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Socio-economic model of the new system of higher environmental education in Russia

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Introduction: The article covers the problem of a reforming system of higher environmental education in the Russian Federation. According to a special decree no. 343 "On some issues of improving the higher education system" in Russia signed by the President Vladimir Putin in May 2023, the country is currently facing the transformation of the levels of its higher education. A new basic and specialized university education is becoming on the agenda, including its environmental profile. The goal of this study is to evaluate and analyze the new system of higher environmental education in Russia from the perspective of its social and economic functioning by referring to the mathematical graph theory.

Methods: Graphs have become an efficient and useful instrument of assessment of various scientific phenomena including the development of the socio-economic model of higher environmental education in the Russian state. A working hypothesis was introduced to debate on the issue of an efficacy of the academic and educational reforms at the country's university level of the environmental acquisition. In the end, the research suggests an opportunistic development of the reforming system of the higher environmental education in Russia on the terms of its economic, ecological, and social principles.

Results: The results of the study have demonstrated that 89.1% of the respondents consider themselves environmentally friendly people striving to follow the principles of sustainable development in the modern world. Simultaneously, almost 94% of young people surveyed believe that university students should be environmentally active and help their university build a more sustainable and healthy academic and research environment. Statistical data in the analyzed graph G has showed the maximum sums of weights on the nodes which reflect the indicators of domestic state policy (20.84); foreign state policy (21.4); demands for environmental specialists in the world (21.01); environmentally caused diseases in Russia and the world (16.00); the knowledge of foreign languages as a tool that expands general educational horizons about sustainable development of the planet (12.50).

Discussion: The study concludes that the Russian Federation is aligning its educational reforms with global trends in sustainable development. Educational programs in universities, focused on the environmental profile of training, should be aimed at highlighting the key environmental challenges in the country. Therefore, the socio-economic model of the new system of higher

environmental education in the Russian Federation is taking place; it is relevant, timely set and has favorable prospects for its further development. In the end, the studied socio-economic model of the higher environmental education in the country can be risk-oriented. Therefore, it is highly recommended focusing on the further research and analysis of the potential risks that can limit the efficacy of the system functioning and evolution in the future.

KEYWORDS

higher environmental education, a socio-economic model, a risk-oriented model, the graph theory, a reforming system of university education, sustainability, a stable development

1 Introduction

Environmental education is one of the most critical concepts of the twenty-first century, as the world faces escalating ecological problems that could lead to severe consequences for humanity. Many scholars recognize environmental education as "a platform for sustainable development" (UNESCO, 2015; Shutaleva et al., 2020; Parmaxi et al., 2024), describing it as "a powerful tool to generate green behavior among citizens" (Varela-Candamio et al., 2018). It is defined not only as a means of rethinking humanity's relationship with the biosphere but also as an instrument for societal transformation toward sustainability (Colom and Antoni, 1981). Furthermore, environmental education is increasingly understood as a "continuous process of training, education, and personal development" (Semernya and Savvateeva, 2022), aimed at cultivating scientific and practical knowledge, value orientations, and behaviors that reflect a responsible attitude toward the environment.

In Russia, the concept of environmental education has gained growing importance in light of economic and social demands for living and working in environmentally friendly conditions aligned with the principles of sustainable development introduced by the United Nations in 2015. However, despite its growing relevance, environmental education in Russia lacks a systematic structure. Current efforts are largely driven by non-profit organizations, passionate educators, and environmental activists (Zakharova, 2021). For example, although the Federal Law "On Environmental Protection" (Chapter XIII, Article 71) underscores the universality and integration of environmental education, it remains underdeveloped as a standardized national framework.

A critical step toward addressing this gap is the integration of environmental education into university curricula. This includes the introduction of disciplines such as "Ecology," which can form the ideological and moral foundations necessary for fostering environmental culture (Lysenko, 2014). In this context, environmental education becomes a dual-faceted approach, focusing on both the development of ethical and moral principles and the acquisition of specific environmental knowledge and skills essential for sustainable development.

The uniqueness of environmental education lies in its ability to set academic goals that evolve at various stages of its implementation. Its ultimate aim is the formation of an ecological culture at both individual and societal levels. In modern Russia, this aim aligns with the reform of the higher education system, announced in 2023, which seeks to create a new ecological system of higher education. This reform is closely tied to the principles of digitalization and the application of sustainable technologies, positioning Russia to address the global challenges of the twenty-first century.

1.1 Theoretical framework and relevance

This study aims to analyze and model the evolution of environmental education in Russia within the context of its higher education reforms. Environmental education is conceptualized as a socio-economic system characterized by interrelated processes, relationships, and interactions. To analyze this complex system, we turn to mathematical graph theory, a versatile branch of discrete mathematics widely used for modeling connections and relationships. Graph theory has proven effective in various fields, including economics, computer science, and network analysis, due to its ability to visually and mathematically represent complex systems (Avondo-Bodino, 1962; Karnaukhova and Dolgopolova, 2015).

The choice of graph theory for this study is motivated by its ability to offer a universal language for analyzing interconnections and interactions. Graphs have been successfully applied in economic modeling as tools for solving problems related to process planning and optimization (Rodionov and Efremova, 2015). Graph theory is a basic branch of discrete mathematics that mainly focuses on the relationship between objects in which some pairs of the objects are in some sense "related." Graphs are common in computer science, network analysis, and many other everyday uses because they provide a good representation of connection, relationship, and process. These attributes make graph theory an ideal framework for representing and analyzing the socio-economic and structural components of higher environmental education in Russia.

