sciendo

CzOTO 2023, volume 5, issue 1, pp. 19-27

IMPROVING PRODUCTS CONSIDERING CUSTOMER EXPECTATIONS AND LIFE CYCLE ASSESSMENT (LCA)

doi: 10.2478/czoto-2023-0003
Date of submission of the article to the Editor: 10/11/2023
Date of acceptance of the article by the Editor: 06/12/2023

Andrzej Pacana[1] – *orcid id: 0000-0003-1121-6352*
Dominika Siwiec[2] – *orcid id: 0000-0002-6663-6621*
[1]Rzeszow University of Technology; Faculty of Mechanical Engineering and Aeronautics, Rzeszow, **Poland**
[2]Rzeszow University of Technology; Faculty of Mechanical Engineering and Aeronautics, Rzeszow, **Poland**

Abstract: Dynamically identifying key product changes is a challenge for enterprises. It is even more complicated if companies strive for the sustainable development of their activities. Therefore, the aim of the article was to develop a method to help predict the direction of product improvement, taking into account its quality level and environmental impact during the life cycle (LCA). The method was based on the design phase of LCA and the process of obtaining and processing customer expectations. Techniques supporting the developed method were: a questionnaire, a seven-point Likert scale, a standardised list of criteria for assessing the product life cycle, the WSM method, and a scale of relative states. The product analysis was carried out according to modified criteria states, which were evaluated according to: i) customer satisfaction (quality criteria), ii) environmental impact of LCA (environmental criteria), and iii) importance of quality and environmental criteria for customers. The originality of the method is to support the product improvement process to make it environmentally friendly within LCA and, at the same time, satisfactory to customers in terms of quality. The method will be used mainly by SMEs that want to initially predict the environmental impact of a product, including taking into account customer expectations.
Keywords: LCA, life cycle assessment, quality, customer expectations, mechanical engineering

1. INTRODUCTION

Companies constantly strive to meet customer demands. This applies to improving the quality of products (Czerwińska and Pacana, 2019; Pacana and Siwiec, 2022a; Ulewicz, 2018; Borkowski 2012). However, interest in environmental issues has increased significantly in recent years (Korzynski and Pacana, 2010; Krynke et al., 2022). For this reason, it is crucial to combine the efforts of companies to improve the quality of products while minimising their negative impact. This includes areas of sustainable development, where in the case of the environment it also concerns the need to assess products throughout their life cycle (Proske and Finkbeiner, 2020, Kuzior, 2019).

Life cycle assessment (LCA) is a method of identifying and quantifying potential environmental impacts. According to ISO 14040, it is a set of procedures and data inputs and outputs that include materials, energy, and their impact on the environment (Means and Guggemos, 2015; Varun et al., 2009). However, the traditional approach to LCA does not include the product quality assessment process in its methodology (Siwiec and Pacana, 2022), or, for example, product costs. Therefore, LCA is used mainly to make final decisions. This is not the most beneficial approach for sustainable products that require significant changes during the improvement process (so-called rethinking design) (Lagerstedt et al., 2003). This is due to the lack of access to detailed data, which is available in LCA in subsequent stages and is then more reliable (Calado et al., 2019; El Badaoui and Touzani, 2022; Ulewicz et al. 2023).
Therefore, the aim of the article was to develop a method to help predict the direction of product improvement, taking into account its quality level and environmental impact during the life cycle (LCA). The method was tested for photovoltaic panels. The originality of the method is to support the product improvement process to make it environmentally friendly within LCA and, at the same time, satisfactory to customers in terms of quality.

