RIGA TECHNICAL UNIVERSITY

**Antra Kalnbaļķīte**

# SUSTAINABLE DEVELOPMENT OF ENVIRONMENTAL ENGINEERING EDUCATION

Summary of the Doctoral Thesis

RTU Press
Riga 2023

**RIGA TECHNICAL UNIVERSITY**
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**Summary of the Doctoral Thesis**

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# DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for defence at the open meeting of RTU Promotion Council on 03.11.2023., at 14:00, at the Faculty of Electrical and Environmental Engineering of Riga Technical University, 12/1 Āzenes Street, Room 115.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for review to Riga Technical University for promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Antra Kalnbaļķīte ……………………………. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an introduction, three chapters, conclusions, 39 images, and 33 tables; the total number of pages is 230. The bibliography contains 262 titles.

# CONTENTS

# INTRODUCTION

## Topicality of the Doctoral Thesis

Environmental education plays a crucial role in sustainable development and achieving the objectives of the Green Deal on climate neutrality. Environmental education is at the forefront of sustainable and resource-efficient development. Green innovations and transforming existing technologies can be achieved through education and transformative knowledge to build sustainable societies. The successful deployment of sustainable technologies requires new skills from higher education graduates, workers, entrepreneurs and policymakers based on a revised model of intellectual development and knowledge-based technology innovation. Intellectual capital acquired through the knowledge-based bioeconomy became crucial in the European Union's development agenda. Therefore, the bioeconomy's implementation in Europe will be closely linked to education and research.

The Green Deal sets ambitious targets for European Member States: to strive for climate neutrality by 2050, with a particular focus on many sectors that play a crucial role in achieving its goals: clean energy, sustainable industry, construction and renovation, sustainable mobility, biodiversity, *farm to fork* and pollution prevention. Implementing the objectives of the Green Deal and the bioeconomy demands a systematic approach, considering different stakeholder groups. Creating greener technologies involves technological feasibility through well-prepared, high-quality human resources, equipment and laboratories. In addition, it requires innovation-driven learning and the acquisition of specific skills.

Environmental education, including academic higher education, lifelong learning and scientific creativity, should adapt to the changing realities of different industrial sectors. It requires reassessment regarding its ability to provide relevant training and learning conditions, methods, strategies and taught skills and competencies. A new assessment methodology should be developed based on a combination of different methods for evaluating the education process.

## The Aim and Tasks of the Doctoral Thesis

To achieve the goals set by the European Union, it is necessary to understand the directions of sustainable educational development. The assessment of the current situation and potential opportunities for the development of environmental engineering is an important step in the process.

To achieve the goal of the study, the following tasks were set:

1) Analyse and evaluate the current situation in academic higher education concerning potential opportunities for implementing environmental engineering study programmes using innovative methods, aids and tools.

2) Develop a lifelong learning study framework to achieve the Green Deal and climate neutrality objectives by promoting co-creation, performance and policy integration.
3) Integrate scientific innovation to strengthen competence- and knowledge-based sustainable higher education, ensuring the development and commercialisation of innovative ideas.

## Hypothesis of the Doctoral Thesis

Multifaceted methods are necessary for continuous knowledge- and competence-based sustainable assessment and analysis of environmental engineering education at three levels: academic higher education, lifelong learning, and scientific creativity.

## Scientific Significance of the Doctoral Thesis

With the help of six different mathematical tools (multi-criteria decision analysis, study programme evaluation, performance, bibliometric, system dynamics, qualitative research), seven modules have been developed, analysed and approbated to assess the potential and opportunities of the sustainable development of environmental engineering education:

1) ranking module;
2) innovative study process module;
3) co-creation implementation module;
4) behaviour module;
5) diplomatic relations module;
6) distance learning module;
7) scientific innovation transfer module.

## Practical Significance of the Doctoral Thesis

The Thesis is of great practical importance in the Latvian and European context, as it illustrates the possibilities of environmental engineering to involve a wide range of specialists who need this knowledge in all sectors of the national economy and all layers of society, from the individual level to the level of enterprises, municipalities and government. The study provides practical proposals for the improvement of environmental engineering education in all three dimensions:

1) Academic higher education study programmes are implemented at Riga Technical University and can be used for the development of sustainable knowledge and competence-based higher education in the future in various study programmes at other universities.
2) Lifelong learning is essential for entrepreneurs and workers looking for new skills and competencies.

3) Scientific creativity is the basis for the development of innovations to create innovative technologies, develop start-ups, and encourage engineering research in doctoral studies and research in the field of environmental engineering in Latvia and Europe.

## Approbation of the Research Results

The Doctoral Thesis results have been presented at nine conferences and in 11 scientific publications.

1. Kalnbaļķīte, A., Pubule, J., Blumberga, D. Education for Advancing the Implementation of the Green Deal Goals for Bioeconomy // International Scientific Conference of Environmental and Climate Technologies – CONECT 2022, Riga Technical University, 2022.
2. Kalnbaļķīte, A., Červinska, E., Blumberga, A., Pubule, J. Development of Massive Online Open Course 'Energy Transition and Climate Change' // International Scientific Conference of Environmental and Climate Technologies – CONECT 2022, Riga Technical University, 2022.
3. Kalnbaļķīte, A., Vēciņa, A., Žihare, L., Rozakis, S., Blumberga, D. Biodiplomacy Attractiveness in Bioeconomy Education. Case Study // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.
4. Kalnbaļķīte, A., Patel, N., Blumberga, D. An Analysis of the Extraction Technologies: Fruit Peel Waste Study // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.
5. Kalnbaļķīte, A., Zlaugotne, B., Žihare, L., Balode, L., Khabdullin, A., Blumberga, D. Multi-Criteria Decision Analysis Methods Comparison // International Scientific Conference of Environmental and Climate Technologies – CONECT 2020, Riga Technical University, 2020.
6. Kalnbaļķīte, A., Pubule, J., Blumberga, A., Rozakis, S., Vēciņa, A., Blumberga, D. Education for Advancing the Implementation of the Bioeconomy Goals: An Analysis of Master Study Programmes in Bioeconomy // International Scientific Conference of Environmental and Climate Technologies – CONECT 2020, Riga Technical University, 2020.
7. Kalnbaļķīte, A., Pubule, J., Teirumnieka, Ē., Blumberga, D. Evaluation of the Environmental Engineering Study Programme at University // International Scientific Conference of Environmental and Climate Technologies – CONECT 2019, Riga Technical University, 2019.
8. Rozentāle, L., Kalnbaļķīte, A., Blumberga, D. Aggregator as a New Electricity Market Player: Case Study of Latvia // 2020 IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020).

9. Valtere, M., Kalēja, D., Kudurs, E., Kalnbaļķīte, A., Terjaņika, V., Zlaugotne, B., Pubule, J., Blumberga, D. The Versatility of the Bioeconomy. Sustainability Aspects of the Use of Bran. // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.
10. Gerinoviča, S., Blumberga, D., Kalnbaļķīte, A., Vēciņa, A. To Be, or not to Be – the Question of Forestry Resources in Bio-Diplomacy // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.

## Publications by the Author


1. Zlaugotne, B., Žihare, L., Balode, L., **Kalnbaļķīte, A.,** Khabdullin, A., Blumberga, D. Multi-Criteria Decision Analysis Methods Comparison. Environmental and Climate Technologies, 2020, Vol. 24, No. 1, pp. 454–471. ISSN 1691-5208. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2020-0028
2. Pubule, J., **Kalnbaļķīte, A.,** Teirumnieka, Ē., Blumberga, D. Evaluation of the Environmental Engineering Study Programme at University. Environmental and Climate Technologies, 2019, Vol. 23, No. 2, pp. 310–324. ISSN 1691-5208. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2019-0070
3. Pubule, J., Blumberga, A., Rozakis, S., Vēciņa, A., **Kalnbaļķīte, A.,** Blumberga, D. Education for Advancing the Implementation of the Bioeconomy Goals: An Analysis of Master Study Programmes in Bioeconomy. Environmental and Climate Technologies, 2020, Vol. 24, No. 2, pp. 149–159. ISSN 1691-5208. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2020-0062
4. **Kalnbaļķīte, A.,** Brakovska, V., Terjanika, V., Pubule, J., Blumberga, D. The tango between the academic and business sectors: use of co-management approach for the development of green innovation. Innovation and Green Development, 2023**,** Vol. 2, No. 4, p. 100073, ISSN 2949-7531, Available: https://doi.org/10.1016/j.igd.2023.100073.
5. Vēciņa, A., **Kalnbaļķīte, A.,** Žihare, L., Rozakis, S., Blumberga, D. Biodiplomacy Attractiveness in Bioeconomy Education. Case Study. Environmental and Climate Technologies, 2021, Vol. 25, No. 1, pp. 1205–1214. ISSN 1691-5208. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2021-0091
6. Gerinoviča, S., Blumberga, D., **Kalnbaļķīte, A.,** Vēciņa, A. To Be, or Not to Be – the Question of Forestry Resources in Bio-Diplomacy. Environmental and Climate Technologies, 2021, Vol. 25, No. 1, pp. 1337–1346. ISSN 1691-5208. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2021-0101
7. Červinska, E., Blumberga, A., **Kalnbaļķīte, A.,** Pubule, J. Development of Massive Online Open Course 'Energy Transition and Climate Change'. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp. 1106–1117. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2022-0083

8. **Kalnbaļķīte, A.,** Pubule, J., Blumberga, D. Education for Advancing the Implementation of the Green Deal Goals for Bioeconomy. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp. 75–83. ISSN 1691-5208. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2022-0007
9. Valtere, M., Kalēja, D., Kudurs, E., **Kalnbaļķīte, A.,** Terjaņika, V., Zlaugotne, B., Pubule, J., Blumberga, D. The Versatility of the Bioeconomy. Sustainability Aspects of the Use of Bran. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp. 658–669. e-ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2022-0050
10. Patel, N., **Kalnbaļķīte, A.,** Blumberga, D. An Analysis of the Extraction Technologies: Fruit Peel Waste. Environmental and Climate Technologies, 2021, Vol. 25, No. 1, pp. 666–675. ISSN 2255-8837. Available: https://doi.org/10.2478/rtuect-2021-0050
11. Rozentāle, L., **Kalnbaļķīte, A.,** Blumberga, D. Aggregator as a New Electricity Market Player: Case Study of Latvia. In: 2020 IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020): Proceedings, Latvia, Riga, 5–7 November 2020. Piscataway: IEEE, 2020, pp. 507–512. ISBN 978-1-7281-9511-7. e-ISBN 978-1-7281-9510-0. Available: https://ieeexplore.ieee.org/document/9316486

## Structure of the Doctoral Thesis

The Doctoral Thesis is a set of eleven thematically related scientific publications published in various scientific journals and available for quotation in several databases of scientific papers. The focus is on assessing the sustainable development of environmental engineering education. The Doctoral Thesis (I) examines the three levels of sustainable environmental engineering education, (II) combines seven developed, analysed and approbated development modules of sustainable environmental engineering education, and (III) involves the use of six research methods.

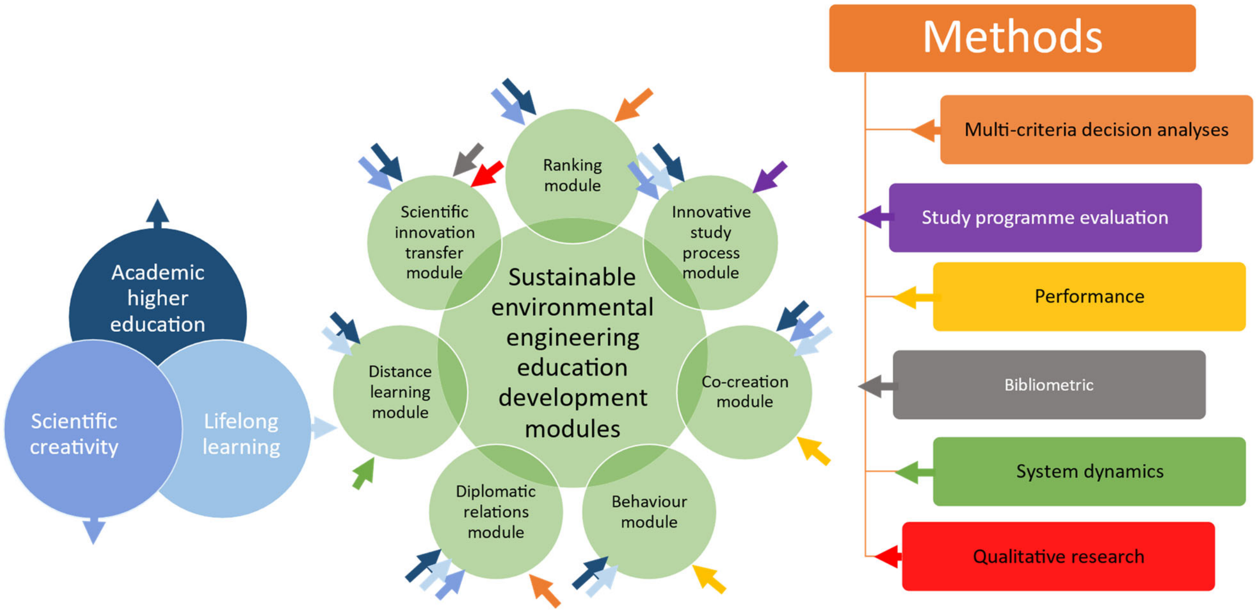



Fig. 1. The structure of the Doctoral Thesis

The Doctoral Thesis consists of an introduction and three chapters: a literature review, research methods and results, and discussions.

In the introduction, the goal and tasks for achieving the goal of the study are outlined. The introduction also puts forward a hypothesis and describes the scientific and practical significance of the Thesis. After that, information is provided on the approbation of research results when participating in international scientific conferences and reflected in scientific publications.

The Doctoral Thesis includes a literature review (Chapter 1), which analyses the sustainable development of environmental engineering, examines and offers innovative teaching and learning approaches, and determines the role of scientific research in environmental engineering education. Chapter 2 describes the research methodologies used in all publications to approbate the modules for the development of sustainable environmental engineering education. Chapter 3 analyses the results of the study achieved using the methods described above. The conclusions are presented after the analysis of the obtained results.

# 1. METHODOLOGY

The Doctoral Thesis uses six research methods to assess the sustainable development of environmental engineering education. Figure 1 illustrates the methods used in the Doctoral Thesis.

