Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Politechniki Morskiej w Szczecinie

2024, 79 (151), 5–13
ISSN 2392-0378 (Online)
DOI: 10.17402/610

Received: *10.06.2024*
Accepted: *25.06.2024*
Published: *30.09.2024*

Model supporting the design and improvement of products in their life cycle considering sustainable development criteria

Dominika Siwiec[1]✉, Andrzej Pacana[2]

[1] https://orcid.org/0000-0002-6663-6621
[2] https://orcid.org/0000-0003-1121-6352

Rzeszow University of Technology
12 Powstańców Warszawy Av., 35-959 Rzeszów, Poland
e-mail: [1]d.siwiec@prz.edu.pl, [2]app@prz.edu.pl
✉ corresponding author

Keywords: quality, LCA, social responsibility, photovoltaic panels, production engineering, mechanical engineering

JEL Classification: Q830, C650, L680

Abstract

A market economy requires continuous improvement of products. The classic case is striving to meet customer expectations, i.e., ensuring product quality. However, in terms of sustainable development, it is also necessary to take actions that contribute to the protection of the natural environment and ensure a positive social impact. It is still a challenge. Therefore, the aim of the article is to develop a model for product improvement by considering the criteria of quality, environment, and social impact. The developed model is an original decision indicator, according to which prototypes of modified products are ranked according to their fulfillment of (i) expected quality, (ii) low environmental impact in the life cycle (LCA), and (iii) social responsibility. Based on the results of the model and the proposed decision indicator, it is possible to determine the direction of improvement of any product by assessing prototypes (product variants) in terms of their sustainable development. The model test is carried out for photovoltaic (PV) panels, popular in recent years, verified according to six prototypes and 15 sustainability criteria regarding their quality, environmental impact, and social responsibility. The test confirmed its effectiveness in the case of photovoltaic panels, but the proposed model can be successfully used to design or improve other products. This is supported by a developed original decision indicator supporting the making of multicriteria quality, environmental, and social decisions at the stage of designing new products or improving existing products.

Introduction

Growing public awareness and negative climate changes mean that companies increasingly consider sustainable development issues (Gawlik, 2016). This is important at the early stage of the product development process (PDP) (Chatty et al., 2022). Then, an elementary activity is to obtain customer requirements regarding the quality of products and then adapt them to changes in these requirements over time (Siwiec & Pacana, 2021a; Gajdzik & Wolniak, 2022). It is increasingly common to recover products from customers for reuse in the supply chain to focus company activities on sustainable production and consumption (Agrawal et al., 2023). This also includes environmental (ecological) aspects, including the effects of environmental loading throughout the life cycle (LCA) of the product (Deja et al., 2023; Ulewicz, Siwiec & Pacana, 2023). Organic production practices are considered the beginning of a contribution to achieving product sustainability goals (Hariadi, Moengin & Maulidya, 2023). In general terms, these practices should focus on reducing the negative environmental impacts of products, including related processes (Casamayor & Su, 2011). This impact is determined by decisions made during product development, which is why it is important to include development perspectives in the methods and tools that support these activities (Relich, 2023). From the perspective of sustainable development, it is also necessary to consider the social aspects of product development, i.e., aspects related to social responsibility (Gawlik, 2018; Siwiec & Pacana, 2024). Social responsibility in terms of corporate management strategies is understood as activities that include, for example, social expectations, relationships between stakeholders (including employees), and environmental aspects (Nagy & Veresné Somosi, 2022).

In addition, a competitive advantage in terms of sustainable development can be achieved through the design and production of radically new products (innovations). These products may contribute to the creation of new markets or be competitive in current markets (Chursin et al., 2023). Risk management in the form of an analysis of the causes and effects of failure with a strategic perspective of sustainable development is also important, preferably at the beginning of product development, to increase the decision-maker's awareness of the existing threats (Schulte & Knuts, 2022). The mentioned social, environmental, and quality aspects should be maintained as an integral part of design requirements at later stages of product development (Siwiec & Pacana, 2021b; Watz & Hallstedt, 2022). However, improving products from a sustainable development perspective is still difficult. There is a lack of coherent methods that support the analysis of current products simultaneously in terms of qualitative (satisfaction with product quality), environmental (negative impact on the natural environment), and social (social responsibility) aspects.

Therefore, the objective of this article is to develop a model for product improvement considering the criteria of quality, environment, and social impact. The developed model is an original decision indicator according to which prototypes of modified products are ranked depending on the fulfillment of the above-mentioned criteria.

