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Evolution of environmental economics & management in the age of artificial intelligence for sustainable development

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Evolution of environmental economics & management in the age of artificial intelligence for sustainable development

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Editorial: Evolution of environmental economics and management in the age of artificial intelligence for sustainable development

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Editorial on the Research Topic
Evolution of environmental economics and management in the age of artificial intelligence for sustainable development

Introduction

An environmental economy is a realm in which economic practices and social and environmental effects are well-balanced and systemically high (Ramzan et al., 2023). This economy shows optimal conditions for implementing a set of environmentally Sustainable Development Goals (SDGs) (Popkova, 2022). The environmental economy includes the transition to climate-resilient (decarbonisation to support SDG13) and clean (renewable–which preserves the heritage of fossil fuel for future generations to support SDG7) energy (Popkova and Sergi, 2021), responsible communities and sustainable territories (SDG 11), practices of responsible production and consumption (SDG 12) and preservation of biodiversity and protection of ecosystems (SDGs 14–15). The COVID-19 pandemic and multiple new zoonotic diseases require coordinating efforts to protect the environment and healthcare. SDG 3 is supported in the environmental economy (Popkova and Shi, 2022).

These new economic practices are deep-rooted in economic systems in developed and developing countries (Sharma et al., 2023). In the 21st century, the Fourth Industrial Revolution led to the evolution of the environmental economy. More perfect and leading technologies became affordable and widespread; they transformed the above institutes and the managerial mechanisms that influence them (Ayakwah and Damoah, 2022).

The Decade of Action is the age of artificial intelligence since artificial intelligence technologies have become widespread and widely used in practice (Haq et al., 2022; Khan et al., 2023; Zador et al., 2023). Decision support, smart technologies and automatised environmental monitoring and control on artificial intelligence outline a new technological landscape of the environmental economy and the horizons of its development until 2030 and, perhaps, further on (Pagallo et al., 2022; Lei et al., 2023; Stahl et al., 2023).

The extant literature described some aspects of using artificial intelligence technologies in the environmental economy (Asha et al., 2022; Ligozat et al., 2022). However, as the general knowledge is fragmentary, this Research Topic aims to delve into current trends and prospects for the environmental economy in the age of artificial intelligence. The Research Topic connects all aspects of adaptation of the environmental economy to the age of artificial intelligence to support sustainable development. In the extant literature, environmental management practices were considered fragmentarily, and this research gap is what Research Topic fills. On the one hand, smart technologies create new opportunities for developing green economic practices. On the other hand, digital innovations can pose a direct danger or hidden threat to nature and environmental management helps disentangle and balance opportunities and threats.

This Research Topic had to reach the three following tasks. The theoretical task: conceptualising the notion and clarifying the essence of environmental AI economy as a category *per se*. The methodological task: describing the economic and managerial foundations of monitoring and regulating the environmental economy in the age of artificial intelligence. The empirical task of the Research Topic is to recommend proposals for the environmental AI economy.

Overview of the Research Topic

This Research Topic sheds light on the international experience of sustainable and environmental development of the energy economy. Amid Industry 4.0 and the digital economy, sustainable and environmental development of the energy economy takes place on Smart Grids and EnergyTech. All papers on the Research Topic elaborate on the notion that environmental management must be flexible enough to adapt successfully to new opportunities and threats in the age of artificial intelligence.

Skiter et al. formulated the concept of smart ecology, which allows for identifying a close association between the conditions of smart ecology and the sustainable development of an enterprise. The authors scrutinised the sustainable development of companies under the conditions of smart ecology. Innovation management under the Fourth Industrial Revolution conditions relates to risks. Since it requires information to support managerial decision-making, the authors developed an expert machine learning and artificial intelligence system that increase the effectiveness of smart ecology technologies.

Ragulina et al. settled the contribution of the environmental AI economy to decarbonisation and waste reduction. The authors created a model of the evolution of the artificial intelligence economy and the environmental AI economy as its ongoing stage by identifying the contribution of each element of digital competitiveness towards decarbonisation and reduction of production and consumption waste. The authors also proposed a set of recommendations for unlocking the potential of the environmental AI economy in support of decarbonisation and waste reduction.

Atabekova et al. studied the role of education and social policy to prove the leading role of universities in the development of responsible production and consumption in the environmental AI economy. By developing knowledge and technologies, the authors also recommended developing education and improving social policy to support responsible production and consumption in the AI economy.

Vagin et al. justified the role of technologies in environmental decision-making and business management, which is related to harmonising the balance of economic and environmental interests. Multiple examples of Russian companies show that high technologies have a potential for decision-making effectiveness in the production sector, AgroTech and other sectors.

Khoruzhy et al. performed an overview of international experience in 2021. The authors' recommendations outlined the priorities in the AI economy for the most effective support of investments in ESG and a new basis for classifying countries. The authors developed a theory of interconnection between ESG and artificial intelligence, proving this at the level of institutes, not only technologies. A novel approach to developing ESG investing in the age of artificial intelligence considers the possibility of using the leading innovative technologies in practice.

Lobova et al. discovered the current trends in the management of the environment associated with the increase in environmental indicators and reduction of rent from natural resources. Sustainable artificial intelligence was reconsidered as an intelligent technology for environmental protection. The authors also discovered its significant potential. Based on the experience of the OECD countries and Russia, the authors showed that the prospects of the economy and management of the environment in the post-COVID-19 period include a better potential for sustainable artificial intelligence.

Chutcheva et al. distinguished three types of activity that make the oil and gas business socially responsible: production and supply, financial and environmental management. Using various case examples, the authors demonstrated that AI could be useful for the environmental management of oil and gas companies during oil and gas field development and transportation.

Osipov and Skryl rethought the role of environmental justice in the Decade of Action. They confirmed that environmental inequality has increased during the COVID-19 pandemic. The example of experience in developed (G7) and developing (BRICS) countries showed that achieving environmental justice lies in social and technological progress and the optimal use of artificial intelligence.

Vorozheykina identified challenges of the age of AI: on the one hand, an increase in CO_2 emissions and the reduction of the share of clean energy in robotisation. On the other hand, support for decarbonising the AI economy. Breakthrough innovations may accelerate or slow down the processes of reduction of CO_2 emissions. The transition to clean energy considers state and corporate sectors while managing environmental and economic development.

Kukushkina et al. proved that AI governs success in slowdown/preventing the depletion of natural resources. The authors described the contribution of artificial intelligence to environmental competitiveness in the context of components of competitiveness and the light of implementing the Sustainable Development Goals (SDG). The authors support artificial intelligence's flexibility and effectiveness in managing environmental and economic development.

Khoruzhy et al. contribute to environmental taxation to maintain the environmental economy in developed and developing countries worldwide. The authors explained a universal tool for environmental protection and preservation of biodiversity and unlocking the potential provided by the AI economy for the maximum increase in the contribution of environmental taxation to the protection of the environment and preservation of biodiversity.

Yankovskaya et al. postulated the development of corporate social responsibility from the standpoint of Stakeholder Theory through the example of the global COVID-19 crisis and the international sanction crisis. The authors proposed a new theoretical interpretation of corporate social responsibility as a socioeconomic and environmental practice that requires systemic management.

Hongsuchon et al. provide evidence that customer trust and commitment are decisive in ensuring the high effectiveness of online commerce platforms. This study includes an original sociological survey for a deep understanding of the nature of online commerce.

Popkova et al. elaborated on the lessons of the COVID-19 pandemic for ecological behaviour and biodiversity in Russia. In the 3P model of sustainable development, the authors corroborated the ecological behaviour in preserving biodiversity during the COVID-19 pandemic. Through the AI economy, they discovered a potential for preserving biodiversity by improving ecological behaviour in the post-COVID period. The authors foresee progress in implementing SDG 14 and SDG 15 by improving ecological behaviour in the AI economy.

Trukhachev and Dzhikiya described a complex chain of cause-and-effect relationships in the development of green finance in the age of artificial intelligence. The authors reflect on green finance and environmental management to discover that green finance can fully realise its potential for development only with intelligent technologies.

Krupnov et al. specified the notion of energy security from the perspective of the Sustainable Development Goals (SDG) and proved a contribution of sustainable and clean energy. Ensuring stability and high effectiveness of the energy system and environmental protection are accomplished more successfully by the fuel and energy complex with sustainable and clean energy development.

Sozinova et al. presented a complete ecological economy and management view. The digital economy and businesses could positively influence the ecological economy and management if the corporate social responsibility of the market participants is high. The authors showed that systemic management of the digital economy and business development in the age of AI is preferable, as it ensures a synergetic effect towards sustainable development.

Thus, the articles filled the literature gap, outlined the distribution of stakeholders' roles in the environmental economy in the age of artificial intelligence and designed a comprehensive view of environmental management.

Conclusion

The Research Topic "Evolution of Environmental Economics & Management in the Age of Artificial Intelligence for Sustainable Development" introduced the notion of an "environmental AI economy". This notion refers to all practices responsive to the environment and decarbonisation. Collectively, the papers enabled the understanding of the complexity of adapting the environmental economy to the age of artificial intelligence. Likewise, the Research Topic systemically expanded a range of directions for adapting the environmental economy to new opportunities for environmental protection. The state's contribution must ensure environmental justice, energy security, competitiveness, environmental taxation improvement and responsible production and consumption development. Society's contribution must be coupled with optimising environmental decisions, environmental awareness, improvement of environmental behaviour to protect biodiversity and preference for ESG investments.

Moreover, the Research Topic processed the cause-and-effect links of the environmental AI economy. It strengthened the concept of sustainable development as the balance of opportunities and threats, nature and technologies and stakeholders' interests. The proposed guidelines let improving the environmental AI economy management and the spreading of the best practices in developed and developing countries. The systemic view of environmental management quickens the selection of practical managerial tools and stakeholders' roles in environmental protection in the age of artificial intelligence.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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References

Asha, P., Natrayan, L., Geetha, B., Beulah, J. R., Sumathy, R., Varalakshmi, G., et al. (2022). IoT enabled environmental toxicology for air pollution monitoring using AI techniques. *Environ. Res.* 205, 112574. doi:10.1016/j.envres.2021.112574

Ayakwah, A., and Damoah, I. S. (2022). Transferring AI technology in medical supply chain: A disruptive approach at addressing political, socioeconomic, and environmental dilemma in developing economies. *Int. J. Technol. Policy Manag.* 22 (4), 325–347. doi:10.1504/ijtpm.2022.126139

Haq, M. A., Ahmed, A., Khan, I., Gyani, J., Mohamed, A., Attia, E. A., et al. (2022). Analysis of environmental factors using AI and ML methods. *Sci. Rep.* 12 (1), 13267. doi:10.1038/s41598-022-16665-7

Khan, A. A., Laghari, A. A., Li, P., Dootio, M. A., and Karim, S. (2023). The collaborative role of blockchain, artificial intelligence, and industrial internet of things in digitalization of small and medium-size enterprises. *Sci. Rep.* 13 (1), 1656. doi:10.1038/s41598-023-28707-9

Lei, Y., Liang, Z., and Ruan, P. (2023). Evaluation on the impact of digital transformation on the economic resilience of the energy industry in the context of artificial intelligence. *Energy Rep.* 9, 785–792. doi:10.1016/j.egyr.2022.12.019

Ligozat, A.-L., and Combaz, J. (2022). Unraveling the hidden environmental impacts of AI solutions for environment life cycle assessment of AI solutions. *Sustain. Switz.* 14 (9), 5172. doi:10.3390/su14095172

Pagallo, U., Ciani Sciolla, J., and Durante, M. (2022). The environmental challenges of AI in EU law: Lessons learned from the artificial intelligence act (AIA) with its drawbacks. *Transforming Gov. People, Process Policy* 16 (3), 359–376. doi:10.1108/TG-07-2021-0121

Popkova, E. G. (2022). *Advanced issues in the green economy and sustainable development in emerging market economies (Elements in the economics of emerging markets)*. Cambridge, UK: Cambridge University Press. doi:10.1017/9781009093408

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Popkova, E. G., and Shi, X. (2022). Economics of climate change: Global trends, country specifics and digital perspectives of climate action. *Front. Environ. Econ.* 1, 935368. doi:10.3389/frevc.2022.935368

Ramzan, M., Abbasi, K. R., Salman, A., Dagar, V., Alvarado, R., and Kagzi, M. (2023). Towards the dream of go green: An empirical importance of green innovation and financial depth for environmental neutrality in world's top 10 greenest economies. *Technol. Forecast. Soc. Change* 189, 122370. doi:10.1016/j.techfore.2023.122370

Sharma, M., Joshi, S., Prasad, M., and Bartwal, S. (2023). Overcoming barriers to circular economy implementation in the oil and gas industry: Environmental and social implications. *J. Clean. Prod.* 391, 136133. doi:10.1016/j.jclepro.2023.136133

Stahl, B. C., Brooks, L., Hatzakis, T., Santiago, N., and Wright, D. (2023). Exploring ethics and human rights in artificial intelligence – a Delphi study. *Technol. Forecast. Soc. Change* 191, 122502. doi:10.1016/j.techfore.2023.122502

Zador, A., Escola, S., Richards, B., Bengio, Y., Boahen, K., Tolias, A. S., et al. (2023). Catalyzing next-generation artificial intelligence through NeuroAI. *Nat. Commun.* 14 (1), 1597. doi:10.1038/s41467-023-37180-x

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Sustainable Development of Enterprises in Conditions of Smart Ecology: Analysis of The Main Problems and Development of Ways to Solve Them, Based on Artificial Intelligence Methods and Innovative Technologies

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Relevance: Currently, the sustainability and profitability of any company is directly related to its interaction with the environment. In the 20th century it was believed that stable development is impossible, if the company focuses its production on the preservation and protection of the environment. Since the second half of the 20th century, ideas have been increasingly heard that sustainable economic development cannot be achieved at the expense of the predatory depletion of natural resources. The environmental agenda plays an important role in the ESG principles, largely formulated by UN Secretary-General Kofi Annan, reflected in Sustainable Development Goals 12–15, reflected in Resolution 70/1 - Transforming our world: the 2030 Agenda for Sustainable Development. Companies such as Tesla Motors, called "green giants", have proven by their experience and development dynamics that in today's environment a business that does not have a negative impact on the environment can be profitable and successful. Thus, modern trends in the development of the world economy determine the relevance of the present study, aimed at studying the new conditions of economic activity by enterprises - the conditions of smart ecology and development of recommendations for the effective transformation of enterprises under these conditions. The purpose of this study is to analyze and identify the main problems of sustainable development of enterprises in terms of preservation and protection of the environment - "smart ecology", and based on the formulated problems the authors have developed ways to overcome them. The subject of the study are managerial and other relationships arising during the implementation of innovative Smart projects by enterprises.

Methods: In the process of analyzing the problems and developing ways to overcome them and the transition of enterprises to the conditions of smart ecology, the authors used methods of system analysis, methods of statistical analysis, methods of artificial intelligence.

Results: The conducted analysis shows that in modern conditions of development of innovative technologies in Russia there is no unified approach to the process of effective management of breakthrough development projects. The analysis proposed the concept of SMART ecology and showed its importance for understanding the processes taking place in the modern world. Factors influencing the effectiveness of the implementation of innovative smart ecology projects have been identified. Methods that can be used during the implementation of these projects were proposed.

Keywords: sustainable development, smart ecology, expert systems, sustainable development issues, artificial intelligence

INTRODUCTION

The relationship between the sustainable development of enterprises and environmental conditions first began to be actively mentioned in the 70–80s of the 20th century, when the problem of resource exhaustion became significant. It was during this period that the UN developed the global concept of sustainable development without harming future generations, which is reflected in the Sustainable Development Goals contained in Resolution 70/1—Transforming our world: the 2030 Agenda for Sustainable Development (Vinuesa, et al., 2020). The concept of sustainable development has become the basis for a profound rethinking of the strategic and tactical behavior of both individual corporations and nations. An important part of the new strategic behavior is concern for the environment, which has now become an integral part of any company's vision of strategic development.

Previously, it was believed that sustainable development of a company was impossible in the context of preserving non-renewable resources and reducing the negative impact on the environment, because such activities are associated with huge investments of capital. Nowadays such companies as Tesla, Chipotle, Ikea, Unilever and others have proved by their own example that economic activities based not on cost minimization but on social benefit are more profitable than those of traditional companies.

Conditions of smart ecology define transition of the enterprises to new conditions of conducting economic activity in which sustainability is defined not by economy of financial resources, but by ways of their reception (Rogachev, 2021a). The distinctive feature of the companies working in the conditions of smart ecology is that the social good, on a par with sustainability, is the main factor of profit.