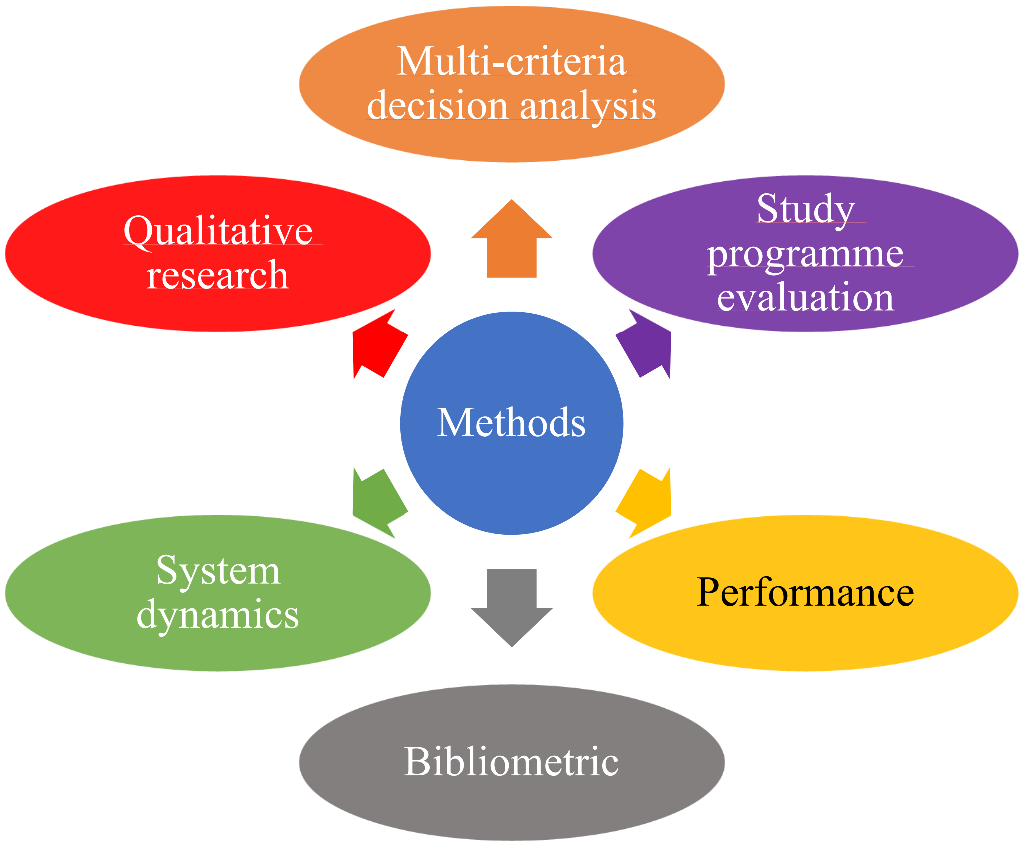



Fig. 1 Thesis methodology.

## 1.1. Multi-criteria decision analysis method

The MCDA method can be used to compare multiple options using different criteria. This method helps to process large amounts of information consistently. MCDA input data can be quantitative and qualitative. MCDA methods can be selected according to their characteristics and requirements.

In the analytic hierarchy process (AHP) method, alternatives are listed and paired according to their contribution to each goal or criterion. Thomas L. Saaty developed this method; it is one of the most popular methods for finding the weight of criteria.

For all the chosen methods, subjective data are the scales of the criteria. The TOPSIS method requires minimal input data, which makes the results comprehensive (the shortest geometric distance to the ideal outcome). The VIKOR method ranks alternatives by proximity to the best solution, and the maximum and minimum values of the criteria affect the result. The COPRAS method considers an alternative performance with the best and the worst values that affect the outcome. Using the MULTIMOORA method, it is possible to determine the goals of conflicting criteria. This method has a ratio system and a method for calculating reference points. The PROMETHEE-GAIA method is based on the calculation of preferential degrees. It shows which alternative would be more suitable for solving the problem and how the weight of the criteria affects the alternative position.

For all the methods chosen, subjective data are the scales of the criteria.

The AHP method is a decision-making system that provides a structured technique to organise and analyse complex decisions based on mathematics and psychology. Initially, the relative importance of the criteria is identified in the AHP algorithm. Reasonable quantitative weights of importance for each criterion are determined. They are calculated with the matrix comparing pairs of criteria. After these calculations, the importance vector – the particular vector of the normalised even criteria matrix – indicates the importance classification of the criteria.

According to the results of AHP, a transition to TOPSIS analysis should be made (Hwang and Yoon developed it in 1981). It is used to make decisions and analyse the significance of goals from various information and data – qualitative and quantitative. TOPSIS uses the distance between the best and worst alternatives to define the importance of suitable options, starting with the most appropriate.

The process of the TOPSIS algorithm begins with the formation of a decision matrix, which reflects the value of satisfaction of each criterion with each alternative. Further steps include normalising the matrix with the desired normalisation scheme and multiplying the matrix by benchmark weights from AHP analysis. After, positive-ideal and negative-ideal solutions are calculated, and the distance of each alternative to these solutions is calculated by distance measurement. Only the alternative from the positive ideal solution should be reported, and the alternatives should be ranked based on relative proximity.

## 1.2. Study programme evaluation method

The study programme evaluation method is used for a more in-depth study process analysis. The first part of the method identifies and analyses the current situation, based on the review of the literature on teaching methods, assessment methods, competencies and indicators that are used to assess study programmes. The analysis of the rules and legal framework is carried out, as well as a compilation of study programmes. The second part defines the purpose and scope of the study programme and its problem. Next, it identifies and selects the most significant indicators that influence the variables that, in turn, affect the transition to competency-based education. Considering the most influential factors for the variables, it is possible to define new and effective competencies, teaching methods and assessment methods.

## 1.3. Performance method

Environmental engineering students must master not only the development of engineering and technological solutions, but also work on the ability to analyse and present these solutions to the public. Therefore, an essential role in education is played by using performance or the performance method. This method teaches students to pay attention to an activity and distinguish important problems from unimportant ones. The performance method is used in role-playing games.

The method involves three stages:

1. At the preparatory stage, students acquire preliminary knowledge in a particular area or problem.
2. The role-playing stage consists of analysing the current situation, proposals and solutions, public consultation and decision-making. The role-playing aims to increase stakeholders' knowledge and understanding of the sustainable development of the sector concerned, its objectives and their achievement.
3. The post-game stage provides feedback to students and discusses the performance of the student and the student group in separate episodes, justifying the level achieved by the students.

In the performance assessment, a rubric (Table 1.1) is used, by which the criteria for assessing biodiplomacy competence are evaluated. The selected number of criteria is adjusted according to the specific competence since the proposed range of criteria is wide. It is preferable to use four criteria since the most appropriate and targeted criteria for a given competence should be chosen from a wide range of possible criteria. Competencies are evaluated from 1 to 4, where level 1 reflects only a small activity (inaccurate, mediocre, incomplete achievement of competence). Level 2 sets the direction towards the general achievement of competence. Level 3 determines the achievement of competence, where the student's participation is accurate. Level 4 indicates that the student is competent and can analyse complex systems.

Table 1.1

The General Form of the Rubric on Performance Evaluation

| | **Trying to achieve/not achieve** | **Approaching** | **Comply** | **Exceeds the requirements** |
|---|---|---|---|---|
| **Evaluation criteria** | 1 | 2 | 3 | 4 |
| | The student's activities are inaccurate and approximate. Performance can only be partially attributed to the acquired competence. | The student's performance is generally usually related to the competence to be acquired. | The student's performance is accurate based on judgments about this criterion. | The student's performance is accurate and convincing; it shows the limitations and complexity of competence. |

## Performance method in combination with technology readiness level

The performance method is used to evaluate the participants identified during the implementation of the co-creation. In conclusion, the level of readiness of the proposed technologies is determined.

The technology readiness level (TRL) is a method used to assess the maturity phase of a new idea and the necessary actions in its development. TRL consists of 9 levels, which can be considered a measurement of such an assessment. The advantages of this method are a structured and comprehensive view of the status of the prototype in its research and production process. The TRL method is aimed at developing and testing prototypes in their real application environment and is divided into 3 phases:

1) research;
2) prototype development;
3) product introduction.

A summary of the TRL methodology according to the study is provided in Table 1.2.

Table 1.2

TRL Summary

| TRL | Description | Goal | Product/evaluation |
|---|---|---|---|
| 1 | Introduction to the current situation and goals of the project | Research | The feasibility of conception |
| 2 | Defining research questions | Research | The feasibility of conception |
| 3 | Analytical research and literature review | Development | Prototypes |
| 4 | The core components are integrated to test the operational capability of the project. | Development | Prototypes |
| 5 | Core components are integrated to test project performance | Development | Prototypes |
| 6 | Building a representative prototype | Development | Prototypes |
| 7 | Prototype testing | Implementation | Prototypes |
| 8 | Research project to complete the project | Implementation | Certified product |
| 9 | Launch of the product | Implementation | Deployed product |

The method assesses the development of cooperation between the academic sector and the industry aimed at training qualified environmental scientists to develop green innovations that meet the requirements of the national economy.

## 1.4. Bibliometric method

The method of bibliometric analysis is widely used to analyse volumes of scientific data. Researchers use this method to identify trends in the performance of various publications and journals. This method allows to study the intellectual structure of a particular area in the existing literature. Bibliometric analysis is especially useful when the report's scope is extensive, and the dataset is too large to be analysed manually.

Databases such as SCOPUS, Web of Science, and Google Scholar can be used as tools to find data for bibliometric research. Databases differ in the volume of publications, methods of built-in analysis tools and the areas of research covered. For example, Google Scholar has the most comprehensive data coverage in all fields, while SCOPUS and Web of Science are used explicitly in engineering.

The research method consists of selecting articles from the Scopus database, processing papers using the bibliography visualisation program *VOSviewer*, analysing results and drawing conclusions (see photo and Fig. 1.1).

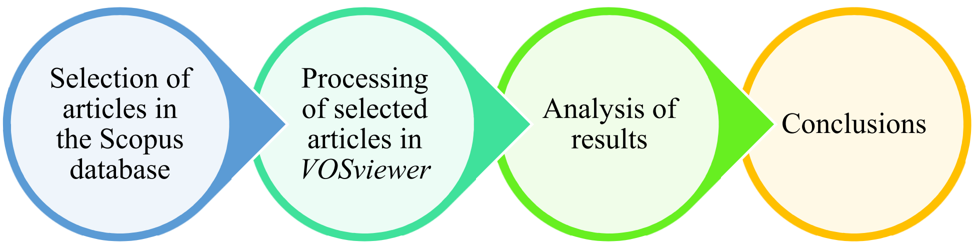



Fig. 1.1. Bibliometric method.

The studies were selected using the Scopus database and entering "Article title, Abstract, Keywords" in the search fields of the word combination. These word combinations are:

1. "*Education*" *AND "Bioeconomy"*;
2. "*Education*" *AND "Bioeconomy" AND "Competences"*;
3. "*Education*" *AND "Bioeconomy" AND "Innovation"*;
4. "*Education*" *AND "Bioeconomy" AND "Skill'*;
5. "*Education*" *AND "Green deal"*;
6. "*Education*" *AND "Green Deal" AND "Innovation"*.

The articles were selected from 2012 onwards, and keyword "bioeconomy" was shown in the science databases, as bioeconomy targets were set in 2012. If the word combination contained the "*Green Deal*", then the articles were chosen from 2019 onwards , as the Green Deal's goals came into effect in 2019.

## 1.5. System dynamics method

The system dynamics method is an assessment method developed in the late fifties and early sixties of the 20th century at the Massachusetts Institute of Technology. The method focuses on agents or managers as information converters who interpret new information or feedback about the ongoing process and transform it into appropriate subsequent actions.

Casual loop diagrams (CLDs) are developed in *Stella Architect 2.1.5* software. Both supply- and demand-side CCDs in the energy sector were created during the study "Energy Transition Policy Consultation Platform: How to Make Complicated Things Simple", which created an Internet-based interface tool for the national energy simulation model as a "hybrid forum" tool. Considering the occasional loop, the diagrams are transformed into general stock and flow structures. They are used as research tools to explain how several sides of energy supply and demand interact in the energy sector, updating and adapting it to the current situation (see Fig. 1.2).

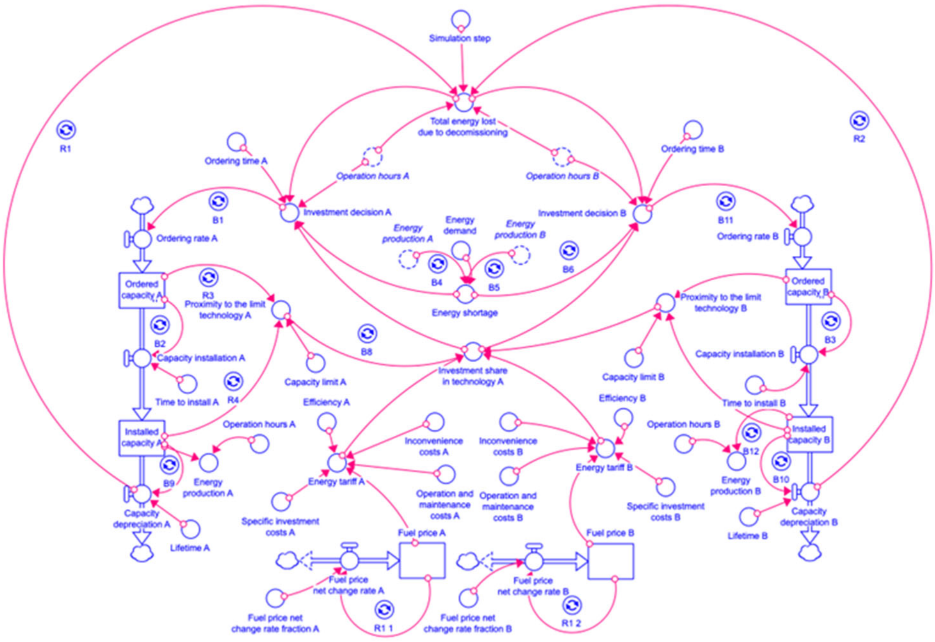



Fig. 1.2. Structure of stocks and flows in the energy supply sector.

## 1.6. Qualitative research methods in environmental engineering

Valuable scientific research leads to innovation and new technologies. Scientific research in environmental engineering has a high added value, as it helps to assess the impact of various processes on the environment and climate change. The development of knowledge-based environmental engineering with the help of scientific research ensures the sustainable development of innovative engineering solutions. Therefore, environmental engineering study programmes include ecological research study courses in two sub-fields of environmental engineering:

– environmental technologies,
– bioeconomy.

This work focuses on qualitative scientific research methods, which are widely used in environmental engineering education programmes. In qualitative scientific research methods, processes are defined herein, and quantitative values do not play a key role since they are used mainly for qualitative comparison. Although quantitative research methods are similar, they are more expensive and require more significant investment in purchasing and maintaining scientific equipment. Four examples of occasional scientific research studies confirm this.

### Integration of the bioeconomy. By-products

The bioeconomy integration study on by-products identifies and evaluates products that can be made using grain by-products. A literature review is initially carried out, and then the multi-criteria analysis method is used.