The model and the indicator presented within it were developed in six main stages: (1) Selection of the product (its variants) and definition of the research goal, (2) Defining and assessing quality criteria, and defining and assessing environmental criteria, and then defining and assessing social responsibility criteria, (3) Calculation of weight indicators for the group of criteria: quality, environment and society, (4) Calculation of indicators of meeting expectations for the group of criteria: quality, environment, and society, (5) Calculation of aggregated quality, environmental, and social indicators, (6) Ranking of products (their variants) according to aggregated indicator. The structure of the article includes presenting how to implement these stages within the general model and then testing them for photovoltaic panels (PV).

On the basis of the model results, it is possible to determine the direction of improvement of any product by assessing its prototypes (product variants) in terms of their sustainable development.

Model design

A product improvement model was developed according to their prototypes of design solutions. This improvement is carried out by assessing products (their variants and alternatives) according to the key criteria of sustainable product development, i.e., quality – customer satisfaction with use, environment – negative impact of the product on the natural environment, and society – with reference to Corporate Social Responsibility (CSR). Based on the ratings awarded, weight indicators are calculated for the group of quality, environment, and society criteria. Then, the indicator of meeting expectations by individual criteria in these groups is calculated. Based on weight assessments and criteria fulfillment assessments, an aggregated quality, environmental, and social indicator is calculated. According to this, a ranking of products (variants) is developed that determines the direction of product improvement in terms of its sustainable development. The general model is presented in Figure 1. The characteristics of the model stages are presented in a comprehensive manner later in the study.

Stage 1. Selection of the product (its variants) and definition of the research goal. The research product results are based on the needs of the entity (expert) using the proposed model. This product may be in a maturity phase or a stage of declining customer interest (Pacana et al., 2014). In addition, the motivation to improve the product may be the desire to meet customer expectations and adapt to the sales market and competitive environment. It is recommended that the product is generally available and widely known by potential users (customers). This product should be considered in terms of possible variants of production solutions (prototypes and alternatives). Based on these variants, the direction of product development is determined. The number of prototypes