1.2 Objective and novelty of the study

Accordingly, the goal of this research is to estimate the new system of higher environmental education in Russia from the perspective of its social and economic functioning (a set of connections, relationships and processes) in the modern Russian

society through mathematical graph theory. The reference to the graph theory is explained, first of all, by the fact that, being an extensive branch of discrete mathematics, graphs are effectively and widely used in solving various economic and managerial tasks, in different spheres of science and the humanities. Besides, graphs help visually represent various complex interactions, including modeling of the new system of higher environmental education.

Therefore, this graph approach toward the estimation and analysis of the system of higher environmental education in the Russian Federation defines the novelty of the current research. The idea to combine the mathematical assessment of the system connections within the socio-economic model of higher environmental education in Russia based on the graph theory will help to perceive the nuances of its further development and give a more accurate forecast on its effective, sustainable functioning in the context of the digital economy of the modern Russian state.

1.3 Structure of the study

To achieve its objectives, the article is structured as follows:

1. Literature Review: A detailed discussion of graph theory and its application in environmental and social modeling, emphasizing its relevance to this study.
2. Methodology: A comprehensive explanation of the graph-based modeling approach used to analyze the system of higher environmental education in Russia.
3. Results and Discussion: Presentation and interpretation of the socio-economic model of higher environmental education, represented through oriented graphs.
4. Conclusion: A reflection on the implications of the findings, their relevance to sustainable development, and potential applications of the proposed model.

This study hypothesizes that the new system of higher environmental education in Russia, represented as an oriented graph, will enable a systematic and sustainable improvement in educational quality. It is also expected to play a pivotal role in fostering environmental consciousness among Russian youth, contributing to the broader goals of sustainability in the twenty-first century.

2 Literature review

2.1 Environmental education in Russian higher education institutions

On May 12, 2023, the President of the Russian Federation signed a special decree no. 343 titled "On some issues of improving the higher education system" in Russia (President of the Russian Federation, 2023). This decree launched a transformative pilot project aimed at restructuring the levels of professional education to address the "long-term needs of economic and social sectors" in Russia. Within this context, environmental education emerges as an essential aspect of sustainable social and economic development (President of the Russian Federation, 2023).

An important aspect of a successful social and economic development in any country in the modern world today is its close ties with the sustainability principles which imply an ecological basis of the production and consumption in society as well as an active integration of ecological or "green" ideology among people of different ages. Simultaneously, ecological culture and upbringing of the younger generation plays a crucial role in the country's future and prosperity (Frank et al., 2011; Osmaev, 2023).

Scott and Vare (2018) argue that environmental education fosters an understanding of the relationship between human culture and life-support systems, promoting social action and sustainable behaviors. This aligns with the view that revisiting human-nature relationships is crucial for modern ecological ideologies (Khusainov et al., 2015).

Environmental education provided by higher education institutions in the world today has an important impact on training and preparing the future generation for a green society (Boca and Saraçli, 2019). Overall, the rise of environmental education in universities, including Russian higher education institutions, is a striking and seemingly global phenomenon which requires "a world society approach" (Frank et al., 2011) toward better understanding of the foundations of a sustainable environment as well as knowledge, attitudes, and abilities of human civilization which is building this new sustainable world.

However, despite the global prominence of this trend, Russian higher education has struggled with systematic integration. Although environmental disciplines such as ecology are offered, they are not mandatory components of Russian higher education curricula (Magomedov, 2022). This lack of systemic inclusion contrasts sharply with the state's educational strategy and the urgent need to address the environmental crises.

Empirical evidence indicates a growing demand for environmental education among Russian students and educators. A significant portion of students (47.56%) believes universities should implement comprehensive environmental education programs, with an additional 31.14% advocating for supplementary programs regardless of their fields of study (Zakharova, 2022). Educators share similar views, recognizing the importance of integrating ecological knowledge into higher education. These findings highlight the gap between societal demand and institutional practices, underscoring the need for reform.

Historically, efforts to incorporate sustainability into Russian higher education began in the late twentieth century. For instance, in 1995, Saint Petersburg State University launched an interdisciplinary project titled "Noosphere and Sustainable Development." This project sought to redefine the "man-nature" relationship, develop sustainability criteria, and propose methodologies for integrating sustainability into education (Verbitskaya et al., 2002). This ecological project of one of the leading universities in Russian Federation was taking place at the epoch of excessive consumerism that triggered the emergence of the so called "waste generation" both in Russia and in the world. This generation has rapidly increased over the years especially in developing countries where the normal practice is to buy use and dispose of with little focus on recycling. While innovative at the

time, these efforts were fragmented and insufficient to address the ecological challenges posed by modern consumerism, which exacerbates environmental degradation globally (Kaza et al., 2018; Ali and Anufriev, 2020).

Modern initiatives, such as campus sustainability measures introduced in institutions like RUDN University and Perm National Research Polytechnic University, represent attempts to mitigate environmental impacts (Ali and Anufriev, 2020). These measures, while localized, underscore the potential of universities as catalysts for sustainability. By fostering ecological awareness and action among students, they contribute to broader societal shifts toward environmental responsibility. These historical and contemporary developments demonstrate the need for a cohesive and systemic approach to environmental education in Russian higher education.