The multi-criteria analysis method can compare several options using different criteria. This method helps to process large amounts of information consistently. MCDA input data can be quantitative and qualitative. TOPSIS is used to compare different products and determine the optimal option. In the TOPSIS method, the result is obtained from the distance of the alternatives to the ideal point. The alternative with the shortest distance to the ideal point is the best.

The methodology was chosen on the basis of peer-reviewed scientific articles in the field of the bioeconomy and their suitability for this study. To identify and evaluate products that can be made using grain by-products, two methods have been selected – literature review and *MCDA.* The algorithm of action can be described by the following five steps, all of which are important and cannot be omitted to obtain accurate results.

1. Identification of products. The step you need to determine the main product, its necessary characteristics and quality.
2. Collection of information in the available literature and its analysis in order to study in depth the selected product, its availability and diversity on the market.
3. Based on the analysis of the literature, a selection of criteria is required for further analysis. The correct choice of criteria will allow you to comprehensively evaluate the product based on the necessary characteristics. For a technology, these criteria may include its level of readiness, market availability and sustainability.
4. Conducting an analysis of the *MCDA* based on selected criteria.
5. Marketing of the product based on the *results* of the MCDA analysis (Figure 1.3 ).

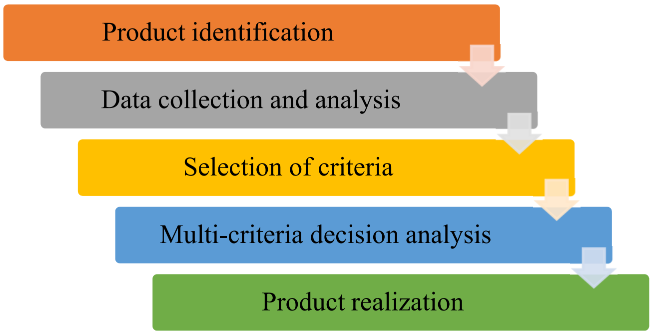



Fig. 1.3. Stages of the method.

**Bioeconomy solutions. Technology**

The study of bioeconomy solutions on technologies compares the performance of four different green extraction methods. For evaluation, a multi-criteria analysis method uses the analytical hierarchy process (AHP) with the preference technique for order of precedence according to the similarity with the ideal solution (TOPSIS*)* method.

The multi-criteria analysis method is used to make decisions and analyse the significance of goals from various types of information and data – qualitative and quantitative data, data from physical and social sciences, politics and ethics to evaluate solutions to problems.

The AHP method divides and analyses problems in a hierarchical structure consisting of a goal, criterion and subcriterion. The AHP methodology was developed by Saaty in 1980. The selected criteria are compared by experts in pairs.

TOPSIS is a popular multi-criteria analysis method developed in 1981 by Hwang and Yoon. The method uses the best and the worst alternatives to define the most suitable alternative.

**Energy demand-side management**

The case study is based on the legal and economic aspects of demand response and compilation and their application to the situation in Latvia.

As J. K. Juferman noted, it is difficult to predict how much traditional production will help ensure flexibility in the future, as this can be entirely based on political decisions as to whether these standard production units will continue to operate (e.g. CHP plants).

The demand response flexibility cannot be based on unpredictable consumer actions since these activities are based on individual interests. A new electricity market participant – the aggregator – has been introduced to organise a clear demand response. Furthermore, Article 17 of Directive 2012/27/EU specifies that:

1) all markets (day-ahead, day-to-day) should be open to demand response, including ancillary services (balancing, backups, etc.);
2) all electricity undertakings or consumers may be required to compensate market participants directly affected by demand response;

3) If compensation is introduced, it shall not constitute an obstacle to demand response and shall only cover costs incurred by suppliers or the supplier balance responsible party.

There are two types of aggregators – independent and combined. A combined aggregator means that the electricity supplier, or balance responsible party or distribution system operator is also an aggregator, so aggregation is an additional function of an existing market participant. On the other hand, an independent aggregator is a separate undertaking that works independently of the aforementioned electricity suppliers, balance responsible parties or system operators. Currently, the combined aggregator is more prevalent in the EU as it is easier for it to enter the market. This is less complicated not only from the legislative point of view but also from the point of view of electricity consumers in cases where the aggregator is the consumer's electricity supplier.

At the same time, the author can argue that the aggregator can be seen as a threat to other market participants, such as electricity suppliers. This means that demand response can be considered as a cost for retailers because:

1. Electricity retailers (balance responsible parties) buy this virtual electricity in the electricity exchange market provided by aggregators. This is not actual electricity but electricity savings at a particular time. Retailers (balance responsible parties) buy this electricity to meet the demand, but they cannot bill consumers for it.
2. The demand response contributes to the physical balancing of the electricity market. However, retailers perceive it as a financial imbalance.

Figure 1.4. reflects all flexibility mechanisms the aggregator provides in different wholesale market segments, where the aggregator can act as a facilitator to offer flexibility where necessary.

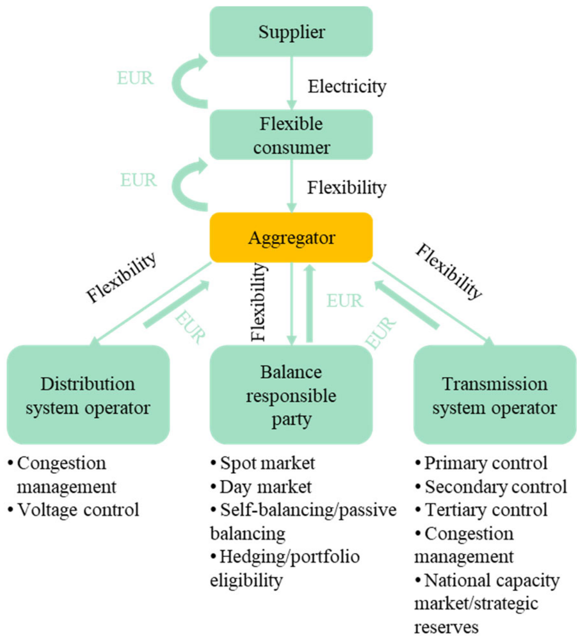



Fig.1.4. Flexibility services provided by the aggregator

Six demand-side ways of managing electricity consumption are illustrated in Fig. 1.5. Combined, these different types of demand management make it possible to relate very closely to production.

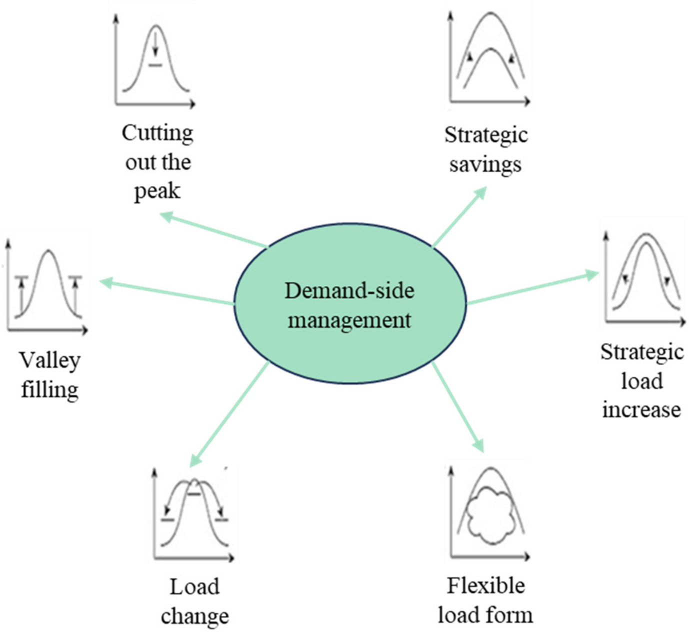



Fig. 1.5. Types of demand-side management.

As electricity demand grows, it can replace part of the production needed to meet the future demand. These types of demand management show us all the opportunities that the aggregator can take advantage of not only shifting the load to another period but also reducing electricity consumption in general through more efficient use of consumer appliances, thus benefiting the EU's climate policy and climate objectives.

# 2. RESULTS AND DISCUSSION

This chapter summarises the results of the methods for the seven environmental engineering education development modules described in the previous chapter. The modules for the sustainable development of environmental engineering are shown in Fig. 2.

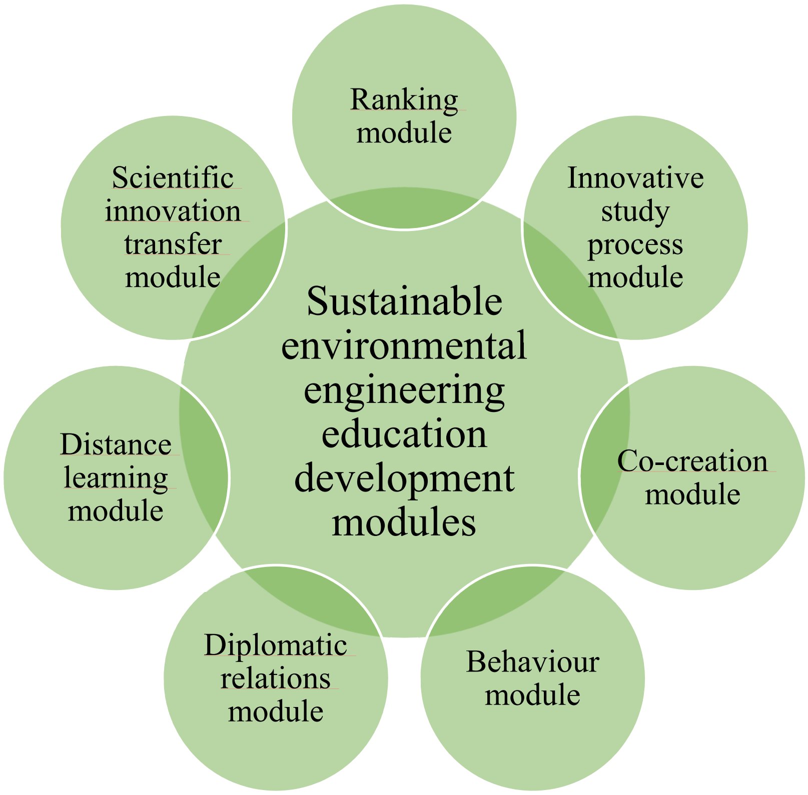



Fig. 2. Approved modules of the Doctoral Thesis

## 2.1. Ranking module

The ranking module helps to compare multi-criteria decision-making analysis methods to select the most appropriate for implementation in future module. A summary of the properties is comparatively described in Table 2.1.

The comparison shows similarities and differences between the methods.

Table 2.1

Summary of MCDA Methods

| | TOPSIS | VIKOR | COPRAS | MULTIMOORA | PROMETHEE-GAIA | AHP |
|---|---|---|---|---|---|---|
| **Normalisation way** | Vector normalisation (square root of the sum (normalisation of L2) | Linear normalisation (L1 normalisation) | Vector normalisation (sum) | Normalisation of vectors (square root of the sum) | Normalisation is carried out automatically | The normalisation of vectors (sum) |
| **Suitability** | Selection problems, ranking problems | Selection problems, ranking problems | Selection problems, ranking problems | Selection problems, ranking problems | Optional problems, ranking problems, and description problems (GAIA) | Selection problems, ranking problems, sorting problems (AHPsort) |
| **Input data** | Ideal and anti-ideal optional weight | The best and worst options weights | The best and worst options weights | The best and worst options weights | Indifference and preference threshold scales | Comparison of a pair on the relationship scale (1–9) |
| **Results** | Complete rank with proximity score for ideal and distance to anti-ideal | Full ranking with a proximity score for the best option | Complete ranking | Complete ranking | Partial and complete order (even degrees of predominance) | Full ranking with results |
| **Preferences feature** | Distance metrics (Euclid distance, Manhattan distance, Chebyshev distance) | Distance metrics (Manhattan distance) | Min Max | Min Max | Ordinary, linear, U-shaped, V-shaped, Level, Gaussian | |
| **Approach** | Qualitative and/or quantitative | Quantitative | Quantitative | Quantitative | Qualitative and/or quantitative | Qualitative |
| **Ranking scale** | 0 to 1 | Positive values | Positive values | Positive values | −1 to 1 | 0 to 1 |
| **The best alternative** | Maximum value | Min value | Max value | Max value | Max value | Max value |
| **Consistency levels** | Without restrictions | Without restrictions | Without restrictions | Without restrictions | 7±2 | 9 |
| **Software** | MS Excel, Matlab,Decerns | MS Excel | MS Excel | MS Excel | Visual Promethee, Decision Lab, D-Sight, Smart Picker Pro | MS Excel, MakeItRational, ExpertChoice, DecisionLens, HIPRE 3+, RightChoiceDSS, Criterium, EasyMind, Questfox, ChoiceResults, 123AHP, DECERNS |

The AHP method compares pairs of criteria by assessing the significance of the criterion over the other criterion. The results are shown in Fig. 3.1. In a pair comparison, value 1 indicates that both criteria are equally important, while value 5 indicates that one criterion is more important than others. Value 9 means that one criterion is the most important. Contrary to the criteria, the comparison values are proportionally opposite. The comparison of the pair was made by three experts in the field of environmental science.

If CR > 10 %, then pair comparisons are inconsistent.

Fig. 2.1 shows all the criteria and their weightings. The most important criterion is the installed electrical capacity, with a weight of 27 %. The next is the criterion of job creation, with a weight of 22 %. The criteria on the levelised cost of electricity and life-cycle $CO_2$ emissions have the most negligible impact on alternatives.

In the TOPSIS method, a significant value is the alternative proximity indicator, which is the final value of the alternative value. Based on the results of the TOPSIS method, the best alternative is a hydroelectric power plant (HPP), followed by a biomass and biogas CHP plant (bioenergy cogeneration). With the VIKOR method, the best alternative is the one with a minimum value. Thus, the best alternative to the method is hydroelectric power plant (HPP), then solar photovoltaic energy.

To compare VIKOR to other methods, it is essential to remember that in VIKOR an important step is to reduce all the criteria for making comparisons.

The COPRAS method is simple. The criteria for weight and index values have the most significant impact on the best alternative. Based on this method, solar PV and hydroelectric power plants (HPP) are the best alternatives. The worst alternative is wind power plants (WPP). Both alternatives have significant differences in their final values, possibly due to each criterion's alternative values.