2. METHOD OF RESEARCH

The idea of the method was to support the product design process. The method supports this process by predicting what product customers expect (satisfaction with the quality level) and what its environmental impact is within the product life cycle (LCA). The method was developed in seven main stages.
Stage 1. Definition of the goal. The entity (expert, decision-maker, company manager, etc.) using the proposed model determines the purpose of the research. For this purpose, it uses the SMART(-ER) method (Lawor and Hornyak, 2012). The goal is assumed to be to predict the direction of product improvement in the design phase of life cycle assessment (LCA). This means that products expected by customers will be anticipated to simultaneously minimize their negative environmental impact at the production stage in the product's life cycle.
Stage 2. Product selection. The choice is made by the entity. It can be any product, for example, one that is being designed or is in the maturity or decline phase (Ostasz et al., 2022; Pacana and Siwiec, 2021). Further analysis will be carried out for this product.
Etap 3. Determining product modifications. Modifications are determined based on the change in the product criteria. Therefore, initially it is necessary to identify the main criteria (according to the catalogue/specification) on which the quality of the product significantly depends. These criteria are selected by a team of experts during a brainstorming session (Putman and Paulus, 2009). Most often, up to 10 criteria are selected that affect customer satisfaction with the use of the product (Ali et al., 2020; Nando et al., 2020; Siwiec et al., 2022, Idzikowski and Cierlicki 2021). Then, all criteria should be characterised according to their current states and possible changes to these states. This is done by describing these criteria, e.g., with a parameter or a range of values.
Stage 4. Determining environmental impact criteria in LCA. To analyze the product improvement process in terms of environmental impact in terms of LCA, a list of environmental impact criteria was established. These criteria were identified according to databases and methods dedicated to life cycle assessment, e.g., OpenLCA, SimaPro (Various authors, 2020). On their basis, 99 criteria were selected, grouped and standardized to create a list of 25 environmental impact criteria, i.e.: (1) climate change,

(2) depletion/destruction/depletion of the ozone layer, (3) toxicity to humans (including carcinogenic effects or not), (4) ecotoxicity of water (fresh/land/marine), (5) terrestrial ecotoxicity, (6) creation of photo-oxidants, (7) acidification (water/soil), (8) eutrophication (water/land), (9) global warming, (10) ozone layer depletion, (11) ozone formation (human health/terrestrial ecosystems), (12) photochemical potential of oxidant formation, (13) waste (hazardous / bulky / radioactive / radioactive / deposited), (14) abiotic depletion (elements/fossil fuels/other resources), (15) particulate matter or inorganic substances in the respiratory system / Effects on the respiratory system, (16) ionizing radiation (human health/ecosystems), (17) land use, (18) resource scarcity / mineral extraction, (19) water consumption/water footprint, (20) heavy metals to water/soil/air, (21) radioactive substances into air/water, (22) water pollution, (23) noise, (24) soil pesticides, (25) major air pollutants.

From the developed list of environmental impact criteria for LCA, the expert team selects only those that may occur for the proposed research subject. According to preliminary research, i.e. (Siwiec et al., 2022), up to 9 environmental criteria are most frequently analysed.

Stage 5. Assessment of environmental impact and obtaining customer expectations. A team of experts assesses the environmental impact of all product criteria (Liu and Dai, 2022; Neramballi et al., 2020). For this purpose, it uses a scale of 1-7, where 1 - the least negative impact, 7 - the most negative impact. Then, customer expectations are obtained regarding i) the importance of the product criteria (quality and environmental), ii) satisfaction with the product criteria states (possible modifications). Customers express their expectations using a scale of 1-7, where 1 - a criterion that is practically unimportant / a criterion that is barely satisfactory, 7 - a criterion that is definitely the most important / a criterion that is definitely satisfactory. The ratings are awarded in a questionnaire, which is one of the most popular techniques for examining customer requirements (Chen et al., 2003; Lee et al., 2019). The research sample (number of customers) should be estimated according to the method presented in (Siwiec and Pacana, 2021a).