Sustainable development of enterprises in a smart ecology is possible if they follow the following principles:

1) Since the sustainability of enterprise development is primarily determined by its policy and strategy, special requirements are imposed on the head of the company. It is the head of the company who should direct the company's work to the conditions of smart ecology, he should promote the concepts of "green economy" and monitor the timely changes in the company, corresponding to changes in the environment.
2) One of the most important factors in ensuring the sustainable development of the enterprise should also be breakthrough innovations, i.e., new developments of the company, corresponding to the conditions of the smart ecology. The peculiarity of such innovations is that they cannot include products and technologies that were used for traditional economic activities and have been upgraded for the conditions of smart ecology.
3) The goals of the enterprise should be reoriented, traditionally the main goal of any economic activity is to make a profit, in the conditions of smart ecology the main goals of the enterprise along with profit should be the introduction of environmentally safe technologies, increasing the welfare of society, reducing the burden on the ecosystem, the preservation of the environment for future generations.
4) The concept of sustainability is a characteristic of the company, not a goal to which it aspires. The smart ecology condition changes the very concept of sustainability, which includes an equitable and economical use of resources, a switch to renewable raw materials and strict compliance with environmental rules and regulations.
5) Accordingly, all of the above-mentioned principles define the requirements for the behavior of employees of the company and the organization as a whole. All employees must be responsible not only to their job duties, but also to the principles determined by the conditions of smart ecology, the company's activities and its results must be transparent to the owners, investors and customers. All activities must be conducted on the basis of mutual cooperation.

All of the above principles are defined by the conditions of smart ecology, formed and developing together with the processes of digital transformation of the economy. The main conditions for classifying enterprises as smart ecology are as follows (AI for Sustainable Development Goals, 2022):

- The activities of enterprises should contribute to the welfare of society.

- The use of resources must be conservative, the share of recycled raw materials must be significantly higher than the share of non-renewable raw materials.
- Enterprises must use the latest saving technologies and technologies that reduce harmful emissions and waste.
- There should be a division of responsibility for environmental pollution between all enterprises and organizations involved in the life cycle of the product.
- Investments of enterprises in the protection of ecosystems and biodiversity, in the preservation, restoration and support of the environment must be constant and continuous in nature.

Thus, based on the principles and conditions of smart ecology, the authors formulated the following definition:

Smart ecology is a branch of science about such interaction of living organisms among themselves and with the environment, which does not have a negative destructive impact on the state of nature, does not deplete natural resources and supports biodiversity, achieved through the widespread use of conservation technologies, modern advances in the IT-sphere and scientific and technological progress.

The development of the smart ecology reflects a fundamental shift from an export-raw business model to a digital one, which requires a redefinition of sustainable enterprise development.

Traditionally, the sustainable development of an enterprise was defined as a positive change in its financial and economic indicators over a long period of time. The authors modernized this concept taking into account the conditions of digital transformation and the development of smart ecology - under the sustainable development of the enterprise the authors understand such an economic activity, which is able not to affect the natural assets, preserve resources and reduce the negative impact on the environment together with the achievement of strategic and operational goals and profit, part of which is necessarily sent to protect the ecosystem and improve the level and quality of life.

Despite the active development of digital transformation processes not only in the economy, but also in all processes of human activity, enterprises pass it and adapt to the conditions of smart ecology at a slow pace. This situation is associated with a number of problems that hinder the pace of digital transformation of companies, corresponding to the conditions of the smart ecology.

As can be seen from **Figure 1**, the authors refer to the main problems:

1) Complexity. Any "smart" technology requires the appropriate software to manage and control it. The problem is that with a significant number of breakthrough technologies, an enterprise is faced with the need to use multiple types of software, which causes the complexity of monitoring and switching between them.
2) Safety. "Smart" technologies are based on the concept of IoT (Internet of Things), which is the ability of "smart" things to interact with each other, excluding humans as an object that controls them by transmitting information. Since all interaction is based on the transmission of certain data, there is a problem of leakage of this data, i.e. the problem of information safety.
3) Increase in production costs. This problem is caused by the high cost of smart technologies and smart equipment, which is necessary for sustainable development, also the constant introduction of breakthrough innovations, requires significant investment in research and bringing them to the stage of implementation. Since one of the factors of sustainable development of the enterprise in a smart ecology is the orientation of the enterprise to preserve the environment and increase the welfare of the population, this leads to high tax deductions, as it is taxes that are the main tool of the income redistribution system, through taxes the funds for environmental protection and funds allocated for social purposes are collected.
4) Increase in the unemployment. Another problem of the functioning of enterprises in a smart ecology is the loss by employees of their jobs. This is primarily due to the fact that the introduction of "smart" technology contributes to the automation of labor and frees up labor resources. Also, due to the fact that some jobs do not meet the conditions of the smart ecology, it is expected that there will be a tendency to reduce them.
5) Employee adaptation. Another important problem is the inability of employees to perceive and use the latest technology. Employees who are used to traditional technologies and do not have the skills necessary to work in a changing environment, do not support the introduction of innovative technologies, and thus hold back the pace of digital transformation.
6) Cultural changes. The conditions of smart ecology do not act selectively, they apply to all spheres of human life and activity, so in addition to the digital transformation of enterprises, cultural transformation of people is necessary (United Nations, 2022).

Based on the peculiarities of the functioning of enterprises in the conditions of smart ecology, the authors have developed the following approaches and options for solving the identified problems.

METHODOLOGY

The purpose of this study was to formulate a definition of smart ecology based on the existing characteristics of economic activity, to identify the features of sustainable development of the enterprise in a smart ecology, to develop possible solutions to the problems arising in the transition of enterprises to new forms of activity.

The following general scientific and private methods and methodological approaches were used in the research—systems theory, analytical and systematic approaches.

Sustainable development of enterprises in modern conditions, in particular in the field of environmental problems, inevitably relies on a set of interrelated innovations. As part of the

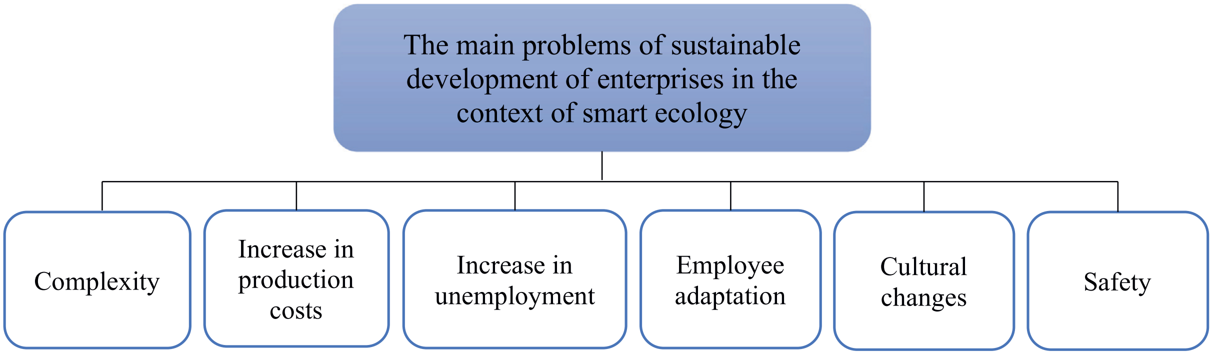

FIGURE 1 | The main problems of sustainable development of the enterprise in the conditions of smart ecology (Open School of Business, 2016).

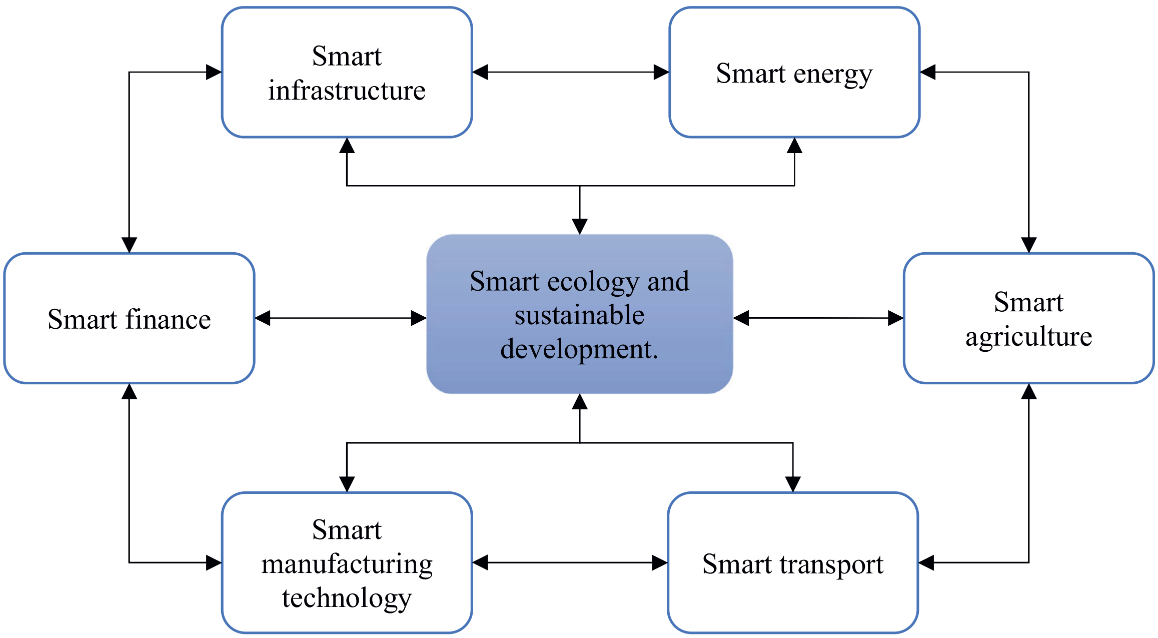

FIGURE 2 | The main directions of solving the problems of sustainable development of enterprises in a smart ecology (Open School of Business, 2016; Investlab, 2020).

development of a new technological mode about once every half century traditionally appears a cluster of closely related and mutually supporting innovations (Glazyev et al., 2019). However, at present, in the process of formation of a new technological mode, it is impossible to determine with a high degree of probability which of the many innovations appearing now will be effective enough on their own; which will give sufficient synergy with other innovations for their rapid development; and which will disappear (**Figure 2**). Nevertheless, enterprises must constantly make decisions to implement innovations that contribute to sustainable development. Sustainable development of enterprises is necessary not only to maintain a high level of competitiveness, but also to prevent or offset huge losses from risk situations that are both natural (such as the diesel fuel leak in 2020 in Norilsk, which occurred as a result of melting permafrost) and political or economic character (such as the introduction of fees for carbon emissions).

Within the emerging cluster of innovative technologies of the sixth technological mode, important elements can be "green" technologies of energy generation; electricity storage technologies; technologies that reduce energy losses and reduce emissions (in particular, recycling technologies of raw materials and other types of resources); technologies that reduce the carbon footprint and so on (Skiter et al., 2021). On the other hand, for example, carbon footprint reduction requirements may affect a company's logistics processes, require changes in technology to move cargo within the company as well as raw materials and finished product between facilities, and even change the degree of flexibility in manufacturing processes, for

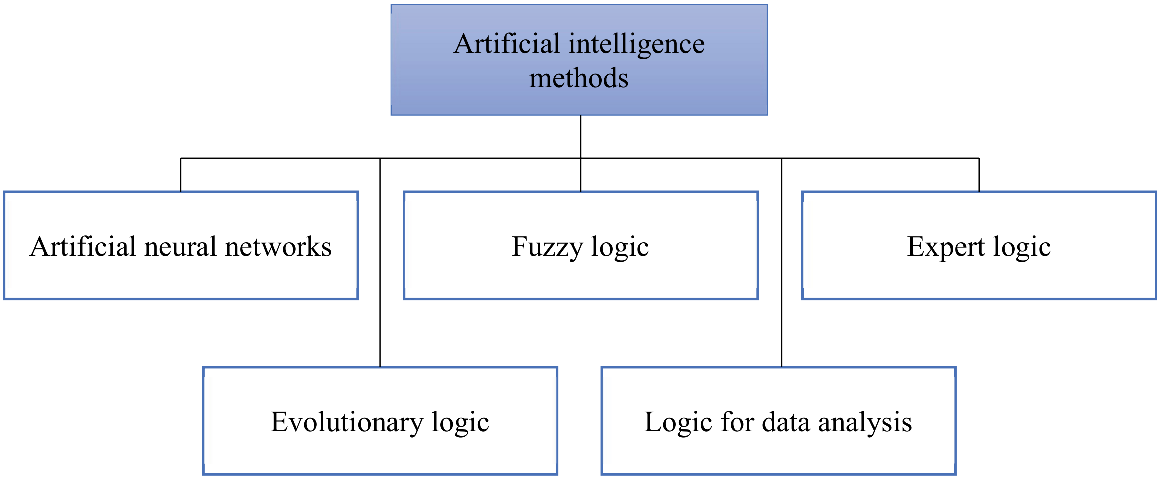

FIGURE 3 | Main groups of AI methods and algorithms (TAdviser, 2020; Codernet, 2021).

example, to reduce inventory levels (or even produce JIT "just-in-time"). And, of course, such large-scale optimization will ensure sufficient efficiency only with the introduction of modern artificial intelligence tools, modern tools for monitoring, analysis of big data, creating channels for continuous exchange of information between enterprises.

First of all, to solve the problems of sustainable development of enterprises, the widespread introduction of breakthrough technologies is necessary, such as:

1) the use of alternative energy sources to replace fossil fuels, both for production purposes and in the home, namely solar, tidal, wind and biomass energy (Naugolnova, 2014).
2) the use of artificial intelligence technologies in agriculture, since this industry uses 70% of the world's fresh water reserves and its share of greenhouse gases in the total amount is 13% (Open School of Business, 2016; Investlab, 2020; Educator's Notes, 2018), the use of IoT, based on special platforms like Arduino, will increase the efficiency of tillage technologies and reduce the amount of used resources.
3) Transition to environmentally friendly transport types will reduce the size of the carbon footprint (Laidlaw, 2022).
4) IT-technologies in production based on special platforms that allow automatic regulation of processes, remote control, monitoring of various values that monitor the condition of conveyors, reactors and other equipment and provide control of pollution levels and the volume of waste.
5) The introduction of smart finance technologies that provide competent taxation, which ensures effective control of the harmful effects on the environment and forms "ecological habits" of business leaders, employees and the population as a whole.
6) Formation of the "smart" infrastructure which will provide effective implementation and functioning of all the above-mentioned technologies.

It should be noted that not all innovations currently being created will be used in 40–50 years. Moreover, the logic of interaction between individual technologies may also change - for example, vehicle weight reduction technologies being developed to reduce the carbon footprint may significantly increase the efficiency of electric motors in these vehicles, reducing energy consumption when traveling long distances - and the inability to store large energy reserves is now one of the main problems of batteries for electric vehicles.

It is very likely that not all innovative technologies have the expected effect. And in this case, enterprises have two ways to implement innovations. The first way is to implement effective innovations, thus reducing the costs associated with technological and market risks caused by the implementation of ineffective innovations. However, it takes quite a long period of time to separate effective innovations from ineffective ones, which creates the risk of lagging behind the leading organizations. In order to overcome this lag, it will require significant scientific potential, large financial investments, and high flexibility in decision-making, so as not to miss the moment when the effectiveness of innovation is already proven, and the lag from the advanced organizations has not yet become critical.

The second way is to independently develop and implement advanced technologies, ensuring itself the role of a leader in sustainable development, attracting cheaper investments and reducing the risks associated with changes in regulation. However, this path creates obvious technological risks associated with the unknown characteristics of the applied innovation; market risks, primarily associated with a possible incorrect assessment of demand for the innovative product and with the unpredictable actions of competitors; reputational risks associated with the possible ineffectiveness of implemented solutions.

