E3S Web of Conferences **408**, 01013 (2023) https://doi.org/10.1051/e3sconf/202340801013
ISCMEE 2023

Qualimetric approaches to assessing sustainable development indicators

Hanna Hrinchenko[1*], *Roman* Trishch[2], *Volodymyr* Mykolaiko[3], and *Oksana* Kovtun[4]

[1] Ukrainian Engineering Pedagogics Academy, 61013 Kharkiv, Ukraine
[2] National Aerospace University "Kharkiv Aviation Institute", 61070 Kharkiv, Ukraine
[3] Pavlo Tychyna Uman State Pedagogical University, 20300 Uman, Ukraine
[4] Hryhorii Skovoroda University in Pereiaslav, 08401 Pereiaslav, Ukraine

Abstract. The study discusses approaches to assessing the quality of sustainable development indicators and analyses sustainable development indicators in general, for which the desirability function and the approach of translating sustainable development indicators into a dimensionless scale are used. This approach makes it possible to analyse the processes of achieving the sustainable development goals and relevant tasks on the basis of statistical data, as well as to compare indicators with different characteristics. For the purpose of qualimetric assessment, the article proposes to divide the indicators of sustainable development into four groups characterized by the following parameters: the lowest value is the best, the highest value is the best, the average value is the best, and the values that simultaneously tend to the lowest and the highest. It is proposed to evaluate sustainable development indicators in accordance with the group, taking into account the significance of the indicator, for which the form parameter and the evaluation step are selected by the expert evaluation method. For example, several sustainable development indicators for different groups are presented, and calculations are made to determine the dimensionless indicator, taking into account its significance according to the opinion of experts. As a result, we obtained dimensionless values for each of the sustainable development indicators (FQ = 0.92, 0.98, 0.86, 0.28, and 0.54), which characterize the achievement of sustainable development goals and allow us to assess progress in both a prospective and retrospective context.

1 Introduction

To ensure the development of the country in the context of globalization, taking into account material and non-material needs, it is necessary to set goals that take into account social progress, economic development and environmental responsibility. These three areas are laid down in the standards being developed, and 17 Sustainable Development Goals have been developed at the global level, the achievement of which is an important task for countries.

* Corresponding author: hrinchenko@uipa.edu.ua

Progress is being made in many areas, but in general, activities to achieve the Goals are not yet being implemented at the required speed and scale. The year 2020 ushered in a decade of ambitious action aimed at achieving the Sustainable Development Goals by 2030. In order to make progress towards the Sustainable Development Goals, specific actions need to be taken at the country, global and individual levels. One of the key elements is to provide funding for the implementation of projects and programs aimed at achieving the Sustainable Development Goals. Countries should increase their investments in development, especially in vulnerable regions and among vulnerable groups. This requires developing innovative financial mechanisms, engaging the private sector, and ensuring partnerships with international financial institutions.

Improving resource efficiency is another important step. It is necessary to introduce energy-efficient technologies, reduce greenhouse gas emissions, work on the use of renewable energy sources, and maintain a balanced approach to the use of natural resources. At the same time, in order to assess the progress in achieving the goals and the effectiveness of implementing sustainable development strategies, financial and economic mechanisms, social projects and programs, it is necessary to have indicators and qualimetric approaches to assess changes. Qualimetric approaches should take into account the heterogeneity of indicators and should be a universal mechanism for assessing the generalized level of change towards achieving the Sustainable Development Goals (SDGs).

Proper assessment of progress is an important step in achieving the SDGs. This requires indicators and qualitative approaches that will allow for objective measurement of changes and determine how well sustainable development strategies are being implemented.

The universal indicators of the Sustainable Development Goals were developed within the framework of the United Nations and include a wide range of areas such as poverty, education, health, gender, economy, environment, etc. These indicators help to track progress and compare achievements between different countries and regions.