Stage 6. Calculation of quality level and environmental impact of product criteria. On the basis of the evaluation of the quality weights of the product criteria and the satisfaction ratings with their modification, the quality levels for product modifications are calculated. However, according to the evaluation of the weights of environmental criteria and the assessment of the environmental impact of these criteria, the level of the environmental impact of the product is calculated for the design phase in LCA. The WSM (Weighted Sum Model) method is used for this purpose (Markatos et al., 2023; Mushtaq et al., 2023), which is an uncomplicated procedure and no need to standardise assessments for various types of criteria. Quality level and environmental level are initially calculated for each product criterion status as shown in formula (1) (Garcia-Ayllon et al., 2021; Tran et al., 2021):

$$Q_i^{WSM} = \sum_{i=2}^{n} w_{ij}^{q} x_{ij}^{q} = q_{ij}^{n}, \quad E_i^{WSM} = \sum_{i=2}^{n} w_{ij}^{e} x_{ij}^{e} = e_{ij}^{n} \tag{1}$$

where: Q – level of quality, E – level of environmental impact, w – assessment of the importance of the criterion, x – assessment of satisfaction in terms of the condition of the criterion or impact on the natural environment, n – customer, i – criterion, j – status of the criterion, i, j, n = 1, …, m.

Quality and environmental levels are presented as decimal values; therefore, a formula is used (2):

$$Q_{ij}^{n} = \frac{q_{ij}^{n}}{1000} \quad and \quad E_{ij}^{n} = \frac{e_{ij}^{n}}{1000} \tag{2}$$

The results from this stage are used in further analyses, as presented in the next part of the article.

Stage 7. Anticipating qualitative-environmental decisions in the product design process that will satisfy the customer. For this purpose, a summary level of quality and environmental impact should be determined in the context of LCA should be determined. A pattern is used for this purpose (3):

$$QE_{ij} = Q_{ij}^{n} + E_{ij}^{n} \tag{3}$$

where: Q – quality, E – environmental impact, i – criterion, j – criterion status.

The qualitative and environmental levels are then analyzed according to the scale of relative states presented in the literature on the subject (Ostasz et al., 2022; Pacana and Siwiec, 2022b; Siwiec and Pacana, 2021b; Siwiec and Pacana 2021c; Ulewicz et al., 2021). According to the quality-environmental levels, it is possible to predict the direction of product improvement within LCA. The levels with the highest values on the scale of relative states are also those that most satisfy customers and have the lowest possible negative environmental impact (Olejarz et al., 2022; Siwiec and Pacana, 2021a, Leda ET AL. 2023).

3. RESULTS

The model test was performed according to the steps of the method. The analysis mainly involved photovoltaic panels (PVs), which have a significant impact on the natural environment. Their choice was based on their universality and popularity, which contributed to the increased production of these products. At the same time, it resulted in the deterioration of the natural environment, mainly as a result of polysilicon mining or the production of cells and modules (Hemeida et al., 2022; Singh et al., 2013). Therefore, the entity that used the method defined the purpose of the research, i.e. predicting favorable decisions in the PV design process that will be satisfactory in terms of quality and environmental impact under LCA. Then, the team of experts selected the key PV criteria. The selection was made according to the product catalogue and these were: (Q1) rated power (Wp), (Q2) short-circuit current (A), (Q3) open-circuit voltage (V), (Q4) efficiency (%), (Q5) number of cells, (Q6) degree of integration. The characteristics of these PV criteria are presented in the literature, that is, (Lucchi et al., 2020; Pacana and Siwiec, 2022b; Sánchez-Pantoja et al., 2021, 2018). Subsequently, in the PV catalogue, these criteria were characterised according to their possible modifications. These were the ranges above and below the current state, i.e.: rated power 315 Wp, short-circuit current 10 A, open-circuit voltage 48 V, efficiency 19 %, number of cells 120, degree of integration particularly.