Thus, this early ecological endeavor demonstrated the importance of environmental education which can be confirmed by the fact that it unites young people with the world around them, teaching them about both natural and artificial habitats. Environmental education raises a university student's awareness of the issues affecting the environment on which humanity depends, as well as the actions that the latter can take to support the sustainable development of the planet today and in the future.

2.2 Pilot project of environmental education at the modern stage of Russian higher education transformation

The ongoing transformation of Russia's higher education system, initiated by Decree no. 343, has significant implications for environmental education. The transition from the bachelor's and master's degree model to basic and specialized higher education is reshaping academic curricula across disciplines, including environmental studies.

Currently, five leading universities—Moscow Aviation Institute (MAI), National University of Science and Technology MISIS, Immanuel Kant Baltic Federal University, Moscow Pedagogical State University (MPGU), and Tomsk State University—are participating in a pilot project designed to revise academic programs. These programs aim to align educational content with contemporary ecological trends and socio-economic needs.

For example, Moscow State Pedagogical University has already developed and presented two environmental academic programs for basic and specialized higher education. The first is a 5-year full-time program in "Geography and Ecology," which awards a degree as a "Teacher of Geography and Ecology." The second is a 2-year full-time specialized program in "Environmental Education," which incorporates ecosystem-based approaches, increases research and innovation, and promotes student-led ecological projects (Zsóka et al., 2013; Moyo and Masuku, 2018).

These reforms reflect a growing recognition of the strategic importance of environmental education. As highlighted by Verbitskaya et al. (2002), education is central to shaping the future of any society, fostering ecological thinking, and developing responsibility for the planet's wellbeing. Knowledge of sustainable development principles equips graduates to make informed decisions in their professional and personal lives, contributing to long-term societal resilience.

However, challenges remain in bridging the gap between sustainability principles and students' motivations and aspirations. Despite the increasing prominence of sustainability in higher education, there is a need for systemic integration and alignment with the broader reforms of Russia's higher education system. This study addresses this gap by analyzing the socio-economic dynamics of higher environmental education through the lens of graph theory, providing a quantitative framework to model its development and future trajectory.

2.3 Research gap and contribution

While previous studies have examined the role of environmental education in sustainability and higher education reforms in Russia, there is limited research on the structural and socio-economic dynamics of environmental education systems. Most existing literature focuses on qualitative assessments of policy and institutional practices without addressing the complex interrelationships that influence these systems.

This study fills this gap by employing mathematical graph theory to model the socio-economic framework of higher environmental education in Russia. Graph theory provides a novel lens to analyze and visualize complex interactions within this system, offering insights into its evolution and potential for sustainable development. By bridging theoretical analysis with empirical application, this research contributes to both the academic discourse and practical efforts to enhance environmental education in Russia.

3 Methodology

To test the hypothesis regarding the successful development of a new socio-economic system of higher environmental education in the Russian Federation in the first quarter of the twenty-first century, this study employs graph theory as the primary analytical framework. Specifically, we focus on the analysis of nodes and weights in an oriented graph to model and evaluate the system.

3.1 Theoretical framework

The system of higher environmental education in Russia is conceptualized as a weakly structured system comprising interconnected elements (subsystems) that exhibit structure, integrity, emergence, and stability. Due to the absence of strict mathematical relationships between these elements, oriented graphs are employed as the most appropriate tool for modeling such a system.

An oriented graph $D = \{V(D), E(D)\}$ consists of:

- a set of nodes ($V(D) = \{V_i\}$) each of which corresponds to an element of the system.

– a set of arcs (oriented edges) ($E(D) = \{e_{ij} = (V_i, V_j)\}$), reflecting the influence of nodes (an element e_{ij} exists if there is an influence of element V_i on element V_j).

Edge orientation is introduced to reflect asymmetric relationships between elements. For example, the relationship between an applicant and their satisfaction with the quality of an academic program at a university is unidirectional. Furthermore, orientation establishes a coordinate system, eliminating ambiguity in the representation of relationships.

A directed graph D is considered weighted when equipped with a weighting function ω: $E(D) \rightarrow N$, expressing the strength of mutual influence between nodes (Ha et al., 2019). The introduction of weights allows quantitative evaluation of system responses to control actions, providing insights into potential transformations.

3.2 Model development

Thus, the use of directed graphs in assessing the current system (as a model) of higher education in Russia will not only display the structure of the interaction of each component (variable) in a complex scientific and academic system, but also make and evaluate possible changes (Kiseleva et al., 2021) and the transformation of the educational model into a new sovereign system of higher education in the Russian Federation. In addition, turning to directed graphs with impulse processes implemented on them is a universal mathematical method for solving various management problems in the socio-economic and environmental spheres of the country (Kiseleva et al., 2021; Burkov et al., 2009).

Decomposition of a weakly structured system into elements can only occur based on the purpose of modeling, as well as taking into account the mandatory fulfillment of the property of system integrity, which, when constructing a model in the form of an oriented graph, is expressed in the property of strong connectivity of the oriented graph. The purpose of constructing a model in our case is to assess the effectiveness of the system of higher environmental education in Russia for sustainable development. Thus, the first step in constructing a model is the selection of elements that characterize the system of higher environmental education and its connection with the socio-ecological-economic system of the country.