However, in addition to universal indicators, it is also important to develop qualitative approaches that take into account the heterogeneity of indicators and the contextual features of each country. This may include national indicators that are adapted to local conditions and reflect specific priorities and challenges. Assessing progress toward the SDGs should be an ongoing process that includes reporting, updating indicators, and analyzing results. This will help identify successes, problem areas, and develop strategies for further development.

Therefore, the purpose of the article is to develop universal qualimetric approaches to assessing sustainable development indicators that take into account the heterogeneity of indicators, the specifics of the importance of individual indicators for a particular country and can be used to assess progress towards achieving the Sustainable Development Goals.

2 Analysis of recent research and publications

In line with Economic and Social Council decision 2015/2016 and previous practice, the UN Secretary-General presented the report of the Inter-Agency and Expert Group on Indicators for the Sustainable Development Goals in 2016. This report provides an overview of the work of the Inter-Agency Expert Group on the development of a global system of indicators for the goals and targets of the 2030 Agenda for Sustainable Development. The report describes the activities carried out by the Group of Experts since its establishment in accordance with the decision of the Statistical Commission, and presents a proposal for global indicators for further activities and review of the 2030 Agenda. Thus, in 2016, the document "Report of the Intergovernmental Panel of Experts on Sustainable Development Goal Indicators" was created, which contains all kinds of different representative data that should be collected around the world [1].

The proposal includes indicators for all the Goals and targets, with some indicators already fully defined and some still needing to be finalized.

Thus, there is now enough high-quality statistical data for analysis and comparison from around the world to determine the trend of approaching the sustainable development goals and to make management decisions on the effectiveness of development strategies and mechanisms in certain areas and in certain countries. To process these statistics, scientifically based qualitative approaches that combine multi-criteria evaluation are needed, as sustainable development indicators have heterogeneous characteristics. For example, Indicator 4.b.1: "Volume of official development assistance flows for scholarships by sector and type of study" is measured in millions of US dollars at constant 2020 prices; Indicator 4.c.1: "Proportion of teachers with minimum required qualifications, by level of education" is measured in percentage, etc. It should also be noted that statistical data have different estimation methods: in some cases, the maximum value is better (e.g., Indicator 4.b.1), in others, the minimum value will be better (e.g., Indicator 3.a.1: "Age-standardized prevalence of current tobacco use among persons aged 15 years and older"). These features should be taken into account when determining the approach to the integrated assessment of the Sustainable Development Goals. The authors of [2–7] studied the development of qualimetric approaches for evaluating objects of different natures. In their works, they proposed approaches to qualimetric assessment of the quality of economic, production, and educational processes and assessment of the risks of low-quality products in production using the probability density function of a random variable. They also considered aspects of disease risk assessment, in particular the probability of contracting COVID-19, using qualitative assessment approaches.

The authors of [8-11] investigated the use of qualimetric methods for quality assessment in energy systems. Their studies have shown that these methods use multifactorial analysis, which takes into account the influence of various factors on the quality of functioning of individual elements and systems of energy facilities. The authors demonstrate that this approach is an effective mechanism for a comprehensive assessment of various parameters, forecasting further operation and making science-based decisions on scheduled and unscheduled maintenance to ensure the quality of operation. This approach allows to take into account the impact of various factors on the quality of energy systems, helps to identify problematic aspects and prioritize the improvement of the efficiency and reliability of energy facilities. The use of qualimetric methods contributes to more accurate forecasting and planning of works to maintain the quality of energy systems.

Qualimetric methods are often used in assessing the quality of education as one of the criteria for sustainable development, which is the subject of works [12-16], which discuss the technology of building factor-criterion models. Paper [12] proposed an approach based on the numerical interpretation of the results obtained using the method of expert evaluation. The authors have developed a set of criteria for expert evaluation of electronic resources that can be easily used to determine their quality during remote competitions. It is proposed to use this toolkit to rank other resources of the educational process by quality features. For example, using this approach can help assess the quality of educational video content. Thus, the method of expert evaluation, using the proposed set of criteria, can be an effective tool for evaluating and ranking various electronic resources used in the educational process.