Then environmental impact criteria were selected within LCA. The selection was made by a team of experts according to a previously presented list of criteria. During brainstorming, the following criteria were selected: (E1) ozone layer depletion, (E2) photochemical potential for oxidant formation, (E3) waste, (E4) abiotic depletion and (E5) resource scarcity. Taking into account the criteria states, they were assessed in terms of environmental impact. This was done by a team of experts. Furthermore, as part of preliminary research, a sample of eight customers was obtained who evaluated their satisfaction with the quality criteria and assessed the importance of quality and environmental criteria. The result is presented in Table 1.

Table 1
Excerpt from the importance ratings, satisfaction ratings and environmental impact ratings for the PV criteria.

Quality criteria			Environmental criteria with weight				
Weight	Satisfaction ratings for states		E1 (6)	E2 (4)	E3 (7)	E4 (5)	E5 (4)
			Environmental impact ratings				
Q1 (6)	State 1	3	2	3	3	4	6
	State 2	4	3	3	2	4	5
	State 3	6	3	4	5	5	5
Q2 (4)	State 1	4	3	5	5	3	3
	State 2	4	2	5	5	2	5
	State 3	5	2	5	6	3	6
…							
Q6 (6)	State 1	4	3	5	6	6	4
	State 2	4	2	5	4	5	3
	State 3	5	1	3	4	4	2

Then, using formulas (1-2), the quality levels of the photovoltaic and the environmental impact levels of the photovoltaic were calculated. The WSM method was used for this purpose. Calculations were made based on assessments of the importance of the criteria, satisfaction with the quality of the criteria, and environmental impact. The qualitative and environmental levels of photovoltaic panel were then assessed. Formula (3) was used for this purpose. Later, the relative state scale was used to predict the beneficial modification of photovoltaic panel in both qualitative and environmental terms (Tab. 2).

Table 2
Ranking of qualitative-environmental levels of PV.

States	Quality level	Environmental impact level	Qualitative-environmental level	Predicting satisfaction	Ranking
State 1	0.12	0.74	0.86	beneficial	1
State 2	0.14	0.49	0.63	moderate	3
State 3	0.19	0.51	0.70	satisfactory	2

Based on the results obtained, it was predicted that the most advantageous would be PV modified in terms of condition number 1. It occupies the first position in the ranking. Its level of quality and environmental impact at the same time is the most favourable. Therefore, designing photovoltaics according to the criteria modified by state number 1 will allow for customer satisfaction with the use of photovoltaics, as well as achieving the lowest possible environmental impact. If a design solution for these states would not be possible (e.g. too high costs), a photovoltaic design should be considered according to state 3 and then according to state 2. If the number of states were larger and the expected satisfactions would be similar, the final decision on the design method should be on the entity using the method. Additionally, the weights of the quality and environmental criteria, as well as the assessment of the status of these criteria, had an impact on the final results of the method. Therefore, in another case, the solutions obtained may be different.

4. DISCUSSION AND CONCLUSION

Product improvement concerns not only meeting customer requirements, but also reducing their negative impact on the natural environment (Shen et al., 2022). This is due to the need to pursue sustainable development, which includes the needs of society, the economy, and the environment. Hence, companies are looking for methods that support making accurate development decisions (Alejandrino et al., 2022; Ziemińska-Stolarska et al., 2021). Therefore, the aim of the article was to develop a method to help predict the direction of product improvement, taking into account its quality level and environmental impact during the life cycle (LCA). The developed method consisted of seven main stages, including: identification and assessment of modifications to product criteria in terms of their importance, meeting customer expectations, and environmental impact. The method was tested for commonly used photovoltaic (PV) panels. These panels were analysed for three different modifications. As a result, a modification ranking was developed, which allows predicting how to design or improve PV to achieve customer satisfaction and reduce the negative environmental impact. The benefits of the proposed method include:

- providing an environmental impact analysis of the product criteria in the context of LCA;
- predicting the direction of product improvement while taking into account the level of product quality and its environmental impact in terms of the life cycle;
- low-cost and simple model supporting initial product development decisions.