The process of constructing and refining the graph-based model consists of the following steps:

1. **Selection of Key Elements (Nodes):** The system of higher environmental education and its connection to the socio-ecological-economic system of the Russian Federation are characterized by the following elements:
    - Number of graduates with higher environmental education (bachelor's and master's levels).
    - Number of highly qualified personnel with academic degrees in ecology.
    - Number of graduates employed in their field of study.
    - Number of young environmental specialists emigrating from Russia.
    - Satisfaction with the quality of education.
    - Environmental policies of the Russian Federation.
    - GDP of the Russian Federation.
    - Level of environmental awareness in society.
2. **Establishing Connections (Edges):** Relationships between nodes are defined based on direct or indirect interactions. If an indirect connection is identified, an additional node representing the intermediary element is introduced.
3. **Analysis and Refinement:** The constructed graph is analyzed for strong connectivity. If necessary, adjustments are made to ensure the integrity of the model. Redundant nodes (with only one incoming and one outgoing arc) are simplified by replacing indirect connections with direct ones, avoiding unnecessary complexity.
4. **Incorporating Weighting Functions:** Weights are assigned to the edges based on the strength of influence between elements. This allows quantitative analysis of the system's behavior under different conditions and control actions.

The results of the described process as applied to our problem are given in the next section.

In this study below we will dwell in more detail on the description and analysis of calculations for the presentation of a new socio-economic and environmental model of higher education in Russia in order to assess its significance for the development of the reformed system of higher education in the country today, as well as the education of the younger generation, focused on supporting and constructing the principles of sustainable development of their country and the planet.

4 Results and discussion

4.1 Presentation of key model parameters and their mathematical sense

The socio-economic model of higher environmental education presented in this study is an oriented graph consisting of 23 vertices (nodes) that represent the system's functioning parameters. Table 1 outlines these vertices and their respective definitions.

Table 1 clearly shows that, first of all, when constructing a model, attention is drawn to the parameter—vertice V1—associated with applicants, that is graduates of general education or secondary specialized schools (secondary specialized) who are interested in obtaining higher environmental education. At the moment, applicants may have a dilemma when choosing an environmental undergraduate program: whether they need to apply for a bachelor's degree or focus on a basic higher environmental education in connection with the reform of the Russian higher education system at the present moment. Nevertheless, this problem of an academic program choice in modern conditions of the Russian education reforms can be partially resolved owing to the target figures for admission to a particular higher education institution, the number of budget places allocated for environmental profiles within the framework of undergraduate or basic higher education.

Receiving an environmental education at a university cannot but determine the level of environmental thinking of graduates of environmental faculties and institutes. From our viewpoint, young people's environmental consciousness today

TABLE 1 Parameters of the socio-economic model (vertices of the orgraph) for constructing a new, reforming system of higher environmental education in the Russian Federation.

Node	Description
V1	Applicant (bachelor's degree; basic higher education)
V2	Graduate (bachelor's degree; basic higher education)
V3	Applicant (master's degree; specialized higher education)
V4	Graduate (master's degree; specialized higher education)
V5	Applicant (graduate student)
V6	Educational program (bachelor's degree; basic higher education)
V7	Educational program (master's degree; specialized higher education)
V8	Postgraduate studies as professional education
V9	Level of environmental consciousness development in society
V10	Internal state policy (number of adopted laws in the field of environmental regulation)
V11	Knowledge of foreign languages as a tool expanding educational horizons on sustainability (% proficiency from B1+ among students)
V12	Satisfaction with the quality of education
V13	Number of environmental events for schoolchildren
V14	Number of environmental publications in traditional and electronic media, social networks and instant messengers
V15	Gross domestic product (GDP) of the Russian Federation
V16	Graduate employed in his (her) specialty
V17	Average salary of an environmental specialist in Russia
V18	Loss of young specialists (percentage of graduates who left Russia)
V19	Environmentally caused diseases in Russia and worldwide (number per 1,000)
V20	External state policy (number of agreements promoting sustainable development)
V21	Demand for specialists (number of vacancies)
V22	Employers cooperating with universities (number of organizations)
V23	Global demand for environmental specialists

is an indispensable parameter of any socio-economic model for representing the levels of greening of modern society and especially its younger generation.

Our survey among young people aged 17–35 shows that 73.7% of the latter completely agree with the statement that environmental awareness of youth is a guarantee of a more successful, healthy and economically developed society in the country. Simultaneously, 26.3% of respondents believe that this statement is more likely to be true than false. Thus, the introduction of the parameter (node) of graph V9 (the level of environmental consciousness development in society) in the model presented within the framework of this study is a mandatory component of modeling and forecasting its further development.

The ecological consciousness of society in the first quarter of the twenty-first century cannot but depend on other characteristics of the functioning of the socio-economic system that determine the quality of environmental education in higher education institution in the Russian Federation. In accordance with this, it seems appropriate to introduce the following nodes of the described oriented graph within the framework of this research: V10 (internal state policy (the number of adopted laws in the field of environmental regulation), V 15 (gross domestic product (GDP) of the Russian Federation), V20 [external state policy (number of agreements in the field of promoting sustainable development)].