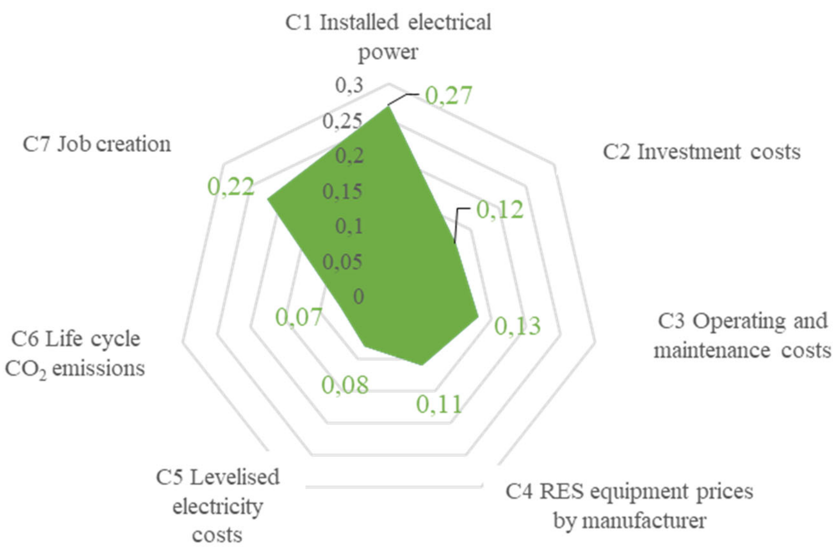



Fig. 2.1. Criteria values and weights.

All final values for each alternative are summarised in Fig. 2.2. The final values are calculated by five multi-criteria decision analyses: TOPSIS, VIKOR, MULTIMOORA, COPRAS, and PROMETHEE GAIA. For the TOPSIS, VIKOR, and PROMETHEE-GAIA methods, the best alternative is an HPP, and after the other two methods – MULTIMOORA and COPRAS – the HPP is ranked second. In the COPRAS and MULTIMOORA methods, solar PV is the best alternative. The most significant influence on the final results comes from criteria, weights and methods, the best alternative definition – the ideal distance of the proximity indicator, the best option of the proximity indicator, the predominance of the pair or ranking with points. The best value of the criteria – minimum or maximum – is also an important indicator.

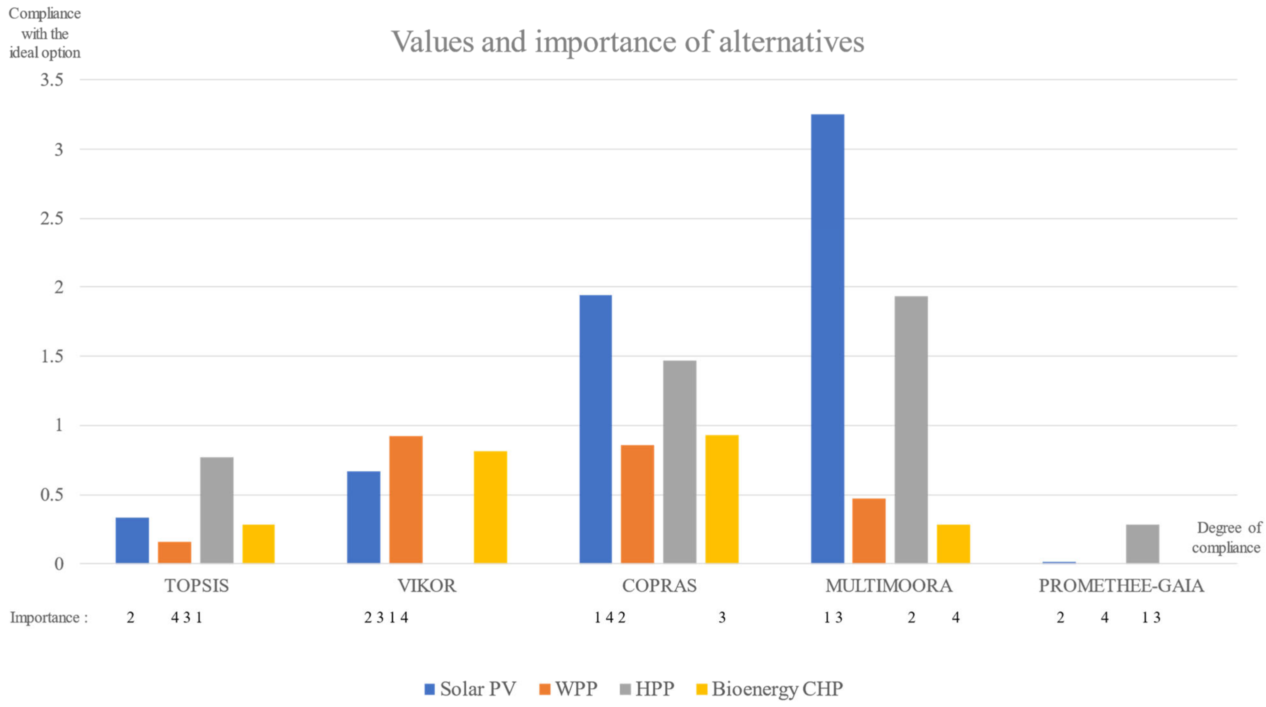



Fig. 2.2. Alternative values and importance.

The results of the MCDA methods are illustrated in Fig. 2.2. These results are evaluated from the best to the worst alternative. With the help of the graph, it is easier to see a trend by which alternatives are ranked higher than others. The best alternative would be a hydroelectric power plant (HPP) and solar PV, as these alternatives are in the first or second place compared to most other alternatives. The lowest ranking is for the alternative to WPP since it is in the last place in three out of five methods.

## 2.2. Innovative study process module

The study programme evaluation method analyses environmental engineering and bioeconomy study programmes.

## Environmental engineering study module

During the study, the experience of several universities in study programme organisation was analysed. As a result of the research, thirteen teaching methods were recognised as suitable for the best results achievement in the study process and providing competence-based environmental engineering education for the master's level of study: anonymous feedback assessment, unified e-learning system (online), survey data collection, group coursework, group tasks, individual research project, lectures, online tasks and term papers, practical laboratories, seminars and workshops, site visits, consultations and role-playing games.

These teaching methods have been applied in the study process in undergraduate and higher study programmes at the Institute of Energy Systems and Environment of Riga Technical University (RTU IESE).

The teaching methods chosen for educational purposes significantly impact the effectiveness of the study process and skills acquisition.

Anonymous feedback evaluation and direct feedback from students can be a valuable and effective method for improving the study process, especially in competency-based education, where students can articulate their study needs and lead to better results in the study process.

A unified e-learning system (intranet), in the case of Riga Technical University, is the site of an ORTUS multifunctional higher education institution. It is essential for competency-based education because, if used comprehensively, it can significantly improve students' flexibility and help to develop creative thinking.

Group work is structured around coursework and group exercises. This fosters the growth of personal, individual, and social skills. Additionally, there is a comprehensive understanding of teamwork and an emphasis on promoting a multidisciplinary approach, among other things. Visits to objects and data collection, seminars, workshops, and laboratory work allow to present the features and concepts of competency-based education in the learning process. Lectures, consultations, and individual research projects are an integral part of any higher education process. However, lectures and consultations are only part of the teaching methods that should be used in the study process.

Role-playing simulations develop basic competitiveness for students of the environmental engineering study programme and are generally considered to be able to enrich the learning environment and make it more authentic. These methods, used in combination, can help to change the path from teaching to learning and provide competency-based education principles in the study process.

MCDA developed four indicators to analyse the following competitive indicators: engineering skills, transferable skills, environmental protection skills, and socio-economic skills. The MCDA's goal was to assess which teaching methods are more appropriate and in what proportions to improve the competitiveness of graduates of the Master's degree programme in environmental engineering. The indicators were developed by evaluating the literature and summarising the assessment of the academic staff of the field. The indicators used by the MCDA to assess teaching methods are shown in Table 2.2.

Table 2.2

Indicators Used in the Assessment of Teaching Methods

| Indicator | Unit | Desired outcome |
|---|---|---|
| Engineering skills | Level of competence | Max |
| Transferable skills | Level of competence | Max |
| Environmental skills | Level of competence | Max |
| Socio-economic skills | Level of competence | Max |

During the study, thirteen teaching methods were evaluated and compared to find the most effective methods for achieving the best results in the study process (Table 2.3).

Table 2.3

Designation of Teaching Methods

| Designation | Environmental engineering teaching methods |
|---|---|
| A1 | Anonymous feedback evaluations |
| A2 | United e-learning system (intranet) |
| A3 | Field data collection |
| A4 | Group coursework |
| A5 | Group exercises |
| A6 | Individual research project |
| A7 | Lectures |
| A8 | Online assignments and coursework |
| A9 | Practical laboratories |
| A10 | Seminars and workshops |
| A11 | Site visits |
| A12 | Tutorials |
| A13 | Role-plays |

Experts from RTU IESE evaluated the criteria weights (w1bi1, w2bi2, w3bi3). The normalised and weighted values from the decision-making matrix to assess teaching methods are shown in Table 2.4.

Table 2.4

Normalised and Balanced Decision-making Matrix

| Criteria / Teaching method | Engineering skills | Transferable skills | Environmental skills | Socio-economic skills |
|---|---|---|---|---|
| | $w1bi1$ | $w2bi2$ | $w3bi3$ | $w3bi3$ |
| **A1** | 0.0015625 | 0.005625 | 0.003125 | 0.00375 |
| **A2** | 0.0046875 | 0.00375 | 0.003125 | 0.00375 |
| **A3** | 0.0078125 | 0.001875 | 0.00625 | 0.00125 |
| **A4** | 0.00625 | 0.0075 | 0.00625 | 0.005 |

Continuation of Table 2.4

| Criteria / Teaching method | Engineering skills | Transferable skills | Environmental skills | Socio-economic skills |
|---|---|---|---|---|
| | *w*1*bi*1 | *w*2*bi*2 | *w*3*bi*3 | *w*3*bi*3 |
| **A5** | 0.0046875 | 0.0075 | 0.0046875 | 0.005 |
| **A6** | 0.00625 | 0.005625 | 0.0046875 | 0.00375 |
| **A7** | 0.0078125 | 0.0075 | 0.0078125 | 0.00625 |
| **A8** | 0.003125 | 0.00375 | 0.0015625 | 0.0025 |
| **A9** | 0.0078125 | 0.005625 | 0.0078125 | 0.005 |
| **A10** | 0.003125 | 0.009375 | 0.0046875 | 0.00625 |
| **A11** | 0.00625 | 0.009375 | 0.00625 | 0.0025 |
| **A12** | 0.0015625 | 0.009375 | 0.0078125 | 0.00625 |
| **A13** | 0.0046875 | 0.001875 | 0.0015625 | 0.00125 |

The assessment of teaching techniques using TOPSIS was conducted within the environmental engineering master's degree programme. The results obtained showed that lectures (A7), site visits (A11), group coursework (A4), and practical laboratories (A9), together with role-plays (A13), allow to acquire the necessary knowledge, skills and competences (Fig. 2.3).

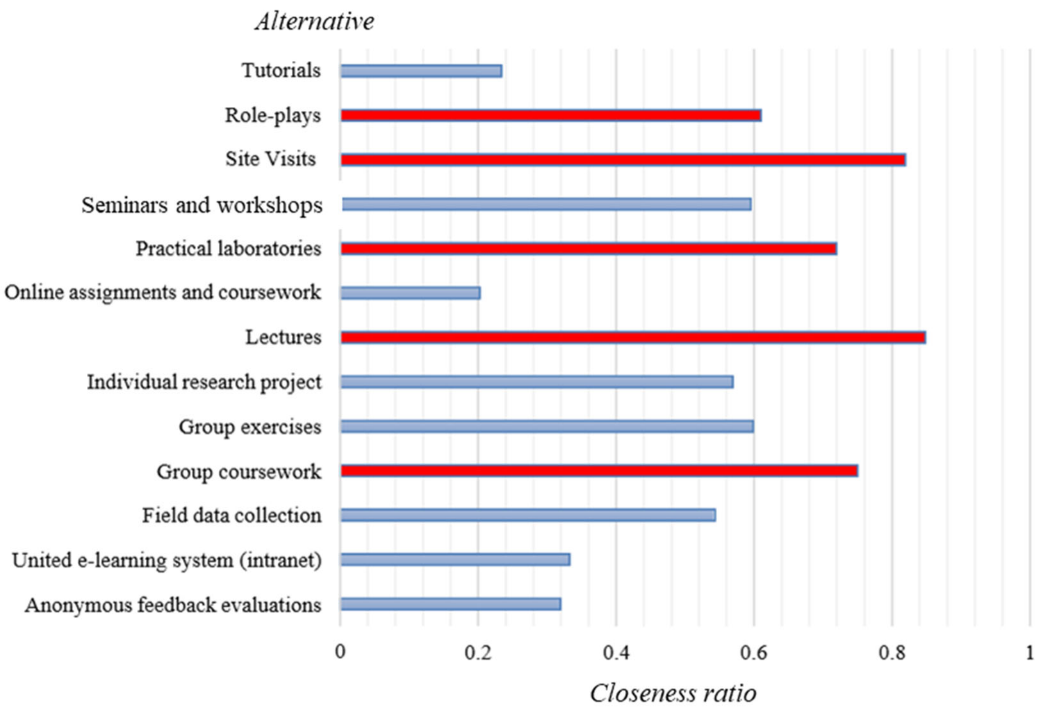



Fig. 2.3. Comparison of ratings of teaching methods.

Evaluation methods for group tasks, group exercises and group coursework can be used. For individual research projects, individual coursework assignments may provide an opportunity to evaluate the work. Research dissertations and written exams are an effective tool in assessing individual work.

An assessment system has been developed to assess the environmental engineering study programme (Fig. 2.4). The proposed evaluation system for evaluating the environmental engineering study programme was tested and approved in the new Master's programme “Environmental Engineering” of Riga Technical University.