In [14-16], a qualimetric approach was used to assess the quality of mastering certain competencies by students in order to determine their success in forming these competencies. The authors point out that the use of qualimetric monitoring to assess the quality of educational processes is an effective management tool. This approach allows tracking the dynamics of changes in the state of the educational process resources and, using statistical methods, establishing their impact on the final result of education.

Similarly, the authors of [15, 16] suggest using the results of the assessment to manage and improve the quality of the educational environment. This allows to identify problematic aspects, monitor the effectiveness of measures and develop strategies to improve the quality of the educational process. The use of a qualimetric approach in this context helps to ensure systematic assessment, monitoring and improvement of the quality of education.

The solution to the issues of qualimetric assessment in the context of achieving the Sustainable Development Goals is presented in [17-20]. The authors of [17-19] built a common system of indicators using big data from open sources and developed an ANN model to effectively assess the overall progress in achieving the SDGs for cities of different sizes, comparing the level of sustainability of cities with different populations, spatial location, and income levels. The proposed systematic methods are based on a study of the SDG Index at the city level in China and are proposed for application to other countries with appropriate adjustments. The authors of [20] propose a methodology for assessing the sustainability of the industrial water cycle based on the calculation of indicators and indices in order to create a synthetic, simple and specific tool for qualitative assessment of water resources. The methodology was built on the basis of geo-referenced data on water availability and sectoral use obtained for Italian sub-basins. The proposed methodology contributes to the assessment of the effectiveness of river basin management measures to achieve sustainable development goals.

The authors of [21-22] propose an assessment of sustainable development based on the developed model of maturity of individual communities or regions using a system based on the analysis of the territorial context (scoping phase), maturity assessment (development phase) and the use of a case study (evaluation phase). The assessment covers all plans, programs, and initiatives necessary to define goals and strategies for improvement that cover all aspects of sustainable development. This enables dynamic management of sustainable development at the local level and allows communities to define sustainable development strategies in which maturity assessment plays a key role, linking the current situation to future improvements. The proposed model can be used as a self-assessment tool, a roadmap for improving sustainability behavior, and a benchmarking tool for assessing and comparing standards and best practices among organizations and supply chains.

3 Statement of basic material and the substantiation of the obtained results

Qualitative approaches to assessing sustainable development indicators are based on the use of qualitative methods of data collection and analysis. They are aimed at obtaining a deep understanding of the essence of sustainable development indicators, their interconnection and impact on socio-economic processes.

The main principles of qualimetric approaches to assessing sustainable development indicators include:

1. Conceptual clarity: defining clear and unambiguous theoretical concepts and definitions of sustainable development indicators.
2. Stakeholder inclusion: involving various stakeholders, such as government agencies, civil society organizations and academia, in the process of developing and assessing sustainable development indicators.
3. Contextual analysis: taking into account the peculiarities of the socio-ecological and economic context in which the sustainable development indicators are used.
4. Integrated approach: using an integrated approach to evaluation that takes into account the relationship between different indicators and their impact on sustainable development.

5. Qualitative analysis: the use of qualitative methods of data collection and analysis, such as expert assessments, focus groups, interviews and in-depth interviews.
6. Application of ranking methods: the use of ranking methods to compare different sustainability indicators and determine their importance.
7. Feedback and refinement: taking into account the results of the assessment of sustainable development indicators to improve the methodology and further refine the assessment system

These approaches allow for a deeper understanding of sustainability indicators and their impact on society, the economy, and the environment. They can serve as a basis for decision-making and policy development aimed at achieving sustainable development.

Assessment of sustainability indicators has its own peculiarities, as it requires an integrated approach and consideration of various aspects of sustainable development. The processes being evaluated are of a different nature, and quality indicators have different units of measurement and different optimal values. Currently, there are many indicators that can be used to measure sustainable development. However, there is no definite number of indicators that have been officially adopted or recognized as generally accepted. The choice of specific indicators depends on the context, the purpose of the assessment, and the needs of the users.