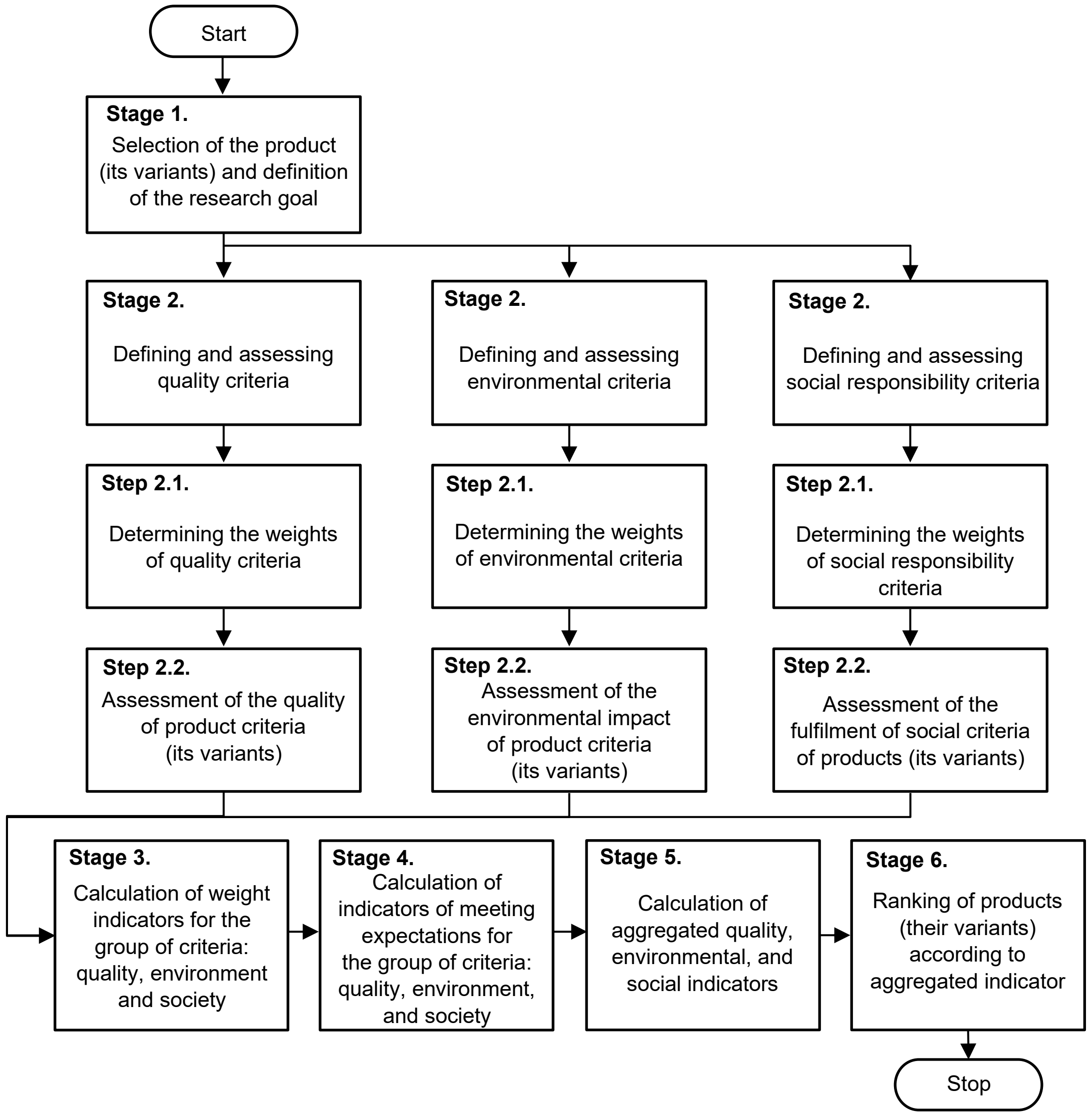

Figure 1. Product improvement model according to key sustainable development criteria

should be in the range of 7 ± 2, as stated by Mu and Pereyra-Rojas (Mu & Pereyra-Rojas, 2017). According to the adopted research subject, the purpose of the analysis is determined. The SMARTER method can be used for this (Edwards & Barron, 1994). In the proposed model, the goal should be to establish a direction for product improvement based on alternatives to design solutions evaluated in three aspects of development: quality level, environmental impact, and social responsibility.

Stage 2. Definition and assessment of qualitative, environmental, and social criteria. The criteria for analysis are selected by a team of experts, who are selected on the basis of the method presented, for example, in Pacana and Siwiec (Pacana & Siwiec, 2021). It is assumed that five criteria should be selected in each of the groups of quality, environmental, and social responsibility criteria, thus meeting the principle of effective decision-making (Mu & Pereyra-Rojas, 2017; Ostasz, Siwiec & Pacana, 2022). Quality criteria are operational (technical) criteria that influence the level of customer satisfaction when using the product (Wang et al., 2015). These criteria are selected from the product catalog (specification). Environmental criteria concern the negative impact of the product on the natural environment, where it is assumed that they should be concerned about the impact of the product in terms of its entire life cycle (LCA) (Proske & Finkbeiner, 2020). The criteria of social responsibility are activities that consider social expectations, activities and relations of stakeholders, and environmental aspects (Proske & Finkbeiner, 2020). Social and environmental criteria are selected according to the classification of criteria from the ISO 26000 standard (PN-ISO 26000:2012).

Production solution alternatives (prototypes) should be characterized according to these three groups of criteria. Qualitative criteria should be described according to the parameter that characterizes them in a given product prototype, e.g., value, range of values, or verbal description. However, environmental impact and social responsibility criteria are qualitative criteria. They apply to all the analyzed products (the so-called reference products of one type) and do not require additional characterization according to their parameters due to their qualitative nature (Ulewicz & Novy, 2019; Diaz et al., 2021).

Step 2.1. Determining the weights of quality, environmental, and social responsibility criteria. The selected criteria for the so-called sustainable development are evaluated in terms of importance. It is assumed that the validity of a criterion is its significance (importance) for customers in the overall context of product use. The weights of the criteria are assigned by the clients and the team of experts (selected in stage 1). A customer is a person who uses the product or who may use it in the future. Customers can be selected according to the method presented in Siwiec and Pacana (Siwiec & Pacana, 2021a). To obtain the weights of the criteria, for example, a survey, questionnaire, or interview can be used (Ponto, 2015). The weights of the criteria are assigned on a popular five-point Likert scale, where 1 is the criterion that is practically unimportant, and 5 is the criterion that is the most important (Sullivan & Artino, 2013). Importance ratings are given to all the product criteria. The quality criteria are assessed by the customer because they include the principles of gaining the customer's voice towards the product to ensure satisfaction with its use (Shen et al., 2022). The environmental and social responsibility criteria are assessed by a team of experts because these assessments require specialist knowledge in this area. Their analysis takes place in the third stage of the model.