Another significant parameter for the analysis and assessment of the modeled orgraph, reflecting the trends in the transformation of the system of higher environmental education in Russia, is nodes V21 and V 23 (see Table 1), which respectively, characterize the demand for environmental specialists in the country (number and vacancies) and in the world. The link between these two nodes is node V22, which reflects the number of employers collaborating with the university, that is number of organizations.

In recent years, interest in the profession of ecologist both in Russia and the world has grown significantly. According to official publications of Russian and foreign media, statistics on the growth dynamics of the number of ecologists in the country and the world reflect a positive growth trend. For example, in 2023, more than 500 vacancies for ecologist were opened in the Krasnodar Region, which is 48% more than in 2022 (Elina, 2024).

Minister of the Moscow Government and Head of the Moscow Department of Education and Science Alexander Molotkov said that the number of vacancies in the field of ecology increased 2.5 times from 2017 to 2021, and by 2030 another 24 million "green" workers may appear in the world places (Sheikh Khalil, 2021).

Thus, the appeal to quality environmental education is a parameter that makes up a node of the directed graph of the socio-economic model described in this study (node V12). It is important to understand that quality education is also associated with the number of environmental activities for schoolchildren, which allow them to become familiar with environmental culture already at the stage of primary education in a comprehensive school and support it in every possible way at all stages of education (parameter V13). High-quality education of a modern ecologist involves not only mastering specialized knowledge, but also improving it by accessing educational and professional materials in foreign languages; cooperation with international environmental schools, organizations, and institutions; meetings and exchange of knowledge and experience with scientists representing other states, universities, and companies. All of these aspects require knowledge of at least one foreign language. Accordingly, in the model described in the study, node V11 is included, which explains the dependence of knowledge of foreign languages as a tool that expands the general educational horizons about the world and the sustainable development of the planet and high-quality environmental education itself, which contributes to the formation and education of an environmentally healthy young personality of a student, and then a professional ecologist.

The final parameter of the socio-economic model for building a new system of higher environmental education in the Russian Federation is the node of the oriented graph V19, which characterizes environmentally caused diseases in Russia and the world (number per 1,000). According to Russian researchers Makosko and Matesheva (2012), at the moment, the relevance of considering the problem of the scale of the spread of

environmentally caused diseases on the territory of the Russian Federation is high. Environmental pollution affects both the prevalence and severity of individual diseases (Savilov, 2007).

To summarize all of the above, it is necessary to pay attention to the strategic importance and significance of adding all the listed and characterized parameters for constructing a socio-economic model of a new reforming system of higher environmental education in the Russian Federation. It is the assessment and analysis of their relationship and interaction within the oriented graph that will make it possible to determine and predict how effectively the new educational system can develop and transform environmental education in Russia, focusing on educating the younger generation of Russians with a high level of both individual and collective environmental consciousness.

4.2 Mathematical assessment of the effectiveness of the socio-economic model of environmental education within the framework of the development of a reforming educational system in Russia

As noted above, the present socio-economic research model is based on the theory of orgraphs, which occupy one of the first places as formal models of real systems. A modern graph system for managing various processes is a powerful tool for effectively modeling socio-economic, environmental and educational connections, since graph analytics quickly and accurately establishes connections without spending a lot of time (Linnik, 2018).

We emphasize that the possibility, demand and relevance of the analyzing model have become feasible due to the existing positive, growing dynamics of interest of the younger generation of Russians in the study of environmental sciences (in particular, ecology), and also searching for work in the environmental sectors of modern Russian society.

Figure 1 reflects statistical data on the number of students who are currently studying (at all levels of university education and educational programs) at the Institute of Environmental Engineering of RUDN University named after Patrice Lumumba from 2019 to the present time (i.e., including indicators for the 2024 academic year).

From Figure 1 above, it is obvious that over the past 5 years the number of students seeking to obtain higher environmental education has increased. An important aspect of the increased interest in environmental programs at the Institute of Environmental Engineering is also the statistical indicators of the 2023 summer campaign, when 2,782 applications were submitted, processed and reviewed from young people living in different regions of the Russian Federation and wishing to continue studying ecology and environmental management at the university level training.

The increased interest in higher environmental education is also supported by the statistics of this study. In particular, a survey of student youth led to the conclusion that 89.1% of respondents consider themselves "environmentally friendly people who strive to follow the principles of sustainable development in the modern world." Moreover, almost 94% of young people surveyed believe that university students should be environmentally active, helping their university create a more sustainable and healthy academic and research environment.

Almost 90% of respondents to this research are confident that in every university, in any specialty, it is advisable to introduce one or two environmental disciplines in order to broaden their general horizons, deepen professional knowledge, as well as develop the intelligence, critical thinking and creative abilities of students.

Thus, the above statistical data on the popularity, demand, as well as the importance of studying environmental disciplines, expanding the range of environmental educational components at different stages of education, and especially in modern higher education in Russia with an emphasis on its national ecological priorities and strengthening the academic and research principles of modern sustainable development made it possible to construct a socio-economic model of a new system of higher environmental education in the country, conventionally designated as graph G (see Figure 2).

The directed graph G is a combination and interaction of 23 variables (nodes), which together provide the dynamics of the development and functioning of the reformed system of higher environmental education in the Russian Federation.

At the moment, graph G cannot be characterized as strongly connected, since its matrix contains zero indicators (see Table 2).

