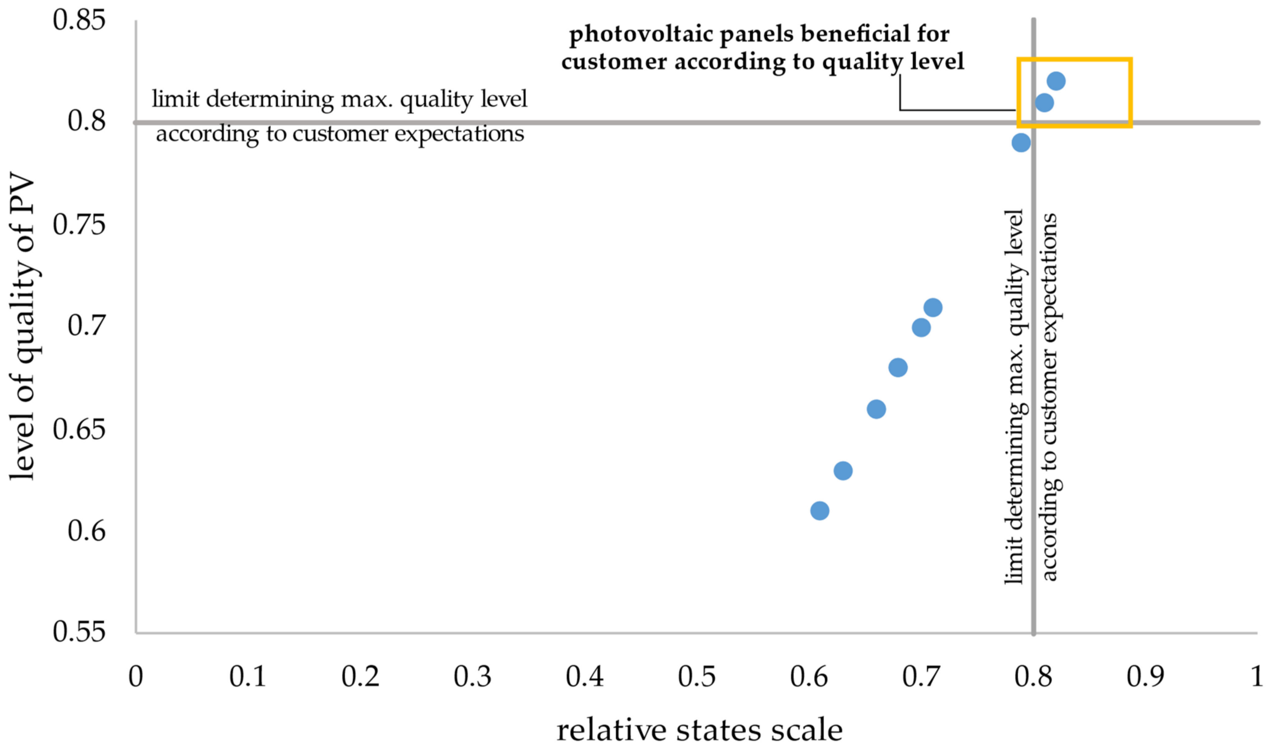


**Figure 11.** The choice of photovoltaic panels is favourable for customer according to the relative state scale. Own study.

## 4. Discussion

Protection of the natural environment and meeting customer expectations are key actions in prospective organizations [1–4,68]. In the last decade, this has been done mainly done through the use of renewable energy (RES). Photovoltaic panels deserve special attention, as they help reduce negative climate changes and improve electricity production [4,7,8]. Despite the growing demand for photovoltaic panels, its effective choice is still problematic [24,25,27]. Mostly, it refers to the need to predict the quality of these panels considering customer expectations and taking into account sustainable development, that is, qualitative, quantitative and aesthetic criteria [16,53–57]. Additionally, the problem is to unify this approach, which will be universal for any customer and interested parties, e.g., expert, bidder, and entities. Therefore, the aim of the considerations was proposed model to prediction of the quality of photovoltaic panels in the context of qualitative–ecological, i.e., by considering achieving the expected quality of photovoltaic panels with simultaneous adherence to the principles of sustainable development and taking care of landscape and customer well-being. The model was verified for photovoltaic panels from a key producer from the EU countries. As a result, it was shown that it is possible to predict the quality of PV considering customer expectations to PV criteria, i.e., qualitative (immeasurable, subjective), aesthetic (landscape) and quantitative (measurable, technical). In addition, it was shown that it is possible to determine qualitative–ecological interactions as part of the sustainable choice of photovoltaic panels. Furthermore, it was shown that it is possible to determine qualitative–ecological interactions as part of the sustainable choice of photovoltaic panels. It includes the awareness of the utility of photovoltaics, the impact of these panels on the environment (landscape), and the well-being of the customers.