In 2015, the United Nations adopted The Sustainable Development Goals Indicators, which includes 17 sustainable development goals with 169 subgoals [1]. Each goal has a set of corresponding indicators that are used to track progress towards achieving these goals. However, other organizations and research groups also develop their own systems of sustainable development indicators according to their needs and priorities.

Consequently, the number of sustainability indicators can vary and depends on the specific framework or system chosen to measure sustainability.

Since indicators have different nature, their quality indicators have different units of measurement and different optimal values, which can be divided into 4 main groups:

Group A. A group of quality indicators in which the optimal (best) value tends to the minimum value. In this case, the lower these indicators are, the better (number of AIDS patients, share of illiterate population, etc.);

Group B. A group of quality indicators in which the optimal (best) value tends to the maximum value. In this case, the higher these indicators are, the better (investment in sustainable development programs, share of the population that is vaccinated, etc;)

Group C. A group of quality indicators in which the optimal (best) value tends to the average value. As a rule, such indicators tend to be in the middle of the tolerance field (for example, equality in getting jobs between men and women)

Group D. A group of quality indicators in which the optimal (best) value tends to the maximum and minimum values at the same time. For example, the highest efficiency of sustainability programs at the lowest cost, sustainable equipment in a limited space, maximum energy efficiency with limited resources, etc.

It should be noted that the assessment of Group C and D parameters is not very common and is used when planning a sustainable development strategy for individual communities, companies or organizations. The most commonly used indicators are those included in Groups A and B. However, to effectively assess such heterogeneous indicators, it is necessary to have all indicators in a single coordinate system. This requires a tool that allows to obtain quality scores on a dimensionless scale.

The theory of qualimetrics, which is based on the use of nonlinear functional dependencies, can be applied to convert multidimensional indicators into a dimensionless scale of assessment. This allows to take into account the different weight of each indicator and the nonlinear relationship between the indicator and its score.

The use of degree functions can be one of the approaches to modeling the nonlinear relationship between quality indicators and their scores. In such a system of functions, each indicator has its own degree, which reflects its importance and impact on the score. These degrees can be set by experts or based on data analysis.

For example, if we have an Environmental Performance indicator that is measured in units of pollution, we can apply a degree function that reflects how this indicator affects the overall sustainability score. The more pollution, the lower the score, but this relationship may be non-linear and depend on specific contextual factors.

It is important to keep in mind that the choice of specific nonlinear functions and their degrees will depend on the specific situation and purpose of the assessment. Qualimetrics methods can be applied to solve this problem and help to transform multidimensional indicators into a dimensionless rating scale, providing a more accurate measurement.

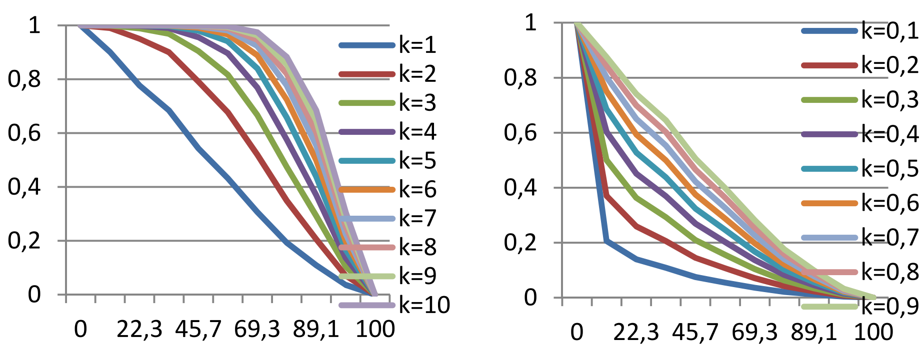
$$F_Q = \left[\frac{Q_i - Q_{imin}}{Q_{imax} - Q_{imin}}\right]^k \quad (1)$$

where: Q_i – measured value (actual) of the quality indicator; Q_{imin} - the minimum value of the quality indicator; Q_{imax} – the maximum value of the quality indicator; k – shape parameter.