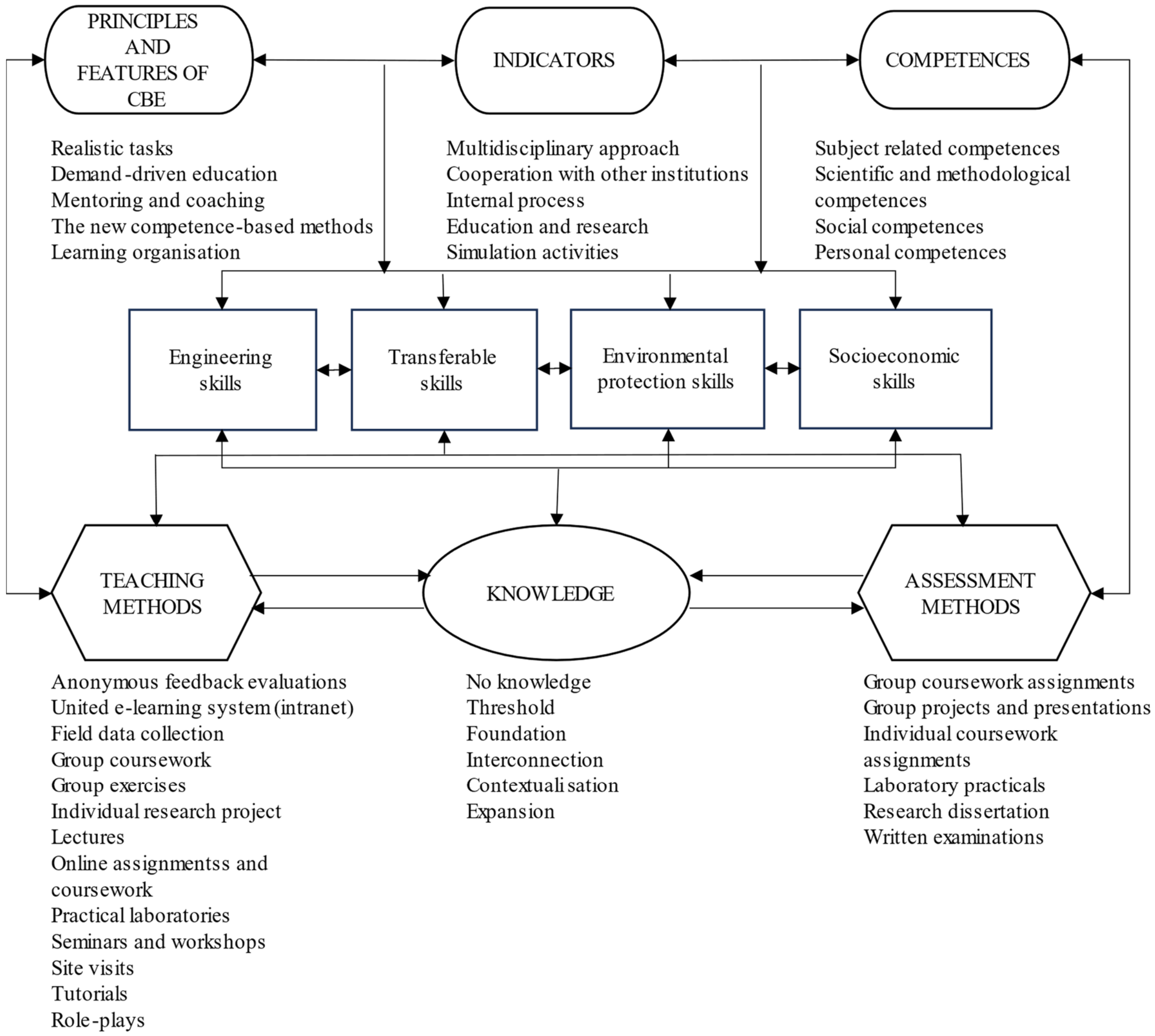



Fig. 2.4. Assessment system of the "Environmental Engineering" study programme evaluation

### Bioeconomy study module

Within the bioeconomy study module framework, European full-time master's study programmes in bioeconomy were initially selected. The results show that most study programmes are in Western Europe, with the Netherlands leading the way with four master's programmes in bioeconomy. Seven master programmes are university study programmes, two are joint master's programmes, and one is the Erasmus Mundus joint master's degree programme. The overall focus of the study programmes is on bioeconomy with specialisation in various aspects of bioeconomy, such as forestry, biotechnology, circular economy, chemical engineering, bio-based materials, bioinnovations, etc. As a result, 10 study programmes were selected (see Table 2.5).

Table 2.5

Master's Study Programmes in Bioeconomy

| University | Name of the programme | Study time | Description |
|---|---|---|---|
| Maastricht University (Netherlands) | Bio-based materials | Two years full-time | Focus on discovering new materials and sustainable methods of production of bioresources. |
| Utrecht University (Netherlands) | Bio-inspired innovation | Two years full-time | Focus on developing circular business models and bio-inspired research and innovation. |
| University of Wageningen and Research (Netherlands) | Bio-based science and biosystems engineering (and biotechnology) | Two years full-time | Focus on the bio-based economy from an interdisciplinary perspective. |
| University of Edinburgh (UK) | Bioeconomy governance Innovation and governance | Two years full-time | Focus on bioeconomy aspects such as sustainable innovation and deploying new technologies in existing and emerging markets. |
| University of Strathleigh (UK) | Industrial biotechnology | One year full-time | Focus on understanding the current development of industrial biotechnology. |
| University of Hohenheim (Germany) | Bioeconomy | Two years full-time | Focus on the bio-based economy through an interdisciplinary and transdisciplinary approach. |
| University of Helsinki (Finland) | Forest Sciences | Two years full-time | Focus on forest bioeconomy entrepreneurship and policy. |
| Joint study programme: University of Eastern Finland (Finland), AgroParisTech (France), University of Freiburg (Germany), University of Leeds (Spain), University of Natural Resources and Life Sciences (Austria), University of Brașów in Transylvania (Romania) | European forestry | Two years full-time | Focus on sustainable resource management, highlighting current bioeconomy issues. |

Continuation of Table 2.5

| University | Name of the programme | Study time | Description |
|---|---|---|---|
| Joint Master's Degree: University of Bologna, University of Milan-Bicoco, University of Naples – Federico II, University of Turin (Italy) | European Master's in the Bioeconomy in a Circular Economy | One year full-time | Focus on the bio-based goods and services sector using biological resources and biotechnological processes. |
| Erasmus Mundus Joint Master's Degree: Paris Institute of Life, Food and Environmental Sciences (France), Reims Champagne-Ardennes University (France), University of Aalto (Finland), Tallinn University of Technology (Estonia), University of Liège (Belgium) | European Master's in Biology and Chemical Engineering for a Sustainable Bioeconomy | Two years full-time | Focus on biotechnology, bioprocess development and expansion, and bio-based product engineering, with an additional focus on soft skills, including project management. |

In the future, bioeconomy competencies will be used to analyse study programmes. Each competence was interpreted within the competence framework. Study programme descriptions and course descriptions for each study programme are used for the analysis of the programme. The aim was to express the integration of bioeconomy competencies in each study programme:

1) little or no integration,
2) minimal integration,
3) moderate integration,
4) good integration.

Table 2.6 provides an overview of the analysis of the study programme "Management of Bioeconomy, Innovation and Governance" at the University of Edinburgh.

Table 2.6

Example of Matrix Analysis of Individual Competence of the Study Programme

| **Bioeconomy competences** / **Competencies of the study programme** | Competence of systemic thinking | Forecasting competence | Regulatory competence | Strategic competence | Interpersonal competence | Transdisciplinary competence | Learning competence | Interdisciplinary competence |
|---|---|---|---|---|---|---|---|---|
| Analysis of trends, opportunities, and challenges along the path of science innovation. | 4 | 4 | 3 | 3 | 2 | 4 | 3 | 4 |
| Promoting entrepreneurship and creative thinking about the future of the bioeconomy. | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 |
| Creating business plans and mapping market routes for new technologies. | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 |

Continuation of Table 2.6

| Competencies of the study programme \ Bioeconomy competences | Competence of systemic thinking | Forecasting competence | Regulatory competence | Strategic competence | Interpersonal competence | Transdisciplinary competence | Learning competence | Interdisciplinary competence |
|---|---|---|---|---|---|---|---|---|
| Foresight and scenario-based methods for managing risk and uncertainty associated with new technologies. | 4 | 3 | 4 | 3 | 3 | 4 | 2 | 4 |
| Negotiation and communication skills in interdisciplinary teams. | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 |

| Designation: | | |
|---|---|---|
| | 1 | Little or no integration |
| | 2 | minimal integration |
| | 3 | moderate integration |
| | 4 | good integration |

Since the analysed study programmes are designed explicitly for bioeconomy studies, the general bioeconomy and sustainable development competencies are effectively integrated into the study programmes. In existing study programmes in Bioeconomy in Europe, transdisciplinary competence, learning competence, interdisciplinary competence and systemic thinking competence are closely integrated into the study programmes. The integration of other competencies, such as foresight, normative, strategic, and interpersonal competencies, can be more robust. It shows the need to strengthen the use of these competencies for sustainable development and the future bioeconomy.

The result of the analysis of the integration of bioeconomy competencies into the competencies of the study programme is shown in Table 2.7.

Table 2.7

Integration of Bioeconomy Competencies into the Competencies of the Study Programme

| Competence matrix of master's study programmes \ Bioeconomy competences | Competence of systemic thinking | Forecasting competence | Regulatory competence | Strategic competence | Interpersonal competence | Transdisciplinary competence | Learning competence | Interdisciplinary competence |
|---|---|---|---|---|---|---|---|---|
| Bio-based materials | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 4 |
| Bioinspired innovation | 4 | 3 | 3 | 3 | 4 | 4 | 4 | 4 |
| Bio-based science and biosystems engineering (and biotechnology) | 4 | 3 | 3 | 4 | 3 | 4 | 4 | 4 |
| Governance of the bioeconomy, innovation and governance | 4 | 3 | 3 | 4 | 3 | 4 | 3 | 4 |
| Industrial biotechnology | 3 | 4 | 3 | 4 | 4 | 3 | 4 | 4 |

Continuation of Table 2.7

| Competence matrix of master's study programmes \ Bioeconomy competences | Competence of systemic thinking | Forecasting competence | Regulatory competence | Strategic competence | Interpersonal competence | Transdisciplinary competence | Learning competence | Interdisciplinary competence |
|---|---|---|---|---|---|---|---|---|
| Bioeconomy | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 4 |
| Forest Sciences | 3 | 4 | 4 | 3 | 3 | 3 | 4 | 3 |
| European forestry | 4 | 3 | 3 | 3 | 4 | 4 | 4 | 4 |
| European Master's in the Bioeconomy in a Circular Economy | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 4 |
| European Master's in Biology and Chemical Engineering for a Sustainable Bioeconomy | 4 | 3 | 3 | 3 | 3 | 4 | 4 | 4 |

Designation: 3 – moderate integration; 4 – good integration

## 2.3. Co-creation module

The co-creation module is characterised by two sides (Fig. 2.5). The first is the audience, characterised by how solid and sound the knowledge is, what module of cooperation exist and can potentially exist to ensure a sense of partnership, and the level of the knowledge of innovation. The other side is the evaluation side, where the participants and the result they aspire are evaluated. The co-creation implementation module combines the performance method with the technology readiness level method.

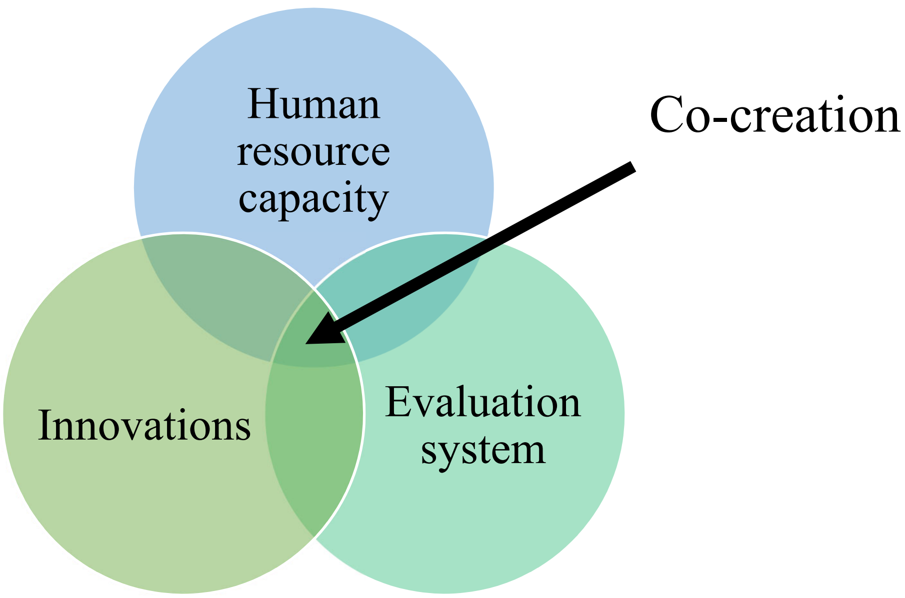



Fig. 2.5. The main elements of the co-creation module

## Human resource capacity

First, it is necessary to define the actors in the green innovation value chain and their role. The leading players considered in the study are academia – students, academic staff, and industry – companies, mentors, industry experts and other stakeholders. As a partner, the university provides motivated students, one of the model's critical elements. Their involvement in the storm of green innovation fosters knowledge-based entrepreneurship, strengthens the cooperation of the academic sector with industry, and ensures the availability of a qualified workforce for economic development in the future. Faculty involvement ensures a continuous learning process and convinces the industry to trust the academic sector's competencies and students' ability to create and potentially commercialise scientific achievements in the field of environmentally friendly inventions. The requirements of the company are the ability to accurately define the challenges that the company itself faces, knowledge of the process of commercialisation and development of environmental technologies, ambitions aimed at international competitiveness, and readiness to provide competent representatives.

It is the joint responsibility of the two main partners, academia and industry, to attract such competent partners, whose presence strengthens the partners' capacities and capabilities to ensure a fully-fledged process of knowledge sharing in developing green innovations. These external mentors and social partners have a role to play in assessing the solution's position in a broader context.

## Innovation

The interaction of partners is based on the needs of each interested party. Their scale and depth determine the degree of involvement and the amount of investment. The aspects in which the parties' needs coincide significantly affect the research results; for example, a student has future career opportunities for personal growth. At the same time, the university must consolidate its status as a modern educational institution, but the company's interest lies in this interaction.

The academic sector needs to step up its efforts to motivate stakeholders, as students' readiness to act depends on the involvement of academics and the involvement of business and competence partners. When the academic and private sectors engage in cooperation, the first step is to find a balance between economic, environmental and social impacts as decisive factors in decision-making:

a) In the field of the environment, the primary objective of the academic sector is the sustainable and responsible use of resources since the solutions are aimed at increasing the quality of life of society.
b) In business, the main goal is to maximise profits. This is required by business owners and the need to ensure a stable financial flow, competitiveness and growth.

The university plays a crucial role in the development of events and technologies as such. In turn, the industrial sector, represented by enterprises, guided by its strategic interests, makes decisions on the optimal work of student teams.

Two systems were created for assessing interests of the parties, which meet the needs of both partners (company and university). Criteria such as ingenuity, quality, environmental impact and the potential for commercialising the idea (innovation) are evaluated. Each criterion is scored on a scale from 1 to 10 (where 1 is the lowest and 10 is the highest). Each criterion, depending on the significance (to be achieved within the event and/or study), is given its importance for the result (Fig. 2.6).

