Ensuring sustainable education through the management of higher education quality indicators

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Abstract. The study is devoted to a multicriteria assessment of the quality indicators of the educational environment sustainability of higher education institutions (HEIs) for the purpose of their effective management. The educational environment is a complex system that has many quality indicators that change over time and have a deterministic and random component. To effectively evaluate such systems, it is necessary to use the tools of mathematical statistics and the principles of qualimetrics. Criteria can have different scales and ranges of measurement, and in order to obtain a comprehensive indicator of the quality of the educational environment, it is necessary to convert all criteria into a single evaluation scale. This makes it possible to integrate them into a single statistical array, considering them as an indicators' system. A system of nonlinear functional dependencies with a stepwise form is proposed. The choice of a particular dependence for converting the criteria into a dimensionless scale depends on the significance of each of them. For each criterion, the panel of experts selects a specific dependency. As a calculations result, the quality indicators (F_I) scores were obtained on a dimensionless scale (0.1).

1 Introduction

For effective management of both educational and production processes, it is necessary to have a clear understanding of the indicators that affect the achievement of the result and the possibilities to influence these indicators. Ensuring the sustainability of education for effective development at the level of higher education institutions allows institutions to increase their competitiveness among educational institutions, improve their ratings in international communities, and become competitive for partnerships and investments.

Sustainability of education is achieved by setting clear goals for achieving certain quality indicators of the educational environment and developing a strategy for managing them.

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The educational environment is a large, complex, open, dynamic, socio-economic system influenced by many exogenous and endogenous factors. As a result, assessments of the quality of the educational environment change over time and have a deterministic and random component. For effective evaluation of such systems, it is necessary to use the mathematical apparatus of mathematical statistics and the theory of qualimetry.

The educational environment is characterized by many criteria. Criteria may have different scales and measurement ranges, for example, the number of published papers, the amount of money received as a result of grant activities, student performance, the citation index of scientific publications, the percentage of employed graduates, material equipment, etc. Assessment of the quality of the educational environment as a multicriteria system requires bringing individual criteria to a single evaluation scale to assess an integral quality indicator. Such an approach will allow combining all indicators and criteria into a single set of statistics and treating them as a single system in order to obtain a comprehensive indicator of the quality of a particular educational environment (department, faculty, educational institution, etc.).

In the current context marked by continuous modernization of education and heightened efforts to enhance the quality of the educational environment in alignment with European and international standards, there is a need for a thorough evaluation of the educational environment's quality. Evaluation and analysis of the quality indicators of the educational environment allows making the right management decisions and identifying critical points and risks of the existing educational environment. Analytics of the quality of the educational environment as a complex of variable indicators allows to predict future activities, respond to changes in time, adapt to new requirements and improve it

2 Analysis of recent research and publications

Currently, there is a significant number of ranking assessments of higher education institutions in Ukraine: "Top 200 Ukraine", "Scopus", "External Independent Evaluation Score for Contract", etc., which use various criteria and indicators to assess the quality of the educational environment and sustainability of the education through a system of specific criteria and indicators. Such rankings are largely based on international qualimetric assessment systems, such as: QS World University Rankings, which includes 6 indicators that can be consider as an quality of the educational environment (Reputation of the HEIs, stakeholders, teacher/student ratios, foreign student/foreign lecturer ratios, citation); Ranking Web or Webometrics (publication ratio); The Times Higher Education Impact Rankings, based on the analysis of success in delivering the United Nations' Sustainable Development Goals (research, stewardship, outreach and teaching); QS Graduate Employability Rankings, which is based on the assessment of higher education institutions by graduate employment opportunities.

The methodology of rating assessment of higher education institutions is based on well-known qualimetric methods and approaches to assessing the quality of the educational environment according to certain criteria. Scientists in various fields and directions are developing such methods used for different purposes. For instance, in references [1-5], the authors suggest methodologies for qualimetric evaluation of both production and educational processes. They delve into assessing the likelihood of the risk of low-quality products and disease, especially highlighting the case of Covid-19, using a stochastic variable probability function.

Authors in references [6-9] elaborate on the application of qualimetric approaches and principles to assess the quality of processes in the energy sector. Using multifactor analysis, the factors affecting the quality of operation of individual processes/elements and systems of power facilities are investigated.