By changing the degree index, which is a parameter of the shape, its steepness changes, which will allow you to select them for evaluating different processes with different quality requirements. If necessary, you can increase or decrease the requirement for a quality indicator.

In other words, for those indicators that are of great importance, a dependence will be applied that will lower its score on a dimensionless scale. For those that are less important, dependencies will be applied that will increase its score.

If the shape parameter k is changed from 0.1 to one in increments of 0.1, the functional relationships will be upwardly curved. (Figures 1a, 2a) If the shape parameter k is changed from one to ten in increments of 1, the functional relationships will be downwardly concave, as shown in Figures 1b, 2b. Examples are given for Group A, when the best value tends to the minimum value (Fig. 1) and Group B, when the best value tends to the maximum value (Fig. 2). These are special cases that allowed us to build a system of dependencies for visualization purposes.



a *b*

Fig. 1. Type of dependence at the condition Q_{imin} = 100; Q_{imax} = 0: (a) the shape parameter k varies from 0.1 to 1 with a step of 0.1; (b) the shape parameter k varies from 1 to 10 with a step of 1.

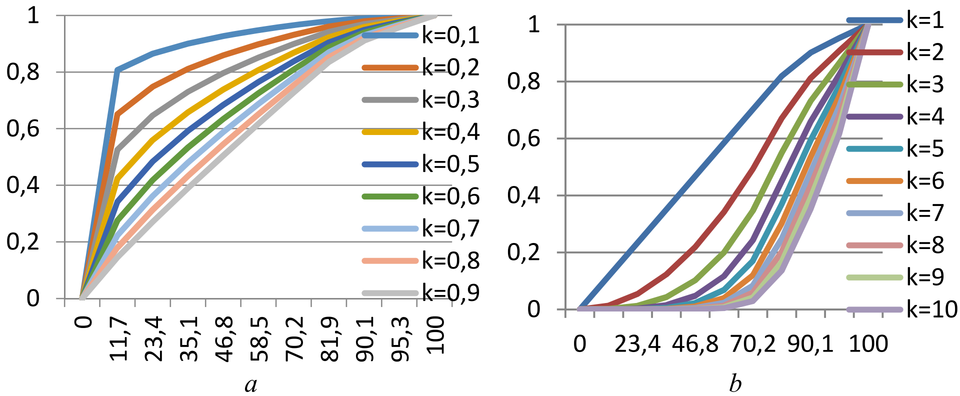


Fig. 2. Type of dependence at the condition Q_{imin} =0; Q_{imax} =100: (a) the shape parameter k varies from 0.1 to 1 with a step of 0.1; (b) the shape parameter k varies from 1 to 10 with a step of 1.

The selection of this or that dependence for each of the indicators will be made by a group of experts. Just visualization of the degree of steepness and the form of dependence will be an auxiliary tool for experts to make a decision with greater efficiency.

To select the parameter of the form k it is proposed to use one of the known methods of expert evaluations. Particular cases of the Delphi method are methods of preference; ranking; pairwise comparisons; and sequential comparisons. At an enterprise, where experts are freelancers and their detachment for additional expert work should be minimal in time, the most acceptable is the method of preference. The essence of this method is as follows.

The results of a survey of experts on the importance of a particular sustainability indicator are collected and calculated using the formula:

$$\tilde{n}_i = \frac{\sum_{j=1}^{N} \tilde{o}_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{N} x_{ij}} \qquad (2)$$

where the sum of weights is calculated for all indicators and for all experts from the matrix of weighting coefficients x_{ij} assigned to the i-th indicator by j-th expert.
The coefficient of agreement used to assess the consistency of expert opinions may vary depending on the specific methodology or approach. In this case, it is proposed to use the agreement coefficient, which is determined by the formula:

$$V = \frac{12\sum_{i=1}^{n} y_i^2}{N^2\left(n^3 - n\right)}, \qquad (3)$$

where N is the number of experts; n is the number of indicators; y is the deviation from the average sum of ranks. The deviation from the average sum of ranks of the i-th indicator is calculated as follows:

$$y_i = \sum_{j=1}^{N} r_{ij} - T \qquad (4)$$

Where $\sum_{j=1}^{N} r_{ij}$ - the sum of ranks of each indicator; r_{ij} - the rank of the i-th indicator in the j-th expert; $T = N\left(\frac{n+1}{2}\right)$- the average sum of ranks. If any indicators receive the same rank, the agreement coefficient is calculated using the formula:

$$V = \frac{\sum_{i=1}^{n} y_i^2}{\frac{1}{12} N^2 \left(n^2 - n\right) - N \sum_{j=1}^{N} T_j} \tag{5}$$

where:

$$T_j = \frac{1}{12} \sum_{j=1}^{g} \left(p^3 - p\right) \tag{6}$$

where *g* is the number of groups of the same rank in the ranking of the j-th expert; *p* is the number of repetitions of the same rank in the j-th group. The value of the coefficient can be from 0 to 1. A value closer to 1 indicates high consistency between expert opinions, while a value closer to 0 indicates low consistency. A value of V = 0.5 - 0.6 is satisfactory.

It is important to note that there are other measures of agreement that can be used depending on the specific context and assessment methodology. In addition, the interpretation of the agreement coefficient may also vary depending on the specific situation and the criteria adopted. An example of the results of applying qualimetric methods for a multi-criteria assessment of progress towards achieving the sustainable development criteria for five indicators is presented in the table. Statistics for 2020 for the Global Indicators are taken from the Report of the Secretary-General: Progress towards the Sustainable Development Goals (E/2022/55). It contains the Statistical Annex of global and regional data and the Supplementary Document to report the progress for the global indicators for the Sustainable Development Goals and targets, adopted by the Statistical Commission at its forty-eighth session in March 2017, by the United Nations Economic and Social Council in June 2017 and by the General Assembly in July 2017.

Table 1. Results of the assessment of sustainable development indicators.

Sustainable development indicators	Q_{imin}	Q_{imax}	Q_i	k	F_Q	**Group**
Indicator 1.4.1 Proportion of population in households with access to basic services (a) Proportion of population using basic drinking water services (Percentage)	0	100	90.1	0.6	0.92	B
Indicator 2.1.1 Prevalence of undernourishment (Percentage)	0	100	9.9	7	0.98	A
Indicator 2.a.1 The agriculture orientation index for government expenditures	0	1	0.51	4	0.86	B
Indicator 2.b.1 Agricultural export subsidies (Millions of U.S. dollars)	0	2,976.5	58.4	4	0.28	B
Indicator 5.5.1 (a) Proportion of seats held by women in national parliaments (single and lower chambers) (Percentage)	0	50	26.2	1	0.54	C

The results presented in the table show that quality indicators have different nature, units of measurement, and different assessment ranges. The results of the experts' work are also presented in the form of a shape parameter. As a result of the calculations, we obtained estimates of quality indicators ($\boldsymbol{F_Q}$) on a dimensionless scale (0-1). This allows for further research to determine the progress in achieving the sustainable development goals in accordance with their indicators and to actually assess the implementation of the tasks of the sustainable development strategy.

The use of functional dependencies allows developing a universal methodology and automating the assessment process, which in turn allows obtaining a comprehensive multi-criteria assessment over time and creating functionally dependent statistics, i.e. a time series of assessments.

The proposed assessment methodology is universal and does not require constant participation of an expert group. After selecting a certain functional dependency, it can automatically work in an automated mode. It is enough to enter new statistical data (collected data on a particular sustainability indicator), and the system will provide comprehensive single assessments of quality indicators and assessments depending on time. This allows you to get an assessment of the process of achieving sustainability goals in a convenient and systematic way.