The main benefits of the proposed model are as follows:

- determining qualitative–ecological interactions based on customer expectations using photovoltaic panels criteria (qualitative, quantitative, and aesthetic);

- standardized analysis of photovoltaic panels criteria, which are included in sustainable development criteria, i.e., qualitative criteria (subjective, immeasurable), aesthetic criteria (landscape) and quantitively criteria (technical, measurable);
- prediction of customer satisfaction according to individual estimated quality of PV;
- including in prediction of the quality of PV the assessment of quality and importance (weights) of photovoltaic criteria;
- personalized the choice of PV criteria and determined its importance (weight) according to the rule of comparison in pairs.
- Additionally, the proposed model has business implications, i.e.,
- the low-cost model supporting entity in the prediction which of photovoltaic panels will be favourable for the customer;
- supporting the customer to determine preferences about the photovoltaic panel;
- possibility to verify any kind and number of photovoltaic panels;
- possibility in verification of any criteria of photovoltaic panels;
- ensuring customer satisfaction with the use of photovoltaic panels;
- improving the process to obtain customer expectations (requirements) of customers.

The limitation was considered to be that the proposed model will not point to the best photovoltaic for all potential customers. It resulted from the destination of this model to the choice of PV according to the individual expectations of the customer. Moreover, this model includes only current customer expectations and does not include possibilities for changes of these expectations over time. The obtained dependencies of PV selection cannot be generalized, because they depend on the assessments of experts and the client for whom the model is used.

Future research refers to extensions of this model with possibilities of its application to a larger group of customers. It is also considered to develop the indicated computer software in the form of an algorithm of mutual correlation of the verified criteria, and then PV quality prediction.

## 5. Conclusions

Developing renewable energy sources (RES) requires an adjustment of these RES to customer expectations. It refers to the quality of the need prediction of RES, which resulted from qualitative–ecological relations. The key tools are photovoltaic panels; therefore, its improvement is adequate as part of sustainable development. Therefore, the aim of the considerations was proposed model to prediction of the quality of photovoltaic panels in the context of qualitative–ecological, i.e., by considering achieving the expected quality of photovoltaic panels with simultaneously adherence to the principles of sustainable development and taking care of landscape and customer well-being. In the model instruments, i.e.: SMART(-ER) method, brainstorming (BM), DEMATEL method, AHP method and WPM method. The model was verified for photovoltaic panels from a key producer from UE countries. Initially, according to the SMART(-ER) method, the purpose of analysis was determined, i.e., the predicted of quality of photovoltaic panels for the household. It was assumed that prediction includes sustainable criteria, i.e., qualitative (immeasurable, determined by customers), quantity (measurable, technical-based criteria of the utility of products), aesthetic (landscape).

Then, twelve photovoltaic panels were selected for verification. Then, customer expectations about photovoltaic energy were obtained according to the questionnaire with a method of comparison in pairs. Among the qualitative criteria customer pointed that important for him were for him: high power, high performance, light weight, high corrosion resistance, minimal energy loss, and high temperature resistance. Moreover, the customer pointed out his own criteria, i.e.: high efficiency and ability to change the settings. In turn, the aesthetic criteria expected by the customer were photovoltaic panels: practically invisible, partially integrated, fully integrated with the landscape (surroundings), smooth, with low light reflection, and low fractality. After brainstorming, the entity determined 14 basis quantity criteria for the selected photovoltaic panels. These criteria were determined according to the public catalogues (specification) of these products. Whereas, after brainstorming (BM) also determined quantitative criteria, i.e.: rated power, short-circuit current, maximum current, no-load voltage, temperature, current factor, efficiency (efficiency), temperature voltage factor, temperature power factor, panel efficiency, weight, warranty, kinematics, dimensions, efficiency of a single cells. The mutual relations between all criteria were determined. These relations allowed to process the customer criteria (qualitative and aesthetic) into technical criteria (quantitative). Additionally, the importance of criteria was determined on these relations. The weights of the criteria were calculated by using the AHP method. Then, the entity (expert) assessed these criteria according to customer expectations. The assessment was done on a Likert scale. These assessments were integrated with criteria weights of criteria in the WPM method. In this way, the quality of PV was calculated. Then, according to the relative state scale, customer satisfaction with the quality of PV was predicted. Two beneficial photovoltaic panels were predicted. Finally, of these panels, the PV4-labeled panel was selected. This was due not only because of its level of quality, but its cost.

It was concluded that the proposed model can be used by any entity (expert broker) to analyze any photovoltaic panels and any criteria. The model can help the subject predict customer expectations. On this basis, it is possible to predict a satisfactory photovoltaic panel for every customer who does not even know about the quality of photovoltaic.

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