Step 2.2. Evaluation of the product criteria (its variants) according to their feasibility. Customers evaluate quality criteria in terms of their quality. However, a team of experts evaluates environmental criteria in terms of their environmental impact and social responsibility criteria in terms of the fulfillment of this responsibility. As in the case of Step 2.1., ratings are given on a five-point Likert scale, where 1 denotes that the criterion practically does not meet expectations, and 5 signifies that the criterion definitely meets expectations (Sullivan & Artino, 2013). Customer expectations can be obtained through a survey, questionnaire, or interview (Ponto, 2015). The analysis of the fulfillment of the criteria takes place in the fourth stage of the model.

Stage 3. Calculation of weight indicators for the group of criteria: quality, environment, and society. The proposed model was developed through the simultaneous analysis of three key groups of criteria. Therefore, it is necessary to determine weight indicators for these criteria, i.e., the weights (importance) of these groups for customers (while considering the opinions of the expert team) in terms of product satisfaction. Based on simplified quality calculation methods, examples of which are given in previous works (Garvin, 1984; Kolman, 1992; Siwiec & Pacana, 2022), indicators have been developed to estimate the weights of a group of quality, environmental, and social responsibility criteria (1) so that:

$$w_A = \frac{\sum_1^5 w_i}{w_{\min(A)}};\ w_B = \frac{\sum_6^{10} w_i}{w_{\min(B)}};\ w_C = \frac{\sum_{11}^{15} w_i}{w_{\min(C)}} \quad (1)$$

where w_A is the weight for a group of quality criteria, w_B is the weight for a group of environmental criteria, w_C is the weight for a group of social criteria, w_i is the weight of the i-th quality criterion, $w_{\min(A)}$ is the minimum weight among quality criteria, w_i is the weight of i-th environmental criterion, $w_{\min(B)}$ is the minimum weight among environmental criteria, w_i is the weight of the i-th social criterion, and $w_{\min(C)}$ is the minimum weight among social criteria.

The indicator values are based on the expectations of customers (including the team of experts) obtained in the second stage of the model.

Stage 4. Calculation of the indicators of meeting expectations for the group of criteria: quality, environment, and society. At this stage, the expectation fulfillment indicators are calculated for the analyzed criteria groups. These indicators were determined on the basis of simplified methods of calculating quality; examples of the latter are given elsewhere (Garvin, 1984; Kolman, 1992; Siwiec & Pacana, 2022). These indicators are calculated according to the following formula:

$$A = \frac{\sum_1^5 j_i}{5};\ B = \frac{\sum_6^{10} e_i}{5};\ C = \frac{\sum_{11}^{15} s_i}{5} \quad (2)$$

where A is an indicator of meeting expectations for quality criteria, B is an indicator of meeting expectations for environmental criteria, C is an indicator of meeting expectations for social criteria, j_i is the quality of the i-th quality criterion, e_i is the quality (meeting expectations) of the *i*-th environmental criterion, s_i is the quality (meeting expectations) of the *i*-th social criterion.

The indicator values are based on the expectations of customers (including the team of experts) obtained in the second stage of the model. Their analysis takes place in the fifth stage of the model.

Stage 5. Calculation of aggregated quality, environmental, and social indicators. To combine the indicator of the importance of the criteria groups and the indicator of the fulfilment of the criteria groups in terms of customer satisfaction, these indicators are aggregated. Products (and their prototypes) are ranked on the basis of quality, environmental, and social indicators. The formula for the aggregate decision index for classification is as follows:

$$Z = \frac{w_A \cdot A + w_B \cdot B + w_C \cdot C}{w_A + w_B + w_C} \tag{3}$$

where A is an indicator of meeting expectations for quality criteria, B is an indicator of meeting expectations for environmental criteria, C is an indicator of meeting expectations for social criteria, w_A is the weight for a group of quality criteria, w_B is the weight for a group of environmental criteria, w_C is the weight for a group of social criteria.

The value of the Z index is determined for all products (and their variants). Its interpretation takes place in the next stage of the model.