The issues of assessing the quality of education are addressed in works [10-12], which consider the technology of building factor-criterion models. The methodology relies on the numerical interpretation of outcomes derived from expert evaluation methods. In reference [10], a collection of criteria is introduced for the expert assessment of electronic resources. This set of criteria facilitates the remote determination of their quality during specific competitions. The proposal suggests applying this toolkit to rank other educational process resources with quality attributes, such as educational video content, as outlined in references [11, 12].

The construction of factor-criterion analysis as an application of one of the qualimetric techniques is used by the authors [13, 14] to assess the quality of individual competences in order to obtain an assessment of students' success in the formation of competences and to establish the minimum acceptable level of their formation.

The employing qualimetric monitoring for evaluating the quality of educational processes serves as a potent management tool. And these tools are aimed at effective management for sustainable development according to certain indicators. It allows to track dynamic changes in the state of resources of the educational process and, using statistical data processing methods, helps to identify their impact on the final educational outcome [15-18]. Likewise, references [19-21] suggest utilizing assessment results for the purpose of managing and enhancing the quality of the educational environment.

However, if we consider the educational environment as a complex of heterogeneous indicators that have the properties of dynamically changing and have different characteristics and parameters, like any multi-process and multi-component system that functions and develops, then there are still issues of its integral multi-criteria assessment. This approach will make it possible to comprehensively assess the quality indicators for a higher education institution, while managing the sustainability of education by individual indicators.

3 Results

For the effective management of sustainability indicators in education, it is very important to identify and systematise them according to certain characteristics. As mentioned earlier, indicators of educational sustainability have different properties, namely the diverse nature of the processes that take place in the educational environment. Due to the diverse nature of the processes within the educational environment, indicators of their quality have different optimal values, characteristics, units and patterns of behaviour. Consequently, it can be categorized the quality indicators of processes into four broad groups:

– A category of quality indicators where the optimal (best) value should be minimized. Examples include the number of expelled students, unemployed applicants, unaccredited programs, uncertified teachers, etc. In this context, smaller values of these indicators are considered better.

– A set of quality indicators where the optimal (best) value should be maximized. This includes metrics such as citation index, academic performance of applicants, and funds obtained from grant activities. Here, higher values of these indicators are considered more favorable.

– Quality indicators falling within a category where the optimal (best) value is sought to be at an average level. Examples include the optimal distribution of teaching load, adherence to the budget plan for research activities, and maintaining ergonomic and environmental parameters in the educational institution (such as air temperature, humidity, etc.). Typically, these indicators aim for values within the middle of the tolerance range.

– Quality indicators forming a category where the optimal (best) value simultaneously aims for both maximum and minimum values.

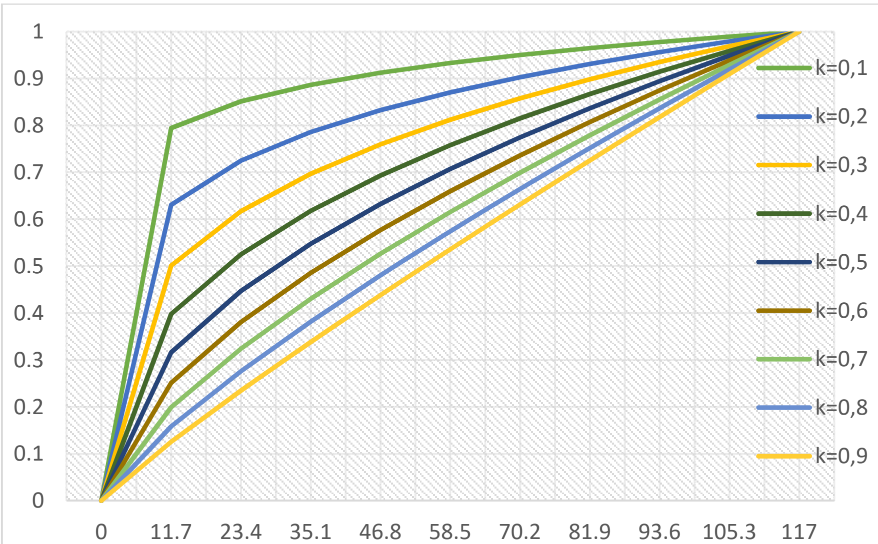
Examples include achieving the highest productivity at the lowest cost and equipping the educational institution with materials within limited space. To effectively evaluate such heterogeneous indicators of the quality of the educational environment, it is necessary for all indicators to be in a unified system of coordinates. To do this, it is needed to use a tool that allows obtaining quality scores on a non-dimensional scale.