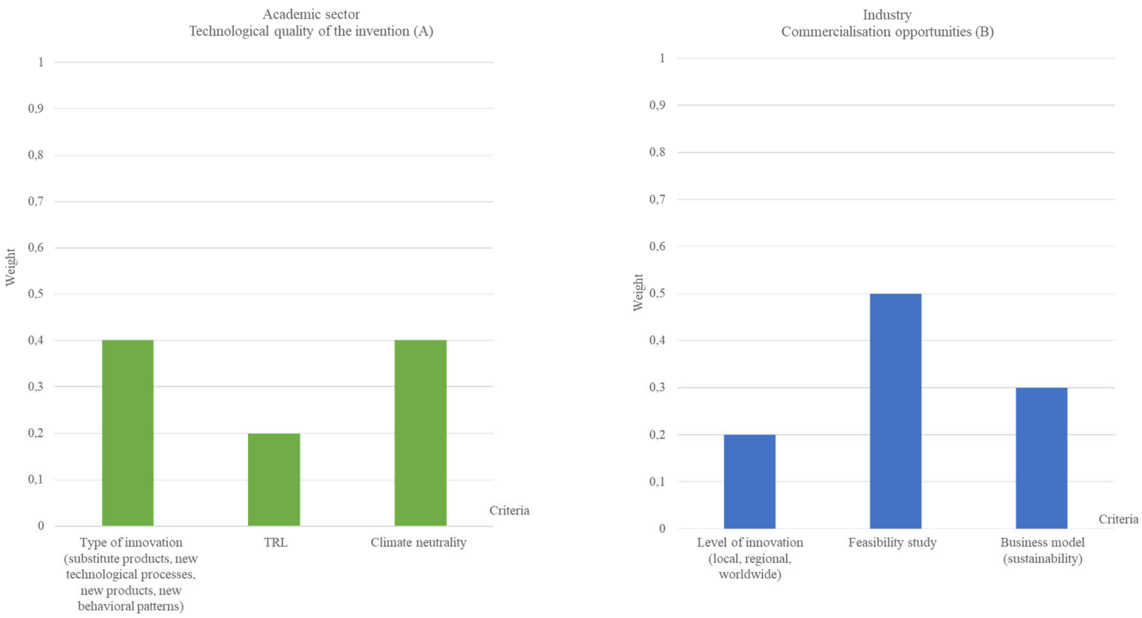



Fig. 2.6. Comparison of criteria for evaluating cooperation between strategic partners (A – academic sector; B – industry).

## Evaluation

Different methods in the learning process allow collaboration between a faculty and students to a new level, allowing students to expand their knowledge of the environment and test their knowledge in practice.

A table of assessment criteria was proposed (see Table 2.8) that can be adapted to different educational programmes. Each criterion is scored on a scale from 1 to 4, where 1 – tries to achieve/does not reach and 4 – exceeds the requirements. Each criterion is given weight depending on the needs of the study programme.

Table 2.8

Evaluation Criteria for the Final Presentation

| Evaluation criteria | Trying to achieve/not reaching | Approaching | Comply | Exceeds the requirements |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| | The activities of students are inaccurate, and the performance can only be partially attributed to the acquired competence. | Students' performance is usually related to the competence to be acquired. | Students' performance is accurate; it is based on judgments on the criteria | Students' performance is precise and persuasive; it shows the limitations and complexity of competence. |

The evaluation criteria were assessed against the criteria in Table 2.9.

Table 2.9

Evaluation of Criteria

| **No.** | **Criteria** | **Weight** |
|---|---|---|
| 1. | Towards a climate-neutral solution | 0.20 |
| 2. | Quality of feasibility studies | 0.20 |
| 3. | Identifiable type of innovation (*Substitute products. New technological processes. New products. New behavioural patterns*) | 0.15 |
| 4. | Quality of the business model (to ensure the sustainability of the solution) | 0.1 |
| 5. | Technology readiness level | 0.1 |
| 6. | Level of innovation (local, Regional, global) | 0.1 |
| 7. | Contribution to the achievement of one or more of the United Nations Sustainable Development Goals | 0.05 |
| 8. | Team performance (presentation quality) | 0.05 |
| 9. | Participants have formulated their role in the implementation of the solution | 0.05 |
| **Total:** | | **1.0** |

The next step in the study is to understand the technological readiness of the project. This understanding would allow to set a goal that the team can achieve in the allotted time.

The implementation of the business model is the second indicator of the quality of the student team solution from the industry's point of view. Business models are usually viewed with other theories and company practices from a value chain perspective. The business model formulates a value proposition for customers and considers how an organisation creates, delivers and perceives value. Academics and business leaders have different understandings of sustainable business models, and there is still a debate whether sustainable business models could replace traditional business models in the future.

## 2.4. Behaviour module

The performance or the performance method is used by integrating role-playing into the training of environmental engineering students since it is essential to form a type of behaviour or activity that requires a lot of attention to detail problems and highlight details that may sometimes seem unimportant. The role-playing must shape the position of the students.

In the role-playing, the participants empathise with the role of a fictional character. Participants determine the activities of their characters depending on their tasks and personalisation, and the success factor depends on the role-playing system and the participants' behaviour: readiness and motivation. What is essential is the settings of the role-playing and the rules within the framework of which players can improvise and creatively look for solutions, whereby their choices affect the direction and outcome of the game.

During the role-playing, participants answered the main question – how to invest in the COVID-19 emergency support means to mitigate the effects of the pandemic (sustainable economic recovery) and maintain the transition to sustainable bioeconomy development. Each of the target groups – forestry, agriculture, fisheries and aquaculture – formulated what they considered to be the best solutions based on research. The Bioeconomy Strategy states that farmers and food producers are the most important to support food security. It should be borne in mind that the remaining part will have to be divided between fisheries and forestry.

In the first part of the preparation, role-playing was developed. In the second part, role-playing was implemented, and in the third part, students' biodiplomacy competencies in bioeconomy were assessed with a post-match performance level rubric.

As a result of the role-playing game, the agricultural group received the most financial support, so this group was further analysed using the post-match performance level rubric. The post-match performance level rubric for the agricultural group for the assessment of biodiplomatic competencies is shown in Table 2.10.

Table 2.10

Post-match Performance Level Rubric for the Agricultural Group

| ***Category 1***<br>Relevance of the product/service/process to the transition from the current paradigm of increasing economic production to a sustainable bioeconomy by promoting the Green Deal and climate neutrality policies | ***Category 2***<br>Reasonable and delicate dialogue and cooperation with target groups. | ***Category 3***<br>In the overall definition of the goals and objectives of society, in the realisation that we are all one, a synergistic approach to solving global problems. |
|---|---|---|
| 1. Not mentioned | 1. There are no scenarios for answering catchy questions. Many questions are not used to start a dialogue. | 1. The proposal on urban agriculture has been openly rejected. |
| 2. Not mentioned | 2. Promises and threats as facilitators of dialogue (what threatens if agriculture is not supported?). A series of questions and answers show two-way communication. Ambiguous arguments in the discussion with investors. | 2. Cooperation with the forestry sector in developing joint proposals for land-use change (afforestation of land, changes within the framework of 1 ha). |
| **3. The group's presentation defines agriculture's goals in the bioeconomy field, which corresponds to a paradigm shift. The expected added value is indicated, obstacles to the development of bioeconomy are analysed, policy instruments are achieved, precise proposals for measures are presented, clear recommendations for improving energy efficiency and reducing emissions, and quantitative arguments (agricultural GDP, exports, etc.) and their analysis, an action plan for the involvement of target groups in education. Events and discussions. Investors are offered innovative options.** | **3. A dialogue has been initiated with local governments to find a solution to everyday social and agricultural problems (involvement of young people and representatives of other professions in seasonal work, increasing the dynamism of the workforce).** | **3. Common goals set with environmental activists to stop the process of urbanisation; the development of a joint programme to attract young people to rural areas.** |
| **4. Not mentioned** | **4. In the group discussion, a resounding determination flows; the decision of politicians to allocate the largest share of funding (victory in the game of awarding grant) indicates a change of mindset in the direction of long-term strategies.** | **4. Not mentioned** |

After the game performance, discussion by the evaluators and the students is essential to clarify and justify the levels achieved. This allows students to identify gaps in their understanding.

## 2.5. Diplomatic relations module

The behavioural module of training for environmental engineering students is gradually replenished with components of the art and science of conversation. This has much to do with diplomacy, which is not only about foreign policy. Diplomacy applies to representatives of various groups who discuss and sometimes disagree on issues topical in society. One such issue that does not disappear from the agenda is the issue of environmental protection and climate change. Therefore, environmental engineering students, including the bioeconomy, must master and build a model of diplomatic relations, understanding various problems.

The primary ten themes for promoting the development of biodiplomacy were identified: economic (C1), social (C2), climate and environment (C3), science and research (C4), engineering (C5), domestic policy (C6), foreign policy (C7), access to finance (C8), examples from other countries (C9), and regional policy (C10). These were established as ten criteria for AHP.

At the beginning of the application of the AHP method, based on the opinions of experts, the relative differences of each criterion against the potential of the forestry sector to become part of Latvian biodiplomacy were determined; in the next step, a normalised matrix for comparing pairs of criteria was compiled to derive importance. After the AHP analysis, particular vectors of the matrix of the normalised criteria pairs were obtained to show the hierarchical structure of the most important criteria. Quantifying, ranking and analysing these responses is the next step in the assessment of the dominant criterion for the forestry diplomacy potential based on a simple weighting scheme. In addition, durability tests (i.e. consistency checks) on the stability of results are also carried out before the transition to the TOPSIS analysis.

Following the above, to complete the AHP analysis, the special vector of the normalised even criteria comparison matrix is represented by the hierarchical structure of the most essential criteria against the potential of the forest sector for obtaining Latvian biodiplomacy, the normalisation of the matrix, and the results are shown in Fig. 2.7.

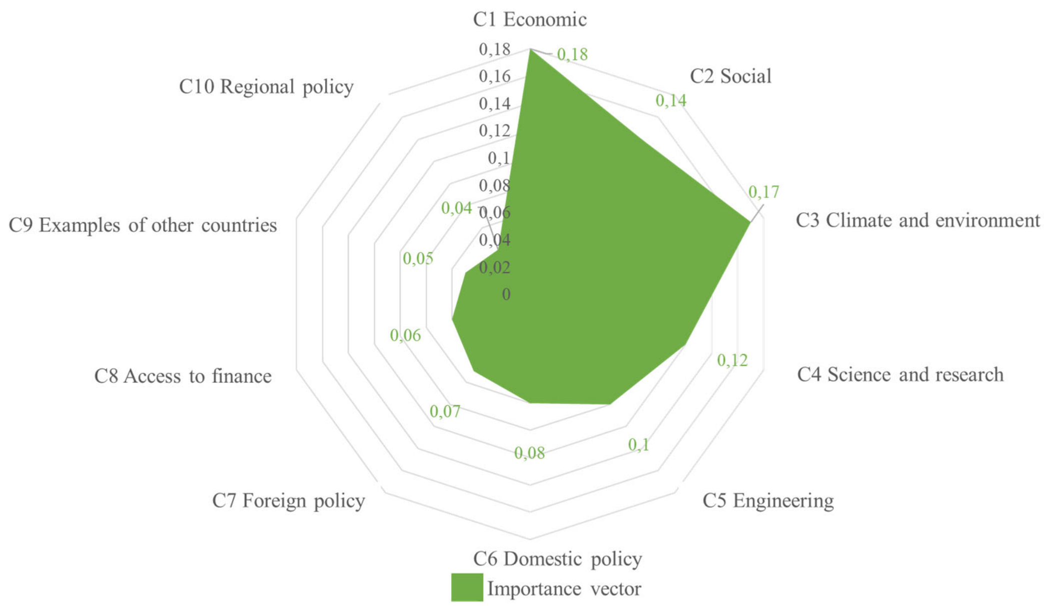



Fig. 2.7. The importance vector shows the classification of weights of absolute meaning.

Of all ten possible criteria that could affect the forestry sector's potential in Latvian biodiplomacy, the most important is the economic factor, followed by social, climate and environmental issues.

By carrying out an appropriate fitness check (Table 2.11), it is reasonable to conclude that this ranking is resilient to rapid changes in the definition of the importance scale, as well as to considerable differences in expert opinions, as evidenced by a consistency factor of 0.07 below the widely accepted threshold (0.1).

Table 2.11

Checking the Consistency of the Results of the AHP Algorithm with $N = 10$ Criteria

| Term | Value |
|---|---|
| Consistency index | 0.11 |
| Random consistency index ($N = 10$) | 1.49 |
| Coefficient of consistency | $(0.11/1.49) = 0.07 < 0.1$ |

For the next step, to better understand which alternatives (volume (A1), acquisition (A2), availability (A3), restoration (A4), disposal options (A5), demand (A6) management/ownership (A7), availability of labour (A8), and availability of specialists (A9)) are the most significant in advancing each criterion as a whole in the decision-making process, topic analysis is used. With the method, it is possible to understand the potential of forestry resources if more factors are considered unrelated to bilateral comparison. Initially, a decision matrix is created to weigh the alternatives against the criteria. After that, the matrix is normalised. Normalisation of the matrix allows to systematically compare alternatives in different criteria regardless of the underlying generation process. Then, the best and worst alternatives in this range of alternatives A1–A9 were identified. That is, starting with the fact that it is determined which alternative is most suitable and least suitable for each criterion.

The proximity ratio ranking was compiled to highlight the best alternative in the range A1 to A9 in Fig. 2.8.

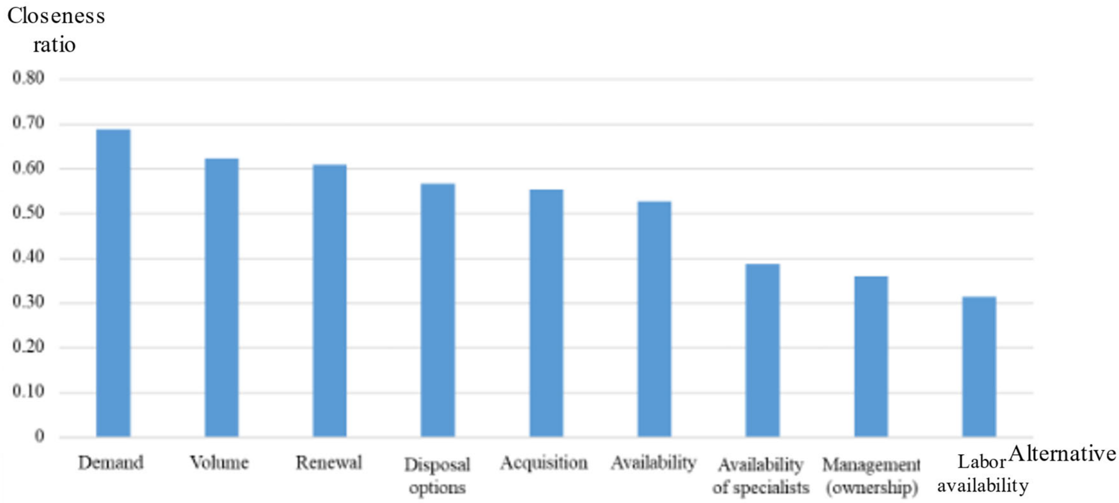



Fig. 2.8. Closeness ratios of each alternative to the best possible alternative.