Nevertheless, the calculation of matrix connections in the analyzed graph allows us to conclude that at the fourth step the predicted model is able to acquire stability due to the disappearance of zero indicators from the matrix (see Table 3).

The multi-criteria assessment of the constructed graph G (method of paired comparisons with weights) allowed us to conclude that the present socio-economic model of the new system of higher environmental education in the Russian Federation has all the opportunities for its successful development in the optimal way for the student, the employer and the economic market of the Russian Federation (see Table 4).

Statistical data, ranging from 0 to ~1, indicates the emergence of a new system of higher environmental education in the country, which can become quite successful, fundamental and stable. The maximum sums of weights fall on nodes reflecting the parameters of domestic state policy (the number of adopted regulations in the field of environmental regulation) (20.84); foreign state policy (number of agreements in the field of promoting sustainable development) (21.4); demand for environmental specialists in the world (21.01); environmentally caused diseases in Russia and the world (number per 1,000) (16.00); as well as knowledge of foreign languages as a tool that expands general educational horizons about peace and sustainable development of the planet (% proficiency from B1 among students) (12.50). We may conclude that all of the above mentioned factors which are domestic and foreign state policy, market demand for professional ecologists with modern relevant education and the knowledge of foreign languages explain the increasing trend of the popularity of environmental jobs. Simultaneously, this rising dynamics reflects the worrying data that demonstrate environmentally caused conditions in the state that must be dealt with owing to the necessary number of environmentalists in the country.

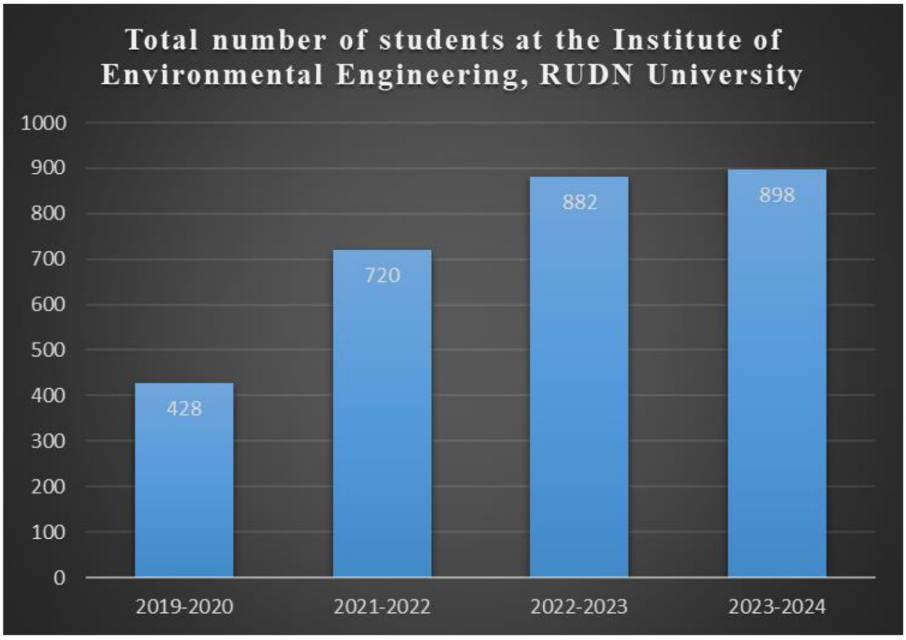

FIGURE 1
The total number of students in environmental programs (2019–2024) at the Institute of Environmental Engineering, RUDN University named after Patrice Lumumba. Source: Data from the Institute of Environmental Engineering, RUDN University named after Patrice Lumumba.

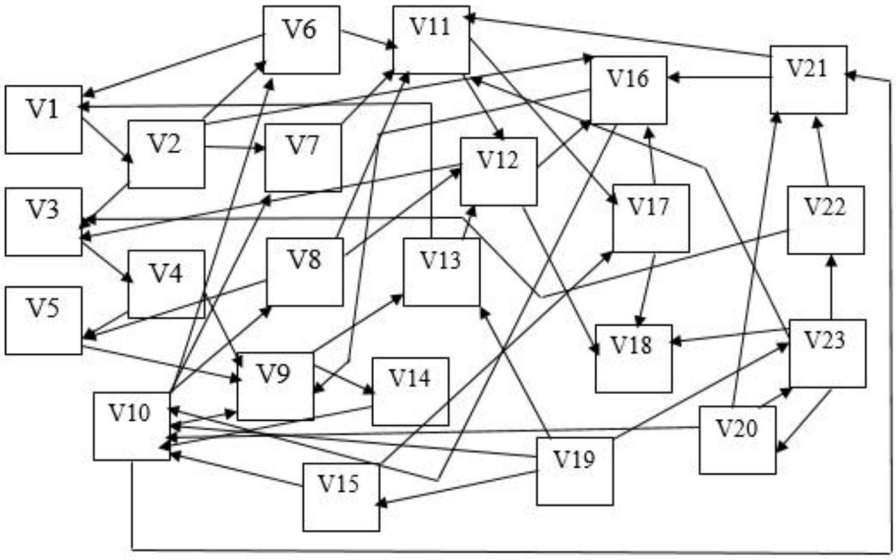

FIGURE 2
Socio-economic model of the new system of higher environmental education in the Russian Federation (based on graph theory)—orgraph G.