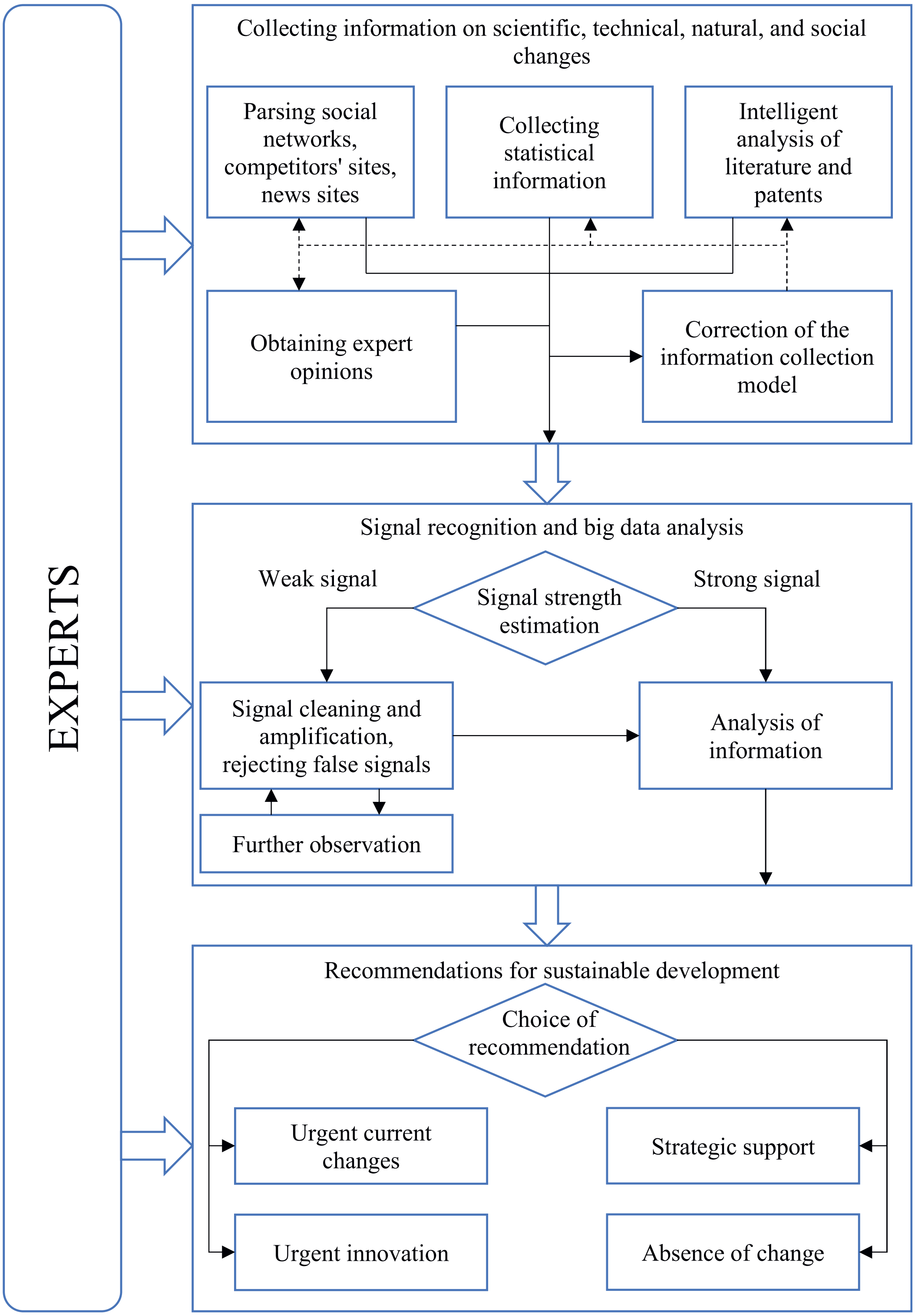

FIGURE 4 | Scheme of functioning of the expert system to support sustainable innovative development (Andreyeva et al., 2015).

RESULTS

Thus, innovation management in the context of the fourth technological revolution is associated with a number of risks, regardless of the strategic path chosen by the enterprise. To manage such risks, it is necessary to work effectively with heterogeneous information arising in the internal and external environment of the organization. This information, in particular, includes the results of the most modern fundamental research; patent analysis; analysis of current and planned changes in legislation; information about the technologies used by competitors; about changes in consumer needs of the product in the main market and the opportunities offered in other markets; and, of course, huge amounts of financial, technological and social information within the organization. To ensure flexible work with such a volume of information, often unstructured, fuzzy, contradictory, and carrying weak signals, the knowledge of individual specialists is obviously not enough. To manage such risks (at least in large organizations) for the purposes of sustainable development it is necessary to create an information system of decision support, organizing the work of experts, collecting and producing analysis of big data and identifying weak signals. Such a system can be developed in individual enterprises, or created as part of the activities of consulting firms or government projects to support innovation.

In our opinion, an effective solution to the totality of the identified problems and tasks is to develop an expert system based on artificial intelligence methods used to support decision-making procedures.

As is known, there are five main groups of artificial intelligence methods used for decision support purposes: artificial neural networks; fuzzy logic; expert logic; evolutionary logic; logic for data analysis (**Figure 3**). For the purposes of solving the problems of enterprise sustainable development in a smart ecology, the authors propose to use the following of them:

- Artificial Neural Networks (ANN), which is reasonable to apply for the purposes of image recognition in "smart" agriculture, speech recognition to adapt employees to breakthrough technologies, recognition of signs and objects for various control procedures (Rogachev, 2021b)
- Fuzzy logic, to involve experts in the decision support process, as these artificial intelligence methods are more qualitative in their analysis than neural networks. This group of methods can be used to make decisions on the implementation of certain innovations, to determine the main objectives and the scale of agricultural production.
- Logic for data analysis is designed to analyze huge amounts (Big Date) of data and find patterns in it. These methods are applicable for the purpose of developing a company strategy, taking into account the conditions of smart ecology.

Based on the highlighted methods of artificial intelligence in the framework of this study, the authors developed the structure of the expert system to support sustainable innovative development of the enterprise, taking into account the features of the tasks arising from qualitative changes in the economy, as well as taking into account the capabilities of modern information technology, reflected in **Figure 4**. This system was developed on the basis of materials (Andreyeva et al., 2015).

At the stage of collecting information, it is necessary to use various methods of recognition, methods of processing big data. Machine learning methods with and without a teacher (expert) may also be in demand. AI makes it much easier to study both innovative and commercial activities aimed at achieving the goals of sustainable development, and to track the achievement of these goals by improving the quality of the collection and processing of primary data on the state of the environment or, for example, poverty in different regions (Alsharkawi et al., 2021).

At the stage of signal recognition and analysis can be used fractal methods used in modern radio systems (Educator's Notes, 2018), mathematical models of decision-making, methods of stability analysis. Mathematical models that take into account ESG issues, which have a significant system component and require the joint work of specialists from different fields, should be widely used.

At the stage of developing recommendations for sustainable development, in our view, neural networks can be widely used, as well as various decision support methods, including methods of data visualization, methods of multicriteria analysis, and so on.

The first module of the described system is designed to collect information from all available sources. As can be seen from **Figure 4**, the database is formed from free Internet sources, statistical data, as well as on the basis of the intellectual analysis of the texts of scientific literature and patents. As part of the intellectual analysis of textual information is carried out pre-processing and transformation of the corpus: document breakdown, identification and extraction of the main content, separation of documents into paragraphs, segmentation, lexemization, labeling with parts of speech. The information is collected within the framework of developed observation plans, trained artificial intelligence systems and other models, which must be adjusted as necessary to ensure the high quality of the collected information under constantly changing conditions. The collected data undergo a cleaning and quality control process. Since the information collection and preparation phase of the analysis and modeling processes is one of the most important, distorted data or omissions in the data can lead to false results. After the data are checked and prepared, they are transferred to the second module.

The second module is designed to process the information collected in the first module. The information is considered as a set of strong and weak signals necessary to assess the changes taking place, possible threats and risks, as well as opportunities (Potapov, 2008). While strong signals can directly become the main for analysis, weak signals are rather noisy and are lost against the background of other, more definite information. Special methods should be used for their purification and amplification. Strong signals and purified weak signals are analyzed by statistical methods and intelligent methods based on specially created models. Also in this module model training, consisting in repeated procedures of signal estimation, and comparison of model predictions with real data is carried out.

The third module should interpret the results of the machine analysis and develop recommendations for changing the innovation policy of the organization, taking into account changes in the external and internal environment. At this stage, based on the information obtained in the previous modules and relying on the tools of artificial intelligence, fuzzy logic, visualization and data representation, experts in the subject areas evaluate scenarios of enterprise development under different variants of system behavior. The pre-designed set of solution options is evaluated on the basis of the information obtained, the dominant solution options are discarded, the possibility of combining solutions to obtain a synergistic effect is studied, and the non-dominant solution alternatives are ranked by potential effectiveness. Also at this stage there is a presentation of recommendations in the most convenient form for potential stakeholders.

DISCUSSION

The result of the system activity is a flow of information for the management of the organization and stakeholders about the opportunities and threats arising for the enterprise due to innovative development in the external and internal environment in the field of smart ecology, as well as recommendations for behavioral adjustments to ensure effective and sustainable development of the organization.

Comparison of the proposed system with the known ones (Andreyeva et al., 2015) allows us to note the following significant differences and advantages:

- the possibility of adjusting the information collection model
- additional evaluation of the quality of the data transferred to the model by means of expert evaluation
- control of the reliability of the obtained results through the use of expert judgments.

In addition, the creation and use of the system described in **Figure 4** will ensure the sustainability of enterprise development in the implementation of innovations that promote ESG transformation, will facilitate the attraction of financial resources for the systematic development of smart ecology, will quickly achieve the goals of creating a green, safe and socially responsible entrepreneurship.

CONCLUSION

One of the important concepts that have appeared in the scientific turnover in the XXI century is the concept of noosphere - a hypothetical sphere of interaction between society and nature, in the boundaries of which intelligent human activity becomes a determining factor of development, it is also sometimes designated by the term "anthroposphere" (Vernadskiy, 1988; Macpherson, 2021). However, in recent decades there is a significant symbiosis between the human mind and artificial intelligence, which complement each other, creating a qualitatively changed noosphere. Human activity is no longer an independent factor influencing nature, but relies heavily on advances in computer technology, which have become part of the human mind from a tool. Under these conditions it is possible to speak not about ecology, but about smartbecology; not about the biosphere or the noosphere, but about the e-noosphere, in which the achievements of modern science become an independent factor influencing the ecology and sustainability of the development of the planet as a whole. In this regard, the study of sustainable development of the enterprise in the new prevailing conditions becomes relevant. Since such conditions of development are only being formed, initially it is necessary to form a theoretical basis of definitions, reflecting their main aspects.

In this study, the authors formulated a concept of smart ecology, which allowed to identify and show the close relationship between the conditions of smart ecology and the sustainable development of the enterprise. The main problems arising for the enterprise in the implementation of a sustainable development strategy in a smart ecology were highlighted, which allowed to consider and evaluate the possibility of using artificial intelligence to solve these problems.

The study shows that artificial intelligence is used to solve a whole range of tasks, both related to smart ecology and related to other goals of sustainable development. AI is used to optimize drip irrigation, identify plant diseases, create digital twins of mobile towers and optimize power consumption on them, solve medical problems, including the fight against COVID-19 (Artificial Intelligence for Sustainable Development, 2020). However, it should be noted that artificial intelligence can both contribute to and hinder the goals of sustainable development. These threats and opportunities are reflected in some detail in the UNESCO working paper (Goralski and Tay, 2020).

As part of the study, the authors have developed a conceptual model of an information expert system based on the application of machine learning and artificial intelligence, which contributes to improving the efficiency of the introduction of smart ecology technologies in specific enterprises, which accordingly has a positive effect on their sustainable development. For the purposes of leveling the negative influence of artificial intelligence methods on the results of machine analysis, the system introduces the procedure of expert evaluation, which will significantly improve their quality.

AUTHOR CONTRIBUTIONS

NS performed an analysis of the main problems. AR described the debatable issues. NK formulated the definition of smart ecology. AS and IT developed a model of expert system.

REFERENCES

AI for Sustainable Development Goals (2022). AI for Sustainable Development Goals (AI4SDGs) Think Tank. Available at: https://www.ai-for-sdgs.academy/ (Accessed February 3, 2022).

Alsharkawi, A., Al-Fetyani, M., Dawas, M., Saadeh, H., and Alyaman, M. (2021). Poverty Classification Using Machine Learning: The Case of Jordan. *Sustainability* 13, 1412. doi:10.3390/su13031412

Andreyeva, N. V., Vermennikova, L. V., and Eroyan, A. E. (2015). Management by Weak Signals and Lean Production as Methods to Ensure the Adaptability of the Enterprise. *Bull. Cauc. Inst. People's Friendsh.* 3 (35), 2.

Artificial Intelligence for Sustainable Development (2020). Artificial Intelligence for Sustainable Development: Theory, Practice and Future Applications. Germany: Springer International Publishing. Available at: https://www.google.ru/books/edition/Artificial_Intelligence_for_Sustainable/kmr6DwAAQBAJ?hl=en&gbpv=0 (Accessed February 11, 2022).

Codernet (2021). Artificial Intelligence and Decision Making: How Does it Work? Available at: https://codernet.ru/articles/drugoe/iskusstvennyij_intellekt_i_prinyatie_reshenij_kak_eto_rabotaet/(Accessed February 11, 2022).

Educator's Notes (2018). 7 Problems of Digital Transformation and How to Deal with Them. Available at: https://waksoft.susu.ru/2018/06/07/7-problem-tsifrovoy-transformatsii-i-kak-s-nimi-borotsya/(Accessed January 30, 2022).

Glazyev, S. Y., Ayvazov, A. E., and Belikov, V. A. (2019). Cyclical-wave Theories of Economic Development and the Outlook for the World Economy. Whether the Medium- and Long-Term Development of the World Economy Is Predictable. *Proc. Free Econ. Soc. Russ.* 5, 177–211.

Goralski, M. A., and Tay, K. T. (2020). Artificial Intelligence and Sustainable Development. *Int. J. Manag. Educ.* 18 (1), 100330. Available at:. doi:10.1016/j.ijme.2019.100330https://www.sciencedirect.com/science/article/pii/S1472811719300138 (Accessed January 20, 2022)

Investlab (2020). We Live Here: Why Should the Economy Go "Green". Available at: https://invlab.ru/ekonomika/chto-takoe-zelenaya-ekonomika/(Accessed January 31, 2022).

Laidlaw, J. (2022). S&P Global. What the Inclusion of Gas and Nuclear in the EU Taxonomy Could Mean for Investors and Asset Managers. Available at: https://www.spglobal.com/esg/insights/what-the-inclusion-of-gas-and-nuclear-in-the-eu-taxonomy-could-mean-for-investors-and-asset-managers (Accessed January 20, 2022).

Macpherson, M. (2021). The AI Journal. Implications for Artificial Intelligence and ESG Data. Available at: https://aijourn.com/implications-for-artificial-intelligence-and-esg-data/(Accessed January 18, 2022).

Naugolnova, I. A. (2014). Domestic and Foreign Experience of Lean Production System Application at Industrial Enterprises. Proceedings of the Russian State Pedagogical University Named after A.I. Gertsen. Available at: http://cyberleninka.ru/article/n/(Accessed January 30, 2022).

Open School of Business (2016). Green Giants. Available at: https://www.obs.ru/article/1521/(Accessed February 20, 2022).

Potapov, A. A. (2008). Fractal Methods for Studying Fluctuations of Signals and Dynamical Systems in the Space of Fractional Dimension. *Fluctuations noise complex Syst. animate inanimate Nat.*, 257–310.

Rogachev, A. F. (2021a). Creating an Artificial Neural Network for Predicting the Dynamics of Retrospective Yield Series. *J. Phys. Conf. Ser.* 2060 (1), 012027. doi:10.1088/1742-6596/2060/1/012027

Rogachev, A. F. (2021b). Systematic Assessment of Food Security by Recurrent Addition of Fuzzy Cognitive Maps. *J. Phys. Conf. Ser.* 1801, 012027. doi:10.1088/1742-6596/1801/1/012027

Skiter, N. N., Ketko, N. V., Simonov, A. B., Kuznetsov, S. Y., and Velikanov, V. V. (2021). Hierarchical Analysis and Modelling of Regional Environmental and Economic Security. *IOP Conf. Ser. Earth Environ. Sci.* 848, 12137. doi:10.1088/1755-1315/848/1/012137

TAdviser (2020). AI in Decision Making: Can a Computer Replace Humans? Available at: https://www.tadviser.ru/index.php/%D0%A1%D1%82%D0%B0%D1%82%D1%8C%D1%8F:%D0%98%D0%98_%D0%B2_%D0%BF%D1%80%D0%B8%D0%BD%D1%8F%D1%82%D0%B8%D0%B8_%D1%80%D0%B5%D1%88%D0%B5%D0%BD%D0%B8%D0%B9:_%D0%BA%D0%BE%D0%BC%D0%BF%D1%8C%D1%8E%D1%82%D0%B5%D1%80_%D0%BA%D0%B0%D0%BA_%D0%B8%D0%BD%D1%82%D0%B5%D0%BB%D0%BB%D0%B5%D0%BA%D1%82%D1%83%D0%B0%D0%BB%D1%8C%D0%BD%D1%8B%D0%B9_%D0%BF%D0%B0%D1%80%D1%82%D0%BD%D0%B5%D1%80_%D1%87%D0%B5%D0%BB%D0%BE%D0%B2%D0%B5%D0%BA%D0%B0 (Accessed January 30, 2022).