Stage 6. Ranking of products (and their variants) according to an aggregated indicator. According to the Z index (i.e., for quality, environmental, and social), a ranking of products and their variants is created. The maximum value of the Z index is the most advantageous product and is the first in the ranking. This means that this product meets the customer's expectations in terms of quality at the highest possible level, while having a low negative impact on the environment and a relatively high level of social responsibility. Therefore, according to the Z index, it is possible to determine the direction of product development, which involves arranging variants of production solutions in terms of quality, environmental, and social aspects. On the basis of the ranking, it is possible to decide on the most favorable alternatives for production solutions that are based on sustainable development criteria. The final decisions about the development of the product rest with the manufacturer, including the expert (entity) using the proposed model.

Results

The developed model was tested on an example of photovoltaic (PV) panels. The choice of this topic of research resulted from its popularity and extensive use throughout the world, mainly in recent years due to the increase in negative factors from climate change. The test was carried out in six main stages of the model.

As part of the first stage, six photovoltaic panels were selected from key manufacturers in the European Union (EU). These panels are conventionally marked PV1–PV6. Photovoltaic panels meet the models' assumptions of the model because they are generally available and widely known by potential customers. Their excessive production is also associated with the deterioration of the natural environment, mainly as a result of the need for photovoltaic recycling, which is still difficult (Bravi et al., 2011; Muteri et al., 2020; Pacana & Siwiec, 2022a). Then, according to the adopted research subject, the goal was defined. In this case, the aim was to set a direction for the improvement of photovoltaic energy based on design solutions assessed in three aspects of the development of these products: quality level, environmental impact, and social responsibility.

In the second stage of the model, a team of experts (including the authors of the article) selected PV criteria in terms of quality, environmental, and social responsibility criteria. It was assumed that there were five criteria in each of these groups. The criteria were selected based on the PV catalog and the ISO 26000 standard. The quality criteria were characterized according to the catalog (specification) according to the PV prototype, as shown in Table 1.

Table 1. PV characterization according to quality criteria parameters

Criterion	PV1	PV2	PV3	PV4	PV5	PV6
Weight [kg]	19	1.9	3.1	6.1	11	15
Dimensions [mm]	1658×1002×35	440×350×25	425×668×25	780×668×30	1485×668×30	1580×808×35
Tension [V]	32.5	18.5	18.3	19.6	19.4	38.4
Power [W]	305	20	40	90	175	215
Color	Black	Graphite	Graphite	Graphite	Black	Black

Table 2. Assessment of the weights and fulfillment of PV criteria from a qualitative, environmental, and social perspective

Criteria	Weights		Assessment of the criterion and group of criteria for PV1–PV6											
			1	2	3	4	5	6	1	2	3	4	5	6
QUALITY														
Weight	2		4	2	2	3	5	5						
Dimensions	4		4	2	3	3	5	4						
Voltage max.	3	9.0	4	3	3	3	3	5	4.4	2.4	2.8	3.2	4.4	4.6
Power	5		5	1	2	3	4	4						
Color	4		5	4	4	4	5	5						
ENVIRONMENT														
Pollution prevention	5		2	5	5	4	3	3						
Sustainable use of resources	4		2	5	4	4	3	3						
Climate change, mitigation, and adaptation	5	7.0	3	4	4	4	4	2	2.6	4.2	4.0	3.8	3.2	2.8
Environmental protection, biodiversity, and restoration of natural habitats	3		3	4	4	4	3	3						
Sustainable consumption	4		3	3	3	3	3	3						
SOCIETY														
Fair competition	3		3	5	4	4	3	3						
Social investments	2		5	3	3	4	5	5						
Promoting social responsibility in the value chain	3	6.5	2	4	4	3	3	3	3.4	3.6	3.2	3.4	3.6	3.8
Community involvement	3		3	3	3	4	4	4						
Development and access to technology	2		4	3	2	2	3	4						

In turn, the environmental criteria analyzed are: pollution prevention; sustainable use of resources; climate change, mitigation, and adaptation; environmental protection, biodiversity, and restoration of natural habitats; sustainable consumption. The criteria for social responsibility are fair competition, social investments, promoting social responsibility in the value chain, community engagement, and technology development and access. Later, according to Steps 2.1. and 2.2., the weights of the quality, environmental, and social responsibility criteria were determined. The fulfillment of these criteria for the analyzed PV panels was also assessed. Weight and feasibility ratings were given on a Likert scale. In the case of qualitative criteria, the customers gave their ratings in the form of a questionnaire. As part of a pilot study, expectations were obtained from seven customers. The environmental and social responsibility criteria were assessed by a team of experts, including the authors of the article.