It is clear from the theory of qualimetry that the measurement values of quality indicators do not depend linearly on their assessment. Thus, to convert the multivariate indicators to a non-dimensional scale, it is recommended to use nonlinear functional dependencies, since each of the indicators is related to its score to a different extent [12-15]. In addition, this relationship is not uniform over the measurement range. It is suggested to use a system of nonlinear functional dependencies that have a step form.

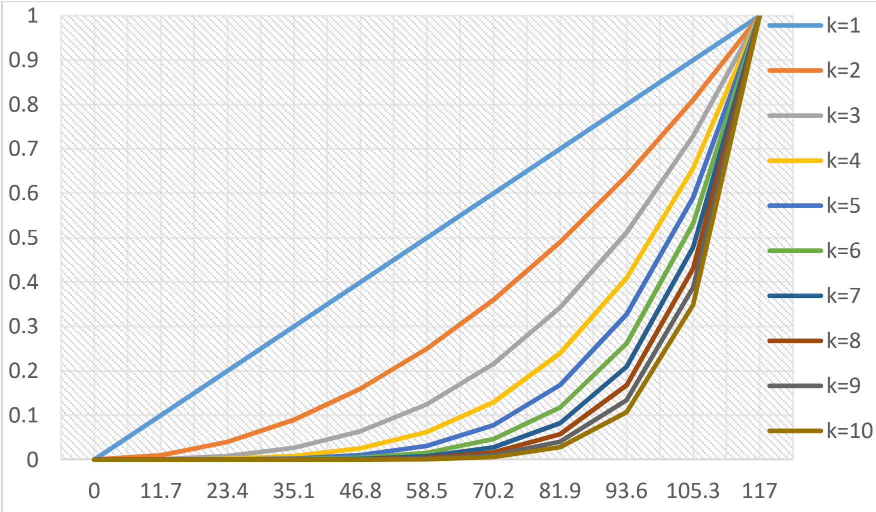
$$F_I = \left[\left(I_q - I_{qmin}\right)/\left(I_{qmax} - I_{qmin}\right)\right]^k \quad (1)$$

where, I_q – actual assessment of the investigated quality parameter; I_{qmin} - minimum possible value of a quality parameter; I_{qmax} - maximum possible value of a quality parameter; k – form indicator that determines the significance of the parameter. The k-indicator makes it possible to increase or decrease the quality requirements for a certain parameter and thus regulate the requirements within the system. In fact, for the most important parameters, a k-indicator will be applied, which reduces the score on a non-dimensional scale, and vice versa to increase the score. When the 'k' indicator changes from 0.1 to 1 (in increments of 0.1), the functional dependencies exhibit an upward concave shape (Figure 1a). Conversely, when the 'k' indicator is adjusted from 1 to 10 in increments of 1, the functional dependencies display a downward concave shape, as illustrated in Figure 1b.

The figures are built for a specific quality indicator for which I_{qmin} =0; I_{qmax} =117. This is a special case, demonstrated by the example of assessing the total h-index of an educational institution (the maximum value is given according to SciVerse Scopus database in April 2023 for Ukrainian higher education institutions), that allows building a system of interdependencies for further analysis.



(a)



(b)

Fig.1. View of the dependence (1) under the condition: (a) form parameter k varies from 0.1 to 1 in steps of 0.1; (b) form parameter k varies from 1 to 10 in steps of 1.

A team of experts will designate a specific relationship for each indicator. By analysing the slope and choosing the form of dependence for a particular parameter, experts make a decision on its assessment, which serves as a useful tool for improving decision-making efficiency.