Thus, it can be assumed that the demand for environmental specialists in the world and in Russia is growing due to the environmental agenda of our time (we are talking about the 17 sustainable development goals announced by the UN in 2015), as well as due to the global trend toward popularizing the profession of ecologist in society at national level and global levels of its actualization. In the modern era, characterized by worsening environmental problems caused primarily by climate change and global warming, there is a need for an environmental "reset" at the state and interstate level.

The Russian Federation is a modern state that strives to follow trends in sustainable development, paying attention to existing environmental problems caused by industrial waste, air pollution, an imperfect landfill management system, etc., which can, as a result, cause environmentally-related diseases among citizens of the Russian Federation. Educational programs in universities,

TABLE 2 Adjacency matrix of the oriented graph G (socio-economic model of the new system of higher environmental education in the Russian Federation).

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
13	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
18	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1
20	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
21	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
22	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
23	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1	0

Here and further: 1–23—vertices of the oriented graph, parameters of the analyzed model (presented above).

focused on the environmental profile of training, should be aimed at highlighting the key environmental challenges in the country in order to effectively solve them and prevent undesirable consequences, which are risk factors for disrupting the ecological and economic balance of Russian society.

It is important to pay attention to the fact that the undergraduate and graduate students themselves in this study (86%) note that studying foreign languages makes it possible to gain access to new information of an environmental nature in different regions of the planet, thereby allowing them to become more environmentally conscious individuals.

One of the positive examples of the eco-friendly behavior among university students has become their active participation in an all-Russian national environmental project "Clean Air." This is a federal ecological program aimed at improving the environmental and hence economic and social situation in the state by reducing emissions of pollutants into the atmosphere across the Russian Federation. The program was launched in 2019 in 12 Russian cities: (Bratsk, Krasnoyarsk, Lipetsk, Magnitogorsk, Mednogorsk, Nizhny Tagil, Novokuznetsk, Norilsk, Omsk, Chelyabinsk, Cherepovets and Chita). Later on, 29 more cities from 16 regions of the state, mainly Siberia and the Far East, joined the project "Clean Air" from September 1, 2023. An important factor of this project was students' involvement into this activity and strive to improve the air pollution problem in the country. The case study of RUDN University students enrolled into environmental curricula has demonstrated young people's intentions to dedicate their final qualification works to the challenges of "Clean Air" project that they witnessed themselves while participating in its performance.

Accordingly, summarizing all of the above, we can conclude that the socio-economic model of the new system of higher environmental education in the Russian Federation is taking place; it is relevant, timely set and has favorable prospects for its further development and effective results in the future. This is a fairly tangible system that requires further study and assessment, allowing us to predict the future evolution of Russian society on the basis of its reformed educational platform, taking into account the new environmental and economic realities of the third millennium. We may also add that the above presented socio-economic model of the Russian new system of higher environmental education can become a prototype for the evolution of present-day educational models in other countries with an important focus on sustainability and economic development going hand in hand in the modern world. An ambitious plan adopted by the United Nations in 2015 to reach the 2030 Agenda for Sustainable Development may be a perfect platform for the reformation of higher institutions not

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TABLE 3 Adjacency matrix of non-zero indicators of the oriented graph G (socio-economic model of the new system of higher environmental education in the Russian Federation)—step 4.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
12	3	6	1	9	4	4	3	11	16	38	29	20	11	9	14	10	15	3	2	3	2	9
20	12	32	8	4	19	19	16	55	51	23	61	14	11	3	42	47	86	16	9	20	9	5
4	2	7	3	4	5	5	5	17	13	11	13	9	7	2	14	8	20	5	1	7	1	3
9	4	15	8	8	15	15	13	54	44	25	25	22	17	5	28	13	35	13	3	15	3	6
7	2	9	6	5	12	12	10	42	34	17	18	15	12	3	15	10	21	10	3	10	3	3
5	9	33	19	10	29	29	23	87	69	34	20	31	24	7	57	9	58	23	2	31	2	11
5	9	33	19	10	29	29	23	87	69	34	20	31	24	7	57	9	58	23	2	31	2	11
15	12	49	36	26	58	58	47	178	137	82	50	70	54	16	88	22	91	47	6	57	6	21
15	7	20	12	16	36	36	34	81	54	47	42	52	42	10	38	20	48	34	3	40	3	13
71	41	118	47	32	93	93	80	300	263	134	206	102	78	24	182	136	291	80	28	98	28	33
31	5	29	35	42	78	78	69	213	148	123	88	110	87	23	60	41	74	69	11	73	11	25
32	8	24	14	36	59	59	58	123	73	101	93	100	79	21	54	47	80	58	7	66	7	25
11	2	11	15	17	35	35	30	90	61	48	28	44	35	9	21	10	20	30	4	30	4	9
41	13	38	8	29	26	26	24	78	80	111	105	71	46	25	81	47	102	24	9	30	9	28
49	13	46	22	41	50	50	44	154	136	147	127	101	70	31	97	57	120	44	13	50	13	34
48	15	47	14	34	38	38	34	120	114	128	123	86	58	28	96	57	123	34	12	40	12	31
30	8	22	12	34	56	56	56	116	68	94	86	96	76	20	52	42	74	56	6	64	6	24
48	15	47	14	34	38	38	34	120	114	128	123	86	58	28	96	57	123	34	12	40	12	31
42	21	68	35	38	95	95	85	237	171	119	121	117	94	23	117	68	159	85	15	97	15	29
81	29	91	35	56	97	97	86	272	228	201	218	148	108	40	164	119	238	86	27	96	27	45
20	13	44	25	27	57	57	51	145	103	81	63	79	62	17	83	30	95	51	5	63	5	23
17	8	26	13	11	25	25	22	79	64	37	51	29	23	6	42	34	69	22	7	26	7	8
57	27	85	46	62	107	107	97	276	211	206	166	177	132	45	168	75	197	97	12	121	12	57

only in the Russian Federation, but also in other developed and emerging countries on the planet.