4 Conclusions

The study provides a thorough analysis of qualimetric approaches to the evaluation of objects of different nature. As a result of the analysis, the features of the processes that determine the mechanism of approaching the achievement of sustainable development goals as an object of qualimetry are identified. It is proposed to use the nonlinear dependence of the quality indicator and its assessment on a dimensionless scale for the multicriteria assessment of sustainable development indicators. To this end, models have been developed to obtain dimensionless estimates of sustainable development indicators. It is proposed to divide the indicators of sustainable development into four groups, which characterize the values according to the following criteria: the lowest value is the best (Group A); the highest value is the best (Group B); the average value is the best (Group C) and the best values are both the highest and the lowest (Group D). For each of the groups, the corresponding estimation models are proposed, which have a shape parameter and can be more accurately used to solve practical estimation problems. To select the shape parameter k, it is proposed to use one of the well-known methods of expert evaluation - the method of preferences.

To visualize the proposed models, graphical dependencies for specific sustainable development indicators included in Group A and Group B are presented. By applying the expert evaluation method, the indicators of the parameter of the form k are selected, and numerical calculations of the actual values of progress in certain indicators of sustainable development are carried out (evaluation scale from 0 to 1). It is found that significant progress has been made in reducing the global statistical indicators in Indicator 2.1. 1 Prevalence of undernutrition: 0.98 (Group A indicator); the average value is reached by Indicator 5.5.1 (a). Proportion of seats held by women in national parliaments (single and lower chambers): 0.54 (Group C indicator).

The proposed approach makes it possible to assess the pace of progress towards achieving the Sustainable Development Goals based on statistical data, both for individual indicators and to analyze the overall trend, in order to implement effective mechanisms for managing and developing a further sustainable development strategy.

References

1. United Nations statistical commission. (2016). Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators. https://unstats.un.org/unsd/
2. Trishch, R., Nechuiviter, O., Dyadyura, K., Vasilevskyi, O., Tsykhanovska, I., & Yakovlev, M. (2021). Qualimetric method of assessing risks of low quality products. MM Science Journal, 4, 4769-4774 https://doi.org/10.17973/MMSJ.2021_10_2021030
3. Ginevičius, R., Trišč, R., Remeikienė, R., Zielińska, A., & Strikaitė-Latušinskaja, G. (2022). Evaluation of the condition of social processes based on qualimetric methods: The COVID-19 case. Journal of International Studies, 15(1), 230-249. https://doi.org/10.14254/2071-8330.2022/15-1/15
4. Trisch, R., Gorbenko, E., Dotsenko, N., Kim, N., & Kiporenko, G. (2016). Development of qualimetric approaches to the processes of quality management system at enterprises according to international standards of the ISO 9000 series. Eastern-European Journal of Enterprise Technologies, 4(3-82), 18-24. https://doi.org/10.15587/1729-4061.2016.75503
5. Trishch, R., Maletska, O., Hrinchenko, H., Artiukh, S., Burdeina, V., Antonenko, N. (2019) Development and validation of measurement techniques according to ISO/IEC 17025:2017. IEEE 8th International Conference on Advanced Optoelectronics and Lasers (CAOL), 1-6. https://doi.org/10.1109/CAOL46282.2019.9019539.
6. Yankovyi, O., Tsimoshynska, O., Kazancoglu, Y., Kotlubai, V., & Filipishyna, L. (2023). Applying fuzzy logic to assessment of latent economic features. Advances in Soft Computing Applications (pp. 1–22). River.
7. Kaminsky, O., Yereshko, J., Vdovenko, N., Bocharov, M., & Kazancoglu, Y. (2023). Evaluating the effectiveness of enterprises' digital transformation by fuzzy logic. In Advances in Soft Computing Applications (pp. 75–90). River.
8. Budanov, P., Hrinchenko, H., Nechuyviter, O., Boyko, T., & Tsykhanovska, I. (2022). Application of qualimetry methods to evaluate complex quality indicators of multi-parameter objects. Engineering, 30, 73-84. https://doi.org/10.32820/2079-1747-2022-30-73-84
9. Budanov, P., Hrinchenko, H., Nechuyviter, O., & Tsykhanovska, I. (2023). Methodological approaches for assessing the quality of multi-parameter energy facilities. Bulletin of the National Technical University "KhPI", 1(15), pp. 27-35, https://doi.org/10.20998/2413-4295.2023.01.04.
10. Hrinchenko, H., Trisch, R., Burdeina, V., & Chelysheva, S. (2019). Algorithm of technical diagnostics of the complicated damage to the continued resource of the circulation pipeline of the nuclear power plant. Problems of Atomic Science and Technology, 120(2), 104-110.
11. Hrinchenko, H., Kupriyanov, O., Khomenko, V., Khomenko, S., Kniazieva, V. (2023). An Approach to Ensure Operational Safety for Renewable Energy Equipment. Circular Economy for Renewable Energy. Green Energy and Technology. Springer, Cham. 1-17. https://doi.org/10.1007/978-3-031-30800-0_1
12. Bachiieva, L., Koeberlein-Kerler, J., Kovalenko, D., Yelnykova, H., & Karpova, L. (2023). Video content creation technology to provide web resources for distance learning and evaluation, using qualimetric tools. Learning in the Age of Digital and Green Transition: Proceedings of the 25th International Conference on Interactive Collaborative Learning (ICL2022), 2, 319-327. https://doi.org/10.1007/978-3-031-26190-9_33