To determine the parameter *k*, a well-known method of expert evaluation is recommended [21]. Having considered various forms of the Delphi method (preference, ranking, pairwise comparison and sequential comparison), it has been chosen the preference method, which is associated with the convenience of application in the case when experts are freelancers and their distraction from additional expert work is crucial. In this method, the results of the expert survey are collected, and the weighting coefficient of the quality indicator is calculated using the equation (2):

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

Using the weighting matrix, the total value for all parameters and all experts is calculated (denoted as x_{ij}, where *i* represents the *i*-th indicator and *j* represents the *j*-th expert). The coefficient of agreement, as determined by the equation, functions as an assessment of the consistency of opinions among the experts (3):

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

where, *N* is the number of experts who give an assessment, *n* is the number of parameters to be evaluated, *y* is the deviation from the average sum of ranks for the *i*-th parameter, which is calculated as follows (4):

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

where, $\sum_{j=1}^{N} r_{ij}$- sum of the ranks of each parameter; r_{ij} - rank of the *i*-th parameter in the *j*-th expert; $T = N\left(\frac{n+1}{2}\right)$ is average rank sum. If any of the parameters have the same rank, the concordance coefficient is determined by the equations (5-6):

$$v = \frac{\sum_{i=1}^{n} y_i^2}{\frac{1}{12}N^2(n^2-n)-N\sum_{j=1}^{N} T_j} \quad (5)$$

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

Value of the concordance coefficient could be considered satisfactory at V = 0.5 - 0.6; V=0 means that there is no agreement in the opinions of experts, and at V = 1 there is complete agreement.

The results of the application of qualimetric methods for multicriteria assessment of the quality of the educational environment on the example of four parameters (Table1).

Table 1. Assessment results of selected parameters of the quality of sustainable education.

Indicator (Parameter of the quality)	I_{qmin}	I_{qmax}	I_q	k	F_I
Total h-index of the educational institution (the maximum value is given according to the SciVerse Scopus database in April 2023 for Ukrainian higher education institutions)	0	117	12	0.3	0.5
The amount of financial receipts based on the results of scientific activities, thousand UAH	0	2468.7	659.9	0.2	0.77
Employed graduates, %.	0	100	52.8	0.4	0.78
Number of defended dissertations per year (the maximum value was chosen for the last 5 years)	0	33	1	0.5	0.17

Table 1 displays results indicating that quality indicators exhibit distinct characteristics, and the results of expert assessments show that experts chose different form parameters for individual indicators, which allowed them to obtain altimetric indicators (F_I) on a dimensionless scale (0.1) and determine a comprehensive indicator of the overall quality of sustainable education. Using the proposed approach makes it possible to obtain a comprehensive multi-criteria assessment that changes over time by obtaining functionally dependent statistics and automate the assessment process. The methodology does not require constant participation of an expert; it is enough to select a particular dependency once and it will work in an automated mode.

Simply introducing new measured criteria for the educational environment would suffice to obtain comprehensive, singular evaluations of quality indicators as well as assessments over time.

4 Conclusions

The research presents a comprehensive analysis of qualimetric methods for evaluating diverse objects. Through the analysis, the study identifies the characteristics of processes that influence the quality of the educational environment, which serves as the object of qualimetry. The study proposes the use of nonlinear dependencies between the quality indicators of education sustainability and their scores on a non-dimensional scale to facilitate a multicriteria assessment of the educational environment.

Accordingly, models have been created to generate non-dimensional estimates of parameters in the educational environment. The main results presented in the article are as follows:

(a) The features of educational environment processes for qualimetric assessment of sustainability are determined.

(b) To evaluate systems with quality parameters characterized by multi-criteria, it is proposed to use a nonlinear dependence for assessment on a non-dimensional scale.

(c) To address specific tasks, various parametric forms that describe processes and allow for more accurate evaluation are proposed. The selection of a particular form enables experts to make more informed decisions regarding quality management and ensuring the sustainability of education.

(d) To determine the steepness of the form, it is recommended to use the expert assessment method, which can be automated in the future, significantly reducing evaluation time and eliminating the subjective influence on the assessment.

Further development of the research is to collect statistical data and process the results of indicators of the quality of the educational environment over time to develop an effective mechanism for influencing the overall quality management system of the educational institution and sustainability of education. System analysis and qualimetric assessment of the educational environment as a complex and multifaceted object makes it possible to implement a successful strategy for the sustainability of an educational institution, take into account risks and develop adaptive management technologies.

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