United Nations (2022). 17 Goals to Transform Our World. URL: https://www.un.org/sustainabledevelopment/(Accessed February 16, 2022).

Vernadskiy, V. I. (1988). *Scientific Thought as a Planetary Phenomenon*. Philosophical thoughts of a naturalist, 520.

Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., et al. (2020). The Role of Artificial Intelligence in Achieving the Sustainable Development Goals. *Nat. Commun.* 11, 233. doi:10.1038/s41467-019-14108-y

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OPINION
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The Environmental AI Economy and its Contribution to Decarbonization and Waste Reduction

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INTRODUCTION

The economy of artificial intelligence (AI) is a technocratic model of the organization of an economic system in which automation is carried out on the basis of "smart" technologies controlled by AI. This new model emerged as a result of the worldwide technology race and embodies the heyday of scientific and technological progress (Ruffolo, 2022).

Globalization dictates the need for countries of the world to transition to an AI-enabled economy, which is reflected in digital competitiveness, the presence (for example, inclusion in the relevant international rankings) and the level of which determines the ability of countries to overcome barriers to entry and expand their presence in global high-tech markets (Feijóo and Kwon, 2020).

The problem is that the transition to an AI-enabled economy is being forced by the pressure of the market mechanism, and the countries of the world cannot fully adapt it to their priorities, among the most important of which are decarbonization and waste reduction. The reason for the problem is that each new technological way first complements and then displaces the previous one. In this regard, the countries of the world cannot simply overlook the Fourth Industrial Revolution, and they must participate in it in order to be able to demonstrate the growth, development and efficiency of the economy, maintain and improve the standard of living of the population.

The consequence of this problem is the environmental risks of the formation of the AI-enabled economy. This is because AI development pursues economic goals that are often accompanied by environmental costs (Arganda et al., 2022; de Chevalier et al., 2022).

Along with this, it is necessary to take into account that environmental protection is an independent direction of the economy, which is increasingly integrated into economic activity. The Sustainable Development Goals (SDGs) cover both the economic and environmental priorities of humanity, which require full and simultaneous consideration.

The AI economy should participate in achieving the SDGs, comply with them and support them, although modern science does not answer questions about to what extent and by what means this could be achieved in practice (Som, 2021; Wilson et al., 2022).

This article aims to explore the essence of the environmental AI economy and its contribution to decarbonization and waste reduction. The originality and uniqueness of the conducted research is ensured through the use of a systemic approach (based on the provisions of evolutionary economics), which allows more in-depth studies of the logic of formation, cause-and-effect relationships of the functioning of the economy of artificial intelligence and thereby form a holistic view of the economic and environmental aspects of the AI economy.

The Evolution of the Artificial Intelligence Economy

To study the prospects for the development of AI-economy, this article is based on the Evolutionary Theory of Economic Change (evolutionary economics) and the Theory of Bifurcations of dynamic systems (in accordance with the systemic approach to conducting scientific research). Based on these theories and the existing literature, the process of AI-economy evolution is modeled.

Initially (on the first tap), the AI economy emerged as a result of spontaneous technological progress. At that time, economic interests prevailed, according to which, with the help of artificial intelligence, developed digital economies tried to take leading positions in developing high-tech markets.

Subsequently (at the second stage), the AI economy began to serve the commercial interests of business, since the spread of "smart" technologies was financed by venture investments. AI was becoming increasingly widespread in the business environment and no longer had an elitist character. Intense competition had formed in the global high-tech markets.

The third stage is associated with a technological shift, in which the technologies of the previous technological order are replaced by digital technologies. To achieve this, there must be massive public support for the economy of artificial intelligence, which is possible only if "smart" technologies begin to serve the interests of society. Scientists have not yet reached agreement on the characteristics of this stage, since it is currently taking place and is determined by the interests of society.

In the works of Venkatesh et al. (2022), Wise (2022), it is noted that the deep and prolonged global economic depression in the context of the COVID-19 pandemic caused the priority attention of society to the restoration of pre-crisis living standards and the acceleration of global economic growth. This implies a secondary priority to environmental protection issues.

In contrast, in their works Donoso et al. (2022), Gwenzi (2022), Shao et al. (2022) indicate that environmental interests are critically important and come to the fore. This is due, firstly, to the great attention to environmental protection in the SDGs, most of which have an environmental focus.

The popularity of the SDGs around the world is very high, and it continues to grow within the framework of the "decade of action". Secondly, It is also a widely held view (Argentiero et al. (2022), Felix et al. (2022), Sarmento et al. (2022) that the pandemic and crisis caused by COVID-19 are of an ecological nature, and therefore green growth is urgently needed to overcome highly probable future environmental crises.

We adhere to the second point of view and, based on it, we hypothesize that at the upcoming, but already outlined, third stage, there is a transition to the environmental economy of artificial intelligence, which contributes to decarbonization and waste reduction.

The Formation of the Environmental Artificial Intelligence Economy at the Present Stage of its Evolution and its Contribution to Decarbonization and Waste Reduction.

To determine whether the modern artificial intelligence economy is aimed at environmental sustainability, its impact on decarbonization (CO_2 emissions from fossil fuel combustion and cement production) and waste reduction (municipal solid waste, production-based SO_2 emissions) is assessed. The most accurate indicators for measuring the AI economy are three elements of digital competitiveness: knowledge, technology and future readiness.

In accordance with the generally accepted separation (differentiation) of the elements of digital competitiveness, the available literature suggests different approaches to managing the development of the environmental AI economy for decarbonization and waste reduction:

—In the works of Fytili and Zabaniotou (2022) the basis for the development of the environmental AI economy is knowledge—personnel for the digital economy, highly qualified specialists and a high level of public consciousness. This approach can be called social; —The publications of Ahmad et al. (2022) indicate the paramount importance of the institutional, financial and telecommunication infrastructure of digital technologies for their use with the purpose of decarbonization and waste reduction. This approach can be called technological; Khan et al. (2022) in their works note the key role of flexibility and environmental consciousness of society and progressiveness of economy (future readiness), in the presence of which AI is used for decarbonization and waste reduction. This approach can be called adaptive.

To determine the approach that most reliably describes the source of achieving environmental benefits in the development of the AI economy, we will conduct an econometric analysis of available statistical data on digital competitiveness (IMD, 2022), as well as on decarbonization, production and consumption waste (UN, 2022) in 2021. The top 15 countries/territories in artificial intelligence were selected as objects for study according to Nature (2022)—the data are given in **Table 1**.

The analysis of the data from **Table 1** allowed to obtain the following results. Firstly, it has been established that the technological approach makes it possible to reduce consumption waste due to the development of infrastructure. The dependence was obtained: $MSW = 1.04 + 0.002k - 0.009t + 0.02fr$, according to which an increase in the level of technology by 1 point contributes to a reduction of municipal solid waste by 0.009 kg/capita/day. The correlation is moderate: 29.54%.

Secondly, it was revealed that the adaptive approach allows to reduce production waste by increasing the flexibility and environmental consciousness of society and the economy. The dependence was obtained: $PBE = 122.84 + 0.83k + 0.25t - 0.61fr$, according to which an increase in the level of future readiness by 1

TABLE 1 | Elements of digital competitiveness, greenhouse gas emissions and production and consumption waste in top15 countries/territories in artificial intelligence in 2021.

Country	Elements of Digital Competitiveness, Score 0–100			Indicators of Environmental Sustainability of the Economy, Characterizing decarbonization and Environmental Pollution		
	Knowledge	Technology	Future Readiness	Municipal Solid Waste (kg/Capita/day)	Production-Based SO_2 Emissions (kg/Capita)	CO_2 Emissions from Fossil Fuel Combustion and Cement Production (tCO2/Capita)
	k	t	fr	MSW	PBE	COE
United States	85,601	87,494	100,000	2,63	51,036	16,06
United Kingdom	76,031	72,122	82,423	1,558	53,919	5,477
Germany	75,854	62,359	72,882	2,198	34,497	8,405
China	82,500	69,231	74,656	0,687	30,02	7,096
France	68,044	74,482	57,537	1,744	26,482	4,968
Canada	81,795	75,181	78,050	2,286	58,059	15,414
Switzerland	86,929	80,237	90,746	2,631	58,308	4,386
Japan	64,759	63,182	64,195	1,034	42,038	8,723
Australia	69,844	71,547	67,754	1,716	144,601	16,308
Netherlands	77,088	86,158	89,777	1,552	50,843	9,056
Italy	50,321	49,636	58,438	1,937	38,704	5,567
Spain	60,979	61,480	55,253	1,481	37,201	5,407
Israel	77,050	65,255	69,543	1,894	113,783	7,532
South Korea	75,489	77,957	88,821	1,198	39,651	11,933
Sweden	86,485	84,570	87,605	1,374	63,332	4,261

The data were obtained from references to IMD (2022), UN (2022).

point contributes to a reduction in production-based so_2 emissions by 0.61 kg/capita. The correlation is moderate: 18.01%.

Thirdly, it has been established that the social approach makes it possible to reduce carbon emissions through the development of knowledge. The dependence was obtained: COE = 2.40–0.09k+0.08t+0.09fr, according to which an increase in the knowledge level by 1 point contributes to a reduction in CO_2 emissions from fossil fuel combustion and cement production by 0.009 tCO2/capita. The correlation is moderate: 32.08%.

Consequently, each of the elements of digital competitiveness is important and makes its own specific contribution for decarbonization and waste reduction, but none of the existing approaches is exhaustive to explain and support the development of the environmental AI economy. Therefore, a new approach is needed that embodies the features of all existing ones.

Systemic Approach to Management of the Development of the Environmental Artificial Intelligence Economy to Maximize Its Contribution to Decarbonization and Waste Reduction.

This paper proposes a systemic approach to management of the development of the environmental AI economy. The new approach is designed to maximize its contribution to decarbonization and waste reduction through targeted and more effective practical application of each of the three elements of digital competitiveness.

In accordance with the authors' approach, it is recommended to develop the infrastructure of the environmental AI economy for reducing consumption waste. The normative-legal system should strictly regulate consumption waste. Financial incentives for environmental responsibility of the population should be provided, for example, tax incentives and, on the contrary, special environmental penalties. The telecommunications infrastructure should offer a large number of massively available free applications with social advertising for environmental protection, as well as clear instructions on everyone's contribution to decarbonization and waste reduction (for example, explanation of the principles of safe waste disposal and sorting for subsequent recycling).

It is proposed to increase the flexibility and environmental consciousness of society and progressiveness of economy to reduce production waste. This radically changes the current practice, which involves direct stimulation of business to reduce production waste. In contrast, indirect stimulation through the development of demand for environmentally responsible products is advisable Regulatory control should be replaced by public control, and government fines should be replaced by consumers' refusal to purchase products from such enterprises that have an insufficiently high level of environmental responsibility (with large volumes of production waste). The AI economy can help with this through automated environmental monitoring of business.

It is recommended to develop knowledge to reduce carbon emissions. Decarbonization should be based on social norms. The danger and harm of greenhouse gases should be explained and clearly understood by every member of society, by every social category. Thanks to this, low-carbon economic practice will become regular, normal. The contribution of the AI economy should be to inform the population about the current carbon emissions and the success achieved in reducing them, as well as to measure the individual contribution of each household and business to the overall result.

DISCUSSION

The conducted research provides new insights into the essence of the environmental AI economy and its contribution to decarbonization and waste reduction. In contrast to Venkatesh et al. (2022), Wise (2022), it is shown that the pandemic and the COVID-19 crisis did not distract, but rather riveted the attention of the world community on environmental protection issues. The AI economy serves these interests by supporting decarbonization and reduction of production and consumption waste.

In contrast to Ahmad et al. (2022), Fytili and Zabaniotou (2022), Khan et al. (2022), it is proved that the development of elements of digital competitiveness separately provides scattered and insignificant results. The existing narrowly focused approaches should be replaced by a systemic approach to management of the development of the environmental AI economy to maximize its contribution to decarbonization and waste reduction, recommendations for practical application of which are proposed in the article.

The contribution of the article to the literature consists in clarifying the cause-and-effect relationships of the development of the environmental AI economy: the contribution of each element of digital competitiveness to achieving the corresponding advantages of decarbonization, reduction of production or consumption waste is determined. The theoretical significance of the article consists in creating a model of the evolution of the artificial intelligence economy and defining the environmental economy of artificial intelligence as its current (ongoing) stage.

The practical significance of the article is ensured by the development of framework applied recommendations in public administration aimed at maximizing the benefits of the current stage of the evolution of the environmental AI economy for decarbonization and waste reduction.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

REFERENCES

Ahmad, M. R., Lao, J., Dai, J.-G., Xuan, D., and Poon, C. S. (2022). Upcycling of Air Pollution Control Residue Waste into Cementitious Product through Geopolymerization Technology. *Resour. Conservation Recycl.* 181, 106231. doi:10.1016/j.resconrec.2022.106231

Arganda, S., Arganda-Carreras, I., Gordon, D. G., Hoadley, A. P., Pérez-Escudero, A., Giurfa, M., et al. (2022). Statistical Atlases and Automatic Labeling Strategies to Accelerate the Analysis of Social Insect Brain Evolution. *Front. Ecol. Evol.* 9, 745707. doi:10.3389/fevo.2021.745707

Argentiero, A., D'Amato, A., and Zoli, M. (2022). Waste Recycling Policies and Covid-19 Pandemic in an E-DSGE Model. *Waste Manag.* 141, 290–299. doi:10.1016/j.wasman.2021.12.036

de Chevalier, G., Bouret, S., Bardo, A., Simmen, B., Garcia, C., and Prat, S. (2022). Cost-Benefit Trade-Offs of Aquatic Resource Exploitation in the Context of Hominin Evolution. *Front. Ecol. Evol.* 10, 812804. doi:10.3389/fevo.2022.812804

Donoso, I., Fricke, E. C., Hervías-Parejo, S., Rogers, H. S., and Traveset, A. (2022). Drivers of Ecological and Evolutionary Disruptions in the Seed Dispersal Process: Research Trends and Biases. *Front. Ecol. Evol.* 10, 794481. doi:10.3389/fevo.2022.794481

Feijóo, C., and Kwon, Y. (2020). AI Impacts on Economy and Society: Latest Developments, Open Issues and New Policy Measures. *Telecommun. Policy* 44 (6), 101987. doi:10.1016/j.telpol.2020.101987

Felix, C. B., Ubando, A. T., Chen, W.-H., Goodarzi, V., and Ashokkumar, V. (2022). COVID-19 and Industrial Waste Mitigation via Thermochemical Technologies towards a Circular Economy: A State-Of-The-Art Review. *J. Hazard. Mater.* 423, 127215. doi:10.1016/j.jhazmat.2021.127215

Fytili, D., and Zabaniotou, A. (2022). Organizational, Societal, Knowledge and Skills Capacity for a Low Carbon Energy Transition in a Circular Waste Bioeconomy (CWBE): Observational Evidence of the Thessaly Region in Greece. *Sci. Total Environ.* 813, 151870. doi:10.1016/j.scitotenv.2021.151870

Gurnani, B., Venkatesh, R., and Kaur, K. (2022). Impact of COVID-19 Pandemic on Carbon Footprint and Strategies to Mitigate Waste Generation. *Indian J. Ophthalmol.* 70 (2), 690–691. doi:10.4103/ijo.IJO_2945_21

Gwenzi, W. (2022). Wastewater, Waste, and Water-Based Epidemiology (WWW-BE): A Novel Hypothesis and Decision-Support Tool to Unravel COVID-19 in Low-Income Settings? *Sci. Total Environ.* 806, 150680. doi:10.1016/j.scitotenv.2021.150680

IMD (2022). World Digital Competitiveness Ranking – 2021. Available at: https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/.

Khan, S., Anjum, R., Raza, S. T., Ahmed Bazai, N., and Ihtisham, M. (2022). Technologies for Municipal Solid Waste Management: Current Status, Challenges, and Future Perspectives. *Chemosphere* 288, 132403. doi:10.1016/j.chemosphere.2021.132403

Nature (2022). Top 25 Countries/territories in Artificial Intelligence. Available at: https://www.natureindex.com/supplements/nature-index-2020-ai/tables/countries.