According to Fig. 2.8, it can be concluded that the most critical factors that can help determine the potential of forest resources for Latvian biodiplomacy are their demand, volume, as well as recovery because they are intuitively closest to the adequate alternative when the decision-maker adequately considers all alternatives. The availability of labour is the last necessary driving force in this analysis.

Demand, volume, and recovery from analysis go hand in hand because to build biodiplomacy, it is necessary to understand whether there is demand, which is considered a leading indicator, and whether volume will satisfy demand. In processes, it must be regarded as a renewal. These results mean that the next step in promoting biodiplomacy is understanding what type of forestry product needs to be developed to increase demand. This product should consider ecodesign principles, as volume is the next important driver. Restoration is the third important factor. Of course, other driving forces in the second part of the priority, such as the availability of specialists, management (ownership) and the availability of labour, even those that are not considered to be critical issues in the development of biodiplomacy, should not be forgotten.

## 2.6. Distance learning module

The distance learning module uses the system dynamics method, which is used as a training tool in the framework of a massive online open course (MOOC*),* "Energy Transition and Climate Change".

The MOOC was placed on the Moodle platform, supported by the Riga Technical University student course portal ORTUS. A new course page that acts as a developed MOOC includes all the resources needed for both parts – theoretical and practical. The practical tasks used in the study course "Energy transition and climate change" vary – some are performed to direct the student's knowledge of the described theory in the form of multiple-choice or "true/false" questionnaires. At the same time, some involve practical work with an interface, after which the user must answer quiz questions about the results achieved by manipulating various variables.

The MOOC was submitted for testing to five students with in-depth knowledge of system dynamics and power systems, after which the results were obtained through structured interviews. The students were selected from Riga Technical University, and the criterion was that the test users had completed the system dynamics course during their undergraduate studies.

The MOOC "Energy Transition and Climate Change" is drafted in English and designed to be 100 % online. It allows students to learn quickly and looks at three important and interrelated aspects of today's energy policy: energy efficiency, renewable energy and climate change.

In the distance learning module, the method was considered using the principles of system dynamics, explaining how the supply and demand side of the energy sector works. The course consists of several sections. Each section included practical tasks to test users' knowledge before, during, and after their studies. The introductory part of the course explains what climate change is and how the energy sector relates to it. The second section takes a deeper look at the energy sector's supply and demand side using the system dynamics principles. The next section describes the main features of the main sectors of energy users (residential, industrial, social, etc.) about the use of electricity and heating/cooling systems. Finally, the final section of the course's introductory part explains the energy transition process's importance, possibilities, and complications.

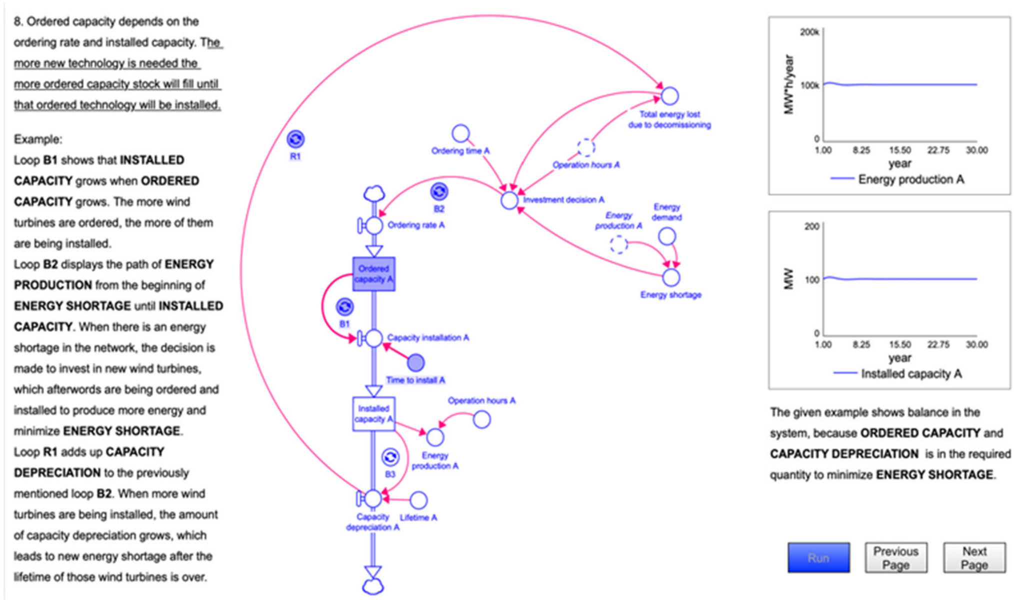



Fig. 2.9. Interface explaining how the structure of stocks and flows in the energy supply sector is constructed.

## 2.7. Scientific research module

Environmental engineering students are offered the opportunity to choose both qualitative and quantitative methods of scientific research in the development of study course papers and final papers. Long-term data compiled by the study process show that 80–85 % of students choose the qualitative method. Therefore, in the Doctoral Thesis, examples of research areas have been selected to illustrate the possibilities of using qualitative scientific methods.

The author implements the research demonstration with four examples of occasional research:

Module 1. Bibliographic analysis module. The importance of research in the field of the bioeconomy, as well as the link to bioeconomy education in the framework of the Green Deal on the European Union climate policy, has been sought and analysed.

Module 2. Zero-waste product ranking module. The possibilities of using by-products of the bio-product (bran transhipment waste) plant for the production of products with high added value have been searched for and analysed.

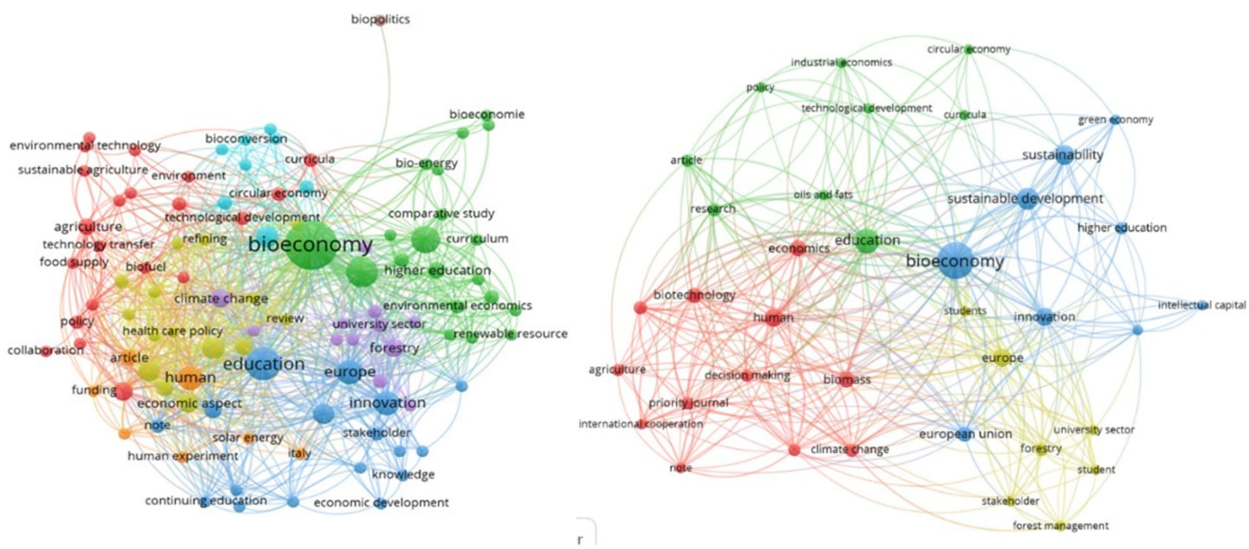
Module 3. Zero-waste technology ranking module. The possibilities of using the technological processes of processing plant's by-products have been searched and analysed.

Module 4. Energy user management module. The opportunities and potential of aggregators are sought and analysed.

### Bibliometric analysis module

The bibliometric analysis module focused on research in the scientific literature related to the importance of the field of study in the bioeconomy sector and linking to the European Union's Green Deal on Climate Action and bioeconomy education. In this module, the bibliometric method using the *VOSViewer software* was used.

Initially, a link was shown between scientific articles using the words "education" and "bioeconomy" (articles selected from 2012 onwards) depicted in Fig. 2.10, respectively, the frequency of repetition of words is successively 2 and 3 times. The minimum frequency of word repetition was changed because it was believed that the word compound should be visualised with more appropriately related words. In Fig. 2.10 A), 101 keywords are displayed to form eight thematic sets, and in Fig. 2.10 B), 37 keywords with four thematic groups.




A) The minimum frequency of appearance of keywords is 2 times

B) The minimum frequency of appearance of keywords is 3 times

Fig. 2.10. Visualisation of the bibliography with the word combination "education" AND "bioeconomy" from 2012 onwards: A) – minimum word repetition frequency – 2 times; B) – minimum frequency of word repetition – 3 times.

Except the words "bioeconomy" and "education", the most common term in 13 scientific articles is "sustainable development" (23 links), 11 scientific articles contain "sustainability" (14 links) and nine scientific articles "man" (28 links), "innovation" (22 links), "Europe" (30 links). The concepts of "bioeconomy" and "education" are the most used and appear in most publications. The words "human", "innovation", and "Europe" appear less in research than the words "sustainable development" and "sustainability", but they have a greater connection with other keywords on the network, which means that authors use more commonly used language and words in their articles to reflect the further development of scientific topics and their importance in science.

In the bibliometric network, with the word combinations "education" and "bioeconomy", using the minimum frequency of occurrence of keywords three times, four thematic clusters were further clustered: linking bioeconomy and education in the agricultural sector (cluster 1), linking bioeconomy and industrial education (cluster 2 ), linking bioeconomy and education with innovation (cluster 3) and linking bioeconomy and education with forestry (cluster 4).

Cluster 1 is keywords related to human involvement in agriculture and bioeconomy development using biotechnology, where knowledge is essential. The need for education in the industrial economy characterises cluster 2, where technological development and research should be considered. Cluster 3 keywords are related to the need for innovation in the bioeconomy, which should involve higher education for sustainable development. Cluster 4 represents the need for the forestry industry and student education to develop the bioeconomy.

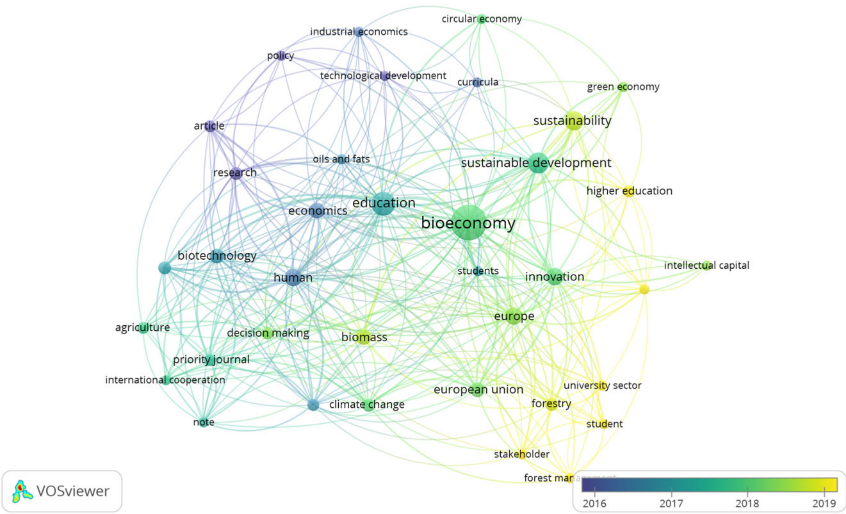



Fig. 2.11. Bibliography (chronological) visualisation with the word combination "education" and "bioeconomy" since 2012 (minimum frequency of word repetition – 3 times).

Figure 2.11 shows the chronological appearance of keywords in studies, where keywords in yellow, such as "forest management", "forestry", "interested party", "student", etc., appear more in current publications, such as in 2019. The latest developments in research, which are being considered in the forestry sector, are presented. More innovative applications in the forestry sector for developing the bioeconomy through education will be considered.

### Zero-waste product ranking module

The zero-free product ranking module searches for and analyses the possibilities of using by-products of a bio-based (bran transhipment waste) plant to produce high-value-added products using the qualitative research method. Information was collected on the possibilities of using grain by-products to develop new products and evaluated which bran products are most suitable for commercialisation based on economic, environmental, social and technical factors.

From the studies described in literature 30 products were selected. The products studied were obtained from four wheat by-products – bran, straw, husks and dust. Bran is the most widely used of these by-products, while dust is used to produce only one product – bio-based packaging. The products were divided into six groups: packaging materials, building materials, adsorbents, fuels, thermal insulation materials and chemicals.

Seven products were selected for MCDA. Of all product groups, fuels and building materials were not further considered since these products do not have a relatively high added value. It was found that wheat bran is the most widely used raw material, so their products were tested in the MCDA. The main criteria were chosen – availability of technology, sustainability, comparison of product prices, market demand, environmental impact and social aspects.

In the next step, the criteria weights were determined using sensitivity analysis. The sensitivity analysis showed that the sustainability aspect has the lowest sensitivity to weight changes, which can also be determined by looking at the input data since all alternatives scored 4 to 5 points. Therefore, this criterion was given the lowest weight (0.05). Also, the technical and social aspects had a slight weight change compared to other criteria, giving them a weight of 0.15. Environmental impacts and market demand became more sensitive to weight changes when the single variable coefficient ranged from 0.5 to 1.5, so the weight given to these criteria was 0.2. The product's price comparison reacted the most to the change in weight, most likely because the input data differed more. After all, they were not expressed on a five-point scale. The sensitivity analysis results for this criterion are shown graphically in Fig. 2.12.

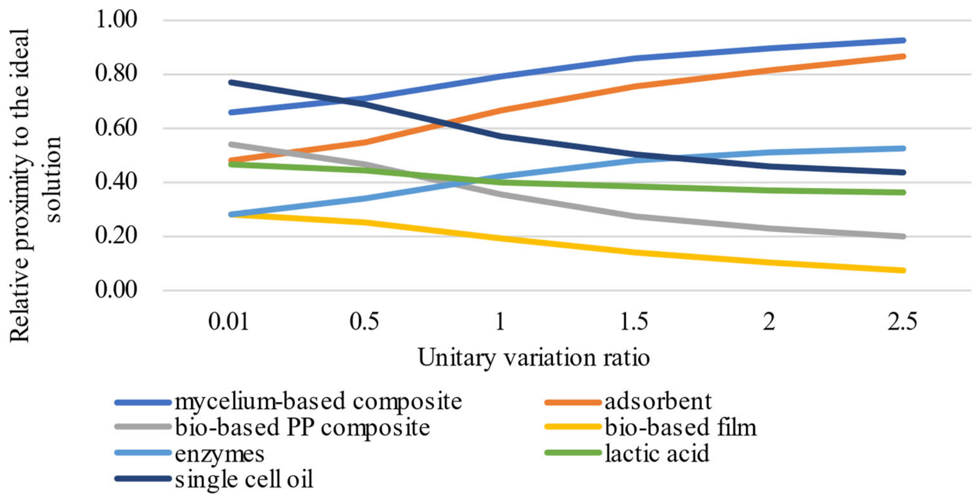



Fig. 2.12. The results of the sensitivity analysis for comparing the prices of products.