As part of the third stage, weight indicators were calculated for a group of qualitative, environmental, and social criteria. Formula (1) was used to obtain $w_A = 9.0$ (importance for a group of quality criteria), $w_B = 7.0$ (importance for a group of environmental criteria), and $w_C = 6.5$ (importance for a group of social criteria). It was observed that the qualitative criteria were the most important, i.e., those regarding the product's usefulness, followed by the environmental impact criteria and, to a lesser extent, the social responsibility criteria ($w_A > w_B > w_C$). Then, formula (2) was used to calculate the indicators of meeting expectations for the group of criteria: quality (A), environment (B), and society (C). The summary result is presented in Table 2.

The aggregated qualitative, i.e., the environmental and social indicator (Z), was then calculated. For this purpose, formula (3) was used. The values of the Z index were determined for all the PV panels, and the obtained values were interpreted according to the developed ranking of these products. The result is shown in Table 3.

PV5 and PV6 were observed to have very similar and the highest values of the aggregate quality-environment-social index (3.81; 3.80). Therefore, they seem to be the most advantageous because

Table 3. PV ranking according to their qualitative, environmental, and social feasibility

Photovoltaic panels	Aggregate Z index	Ranking	Decision
PV1	3.55	3	Favorable
PV2	3.31	5	Moderate
PV3	3.29	6	Bad
PV4	3.44	4	Good
PV5	3.80	2	The most advantageous
PV6	3.81	1	

of the level of quality, environmental friendliness, and social responsibility. In this case, it can be said that it would be beneficial to strive to develop photovoltaic panels that are geared toward these two most advantageous production solutions. If the company cannot undertake improvement activities designated by PV5 and PV6, it is reasonable to consider subsequent PV panels from the ranking, e.g., PV1. However, it should be remembered that the results presented are illustrative and test the model. Therefore, depending on the method of analysis adopted, the results may be different. However, the test confirms the performance of the model in determining the direction of product development in terms of key sustainability criteria.

Discussion and conclusions

Taking sustainability into account when designing and improving products remains a challenge (Casamayor & Su, 2011; Pacana & Siwiec, 2022b). Solutions are still being sought to support the multicriteria analysis of products in terms of key aspects, that is, meeting customer expectations in terms of product quality, reducing the negative environmental impact in LCA, and meeting social responsibility (Pacana et al., 2015; Hariadi, Moengin & Maulidya, 2023). Although there are several tools supporting this process, they are not dedicated to simultaneous analysis of these aspects and adapting the design and improvement of products to the optimal solutions accompanying them (Agrawal et al., 2023).

Therefore, the objective of the article was to develop a model for product improvement considering the criteria of quality, environment, and social impact. The model developed an original decision indicator according to which prototypes of modified products depend on the satisfaction of these criteria. The model was tested on examples of photovoltaic (PV) panels, which have been popular in recent years. There were six different photovoltaics, which were analyzed in terms of (i) quality criteria, i.e., weight, dimensions, voltage, power, and color, (ii) environmental criteria, i.e., pollution prevention, sustainable use of resources, climate change mitigation and adaptation, environmental protection, biodiversity and restoration of natural habitats, and sustainable consumption, (iii) social responsibility criteria, i.e. fair competition, social investments, promotion of social responsibility in the value chain, community engagement, and technology development and access. The validity of these criteria and their fulfillment for the six analyzed PV panels were evaluated on a five-point Likert scale. These assessments were then processed according to a dedicated mathematical model, which ultimately generated an aggregated quality-environment-social indicator. According to this, PV panels have been resolved in the ranking. According to the assumptions made, in this case, PV5 and PV6 were the most preferred. At the same time, they have the best quality level, are relatively environmentally friendly in their life cycle, and meet the principles of social responsibility at the expected level. On the basis of these conclusions, it can be established that it would be beneficial to strive to develop photovoltaic panels that are geared toward these two most advantageous production solutions. At the same time, it was confirmed that the model allows for setting the direction of product improvement according to the assessment of its prototypes (product variants) in terms of their sustainable development.

One limitation of the model is that the assessment of products against sustainable development criteria depends on the knowledge and experience of the selected team of experts. A different team of experts, adopting different assumptions, may make a different assessment, which contributes to the lack of comparability of the model results. Therefore, as part of future research, it is planned to develop new assumptions of model by implementing other tools and methods supporting assessments in a more objective manner, e.g., sheets containing standardized questions leading to more precise assessments by experts or methods based on life cycle assessment (LCA), including computer software dedicated to these issues.