Ruffolo, M. (2022). The Role of Ethical AI in Fostering Harmonic Innovations that Support a Human-Centric Digital Transformation of Economy and Society. *Lect. Notes Netw. Syst.* 282, 139–143. doi:10.1007/978-3-030-81190-7_15

Sarmento, P., Motta, M., Scott, I. J., Pinheiro, F. L., and de Castro Neto, M. (2022). Impact of COVID-19 Lockdown Measures on Waste Production Behavior in Lisbon. *Waste Manag.* 138, 189–198. doi:10.1016/j.wasman.2021.12.002

Shao, P., Han, H., Yang, H., Li, T., Zhang, D., Ma, J., et al. (2022). Responses of above- and Belowground Carbon Stocks to Degraded and Recovering Wetlands in the Yellow River Delta. *Front. Ecol. Evol.* 10, 856479. doi:10.3389/fevo.2022.856479

Som, T. (2021). Sustainability in Energy Economy and Environment: Role of AI Based Techniques. *Model. Optim. Sci. Technol.* 18, 647–682. doi:10.1007/978-3-030-72929-5_31

UN (2022). Sustainable Development Report 2021. Available at: https://dashboards.sdgindex.org/rankings.

Wilson, M., Paschen, J., and Pitt, L. (2022). The Circular Economy Meets Artificial Intelligence (AI): Understanding the Opportunities of AI for Reverse Logistics. *Meq* 33 (1), 9–25. doi:10.1108/MEQ-10-2020-0222

Wise, J. (2022). Covid-19: Pandemic Waste Threatens Human and Environmental Health, Says WHO. *Bmj* 376, o266. doi:10.1136/bmj.o266

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OPINION
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Environmental CSR From the Standpoint of Stakeholder Theory: Rethinking in the Era of Artificial Intelligence

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INTRODUCTION

Environmental corporate social responsibility (CSR) is the practice of voluntary environmental protection by business in excess of fulfilling mandatory requirements (norms, standards, environmental taxes and fees, etc.) of the state, manifested in the form of environmental initiatives (for example, the creation of an environmentally friendly urban environment), in the form of the introduction of "green" innovations (for example, waste reduction) and in the form of responsible investments (for example, co-financing of clean energy development programs) (Popkova et al., 2021; Popkova and Zavyalova, 2021; Huo et al., 2022; Lin et al., 2022; Zhang and Cheng, 2022).

In the existing literature, Madaleno et al. (2022), Schiessl et al. (2022), Yang et al. (2022), Yu et al. (2022) indicate the non-commercial nature of environmental CSR. The development of this responsibility is associated with the progress of society. The prevalence of environmental CSR practices is explained, on the one hand, by the ability of society (consumers) to assess the importance of these practices and the tendency to give preference to responsible business products and, on the other hand, by the internal motivation of business leaders to protect the environment. Since society is continuously progressing, the process of development of environmental CSR is considered linear and is described as an upward trend.

The works of Awawdeh et al. (2022), Cheng and Zhang (2022), Godefroit-Winkel et al. (2022), Sadiq et al. (2022) note the contradictory interests of business and society in the implementation of environmental CSR. Consumers expect companies to be willing to donate part of their profits to environmental CSR as a charity and therefore do not always give preference to "green" products with similar consumer properties compared with less environmentally friendly analogues. For businesses, in turn, environmental CSR is associated with additional costs, while sources of financing are often limited, and high market competition dictates the need to recover their investments. The noted conflict of interests constrains the development of environmental CSR and limits its scale.

In the works of Inshakova and Solntsev (2022), Liu and Gao (2022), Madaleno et al. (2022), breakthrough technologies are considered as a deterrent to environmental CSR. Since this responsibility increases the cost of products anyway, technological modernization further increases this cost and limits the possibility of selling products on the target market (Astafyeva et al., 2020; Osipov et al., 2022).

In this regard, the scientific and practical problem of the development of environmental CSR in the era of artificial intelligence (the AI era) comes to the fore. The combination of intensive social progress (the development of society and the knowledge economy) with technological progress can

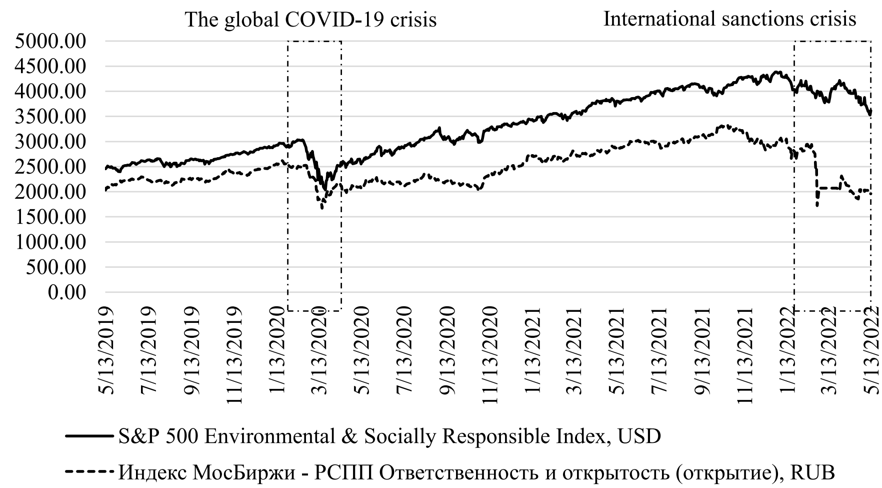

FIGURE 1 | Dynamics of equity indices of environmental CSR of Dow Jones (United States) and Moscow Exchange (Russia) in 13.05.2019–13.05.2022.

exacerbate the conflict of stakeholders' interests, thereby increasing barriers to the development of environmental CSR. Nevertheless, environmental CSR in the AI era is poorly studied, which is as a gap in the literature. This gives rise to the following research question (RQ): What is the impact of technological capabilities of the AI era on environmental CSR?

The available individual scientific studies (Gao et al., 2021; Wang et al., 2021) demonstrate the advantages of technological progress for environmental CSR. In his work, Camilleri (2021) outlined the strategic attributes of corporate social responsibility and environmental management. Camilleri (2022) justified the significance of ISO 14001 certification for corporate social responsibility and environmental management of business. Ligozat et al. (2022) proved that artificial intelligence (AI) solutions have an impact on the environment throughout the life cycle of these solutions. Tavana Amlashi et al. (2021) demonstrated that AI allows creating environmentally friendly practical solutions for the production sector. Pagliarini and Lund (2020) developed and introduced an eco-friendly approach to artificial intelligence and robotics.

Based on this, the hypothesis is put forward that the breakthrough technologies available in the AI era do not aggravate, but enable solving the problem with the right approach to their use in the practice of environmental CSR. The purpose of the article is related to the study of the prospects for the development of environmental CSR in the AI era. To achieve this goal, further in this article, a factor analysis of environmental CSR is carried out on the example of the United States and Russia in 2019–2022. Then environmental CSR is reinterpreted from the standpoint of Stakeholder Theory and technological capabilities of the AI era.

The originality of the study consists in the fact that environmental CSR is studied from the standpoint of Stakeholder Theory and is reinterpreted taking into account the new context that has developed in the AI era. Stakeholder Theory allows us to form a systematic understanding of the existing practices of implementing environmental CSR, as well as to offer recommendations for improving environmental CSR practices based on breakthrough technologies, taking into account the current era of artificial intelligence.

Factor Analysis of Environmental CSR on the Example of the United States and Russia in 2019–2022

To determine the factors of environmental CSR development, we will analyze the dynamics of changes in the corresponding equity indices on the example of the United States and Russia in 2019–2022. (**Figure 1**).

Source: built by the authors based on materials from Dow Jones (2022), Moscow Stock Exchange (2022).

The dynamics of the Dow Jones (United States) and Moscow Stock Exchange (Russia) environmental CSR equity indices in 2019–2022 and the factor analysis of environmental CSR based on it on the example of the United States and Russia in 2019–2022 showed that the development of environmental CSR is largely determined by financial and economic factors. This is evidenced by the fact that in conditions of stability (in 2019 and in 2021), due to social progress, environmental CSR indices are increasing. And in conditions of instability and crisis, in particular, the global COVID-19 crisis in 2020 and the international sanctions crisis in 2022, these indices show a sharp decline. This indicates the cyclical development of environmental CSR, which coincides with the cyclical development of the economy.

To make the obtained results of a quantitative factor analysis more specific, we shall supplement them with a qualitative factor analysis. Amid the global COVID-19 crisis, in the course of implementation of environmental CSR, environmental concern came to the fore to prevent the spread and emergence of a new viral threat. The works of many scientists, such as Gaisie et al. (2022), Hu et al. (2022) are indicative of natural causes of emergence (COVID-19 as a zoonotic disease which originated from introduction of infection from a sick animal to a human) and spread (poor level of sanitation which promotes the transmission of viruses in society, and an increase in the level of sanitation and social distancing as the measures to reduce the disease incidence) of the COVID-19 pandemic.

Amid the international sanctions crisis, environmental CSR has taken on new significance. Environmental concern has become a mechanism for linking companies to communities (Larch et al., 2022). Environmental CSR can and most likely will become a significant criterion making decisions on the inclusion of companies in newly-emerging international value chains (Le and Hoang, 2022). In the coming years, environmental ECO may transform from a voluntary environmental initiative of business to a new form of competition (environmental competition) and even a new (environmental) market barrier to international expansion (Hagen and Schneider, 2021).

Therefore, environmental CSR depends not only on financial and economic factors (stability of the market environment and favorability of the cyclical phase), which are the same for crises, but also on social factors which are specific to each crisis. Thus, amid the global COVID-19 crisis in environmental CSR, companies and local communities preferred waste minimization and circular business practices, while amid the international sanctions crisis—to "green" workplaces and the reduction of resource consumption (improved resource efficiency of business). This requires a flexible approach to environmental CSR management taking into account the financial, economic and social nature of each particular crisis.

Rethinking of Environmental CSR From the Perspective of Stakeholder Theory and Technological Capabilities of the AI Era

As a result of rethinking of environmental CSR from the standpoint of Stakeholder Theory, the following prospects and advantages of using technological capabilities of the AI era have been established. Entrepreneurs with the help of artificial intelligence can rationalize their practice of environmental CSR, receiving intellectual support for the growth of its effectiveness both by saving resources (reducing costs) and by increasing the return on investment (high-precision forecasting of demand for products with improved environmental properties). Also, enterprises get the opportunity to automate the process of notifying all other stakeholders about the implemented practices of environmental CSR. This will provide more complete informational support for environmental CSR and increase its value for stakeholders (Wut and Ng, 2022).

Shareholders and investors, thanks to the high technologies of the AI era, become more fully aware of the activities of the business they finance in the field of environmental CSR. This helps to increase the transparency of environmental CSR and prevent a formal business approach to its implementation. Also, due to artificial intelligence, shareholders and investors can conduct flexible analysis of the effectiveness of environmental CSR and make more informed investment decisions (Ben Hmiden et al., 2022; Halkos et al., 2022; Islam et al., 2022).

Employees of companies can be more aware of the activities of their companies in the field of environmental CSR. This makes it possible to overcome the fragmentation of knowledge, when an employee knows only about his contribution, but is not aware of all the "green" initiatives implemented by the business. Breakthrough artificial intelligence technologies make it possible to turn environmental CSR into a powerful tool for attracting and retaining the best personnel, as well as non-financial motivation to increase productivity and innovative activity of employees with high ecological values. With the use of artificial intelligence, it is possible to form working and professional teams with similar eco-friendly motives and values, as well as to develop highly effective work incentive programs for them (Hongxin et al., 2022; Latif et al., 2022).

State regulators and non-governmental independent organizations (for example, audit companies, industry expert organizations and rating agencies) can conduct automated environmental monitoring of business, compile environmental ratings of companies. Thanks to this, state regulators are able to stimulate environmental CSR by providing tax, credit and other incentives depending on this responsibility (Karwowski and Raulinajtys-Grzybek, 2021; van Balen et al., 2021).

Consumers and the general public get the opportunity to rationalize consumer behavior in the market. High technologies of the AI era can automatically pick up a product with the best (specified) characteristics of price, quality and environmental friendliness. This allows us to support social progress, increasing environmental values with each responsible purchase and stimulating further responsible purchases. The purchase of products from environmentally responsible suppliers can become a social trend, increasing the supply and demand of these products, as well as keeping an equilibrium (fair) price for it (Ye et al., 2021; Yin et al., 2021).

DISCUSSION

The contribution of the article to the literature is related to the development of scientific provisions of the concept of environmental CSR. In contrast to Madaleno et al. (2022), Schiessl et al. (2022), Yang et al. (2022), Yu et al. (2022), it has been proved that environmental CSR has not only a non-commercial nature, but combines commercial (due to economic factors) and non-commercial (determined by social factors) nature. In this regard, the most comprehensive and clear criteria for assessing the potential for the development of environmental CSR are the market opportunities for the payback of responsible investments and the volume of effective demand for "green" products. The development of environmental CSR is not linear, but cyclical—it is superimposed on the model of the economic cycle. In the phase of economic recovery, social factors prevail and the non–commercial nature manifests itself, and in the phase of economic recession, financial and economic factors prevail and the commercial nature of environmental CSR manifests itself.

In contrast to Awawdeh et al. (2022), Cheng and Zhang (2022), Godefroit-Winkel et al. (2022), Sadiq et al. (2022), it has been proved that the interests of stakeholders (interested parties) do not contradict each other, but on the contrary are balanced with environmental CSR. That is, environmental CSR is a mechanism for establishing and maintaining the balance of industrial markets. Unlike Inshakova and Solntsev (2022), Liu and Gao (2022), Madaleno et al. (2022), it has been proved that breakthrough technologies of the AI era do not aggravate, but allow overcoming the "market failure" of environmental CSR associated with the conflict of interests of stakeholders. Thanks to the technological capabilities of the era of artificial intelligence, the potential of environmental CSR is most fully used to balance the interests of stakeholders and maintain market equilibrium. Therefore, artificial intelligence does not constrain, but stimulates the development of environmental CSR.

CONCLUSION

Thus, the article filled a gap in the literature, clarifying the essence and prospects for the development of environmental CSR in the AI era. The theoretical significance of the results obtained in the article is related to the fact that they clarified the essence of environmental CSR from the standpoint of Stakeholder Theory. This made it possible to substantiate a new (previously unknown) role of environmental CSR associated with overcoming and ensuring a balance of interests of stakeholders (interested parties).

Further theoretical significance of this paper is that it has revealed social factors of environmental CSR amid the crisis. Drawing on the example of the global COVID-19 crisis and the international sanctions crisis, it has been demonstrated that social factors determine the priorities of environmental CSR amid the crisis, and determine the economic potential of environmental CSR through the loyalty of stakeholders to companies. This has given rise to a new idea of environmental CSR, which, from mainly environmental practical experience, has got a new theoretical interpretation—as a socioeconomic and environmental practice that requires system management from the perspective of sustainable development.