The limitations of the method include, for example, the need to acquire an appropriate number of customers to meet market requirements and the lack of quantitative analyses in the assessment of the entire life cycle. Hence, future research will be based on extending the model to subsequent LCA phases. At the same time, the method will be tested with a larger number of customers and for other products. The method can be used by any entity to determine the direction of improvement of the product. It can be used mainly by small and medium-sized enterprises (SMEs) that want to initially predict the environmental impact of a product, including taking into account customer expectations.

LITERATURE

Alejandrino, C., Mercante, I.T., Bovea, M.D., 2022. *Combining O-LCA and O-LCC to support circular economy strategies in organizations: Methodology and case study,* J Clean Prod, 336, 130365. DOI: 10.1016/j.jclepro.2022.130365

Ali, A., Hafeez, Y., Hussain, S., Yang, S., 2020. *Role of Requirement Prioritization Technique to Improve the Quality of Highly-Configurable Systems,* IEEE Access, 8, 27549–27573. DOI: 10.1109/ACCESS.2020.2971382

Borkowski, S., Ulewicz, R., Selejdak, J., Konstanciak, M., Klimecka-Tatar, D. 2012. *The use of 3x3 matrix to evaluation of ribbed wire manufacturing technology*, METAL 2012 - Conference Proceedings, 21st International Conference on Metallurgy and Materials, 1722–1728

Calado, E.A., Leite, M., Silva, A., 2019. *Integrating life cycle assessment (LCA) and life cycle costing (LCC) in the early phases of aircraft structural design: an elevator case study,* Int J Life Cycle Assess, 24, 2091–2110, DOI: 10.1007/s11367-019-01632-8

Chen, C.-H., Khoo, L.P., Yan, W., 2003. *Evaluation of multicultural factors from elicited customer requirements for new product development,* Res Eng Des, 14, 119–130, DOI: 10.1007/s00163-003-0032-6

Czerwińska, K., Pacana, A., 2019. *Analysis of the implementation of the identification system for directly marked parts - DataMatrix code,* Production Engineering Archives 23, 22–26. DOI: 10.30657/pea.2019.23.04

El Badaoui,M. Touzani, A. 2022. *AHP QFD methodology for a recycled solar collector,* Production Engineering Archives,28(1) 30-39.DOI: 10.30657/pea.2022.28.04

Garcia-Ayllon, S., Hontoria, E., Munier, N., 2021. *The Contribution of MCDM to SUMP: The Case of Spanish Cities during 2006–2021,* Int J Environ Res Public Health, 19, 294, DOI: 10.3390/ijerph19010294

Hemeida, M.G., Hemeida, A.M., Senjyu, T., Osheba, D., 2022. *Renewable Energy Resources Technologies and Life Cycle Assessment: Review. Energies (Basel),* 15, 9417. DOI: 10.3390/en15249417

Idzikowski, A., Cierlicki, T., 2021. *Economy and energy analysis in the operation of renewable energy installations - A case study*, Production Engineering Archives, 27(2), 90–99

Korzynski, M., Pacana, A., 2010. *Centreless burnishing and influence of its parameters on machining effects*, J Mater Process Technol, 210, 1217–1223. DOI: 10.1016/j.jmatprotec.2010.03.008

Krynke, M., Ivanowa, T., Revenko, N., 2022. *Factors, Increasing the Efficiency of Work of Maintenance, Repair and Operation Units of Industrial Enterprises,* Management Systems in Production Engineering, 30(1), 91-97, DOI: 10.2478/mspe-2022-0012

Kuzior, A., Kwilinski, A., Tkachenko, V., 2019, *Sustainable development of organizations based on the combinatorial model of artificial intelligence*, Entrepreneurship and Sustainability Issues, 7(2), 1353–1376; DOI: 10.9770/jesi.2019.7.2(39)

Lagerstedt, J., Luttropp, C., Lindfors, L.-G., 2003. *Functional priorities in LCA and design for environment,* Int J Life Cycle Assess, 8, 160–166, DOI: 10.1007/BF02978463

Lawor, B., Hornyak, M., 2012. *SMART Goals: How The Application Of Smart Goals Can Contribute To Achievement Of Student Learning Outcomes,* Developments in Business Simulation and Experiential Learning, 39, 259–267.