The model is primarily dedicated to manufacturing companies that produce new products or improve existing ones. These may be companies that are beginning efforts to develop sustainable products, and this model will, in an easy and simplified way, support making development decisions from a qualitative, environmental, and social perspective.

References

1. Agrawal, D., Dwivedi, A., Patil, A. & Paul, S.K. (2023) Impediments of product recovery in circular supply chains: Implications for sustainable development. *Sustainable Development* 31, pp. 1618–1637, doi: 10.1002/sd.2472.
2. Bravi, M., Parisi, M.L., Tiezzi, E. & Basosi, R. (2011) Life cycle assessment of a micromorph photovoltaic system. *Energy* 36, pp. 4297–4306, doi: 10.1016/j.energy.2011.04.012.
3. Casamayor, J.L. & Su, D.Z. (2011) Environmental impact assessment of lighting products. *Key Engineering Materials* 486, pp. 171–174, doi: 10.4028/www.scientific.net/KEM.486.171.

4. Chatty, T., Harrison, W., Ba-Sabaa, H.H., Faludi, J. & Murnane, E.L. (2022) Co-creating a framework to integrate sustainable design into product development practice: Case study at an engineering consultancy firm. *Sustainability* 14, 9740, doi: 10.3390/su14159740.
5. Chursin, A., Chupina, Z., Ostrovskaya, A. & Boginsky, A. (2023) The creation of fundamentally new products as a factor of organizations' sustainable economic development. *Sustainability* 15, 9747, doi: 10.3390/su15129747.
6. Deja, A., Ślączka, W., Dzhuguryan, L., Dzhuguryan, T. & Ulewicz, R. (2023) Green technologies in smart city multifloor manufacturing clusters: A framework for additive manufacturing management. *Production Engineering Archives* 29(4), pp. 428–443, doi: 10.30657/pea.2023.29.48.
7. Diaz, A., Schöggl, J.-P., Reyes, T. & Baumgartner, R.J. (2021) Sustainable product development in a circular economy: Implications for products, actors, decision-making support and lifecycle information management. *Sustainable Production and Consumption* 26, pp. 1031–1045, doi: 10.1016/j.spc.2020.12.044.
8. Edwards, W. & Barron, F.H. (1994) SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organizational Behavior and Human Decision Processes* 60 (3), pp. 306–325, doi: 10.1006/obhd.1994.1087.
9. Gajdzik, B. & Wolniak, R. (2022) Smart production workers in terms of creativity and innovation: The implication for open innovation. *Journal of Open Innovation: Technology, Market, and Complexity* 8, 68, doi: 10.3390/joitmc8020068.
10. Garvin, D.A. (1984) What does "product quality" really mean? *Sloan Management Review* 25, pp. 25–43.
11. Gawlik, R. (2016) Methodological aspects of qualitative-quantitative analysis of decision-making processes. *Management and Production Engineering Review* 7, pp. 3–11, doi: 10.1515/mper-2016-0011.
12. Gawlik, R. (2018) Encompassing the work-life balance into early career decision-making of future employees through the analytic hierarchy process. In: Kantola, J., Barath, T., Nazir, S. (eds) *Advances in Human Factors, Business Management and Leadership. AHFE 2017. Advances in Intelligent Systems and Computing*, vol 594, pp. 137–147. Springer, Cham, doi: 10.1007/978-3-319-60372-8_14.
13. Hariadi, S., Moengin, P. & Maulidya, R. (2023) Impact of green practices through green product and service innovation: sustainable product-service system performance model. *International Journal of Sustainable Engineering* 16, pp. 1–15, doi: 10.1080/19397038.2023.2205873.
14. Kolman, R. (1992) *Quality Engineering*. Warsaw: PWE (in Polish).
15. Mu, E. & Pereyra-Rojas, M. (2017) *Practical Decision Making*. Springer International Publishing, Cham, doi: 10.1007/978-3-319-33861-3.
16. Muteri, V., Cellura, M., Curto, D., Franzitta, V., Longo, S., Mistretta, M. & Parisi, M.L. (2020) Review on life cycle assessment of solar photovoltaic panels. *Energies* 13, 252, doi: 10.3390/en13010252.
17. Nagy, S. & Veresné Somosi, M. (2022) The relationship between social innovation and digital economy and society. *Regional Statistics* 12, pp. 3–29, doi: 10.15196/RS120202.
18. Ostasz, G., Siwiec, D. & Pacana, A. (2022) Universal model to predict expected direction of products quality improvement. *Energies* 15, 1751, doi: 10.3390/en15051751.