The practical significance of the authors' conclusions is that broad prospects and favorable opportunities for the development of environmental CSR in the AI era are revealed. The social significance of the research results lies in the fact that the advantages of using breakthrough technologies of the AI era for each stakeholder, justified in this article, allow us to increase the scale and effectiveness of environmental CSR through making it a widespread practice, as well as using its potential in striking a balance between branch markets.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.953996/full#supplementary-material

REFERENCES

Astafeva, O. V., Astafyev, E. V., Khalikova, E. A., Leybert, T. B., and Osipova, I. A. (2020). XBRL Reporting in the Conditions of Digital Business Transformation. *Bus. Transformation//Lect. Notes Netw. Syst.* 84, 373–381. doi:10.1007/978-3-030-27015-5_45

Awawdeh, A. E., Ananzeh, M., El-khateeb, A. I., and Aljumah, A. (2022). Role of Green Financing and Corporate Social Responsibility (CSR) in Technological Innovation and Corporate Environmental Performance: a COVID-19 Perspective. *Cfri* 12 (2), 297–316. doi:10.1108/CFRI-03-2021-0048

Ben Hmiden, O., Rjiba, H., and Saadi, S. (2022). Competition through Environmental CSR Engagement and Cost of Equity Capital. *Finance Res. Lett.* 47, 102773. doi:10.1016/j.frl.2022.102773

Camilleri, M. A. (2021). *Strategic Attributions of Corporate Social Responsibility and Environmental Management: The Business Case for Doing Well by Doing Good!*, 30. Sustainable Development, 409–422. doi:10.1002/sd.2256Strategic Attributions of Corporate Social Responsibility and Environmental Management: The Business Case for Doing Well by Doing Good!*Sustain. Dev.*

Camilleri, M. A. (2022). The Rationale for ISO 14001 Certification: A Systematic Review and a Cost-Benefit Analysis. *Corp. Soc. Responsib. Env*. doi:10.1002/csr.2254

Cheng, S., and Zhang, F. (2022). Regulatory Pressure and Consumer Environmental Awareness in a Green Supply Chain with Retailer Responsibility: A Dynamic Analysis. *Manage Decis. Econ.* 43 (4), 1133–1151. doi:10.1002/mde.3444

Gaisie, E., Oppong-Yeboah, N. Y., and Cobbinah, P. B. (2022). Geographies of Infections: Built Environment and COVID-19 Pandemic in Metropolitan Melbourne. *Sustain. Cities Soc.* 81, 103838. doi:10.1016/j.scs.2022.103838

Gao, F., Liu, H., Zhao, C., Li, X., and Shi, J. (2021). Research on the Impact of Green Technological Innovation and Environmental Responsibility on the Performance of Resource-Based Enterprises under the Low-Carbon Background. *Conf. Proc. 9th Int. Symposium Proj. Manag. ISPM* 2021, 661–667.978-192171277-7

Godefroit-Winkel, D., Schill, M., and Diop-Sall, F. (2022). Does Environmental Corporate Social Responsibility Increase Consumer Loyalty? *Ijrdm* 50 (4), 417–436. doi:10.1108/IJRDM-08-2020-0292

Hagen, A., and Schneider, J. (2021). Trade Sanctions and the Stability of Climate Coalitions. *J. Environ. Econ. Manag.* 109, 102504. doi:10.1016/j.jeem.2021.102504

Halkos, G., Nomikos, S., and Tsilika, K. (2022). Evidence for Novel Structures Relating CSR Reporting and Economic Welfare: Environmental Sustainability-A Continent-Level Analysis. *Comput. Econ.* 59 (2), 415–444. doi:10.1007/s10614-020-10091-5

Hongxin, W., Khan, M. A., Zhenqiang, J., Cismaş, U., and Ali, L. (2022). Unleashing the Role of CSR and Employees' Pro-environmental Behavior for Organizational Success: The Role of Connectedness to Nature. *Sustain. Switz.* 14(6), 3191. doi:10.3390/su14063191

Hu, Z., Yang, L., Han, J., Zhu, L., and Hu, B. (2022). Human Viruses Lurking in the Environment Activated by Excessive Use of COVID-19 Prevention Supplies. *Environ. Int.* 163, 107192. doi:10.1016/j.envint.2022.107192

Huo, W., Ullah, M. R., Zulfiqar, M., Parveen, S., and Kibria, U. (2022). Financial Development, Trade Openness, and Foreign Direct Investment: A Battle between the Measures of Environmental Sustainability. *Front. Environ. Sci.* 10, 851290. doi:10.3389/fenvs.2022.851290

Inshakova, A. O., and Solntsev, A. M. (2022). *Advances in Research on Russian Business and Management*. Charlotte, NC, USA: Information Age Publishing, 267–276.Modification of International Mechanisms for Protecting Human Rights under Conditions of Anthropogenic Environmental Impact with the Intensive Development of Technology of the Sixth Technological Order

Islam, T., Ahmad, S., and Ahmed, I. (2022). Linking Environment Specific Servant Leadership with Organizational Environmental Citizenship Behavior: the Roles of CSR and Attachment Anxiety. *Rev. Manag. Sci.* doi:10.1007/s11846-022-00547-3

Jones, Dow (2022). *S&P 500 Environmental & Socially Responsible Index*. URL: https://www.spglobal.com/spdji/en/indices/esg/sp-500-environmental-socially-responsible-index/#overview (data accessed 05 14, 2022).

Karwowski, M., and Raulinajtys-Grzybek, M. (2021). The Application of Corporate Social Responsibility (CSR) Actions for Mitigation of Environmental, Social, Corporate Governance (ESG) and Reputational Risk in Integrated Reports. *Corp. Soc. Responsib. Environ. Manag.* 28 (4), 1270–1284. doi:10.1002/csr.2137

Larch, M., Shikher, S., Syropoulos, C., and Yotov, Y. V. (2022). Quantifying the Impact of Economic Sanctions on International Trade in the Energy and Mining Sectors. *Econ. Inq.* 60 (3), 1038–1063. doi:10.1111/ecin.13077

Latif, B., Ong, T. S., Meero, A., Abdul Rahman, A. A., and Ali, M. (2022). Employee-Perceived Corporate Social Responsibility (CSR) and Employee Pro-environmental Behavior (PEB): The Moderating Role of CSR Skepticism and CSR Authenticity. *Sustain. Switz.* 14 (3), 1380. doi:10.3390/su14031380

Le, H. T., and Hoang, D. P. (2022). Economic Sanctions and Environmental Performance: The Moderating Roles of Financial Market Development and Institutional Quality. *Environ. Sci. Pollut. Res.* 29 (13), 19657–19678. doi:10.1007/s11356-021-17103-3

Ligozat, A.-L., Lefevre, J., Bugeau, A., and Combaz, J. (2022). Unraveling the Hidden Environmental Impacts of AI Solutions for Environment Life Cycle Assessment of AI Solutions. *Sustain. Switz.* 14 (9), 5172. doi:10.3390/su14095172

Lin, R., Ma, X., Li, B., Chen, X., and Liang, S. (2022). A Study on the Participation of Peasants in Rural Environmental Improvement from the Perspective of Sustainable Development. *Front. Environ. Sci.* 10, 853849. doi:10.3389/fenvs.2022.853849

Liu, T., and Gao, H. (2022). Does Supply Chain Concentration Affect the Performance of Corporate Environmental Responsibility? the Moderating Effect of Technology Uncertainty. *Sustain. Switz.* 14 (2), 781. doi:10.3390/su14020781

Madaleno, M., Dogan, E., and Taskin, D. (2022). A Step Forward on Sustainability: The Nexus of Environmental Responsibility, Green Technology, Clean Energy and Green Finance. *Energy Econ.* 109, 105945. doi:10.1016/j.eneco.2022.105945

Moscow Exchange (2022). RUIE Index Sustainable Development Vector. URL: https://www.moex.com/ru/index/MRRT (data accessed 05 14, 2022).

Osipov, V. S., Vorozheykina, T. M., Bogoviz, A. V., Lobova, S. V., and Yankovskaya, V. V. (2022). Innovation in Agriculture at the Junction of Technological Waves: Moving from Digital to Smart Agriculture. *Smart Innovation, Syst. Technol.* 264, 21–27. doi:10.1007/978-981-16-7633-8_3

Pagliarini, L., and Lund, H. H. (2020). Approaching AI and Robotics in an Eco-Friendly Way. *J. Robotics, Netw. Artif. Life* 6 (4), 217–220. doi:10.2991/jrnal.k.200222.002

Popkova, E., DeLo, P., and Sergi, B. S. (2021). Corporate Social Responsibility amid Social Distancing during the COVID-19 Crisis: BRICS vs. OECD Countries. *Res. Int. Bus. Finance* 55, 101315. doi:10.1016/j.ribaf.2020.101315

Popkova, E. G., and Zavyalova, E. (2021). "New Institutions for Socio-Economic Development: The Change of Paradigm from Rationality and Stability to Responsibility and Dynamism. New Institutions for Socio-Economic Development," in *The Change of Paradigm from Rationality and Stability to Responsibility and Dynamism*, 1–192. doi:10.1515/9783110699869

Sadiq, M., Nonthapot, S., Mohamad, S., Ehsanullah, S., and Iqbal, N. (2022). Does Green Finance Matter for Sustainable Entrepreneurship and Environmental Corporate Social Responsibility during COVID-19? *China Finance Rev. Int.* 12 (2), 317–333. doi:10.1108/CFRI-02-2021-0038

Schiessl, D., Korelo, J. C., and Mussi Szabo Cherobim, A. P. (2022). Corporate Social Responsibility and the Impact on Economic Value Added: the Role of Environmental Innovation. *Eur. Bus. Rev.* 34 (3), 396–410. doi:10.1108/EBR-03-2021-0071

Tavana Amlashi, A., Alidoust, P., Pazhouhi, M., Khabiri, S., and Ghanizadeh, A. R. (2021). AI-Based Formulation for Mechanical and Workability Properties of Eco-Friendly Concrete Made by Waste Foundry Sand. *J. Mater. Civ. Eng.* 33 (4), 04021038. doi:10.1061/(ASCE)MT.1943-5533.0003645

van Balen, M., Haezendonck, E., and Verbeke, A. (2021). Mitigating the Environmental and Social Footprint of Brownfields: The Case for a Peripheral CSR Approach. *Eur. Manag. J.* 39 (6), 710–719. doi:10.1016/j.emj.2021.04.006

Wang, Y., Yang, Y., Fu, C., Fan, Z., and Zhou, X. (2021). Environmental Regulation, Environmental Responsibility, and Green Technology Innovation: Empirical Research from China. *PLoS ONE* 16 (9 September), e0257670. doi:10.1371/journal.pone.0257670

Wut, T. M., and Ng, P. M.-L. (2022). Perceived CSR Motives, Perceived CSR Authenticity, and Pro-environmental Behavior Intention: an Internal Stakeholder Perspective. *Soc. Responsib. J.* doi:10.1108/SRJ-08-2020-0350

Yang, D., Song, D., and Li, C. (2022). Environmental Responsibility Decisions of a Supply Chain under Different Channel Leaderships. *Environ. Technol. Innovation* 26, 102212. doi:10.1016/j.eti.2021.102212

Ye, Q., Rafique, Z., Zhou, R., Anwar, M. A., and Siddiquei, A. N. (2021). Embedded Philanthropic CSR in Digital China: Unified View of Prosocial and Pro-environmental Practices. *Front. Psychol.* 12, 695468. doi:10.3389/fpsyg.2021.695468

Yin, C., Ma, H., Gong, Y., Chen, Q., and Zhang, Y. (2021). Environmental CSR and Environmental Citizenship Behavior: The Role of Employees' Environmental Passion and Empathy. *J. Clean. Prod.* 320, 128751. doi:10.1016/j.jclepro.2021.128751

Yu, F., Jiang, D., and Wang, T. (2022). The Impact of Green Innovation on Manufacturing Small and Medium Enterprises Corporate Social Responsibility Fulfillment: The Moderating Role of Regional Environmental Regulation. *Corp. Soc. Responsib. Environ. Manag.* 29 (3), 712–727. doi:10.1002/csr.2231

Zhang, C., and Cheng, J. (2022). Environmental Regulation and Corporate Cash Holdings: Evidence from China's New Environmental Protection Law. *Front. Environ. Sci.* 10, 835301. doi:10.3389/fenvs.2022.835301

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Environmental competitiveness of the economy: Opportunities for its improvement with the help of AI

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Introduction

The ecological competitiveness of the economy is a new concept that emerged in the era of the Sustainable Development Goals under the influence of the United Nations (UN) global initiative. The ecological competitiveness of the economy is understood, on the one hand, as a set of conditions created to protect the environment (for example, the predominance of responsible production and consumption practices, the predominance of sustainable communities and territories), and on the other hand, the environmental results achieved (for example, the state of the climate, the level of biodiversity, the purity of water and air), as well as the correlation of these results with other economic systems (AlAbri et al., 2022; Del-Aguila-Arcentales et al., 2022; Martínez and Poveda, 2022).

Every year the environmental competitiveness of the economy increasingly determines the attractiveness of economic systems for:

– Living (which is especially important for aging societies, as it forms their potential to overcome demographic crises) (Wu, 2022);
– Work (attracting and retaining highly qualified personnel, including among migrant workers) (Sabbir and Taufique, 2022);
– Investment ("green" finance is gaining popularity around the world) (Awawdeh et al., 2022);
– International foreign economic cooperation (an example is the introduction of a carbon tax for exporters in the European Union) (Owusu Kwateng et al., 2022).

The problem lies in the uncertainty of the prospects for improving the environmental competitiveness of the economy in the era of artificial intelligence (AI). In this article, a scientific search for a solution to the problem is carried out. The hypothesis of this research is that artificial intelligence improves the environmental competitiveness of the economy. The advanced hypothesis is based on evidence that artificial intelligence (AI) enables automated ("smart") environmental monitoring, promptly identifying and eradicating violations of environmental legislation, presented in works by Asha et al. (2022), Bakirman (2022), Sasaki et al. (2019).

With the accumulation of experience in "smart" monitoring, it is becoming a preventive measure. Fraga-Lamas et al. (2021), Wilson et al. (2022) also point out in their papers that artificial intelligence (AI) can be used for "smart" organization and management of circular production works, automated and highly-accurate sorting of production and consumption waste. As a result, environmental pollution is reduced.

Philip and Kavitha (2022), Yankovskaya et al. (2022) point out in their works that artificial intelligence (AI) allows developing "green" corporate management, providing intelligent support for managerial decision making. For example, through the selection of directions for business development associated with the lowest ecological costs.

As is noted in the work by Guchhait et al. (2021), artificial intelligence (AI) also supports the development of green finance by automatically sorting and selecting the most ecologically responsible investment opportunities. Further, "smart" environmental tax optimization is possible through an automated search for ways to reduce the environmental tax burden of business, which is particularly topical in the context of the introduction of carbon tax.

The article is aimed at determining the prospects and advantages of improving the environmental competitiveness of the economy with the use of artificial intelligence. The article also contains applied economic policy implications.

The potential of artificial intelligence in improving the environmental competitiveness of the economy

Environmental competitiveness is a special component of the competitiveness of the economic and social system, associated with peculiarities of the management of natural resources (Del-Aguila-Arcentales et al., 2022). It shall be understood to mean the ability of the economic system to use natural resources in the most efficient (sustainable, prudent and environmentally friendly) way, avoiding their depletion with a view to creating the most favourable ecosystem for human life, as well as preserving the heritage for future generations (AlAbri et al., 2022; Wang M. et al., 2022).

The Global Sustainable Competitiveness Index: SolAbility (2022) occupies a central place among the indicators of environmental competitiveness of the economy. Therefore, the research in this article is based on this indicator. It provides full and detailed information of the essence of the ecological competitiveness of the economy, highlighting the following components in its structure and calculating separately:

- Natural capital: Favorable natural environment in the economic system (Congjuan et al., 2022);
- Resource Intensity: Resource efficiency of the economy (Wang N. et al., 2022);
- Social capital: Social cohesion in environmental issues (Popkova et al., 2021);
- Intellectual capital: The level of environmental education and the availability of "green" innovations (Popkova et al., 2018);
- Governance: The level of development of "green" infrastructure and the state regulators' commitment to environmental priorities (Mahmoodi and Dahmardeh, 2022).

In the works of Adamova et al. (2021), Asha et al. (2022), Li et al. (2021), Ligozat et al. (2022), Sasaki et al. (2019), it is noted that artificial intelligence (AI) has the greatest potential in increasing the environmental competitiveness of the economy in terms of resource efficiency of the economy (through monitoring of resource consumption and automation of resource conservation), intellectual capital (through the generation of "green" innovations) and government regulation (through increasing transparency, accountability and manageability of environmental economics and management).

Dong and Meng (2021), Rana et al. (2021) point out in their works that artificial intelligence (AI) significantly contributes to improving the overall competitiveness of the economy and, in particular, to improving digital competitiveness. Nevertheless, the contribution to the ecological competitiveness of the economy has not been studied much, so it remains unclear what research gap is being filled in this article.

AI's contribution to ensuring the ecological competitiveness of the economy: An overview of international best practices

This article uses the Global Sustainable Competitiveness Index (SolAbility, 2022), based on five equisignificant indicators of environmental competitiveness, as an empirical research base:

Natural Capital: A specified natural habitat, including the availability of resources and the degree of their depletion;
Social Capital: Health, security, freedom, equality, and life satisfaction that contribute to social advance;
Resource Efficiency: Efficiency of utilization of limited attainable resources;

TABLE 1 The level of artificial intelligence (AI) development and environmental competitiveness of the top 15 economies in the SolAbility rating (2022) in 2021.