Leda, P., Idzikowski, A., Piasecka, I., Bałdowska-Witos, P.,; Cierlicki, T., Zawada, M., 2023. *Management of Environmental Life Cycle Impact Assessment of a Photovoltaic Power Plant on the Atmosphere*, Water, and Soil Environment. Energies, 16, 4230, DOI: 10.3390/en16104230

Lee, Chen, Lin, Li, Zhao, 2019. *Developing a Quick Response Product Configuration System under Industry 4.0 Based on Customer Requirement Modelling and Optimization Method,* Applied Sciences, 9, 5004, DOI: 10.3390/app9235004

Liu, F., Dai, Y., 2022. *Product Processing Quality Classification Model for Small-Sample and Imbalanced Data Environment,* Comput Intell Neurosci, 2022, 1–16, DOI: 10.1155/2022/9024165

Lucchi, E., Polo Lopez, C.S., Franco, G., 2020. *A conceptual framework on the integration of solar energy systems in heritage sites and buildings,* IOP Conf Ser Mater Sci Eng, 949, 012113, DOI: 10.1088/1757-899X/949/1/012113

Markatos, D.N., Malefaki, S., Pantelakis, S.G., 2023. *Sensitivity Analysis of a Hybrid MCDM Model for Sustainability Assessment—An Example from the Aviation Industry,* Aerospace, 10, 385, DOI: 10.3390/aerospace10040385

Means, P., Guggemos, A., 2015. *Framework for Life Cycle Assessment (LCA) Based Environmental Decision Making During the Conceptual Design Phase for Commercial Buildings,* Procedia Eng, 118, 802–812, DOI: 10.1016/j.proeng.2015.08.517

Mushtaq, F., Farooq, M., Tirkey, A.S., Sheikh, B.A., 2023. *Analytic Hierarchy Process (AHP) Based Soil Erosion Susceptibility Mapping in Northwestern Himalayas: A Case Study of Central Kashmir Province,* Conservation, 3, 32–52, DOI: 10.3390/conservation3010003

Nando, F.T., Amrina, E., Alfadhlani, 2020. *Prioritizing design requirements on traditional arrow using quality function deployment*, 040020, DOI: 10.1063/5.0000983

Neramballi, A., Sakao, T., Willskytt, S., Tillman, A.-M., 2020. *A design navigator to guide the transition towards environmentally benign product/service systems based on LCA results,* J Clean Prod, 277, 124074, DOI: 10.1016/j.jclepro.2020.124074

Olejarz, T., Siwiec, D., Pacana, A., 2022. *Method of Qualitative–Environmental Choice of Devices Converting Green Energy,* Energies (Basel), 15, 8845, DOI: 10.3390/en15238845

Ostasz, G., Siwiec, D., Pacana, A., 2022. *Universal Model to Predict Expected Direction of Products Quality Improvement,* Energies (Basel), 15, DOI: 10.3390/en15051751

Pacana, A., Siwiec, D., 2021. *Universal Model to Support the Quality Improvement of Industrial Products,* Materials, 14, 7872, DOI: 10.3390/ma14247872

Pacana, A., Siwiec, D., 2022a. *Method of Determining Sequence Actions of Products Improvement,* Materials, 15, 6321, DOI: 10.3390/ma15186321

Pacana, A., Siwiec, D., 2022b. *Model to Predict Quality of Photovoltaic Panels Considering Customers' Expectations,* Energies (Basel), 15, 1101, DOI: 10.3390/en15031101