13. Yelnykova, H. (2022). Qualimetric approach for new valeological disciplines assessing in Ukrainian electrical and power engineering education. IEEE 4th International Conference on Modern Electrical and Energy System, pp. 1-5. https://doi.org/10.1109/MEES58014.2022.10005712
14. Yelnykova, H. & Ryabova, Z. (2021). Adaptive Technologies for Training of Specialists. IOP Conf. Ser.: Mater. Sci. Eng. 1031, 012-125. https://doi.org/10.1088/1757-899X/1031/1/012125
15. Kiporenko, A. (2016) The implementation of European standards of higher education in the teaching of technical disciplines for future engineers-teachers. Problems of Engineer-Pedagogical Education, 52-53, 45-53.
16. Hrinchenko, H., Kovtun, O., Mykolaiko, V. (2023) Implementation in the educational process a systematic approach to teaching the principles of sustainable development. Monograph "Modern approaches to ensuring sustainable development", The University of Technology in Katowice Press, 33-42. https://doi.org/10.54264/M020
17. Liu, Y., Huang, B., Guo, H. et al. (2023). A big data approach to assess progress towards Sustainable Development Goals for cities of varying sizes. Commun Earth Environ, 4, 66. https://doi.org/10.1038/s43247-023-00730-8
18. Xu, Z., Chau, S.N., Chen, X. et al.(2020). Assessing progress towards sustainable development over space and time. Nature, 577, 74–78. https://doi.org/10.1038/s41586-019-1846-3
19. Liu, Y., Du, J., Wang, Y., Cui, X., Dong, J., Hao, Y., Xue, K., Duan, H., Xia, A., Hu, Y., Dong, Z., Wu, B., Zhao, X., & Fu, B. (2021). Evenness is important in assessing progress towards sustainable development goals. National Science Review, 8(8), nwaa238. https://doi.org/10.1093/nsr/nwaa238
20. Sabia, G., Mattioli, D., Langone, M., & Petta, L. (2023). Methodology for a preliminary assessment of water use sustainability in industries at sub-basin level. Journal of Environmental Management, 343(118163), 118163. https://doi.org/10.1016/j.jenvman.2023.118163
21. Sara Toniolo, Chiara Pieretto, Daniela Camana, (2023) Improving sustainability in communities: Linking the local scale to the concept of sustainable development, Environmental Impact Assessment Review, 101, 107-126. https://doi.org/10.1016/j.eiar.2023.107126
22. Correia, E.; Garrido-Azevedo, S.; Carvalho, H. (2023) Supply Chain Sustainability: A Model to Assess the Maturity Level. Systems, 11, 98. https://doi.org/10.3390/systems11020098