	Country	Indicators of environmental competitiveness, points 1–100					Use of big data and analytics, places 1–64
		Natural capital	Resource intensity	Social capital	Intel-lectual capital	Gover-nance	
Empirical data	Sweden	60.2	58.0	62.4	67.9	57.6	10
	Finland	59.8	50.6	62.3	64.3	66.3	16
	Switzerland	55.4	61.8	59.8	62.7	62.2	23
	Denmark	53.2	56.4	60.4	66.8	64.0	13
	Norway	62.5	48.9	63.5	64.4	59.9	9
	Iceland	65.2	43.0	64.1	62.5	64.1	20
	Irish	51.4	57.7	55.8	51.2	71.7	30
	France	54.2	57.3	55.4	58.7	58.3	52
	Austria	49.1	50.3	60.7	58.7	64.0	27
	Germany	46.2	52.3	56.1	63.2	65.0	53
	Estonia	48.1	43.8	60.4	54.9	73.2	34
	Japan	40.6	47.7	58.2	65.3	64.7	63
	Croatia	61.4	47.0	54.5	49.1	63.6	61
	New Zealand	60.2	47.2	56.0	46.9	64.4	33
	Portugal	49.5	48.6	59.4	55.5	60.9	58
Regression statistics of dependence on the use of big data and analytics	Constant	61.06	53.74	63.22	64.27	63.65	—
	Regression coefficient	−0.20	−0.07	−0.12	−0.14	0.01	—
	Significance of F	0.037*	0.386	0.0002**	0.122	0.869	—
	Correlation	0.5404	0.2412	0.7275	0.4173	0.0465	—

Significance level (α): * 0.05; **0.01. Source: Composed by the authors based on materials of IMD Business School (2022), SolAbility (2022).

Intellectual Capital: The ability to create wealth and jobs through innovations and value creation by economic sectors in open (free, global) markets.
Governance Performance: The framework for sustainable development and social well-being, achieved through the equitable distribution of resources, infrastructure, regulation of markets and employment.

To test the hypothesis put forward in the article, the influence of use of big data and analytics [as an artificial intelligence (AI) indicator] is determined according to the assessment of IMD Business School (2022) on the indicators of environmental competitiveness according to the assessment of SolAbility (2022). The study is conducted using the regression analysis method in 2021 on the example of the top 15 countries with the highest environmental competitiveness of the economy (leaders of the SolAbility rating of the same name, 2022). Empirical data and analysis results are presented in Table 1.

The results obtained in Table 1 showed that, firstly, there is a reliable pattern of growth of natural capital and social capital as artificial intelligence (AI) spreads. Thus, the improvement of the position of the sample countries in the IMD rating (2022) according to the use of big data and analytics indicator contributes to the increase of natural capital by 0.20 points (correlation 54.04%, the pattern is reliable at the significance level of 0.05) and the growth of social capital by 0.12 points (correlation 72.75%, the pattern is reliable at the significance level of 0.01). Based on the established regression patterns, it was revealed that at the maximum level of artificial intelligence (AI) development (1st place), an increase in natural capital by 11.75% and social capital by 6.48% is achieved.

Secondly, the spread of artificial intelligence (AI) does not contribute to improving the sustainability of governance, as evidenced by unreliable regression and weak correlation. Thirdly, despite the absence of a sufficiently reliable regression dependence, the close relationship of the remaining indicators with artificial intelligence (AI) is evidenced by a pronounced correlation: with resource intensity (24.12%) and with intellectual capital (41.73%). Consequently, these indicators of the environmental competitiveness of the economy can be improved through the use of AI, but these advantages are not guaranteed (they do not occur in all countries and not in all cases).

The obtained results validate the advanced hypothesis and prove that artificial intelligence opens up new opportunities for improving the environmental competitiveness of the economy.

Artificial intelligence allows slowing down/preventing the depletion of natural resources (to preserve natural capital), and supporting social advance through health, security, freedom, equality, and life satisfaction (development of social capital).

Prospects for improving the environmental competitiveness of the economy using AI: Economic policy implications

In this article, it is suggested to focus on those components of this competitiveness that are most closely related to the development of artificial intelligence (AI) in order to maximize the actual contribution of artificial intelligence (AI) in practice, aimed at improving the environmental competitiveness of the economy. The following main (priority) measures are proposed:

- To develop natural capital, it is recommended to use the so-called “AI imagination” to discover new ways of regenerative nature-based management. In this regard, it is necessary to inform artificial intelligence (using a digital code) of the advantages of various practices of ecological economics and management, teach and program it to search for the most optimal combination of business practices that can improve the environmental situation;
- To strengthen social capital, it is proposed to create an even greater number of more “smart” chatbots (both private and public) in order to increase the awareness of communities about current environmental problems and the opportunities available to them to solve these problems through responsible production and consumption practices.

The following additional measures are proposed:

- To increase resource intensity and increase intellectual capital, it is advisable to expand the use of artificial intelligence (AI) in R&D conducted by both research institutes (for the economy as a whole) and individual business structures (for their own needs). This will make it possible to create both universal and unique applied solutions to improve the resource efficiency of environmental economics and management.

The proposed recommendations will allow integrating artificial intelligence (AI) into environmental economics and management practices and thereby increase their scale and their efficiency.

Discussion

The article contributes to the development of the Theory of environmental economics and management by clarifying the role and importance of artificial intelligence (AI) in ensuring the ecological competitiveness of the economy. The increment of scientific knowledge in the article is provided due to the justification that, unlike the assumptions made in the works of Adamova et al. (2021), Asha et al. (2022), Li et al. (2021), Ligozat et al. (2022), Sasaki et al. (2019), the potential artificial intelligence (AI) in improving the environmental competitiveness of the economy is most pronounced in the field of natural and social capital development, and not in relation to the resource efficiency of the economy, intellectual capital and government regulation, as previously assumed in these publications.

As a result of the study, it was possible to prove that artificial intelligence (AI) makes a reliable and stable contribution to the development of natural capital (improving environmental conditions in the economic system and supporting the implementation of SDGs 13-15) and social capital (increasing social cohesion in environmental protection and supporting SDG 11). At the same time, it is observed less pronounced and insufficiently reliable for the global economy as a whole, but perhaps reliable enough in individual countries, AI’ contribution to increasing resource Intensity (improving the resource efficiency of the economy and supporting the implementation of SDG 12) and the development of intellectual capital (increasing the level of environmental education and the availability of “green” innovations and supporting the achievement of SDG 4). Nevertheless, on a global economic scale, no significant AI’ contribution to governance has been identified (increasing the level of development of “green” infrastructure and the commitment of state regulatory authorities to environmental priorities, that is, in support of achieving SDG 9).

Conclusion

So, the hypothesis put forward in the article has been proved: artificial intelligence determines success in slowing down/preventing the depletion of natural resources by 54.04%, and determines social advance by 72.75%. It opens up broad prospects for improving the environmental competitiveness of the economy in the artificial intelligence (AI) era. The theoretical significance of the results obtained in this study lies in the reasoned position that, despite the overall positive contribution to improving the environmental competitiveness of the economy, artificial intelligence (AI) has a significantly different potential in the development of individual components of this competitiveness. This makes it possible to use artificial intelligence (AI) more flexibly and effectively in improving environmental economics and management. The article has also revealed AI’ contribution to improving the environmental competitiveness of the economy in the context of the components of this competitiveness, as well as in the light of the implementation of the Sustainable Development Goals (SDGs).

The empirical value of the article consists in revealing the prospects for improving the environmental competitiveness of the economy in the artificial intelligence (AI) era. In particular, it has been proved that natural capital can be increased by 11.75%, and social capital—by 6.48%. The outlined prospects and the proposed economic policy implications for improving the environmental competitiveness of the economy with the use of artificial intelligence (AI) make it possible to improve the practice of state and corporate management of the environmental economics, focusing the use of artificial intelligence (AI) in the most promising areas.

In conclusion, it is necessary to pay attention to the limitations of the results obtained in the article due to the fact that no significant AI' contribution to the development of resource intensity, intellectual capital and governance has been identified. The fact that positive and sufficiently reliable connections have not been revealed in this study does not necessary mean that they are actually absent. In future studies, the sample should be expanded to include, in particular, developing countries. In addition, it is advisable to conduct case studies that will help to identify hidden connections between artificial intelligence (AI) and the environmental competitiveness of the economy.

Author contributions

All authors contributed to manuscript writing revision, read, and approved the submitted version.

Conflict of interest

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References

Adamova, M. A., Kardanova, M. L., Yakusheva, A. V., Dyakonova, M. A., and Mankieva, A. V. (2021). Artificial intelligence in politics global leadership and the risks of competitive struggle. *Adv. Res. Russ. Bus. Manag.* 2021, 409–417.

AlAbri, S., Taghizadeh, S. K., Khan, G. M., and Rahman, S. A. (2022). Exploratory innovation, exploitative innovation and operational performance: Influence of informal social relations in environmental competitiveness. *Qual. Quant.* 56 (3), 1223–1244. doi:10.1007/s11135-021-01173-z

Asha, P., Natrayan, L., Geetha, B. T., Beulah, J. R., Sumathy, R., Varalakshmi, G., et al. (2022). IoT enabled environmental toxicology for air pollution monitoring using AI techniques. *Environ. Res.* 205, 112574. doi:10.1016/j.envres.2021.112574

Awawdeh, A. E., Ananzeh, M., El-khateeb, A. I., and Aljumah, A. (2022). Role of green financing and corporate social responsibility (CSR) in technological innovation and corporate environmental performance: A COVID-19 perspective. *Cfri* 12 (2), 297–316. doi:10.1108/CFRI-03-2021-0048

Bakirman, T. (2022). AI-based environmental monitoring with UAV systems. *Photogrammetric Eng. Remote Sens.* 88 (2), 102.

Congjuan, L., Abulimiti, M., Jinglong, F., and Haifeng, W. (2022). Ecologic service, economic benefits, and sustainability of the man-made ecosystem in the taklamakan desert. *Front. Environ. Sci.* 10, 813932. doi:10.3389/fenvs.2022.813932

Del-Aguila-Arcentales, S., Alvarez-Risco, A., Jaramillo-Arévalo, M., De-La-cruz-diaz, M., and Anderson-Seminario, M. d. l. M. (2022). Influence of social, environmental and economic sustainable development Goals (SDGs) over continuation of entrepreneurship and competitiveness. *JOItmC* 8 (2), 73. doi:10.3390/joitmc8020073

Dong, T., and Meng, L. (2021). Assessment of international competitiveness of AI industry based on positive and negative ideal points weighting method. *Mob. Inf. Syst.* 2021, 1–9. doi:10.1155/2021/9119262

Fraga-Lamas, P., Lopes, S. I., and Fernández-Caramés, T. M. (2021). Green iot and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: An industry 5.0 use case. *Sensors* 21 (17), 5745. doi:10.3390/s21175745

Guchhait, R., Sarkar, M., and Sarkar, B. (2021). How much green investments are efficient for a smart production system? *IFIP Adv. Inf. Commun. Technol.* 632 IFIP, 450–459. doi:10.1007/978-3-030-85906-0_50

IMD Business School (2022).. World Competitiveness Ranking 2021. URL: https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/ (data accessed 05 16, 2022).

Li, V. O. K., Lam, J. C. K., and Cui, J. (2021). AI for social good: AI and big data approaches for environmental decision-making. *Environ. Sci. Policy* 125, 241–246. doi:10.1016/j.envsci.2021.09.001

Ligozat, A.-L., Lefevre, J., Bugeau, A., and Combaz, J. (2022). Unraveling the hidden environmental impacts of AI solutions for environment life cycle assessment of AI solutions. *Sustainability* 14 (9), 5172. doi:10.3390/su14095172

Mahmoodi, M., and Dahmardeh, N. (2022). Environmental kuznets curve hypothesis with considering ecological footprint and governance quality: Evidence from emerging countries. *Front. Environ. Sci.* 10, 849676. doi:10.3389/fenvs.2022.849676

Martínez, C. I. P., and Poveda, A. C. (2022). The effects of environmental performance on competitiveness and innovation: A stochastic Frontier approach for Colombia. *Environ. Syst. Decis.* 42 (1), 51–62. doi:10.1007/s10669-021-09828-w

Owusu Kwateng, K., Tetteh, F. K., Atchulo, H. B., and Opoku-Mensah, S. (2022). Effect of corporate environmental strategies on firms' competitiveness, the mediating role of supply chain collaboration. *Jgr.* doi:10.1108/JGR-02-2021-0026

Philip, J. M., and Kavitha, N. S. (2022). Smart waste management system using optimised routing for environmental protection. *J. Environ. Prot. Ecol.* 23 (3), 1020–1030.

Popkova, E., Bogoviz, A. V., and Sergi, B. S. (2021). Towards digital society management and 'capitalism 4.0' in contemporary Russia. *Humanit Soc. Sci. Commun.* 8 (1), 77. doi:10.1057/s41599-021-00743-8

Popkova, E., Gornostaeva, Z., and Tregulova, N. (2018). Role of innovations in provision of competitiveness and innovational development of economy and overcoming of "underdevelopment whirlpools" in Russia and countries of Eastern Europe. *Jeee* 10 (3), 511–523. doi:10.1108/JEEE-12-2017-0100

Rana, N. P., Chatterjee, S., Dwivedi, Y. K., and Akter, S. (2021). Understanding dark side of artificial intelligence (AI) integrated business analytics: Assessing firm's operational inefficiency and competitiveness. *Eur. J. Inf. Syst.* 31, 364–387. doi:10.1080/0960085X.2021.1955628

Sabbir, M. M., and Taufique, K. M. R. (2022). Sustainable employee green behavior in the workplace: Integrating cognitive and non-cognitive factors in corporate environmental policy. *Bus. Strat. Env.* 31 (1), 110–128. doi:10.1002/bse.2877

Sasaki, S., Kiyoki, Y., Sarkar-Swaisgood, M., Shaw, R., and Veesommai, C. (2019). 5D world map system for disaster-resilience monitoring from global to local: Environmental artificial intelligence (AI) system for leading SDG 9 and 11. *Front. Artif. Intell. Appl.* 321, 306–323. doi:10.3233/FAIA200022

SolAbility (2022). *The global sustainable competitiveness Index*. URL: https://solability.com/the-global-sustainable-competitiveness-index/downloads (data accessed 05 16, 2022).

Wang, M., Li, Y., and Liao, G. (2022a). Spatial spillover and interaction between high-tech industrial agglomeration and urban ecological efficiency. *Front. Environ. Sci.* 10, 829851. doi:10.3389/fenvs.2022.829851

Wang, N., Zhang, S. J., and Wang, W. (2022b). Impact of environmental innovation strategy on green competitiveness: Evidence from China. *Ijerph* 19 (10), 5879. doi:10.3390/ijerph19105879

Wilson, M., Paschen, J., and Pitt, L. (2022). The circular economy meets artificial intelligence (AI): Understanding the opportunities of AI for reverse logistics. *Meq* 33 (1), 9–25. doi:10.1108/MEQ-10-2020-0222

Wu, G. (2022). Research on the spatial impact of green finance on the ecological development of Chinese economy. *Front. Environ. Sci.* 10, 887896. doi:10.3389/fenvs.2022.887896

Yankovskaya, V. V., Bogoviz, A. V., Lobova, S. V., Trembach, K. I., and Buravova, A. A. (2022). Framework strategy for developing regenerative environmental management based on smart agriculture. *Smart Innovation, Syst. Technol.* 264, 281–286. doi:10.1007/978-981-16-7633-8_31

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The effect of customer trust and commitment on customer sustainable purchasing in e-marketplace, the antecedents of customer learning value and customer purchasing value

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The e-marketplace is a platform used by vendors to conduct transactions and shopping. The success of implementing an e-marketplace depends on customers' sustainable purchasing. This study integrates customer learning (formative construct) and purchasing (reflective construct) values to measure the level of customer trust and commitment in the e-marketplace to examine their effects on sustainable customer purchases. A total of 428 valid respondents were processed using SmartPLS 3. The results show that the six proposed hypotheses have positive values and significant effects. Customer learning and purchasing values have positive values and significant effects on customer trust and loyalty and have indirect positive values and significant effects on sustainable customer purchases. In other words, customer trust and loyalty have positive values and significant effects on sustainable customer purchases. Thus, the findings of this study have implications for other researchers and practitioners conducting studies on e-marketplaces.

KEYWORDS

e-marketplace, customer learning value, customer purchasing value, customer sustainable purchasing, customer trust, customer commitment

1 Introduction

The recent increase in Internet needs has influenced many activities, including online shopping transactions. It does not occur in only one region but also globally. Interest in e-business transactions affects the scope of studies. This correlates with the perspective of customer purchasing value (Huré et al., 2017). Having knowledge and experience makes it possible for customers to trust products or services that can be used effectively. It provides an opportunity for sustainable customer purchases in digital transactions (Huang and Benyoucef, 2013). The growth of digital transactions in e-commerce affects customer perspectives on digital business knowledge. Hence, e-commerce vendors and marketplaces should be more competitive in keeping their customers loyal (Abhishek et al., 2016).