The weights of all criteria are shown in Fig. 2.13.

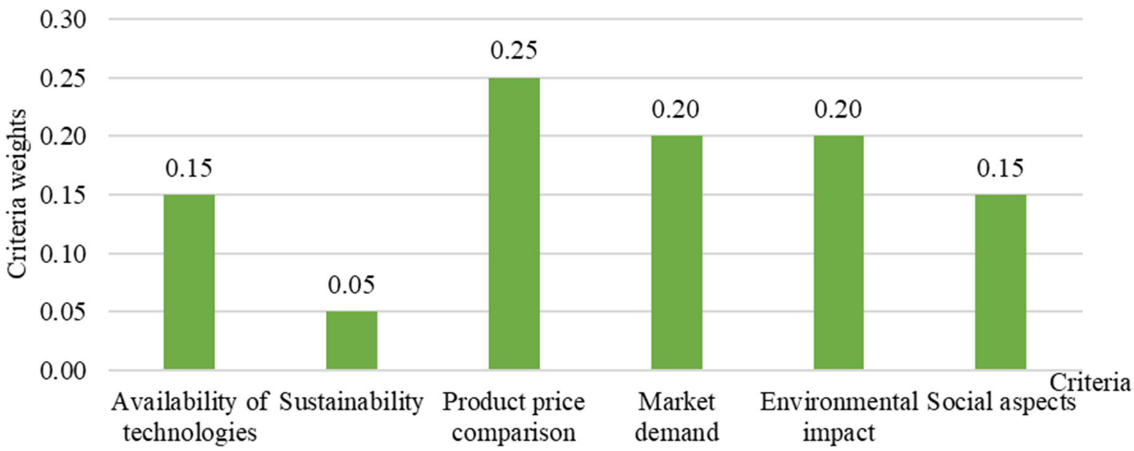



Fig. 2.13. Criteria weight in TOPSIS calculations.

Input data and the obtained benchmark weights were used in TOPSIS calculations. The results obtained are shown graphically in Fig. 2.14. The results show that the most significant relative proximity to the ideal variant of the analysed products is the biocomposite material based on mycelium. This is primarily due to the relatively high difference in product prices. Had this criterion not been considered, the unicellular oil would have obtained the highest result, which can also be estimated by looking at the input data. The adsorbent also has relatively good results since its price and environmental impact are much lower than those of the adsorbents currently used. A food film with antioxidant properties obtained the worst outcome. This is because the data for this product were used from PLA parameters, and PLA was compared with LDPE, which currently has lower production emissions and prices than bioplastics. Bioplastics also have lower market demand, which should be improved. The product parameters are better because they are obtained from bran rather than corn, with different extraction properties such as water consumption and yield.

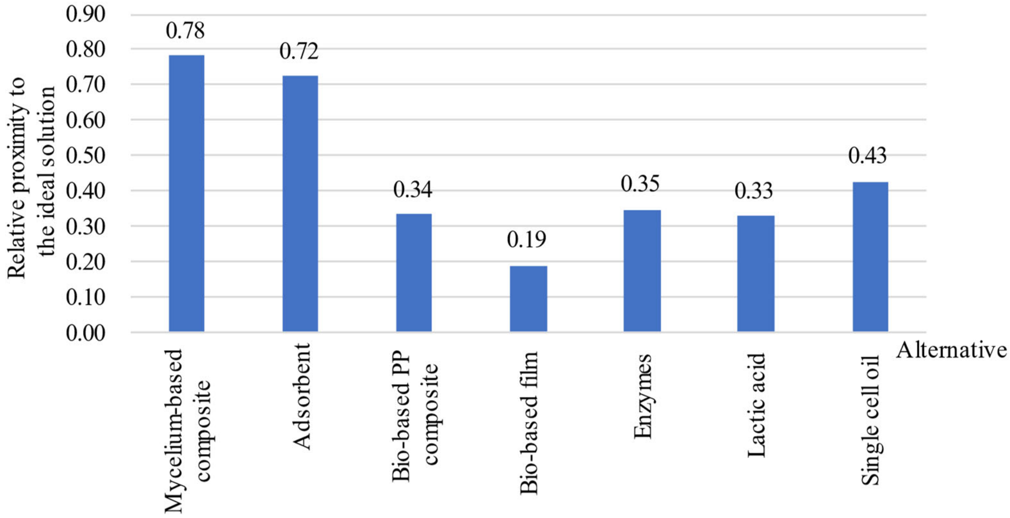



Fig. 2.14. TOPSIS results.

**Zero-waste technology ranking module**

The scientific research module, specifically the zero-waste technology ranking module, uses a qualitative research method with an approach from bioeconomy solutions in the context of potential applications of technologies. A comparison was made with the method to choose the best technology for extracting essential oils from fruit waste. The module used multi-criteria analysis methods AHP and TOPSIS. Four different approaches to extraction methods were evaluated: steam distillation, cold pressing, solvent extraction and hydrodistillation. The method’s approaches were compared considering environmental, economic, social, and technological criteria. According to the calculations, the weight of the technological criterion is the most important, with a result of 0.45. The second most crucial weight is that of the economic criterion – 0.25, the third and fourth criteria are environmental and social, 0.22 and 0.08, respectively.

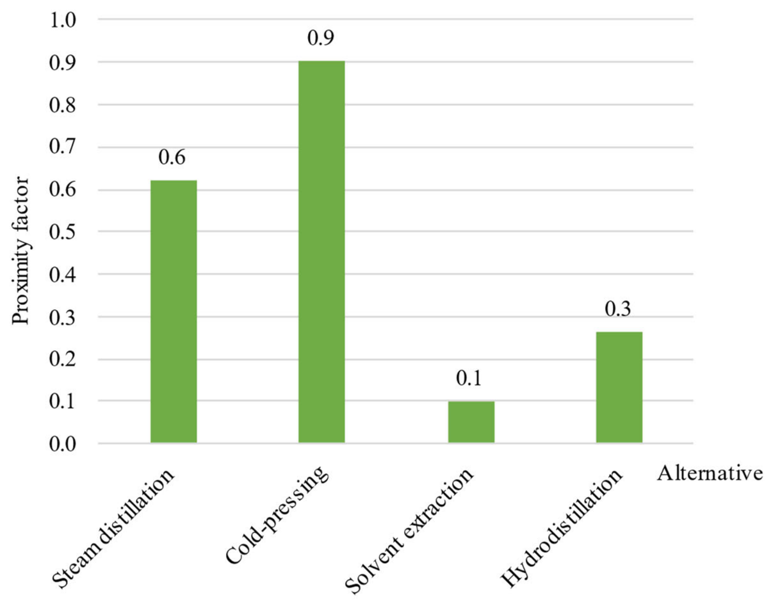



Fig. 2.15. TOPSIS ranking technology results.

The results of the TOPSIS analysis are shown in Fig. 2.15. Cold pressing is the closest alternative to the best solution, with a score of 0.9. Steam distillation ranks as the second technology, obtaining a rating of 0.6, and the third possible technological solution is hydrodistillation with a result of 0.3. The solvent extraction result is 0.1.

**Energy user management module**

A case study in the context of the development of environmental engineering education characterises one of the research directions in the sub-field of environmental engineering – management of energy users. In the energy user management module, the central object of qualitative research is the study of the implementation potential of the aggregator. Expanding research issues ensures the development of innovations, knowledge and their potential application.

According to the study, the aggregator should be able to participate in all types of electricity markets. Currently, the aggregator operates mainly in the balancing market, becoming a provider of balancing services activating the balancing energy to ensure equilibrium in the electricity system. Latvian Cabinet of Ministers approved the first regulations on the operation of aggregators in Latvia only in the beginning of 2020. Latvian legislation stipulates that an aggregator is a new type of energy service provider that can increase or decrease electricity consumption of a group of consumers per network's total electricity demand, thus allowing the consumer to become flexible.

Two different approaches to aggregation were distinguished – household aggregation and aggregation in manufacturing. In the household sector, the total amount of electricity is much smaller. An aggregator working with households would need an extensive portfolio of homes to make an impact and conduct a profitable business. The aggregator must have at least 10,000 consumers who save 5 kWh daily to make it profitable. For example, a general overview of online offers of electrical appliances assumes that, on average, a central air conditioner/heat pump consumes around 5–15 kW per hour. Hence, a reduction in electricity consumption by 5 kWh per day is not significant, given that part of the electricity would still be consumed at another time of the day when electricity prices are lower. Figure 2.16 shows the demand for electricity in Latvia on 3 August 2020. The red line is the actual demand, but the author has drawn the blue line to show how the aggregator could equalise the demand during peak hours by shifting it to another time of day.

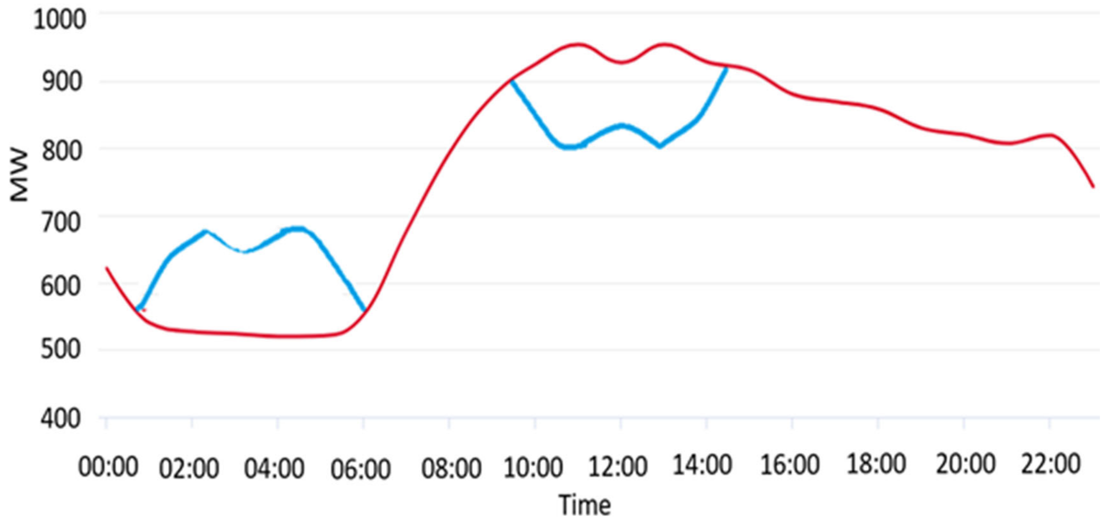



Fig. 2.16. Electricity consumption in MWh/hour in Latvia on 3 August 2020.

Assuming that the aggregator has aggregation agreements with 10,000 consumers, it would reduce consumption by at least 1 kWh per day (instead of 5 kWh, since most of the total volume is transferred to another reference period and is not reduced). In that case, it is 10 MWh per day or 3650 MWh per year according to rough estimates. The annual electricity consumption of Latvia is around 7 TWh. This means that the aggregator could reduce the electricity consumption in Latvia by at least 0.05 %. This may not seem much, but for one aggregator, it is not a bad result and would contribute to national energy and climate goals.

# CONCLUSIONS

- The use of multifaceted methods can assess ongoing knowledge- and competence-based sustainable environmental engineering education and analyse it at three levels: academic higher education, lifelong learning and scientific creativity.

- The objectives of climate neutrality and the Green Deal can be achieved through knowledge- and competence-based environmental engineering education at higher academic level, lifelong learning and scientific creativity.

- The bibliometric method in the bibliometric analysis module can search for and analyse the importance of the field of research in the field of bioeconomy, as well as the link with bioeconomy education within the framework of the Green Deal on climate policy of the European Union.

- Sustainable innovation and bioeconomy indicators and sustainable development competences in bioeconomy education include interdisciplinary competence, learning competence, transdisciplinary competence and systemic thinking competence, foresight competence, normative competence, strategic competence and interpersonal competence. All these competences have proven to be most important for the implementation of bioeconomy objectives and the transition to a knowledge-based sustainable bioeconomy.

- The results of multifactorial analysis dictate that lectures, site visits, group courseworks and laboratory works, along with role-play simulations, should be included in most of the study processes. With the developed assessment system, the study programme of environmental engineering can be evaluated.

- In the co-creation implementation module, analysing the feedback from company representatives, the author of the study can conclude that the company begins to realize certain needs only at the end of the event. Close cooperation with academic staff allows you to identify hidden goals. The results of the survey show that, in general, the participants are satisfied with the event itself and its consequences. Team members highly appreciate their contribution to the overall result of the team and assume that the experience gained will help them to achieve results more successfully in the future.

- As shown by the results of multifactorial analysis, the development of higher academic education can be realized through the use of innovative methods and tools.

- Forest resources have the potential to become an essential part of Latvian biodiplomacy. The significance of the results is that policymakers should build biodiplomacy, take into consideration key drivers such as demand, volume and renewal, where there should be emphases.

- The behavioural simulation achieved: (1) the role-play objective of distributing the funding of the COVID-19 emergency recovery support taking into account the objectives of the EU Bioeconomy Strategy and the impact of COVID-19 on the production and use of primary resources between three main groups of bioresources: forestry, agriculture, fisheries and aquaculture; (2) taking into account the lessons learned, ideas shall be submitted to the Cabinet of Ministers, local governments, various responsible institutions, etc.; (3) members of the agricultural group have acquired biodiplomacy competencies in the context of bioeconomy that characterises biodiplomats. The higher the assessment of the category criteria for a given competence, the more likely it is that the objectives set out in the Green Deal will be achieved.

- The established framework for lifelong learning studies shows an approach to achieving the Green Deal and climate neutrality objectives through co-creation, performance and integration of policy instruments.

- During the study, one can acquire appropriate competencies to solve current and future energy and climate problems through the theory and prism of system thinking with the developed trial version of the free array open online course suitable for the target audience.

- As evidenced by the qualitative and multifactorial results of analysis, science-based education and scientific creativity make it possible to develop commercialisation and new ideas.

- With the qualitative research method, the waste-free technology ranking module can search for and analyse the possibilities of using the technological processes of processing by-products of the plant.

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