Proske, M., Finkbeiner, M., 2020. *Obsolescence in LCA–methodological challenges and solution approaches,* Int J Life Cycle Assess, 25, 495–507, DOI: 10.1007/s11367-019-01710-x

Putman, V.L., Paulus, P.B., 2009*. Brainstorming, Brainstorming Rules and Decision Making,* J Creat Behav, 43, 29–40, DOI: 10.1002/j.2162-6057.2009.tb01304.x

Sánchez-Pantoja, N., Vidal, R., Pastor, M., 2021. *EU-Funded Projects with Actual Implementation of Renewable Energies in Cities. Analysis of Their Concern for Aesthetic Impact,* Energies (Basel), 14, 1627, DOI: 10.3390/en14061627

Sánchez-Pantoja, N., Vidal, R., Pastor, M.C., 2018. *Aesthetic impact of solar energy systems,* Renewable and Sustainable Energy Reviews, 98, 227–238, DOI: 10.1016/j.rser.2018.09.021

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,* Comput Ind Eng, 169, 108233, DOI: 10.1016/j.cie.2022.108233

Singh, A., Olsen, S.I., Pant, D., 2013*. Importance of Life Cycle Assessment of Renewable Energy Sources*, 1–11, DOI: 10.1007/978-1-4471-5364-1_1

Siwiec, D., Bełch, P., Hajduk-Stelmachowicz, M., Pacana, A., Bednárová, L., 2022. *Determinants Of Making Decisions In Improving The Quality Of Products,* Scientific Papers of Silesian University of Technology. Organization and Management Series 2022, 497–507, DOI: 10.29119/1641-3466.2022.157.31

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

Siwiec, D., Pacana, A., 2021b. *Model of Choice Photovoltaic Panels Considering Customers' Expectations,* Energies (Basel), 14, 5977, DOI: 10.3390/en14185977

Siwiec, D., Pacana, A., 2021c. *Model supporting development decisions by considering qualitative–environmental aspects,* Sustainability (Switzerland), 13(16), 9067, DOI: 10.3390/su13169067

Siwiec, D., Pacana, A., 2022. *A New Model Supporting Stability Quality of Materials and Industrial Products,* Materials 15, 4440, DOI: 10.3390/ma15134440

Tran, N.H., Yang, S.-H., Tsai, C.Y., Yang, N.C., Chang, C.-M., 2021. *Developing Transportation Livability-Related Indicators for Green Urban Road Rating System in Taiwan,* Sustainability, 13, 14016, DOI: 10.3390/su132414016

Ulewicz, R. 2018. Customer satisfaction survey in the furniture industry, Increasing the Use of Wood in the Global Bio-Economy - Proceedings of Scientific Papers, 19-29

Ulewicz, R., Siwiec, D., Pacana, A., Tutak, M., Brodny, J., 2021. *Multi-Criteria Method for the Selection of Renewable Energy Sources in the Polish Industrial Sector,* Energies (Basel), 14, 2386. DOI: 10.3390/en14092386

Ulewicz, R., Siwiec, D., Pacana, A. 2023. *Sustainable Vehicle Design Considering Quality Level and Life Cycle Environmental Assessment (LCA*). Energies, 16, 8122. https://doi.org/10.3390/en16248122

Various authors, Pr.S., 2020. *SimaPro database manual - Methods library*, PRé Sustainability B.V. 4.15.

Varun, Bhat, I.K., Prakash, R., 2009. *LCA of renewable energy for electricity generation systems—A review,* Renewable and Sustainable Energy Reviews 13, 1067–1073, DOI: 10.1016/j.rser.2008.08.004

Ziemińska-Stolarska, A., Pietrzak, M., Zbiciński, I., 2021. *Application of LCA to Determine Environmental Impact of Concentrated Photovoltaic Solar Panels—State-of-the-Art.* Energies (Basel), 14, 3143, DOI: 10.3390/en14113143