5 Conclusion

Modern Russia is a state focused on an economic model designed within the framework of the international environmental concept of sustainable development. It was officially approved in the country by Decree no. 1912-r of the Government of the Russian Federation dated back to July 14, 2021. The decree confirms that the Russian state policy should be focused on the projects related to a positive impact on the environment, the development of social relations, and other areas of sustainable development defined by international treaties of the Russian Federation. One of the leading aspects of the country's sustainability policy is the successful education and upbringing of an environmentally conscious individual.

It is the environmentally friendly approach of the younger generation, professing the principles of respect for the environment and promoting the concept of sustainable development in the country where they plan to study, live and work, that is a strategic tool for the preservation and successful evolution of the state at any historical point in time.

Correspondingly, consideration of the socio-economic model of the new system of higher environmental education in the Russian Federation, outlined in this study, is not only a pressing research issue, but also in demand within the framework of the current debate about the further path of evolution of the higher education system in the Russian state.

In our paper, the focus of attention was the multi-criteria analysis of the oriented graph G. This study has shown the possibility to identify the positive, stable dynamics of the development of the system of higher environmental education in the country, which is currently in the process of reform. Owing to the identified weighting coefficients (23 indicators in total), we managed to establish the most significant of them, which have a greater impact on the formation and development of the studied system. First of all, it is necessary to mention such influencing factors as the foreign and domestic government policy of the Russian Federation, which pays attention to global environmental problems discussed in the world (for example, climate change, the transition to alternative energy sources, an ecosystem approach to social life, etc.). Next, one should take into account the interest in higher environmental education on the part of the younger

TABLE 4 Multi-criteria assessment of the potential functioning of the socio-economic model of the new system of higher environmental education in the Russian Federation.

Variable	Amount (weight)
1	2.08
2	4.80
3	1.39
4	3.21
5	2.26
6	4.97
7	4.97
8	9.92
9	5.82
10	20.84
11	12.50
12	10.25
13	5.00
14	8.80
15	12.49
16	11.06
17	9.62
18	11.06
19	16.00
20	21.40
21	9.78
22	5.31
23	21.01

Red-colored values in the table denote the highest recorded sums of weights for the respective parameters, signifying their dominant influence on the assessment of the higher environmental education system.

generation. This study confirmed the demand for an environmental approach in relation to any specialty in higher education in the Russian Federation. This view was based on the results of young respondents' survey conducted in this research who are confident that modern higher education should be sustainable and eco-friendly. It should also represent environmental awareness as a guarantee of a more successful, healthy and economically developed society in the country and the state.

Therefore, our working hypothesis on the construction of the new socio-economic system of higher environmental education in Russia, presented in the form of an oriented graph, which will gradually and steadily develop and be embedded into the reforming landscape of the Russian higher education has been accepted.

However, at the same time, the modeled socio-economic system of the higher environmental education in Russia may encounter a certain set of risks, which are a natural pattern of its development. Therefore, we recommend further research of all the potential risks that can occur during the formation and evolution of the generated socio-economic model of the higher environmental education in the country.

6 Limitations and future studies

On the basis of the promising findings presented in this paper, work on the remaining issues is continuing and will be presented in future studies. As it was mentioned above, a reforming system of higher environmental education in Russia may face potential risks of its possible insufficient efficiency. In this regards, the question arises of analyzing and assessing the hypothetical risks that the new socio-economic model of higher environmental education of the Russian state will be at stake. For this reason, it is recommended to refer to the basis of such effective risk-management instruments as PEST-analysis and SWOT-analysis of the risk-oriented events that may influence the successful development of the reforming higher environmental education system. Simultaneously, the evaluation of the risks that follow the formation of the socio-economic model of the higher environmental education in Russia can be deeply analyzed by means of the mathematical assessment of the risky events that can happen for each of the 23 parameters of the presented model. In this case we suggest using the function of the normal (Gaussian) distribution of a random variable which can effectively calculate the risk weighting factor as well as visualize graphically the resulting final risk assessment.

Higher environmental education in Russia is a risk-oriented system in which every parameter defines its vitality and stable development. Therefore, the analysis of the economic, ecological, and social risks should become mandatory so as to single out the key risky events, avoid them and manage the successful development of the reforming system of the higher environmental education in the Russian Federation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AG: Project administration, Supervision, Writing – original draft, Writing – review & editing. KI: Conceptualization, Investigation, Methodology, Writing – review & editing. TL: Project administration, Software, Supervision, Visualization, Writing – original draft. NV: Conceptualization, Methodology, Resources, Software, Writing – review & editing. NG: Investigation, Methodology, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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