19. Pacana, A., Bednarova, L., Pacana, J., Liberko, I., Woźny, A. & Malindzak, D. (2014) Effect of selected factors of the production process of stretch film for its resistance to puncture. *Przemysł Chemiczny* 94 (8), pp. 1334–1336.
20. Pacana, A., Radon-Cholewa, A., Pacana, J. & Woźny, A. (2015) The study of stickiness of packaging film by Shainin method. *Przemysł Chemiczny* 93 (12), pp. 2263–2264.
21. Pacana, A. & Siwiec, D. (2021) Universal model to support the quality improvement of industrial products. *Materials* 14, 7872, doi: 10.3390/ma14247872.
22. Pacana, A. & Siwiec, D. (2022a) Model to predict quality of photovoltaic panels considering customers' expectations. *Energies* 15, 1101, doi: 10.3390/en15031101.
23. Pacana, A. & Siwiec, D. (2022b) Method of determining sequence actions of products improvement. *Materials* 15, 6321, doi: 10.3390/ma15186321.
24. PN-ISO 26000:2012. *Wytyczne dotyczące społecznej odpowiedzialności*. Warszawa: PKN.
25. Ponto, J. (2015) Understanding and evaluating survey research. *Journal of the Advanced Practitioner in Oncology* 6(2), pp. 168–171.
26. Proske, M. & Finkbeiner, M. (2020) Obsolescence in LCA–methodological challenges and solution approaches. *International Journal of Life Cycle Assessment* 25(2), pp. 495–507, doi: 10.1007/s11367-019-01710-x.
27. Relich, M. (2023) A data-driven approach for improving sustainable product development. *Sustainability* 15, 6736, doi: 10.3390/su15086736.
28. Schulte, J. & Knuts, S. (2022) Sustainability impact and effects analysis – A risk management tool for sustainable product development. *Sustainable Production and Consumption* 30, pp. 737–751, doi: 10.1016/j.spc.2022.01.004.
29. Shen, Y., Zhou, J., Pantelous, A.A., Liu, Y. & Zhang, Z. (2022) A voice of the customer real-time strategy: An integrated quality function deployment approach. *Computers & Industrial Engineering* 169, 108233, doi: 10.1016/j.cie.2022.108233.
30. Siwiec, D. & Pacana, A. (2021a) A pro-environmental method of sample size determination to predict the quality level of products considering current customers' expectations. *Sustainability* 13, 5542, doi: 10.3390/su13105542.
31. Siwiec, D. & Pacana, A. (2021b) Model of choice photovoltaic panels considering customers' expectations. *Energies* 14, 5977, doi: 10.3390/en14185977.
32. Siwiec, D. & Pacana, A. (2022) A new model supporting stability quality of materials and industrial products. *Materials* 15, 4440, doi: 10.3390/ma15134440.
33. Siwiec, D. & Pacana, A. (2024) Predicting design solutions with scenarios considering the quality of materials and products based on a life cycle assessment (LCA). *Materials* 17, 951, doi: 10.3390/ma17040951.
34. Sullivan, G.M. & Artino, A.R. (2013) Analyzing and interpreting data from Likert-type scales. *Journal of Graduate Medical Education* 5(4), pp. 541–542, doi: 10.4300/JGME-5-4-18.
35. Ulewicz, R. & Novy, F. (2019) Quality management systems in special processes. *13th International Scientific Conference on Sustainable, Modern and Safe Transport (TRANSCOM)* 40, pp. 113–118, doi: I10.1016/j.trpro.2019.07.019.
36. Ulewicz, R., Siwiec, D. & Pacana, A. (2023) Sustainable vehicle design considering quality level and life cycle environmental assessment (LCA). *Energies* 16, 8122, doi: 10.3390/en16248122.

37. Wang, F., Li, H., Liu, A. & Zhang, X. (2015) Hybrid customer requirements rating method for customer-oriented product design using QFD. *Journal of Systems Engineering and Electronics* 26, pp. 533–543, doi: 10.1109/JSEE.2015.00061.
38. Watz, M. & Hallstedt, S.I. (2022) Towards sustainable product development – Insights from testing and evaluating a profile model for management of sustainability integration into design requirements. *Journal of Cleaner Production* 346, 131000, doi: 10.1016/j.jclepro.2022.131000.

Cite as: Siwiec, D., Pacana, A. (2024) Model supporting the design and improvement of products in their life cycle considering sustainable development criteria. S*cientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Politechniki Morskiej w Szczecinie* 79 (151), 5–13.