Previous studies have confirmed that two perspectives, customer satisfaction and customer commitment, have a significant impact on sustainable customer purchasing. It gives value to product quality from a customer perspective, particularly in e-commerce transactions (Shin et al., 2013). For customers, satisfaction is the most important part of the continuity of product use, particularly in mobile application services (Zhou et al., 2012). Hence, customer shopping value will be positive for customer commitment and sustainable customer purchases (Zhou et al., 2012). Furthermore, hedonic customers have become one of the reasons that customers are willing to buy a product or service (Bui and Kemp, 2013). Another aspect is that strong customer commitment affects the positive value to the continuity of customer purchases (Zhou et al., 2012). In retail marketing studies, variables of commitment are classified based on three factors: commitment based on measurement, normative commitment, and affective commitment (Beatty et al., 2012). Nevertheless, in another study on social media e-commerce and online hotel reservation, commitments were reduced into two categories: commitment based on measurement and commitment based on affective aspects (Beatty et al., 2012; Bilgihan and Bujisic, 2015; Bui and Kemp, 2013; Zhou et al., 2012). Studies on organizational behavior classify commitment into three parts: commitment based on measurement, normative commitment, and affective commitment (Meyer et al., 2002; Bhati and Verma, 2020). This study confirmed that affective commitment is more dominant in affecting the behavior and performance of an organization. The other two studies that involve customer behavior in e-commerce transactions have confirmed that the variables of trust and commitment from the customer can provide value and benefit for customers and vendors (Wang et al., 2016; Cui et al., 2020).

The dynamic exploration of the variables of trust and commitment becomes an opportunity for research in other fields of study, particularly in customer digital experiences, regarding the antecedent factors. It also provides opportunities for researchers to assess customer behavior and intention in the digital market. In the case of mobile applications that involve the variables of trust and commitment, antecedents such as social distance, customer satisfaction, and opportunistic behavior are required. Moreover, studies on mobile commerce have confirmed that high customer trust and strong customer commitment have a significant effect on sustainable customer intention (Cui et al., 2020); however, it does not explain the effect of mediator variables.

This study adopts several previous studies to determine the factors and variables that correspond to the transaction concept and activity of the e-marketplace to identify the behavior of customer purchasing (Cui et al., 2020). This study also elaborates on new variables. Trust and commitment variables were built and integrated as factors that support sustainable customer purchases. The other two variables, customer learning (formative construct) and purchasing values (reflective construct), become antecedents of the trust and commitment variables. This study proposes that customer learning value has two basic elements: product and marketplace knowledge. Besides, the customer purchasing value variable has three elements: monetary value, cost evaluation, and product/vendor reputation. Overall, this study focused on two aspects.

1) How does the variable of customer learning value affect sustainable customer purchases with the mediator variable of customer trust and commitment in e-commerce online transactions? (2) How does the variable of customer purchasing value affect sustainable customer purchases with the mediator variable of customer trust and commitment in marketplace online transactions? This study measures the direct effect of customer learning and purchasing values on the variables of customer trust and commitment. It also assesses the direct effect of customer trust and commitment on sustainable customer purchases.

The contribution of this study is the integration of customer learning value as the formative construct and customer purchasing value as the reflective construct, as well as the variable of customer trust and commitment on online transactions in the marketplace to a model. The variable of customer learning value is built based on product and marketplace knowledge. The variable of customer purchasing value is built based on monetary value, cost evaluation, and product/vendor reputation. These variables have been examined systematically to provide information and knowledge in the field of digital transactions, particularly e-commerce (Wang et al., 2016; Cui et al., 2020). Furthermore, this study integrates and assesses the variables of customer trust and commitment to provide the best perspectives and mechanisms to vendors and customers to increase sustainable customer purchases.

2 Literature review

The framework developed in this study is an elaboration of the variables used in previous studies. The result of the elaboration is customer learning value as a formative construct and customer purchasing value as a reflective construct. It also provides variables for customer trust, commitment, and sustainable customer purchases. It is assumed that customer trust and commitment are directly affected by customer learning and purchasing values. It is also assumed that customer learning and purchasing values can affect

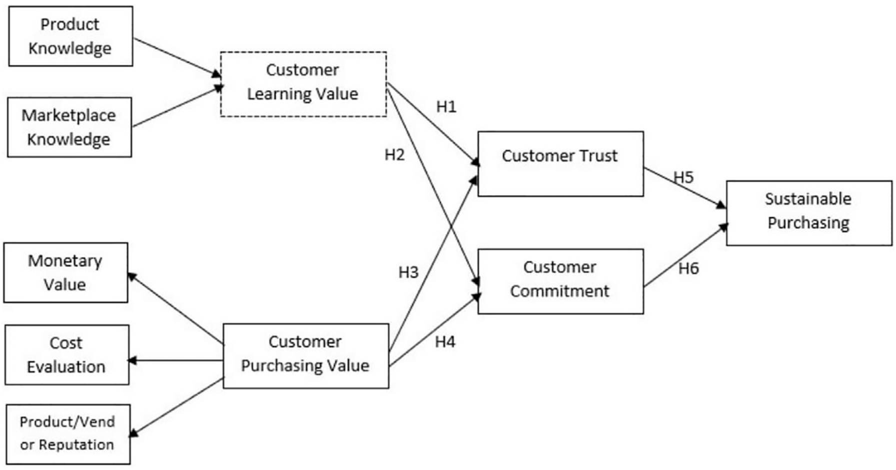

FIGURE 1
Research framework and Hypotheses.

sustainable customer purchases, which are mediated by customer trust and commitment. Another assumption is that customer trust and commitment have a direct effect on sustainable customer purchases. Furthermore, it is proposed that customer purchasing value as a reflective construct is based on two elements: product and marketplace knowledge, whereas customer purchasing value as a reflective construct is based on three elements: monetary value, cost evaluation, and product/vendor reputation. The concrete framework of this study and the proposed hypotheses are presented in Figure 1.

2.1 Institutional trust: commitment mechanism

Previous studies have confirmed that building a good relationship between customers and vendors requires strong trust and commitment to maintain the continuity of the relationship (Wei et al., 2019). Individual behavior relates to psychology, so that behavior makes an unforgettable sense and experience. This implies commitment (Cui et al., 2020). A strong commitment of customers affects good relationships and benefits vendors (Akrout and Nagy, 2018). Another study confirmed that the commitment variable is more strongly related to the customer's sustainable intention than the trust variable (Wang et al., 2016).

Trust is part of an individual or group's beliefs in certain attributes, such as integrity, reliability, and skill (Noor, 2013; Akrout and Nagy, 2018). Studies on online activities have proven that trust becomes a factor that drives customer satisfaction (Dimoka, 2010; McKnight et al., 2017; Punyatoya, 2019). Strong trust in customers stimulates them to be loyal to a product or service, so that they will continually use the service or purchase the product. Commitment can be defined as the customer perception that relates to customer needs; however, it has long-term implications for the vendor relationship (Wang et al., 2016). Customer commitment can be defined as the way of viewing or assessing a product or service so that a strong relationship is built between them (Meyer et al., 2002; Bui and Kemp, 2013). Furthermore, previous studies have confirmed that there are eight factors that become customer standards to strengthen their belief in building commitment and trust in a product or service. In other words, customer satisfaction can strengthen customer trust and commitment (Cui et al., 2020). This study refers to Zhou et al. (2012) and Cui et al. (2020) who confirmed that customer trust and commitment are two mediator variables that can be used to determine a customer's sustainable purchasing. The antecedents of these two variables are customer learning and purchasing values. The context is online transactions in an e-marketplace. Furthermore, this study integrates product and marketplace knowledge as elements that make customer learning value a part of the formative construct, while monetary value, cost evaluation, and product/vendor reputation are used as elements of customer purchasing value to be part of the reflective construct.

This study implements the variables of customer trust and commitment as the main instruments to correlate with sustainable customer purchases. Customer learning and purchasing values are two instruments used as antecedents to correlate with customer trust and commitment in the context of research on online transactions in the e-marketplace. Trust and commitment variables are real activities conducted by customers during transactions in the e-marketplace. Generally, customers require strong protection during a transaction for a product or service delivery. Unfortunately, they did not have access to protection. Thus, the vendor and the marketplace become parties that guarantee transaction safety. This can build strong customer product knowledge, trust, and commitment. In customer learning value, there are two factors that build customer motivation and marketplace knowledge, whereas monetary value, cost evaluation, and product/vendor reputation are the three factors that build customer purchasing value.

2.2 Customer learning value

This study relates to customer learning value and refers to the traditional concept that learning value is regarded as a part of human genetic patterns (Chen et al., 2017). Customers tend to focus on the information about the product or service displayed in the marketplace, so it needs some supporting features to ease transactions (Shin et al., 2013; Benn et al., 2015). This process has been confirmed by a previous researcher, and it has been proven to affect customer purchasing behavior. This process is known as learning value (Shin et al., 2013).

Based on e-commerce, customers tend to be careful in obtaining information about a product or service in a marketplace. This affects customer learning value (Wang and Yu, 2017). The process of learning value during transactions possibly allows customers to share their information and experience by reviewing chat columns in the marketplace (Yoon et al., 2013; Chen et al., 2017).

The variable of customer learning value (formative construct) is an antecedent of product and marketplace knowledge. Both are the results of previous studies and have been confirmed (Yoon et al., 2013). Product and marketplace knowledge are crucial elements for customers to know more about the product or service, particularly in terms of price and quality. In addition, the variable of marketplace knowledge becomes an element that is required by the customer to understand the information on the platform used to perform digital transactions, such as the ease of using features, transaction security, information, and interaction between customers and providers, as well as the review of other customers. Previous studies have confirmed that variables that involve product knowledge indirectly impact sustainable customer purchases (Yoon et al., 2013). However, customer perception of the marketplace or marketplace knowledge has a significant impact on sustainable customer purchases (Yoon et al., 2013; Chen et al., 2017).

The result of previous studies builds a variable of customer learning value (formative construct) based on product and marketplace knowledge. Customer learning value is assumed to be positive for customer trust and commitment in marketplace transactions. The price of a product or service offered in the marketplace correlates with customer trust and commitment. The variables of product and marketplace knowledge on customer learning value indirectly affect customers' sustainable purchasing. Therefore, the proposed hypotheses are as follows:

Hypothesis 1. (H1): Customer learning value is positive and significantly affects customer trust. (H1a) Customer learning value is positive and significantly affects sustainable customer purchases, which is mediated by customer trust.

Hypothesis 2. (H2): Customer learning value is positive and significantly affects sustainable customer purchases, which is mediated by customer commitment.

2.3 Customer purchasing value

Hedonic or consumptive customers are the support agents of customer purchasing value in e-commerce transactions (Kim et al., 2012). Customer purchasing value impacts other variables such as fun and pleasure. It has a significant impact on customer convenience, trust, and commitment (Sarkar, 2011). Another study confirmed that customer purchasing value can be supported by other variables, such as customer satisfaction, entertainment, and social status, so that it has a positive value and significant effect on customer trust, loyalty, and repurchasing (Atulkar and Kesari, 2017). Previous studies have confirmed that the variable of customer purchasing value has a positive value, significantly impacts customer satisfaction and trust, and indirectly impacts sustainable customer purchases (Sarkar, 2011; Kim et al., 2012; Albayrak et al., 2020). Another study confirmed that the value of a product or service depends on customer perception, which is known as monetary value (Gupta and Kim, 2010). Monetary value can be defined as customer benefit, which is the cost evaluation, and product reputation belongs to an integrated part of customer assessment (Chang et al., 2020). In another study, product reputation is seen as the result of positive value or positive customer reviews, so that the customer can make a decision on sustainable purchase (Kim et al., 2016; Chang et al., 2020). Customer purchasing value determines a customer's sustainable intention (Kim et al., 2016). Based on previous studies, customer purchasing value have different dimensions (Gupta and Kim, 2010; Kim et al., 2012; Sullivan and Kim, 2018).

This study builds three basic variables to support customer purchasing value (reflective construct): monetary value, cost evaluation, and product/vendor reputation. To deliver results that relate to existing facts, an empirical approach was applied (Kim et al., 2012; Huré et al., 2017; Chang et al., 2020). Previous studies have been observed and reviewed. It is concluded that the high performance of customer purchasing value is positive and directly affects customer trust and commitment. This indirectly affects the performance of sustainable customer purchases. Hence, this study assumes that monetary value is a part of customers' viewpoints of products or services offered by the e-marketplace. The perception can be about the waiting time in transactions, price of the product or service, and value or function of the product. Furthermore, cost value is customer viewpoints to the value of a product based on the cost of a product or service. Whereas, product or vendor reputation is the causality effect of a vendor's product or service performance. In other words, product reputation is a positive impression on customers.

One study showed that reputation is a part of the long-term marketing strategy of a product, and reputation can affect customer behavior in determining sustainable purchases (Sengupta et al., 2018). Furthermore, another study stated that a good reputation can affect customer commitment to using a service (Lai, 2019). Meanwhile, positive information about a product or service obtained by the customer can build a good reputation and vice versa (Wang and Yang, 2010). This study describes reputation as the perception of customer experience after using a product or service. Perception relates to cost value or benefit, product or service image, and lifestyle. Customers not only consider the benefit of choosing or using a certain product or service but also consider their desire and lifestyle. Customer social status can be used to define a customer's reputation. Customers' desire to use a product or service results from customer trust, satisfaction, and strong commitment.

In this study, the customer purchasing value consists of three variables. These are monetary value, cost evaluation, and product/vendor reputation. This study assumes that customer purchasing value is correlated with customer trust and commitment, particularly in e-marketplace transactions. However, customer purchasing value is indirectly correlated with sustainable customer purchases. Hence, the proposed hypotheses are as follows:

Hypothesis 3. (H3): Customer purchasing value is positive and affects customer trust. (H3a) Customer purchasing value is positive and indirectly affects sustainable customer purchases, which is mediated by customer trust.

Hypothesis 4. (H4): Customer purchasing value is positive and significantly affects customer commitment. (H4a) Customer purchasing value is positive and significantly affects sustainable customer purchases, which is mediated by customer commitment.

2.4 Customer sustainable purchasing

Customer trust and commitment have been confirmed by previous studies to have a significant effect and positive value on customer behavior intention/purchase, particularly in e-commerce (Zhou et al., 2012). Studies on the concepts of web quality, service quality, and information quality have confirmed that a variable of trust is used as an element to build customer intention to purchase (Punyatoya, 2019). Loyalty can be defined as a customer's intention to use a product or service in the context of traditional transactions (Sirdeshmukh et al., 2018). The present study constructs the variables of customer trust and commitment as the elements that affect sustainable customer purchases. This is consistent with the results of previous studies. This supports and confirms that both variables are the principal factors affecting sustainable customer purchases or use in the perception of information system adoption (Zhang et al., 2011; Zhou et al., 2012).

This study proposes that sustainable customer purchase is determined by the strength of customer trust and commitment. This means that the available product or service in the marketplace should be able to ensure that they correspond to customers' expectations. Customer reviews are also important for strengthening the trust of other customers in ensuring the quality of a product or service. Repeated customer experience can convince the customer, and then a strong commitment is built. Therefore, we propose the following hypotheses:

Hypothesis 5. (H5). Customer trust affects the sustainable purchasing of a product or service in the marketplace.

Hypothesis 6. (H6). Customer commitment affects the sustainable purchasing of a product or service in the marketplace.

3 Research methodology

3.1 Model development and measurement

The object of this research is e-commerce platforms, such as Shopee, Tokopedia, Lazada, and Blibli. These platforms are believed to be trustworthy by customers and are famous in Indonesia. These platforms also improve the quality of service to vendors and customers. Improving the number of customers means improving customer trust in the vendor and platform (Hoffman et al., 1999; Pennington et al., 2003). The e-commerce platform used in this study is trustworthy and easy to access. The features provided are personally understandable. Furthermore, this study uses a 7-point Likert-type scale, ranging from 1 (strongly disagrees) to 7 (strongly agree). Each variable has

TABLE 1 Demographics of the study population.

Demographic sample (N = 428)	Frequency	Percentage	(%)
Customer sex	Female	308	72
	Male	120	28
Customer age	20–25 years old	94	22
	26–35 years old	180	42
	36–45 years old	154	36
Customer experience	<1 year	43	10
	1–3 years	150	35
	>3 years	235	55

TABLE 2 Items construct.

Monetary value (MV) please add the details as required Chang et al. (2020); Kim et al. (2016)	
MV1	I think the product offered is valuable and has an appropriate price
MV2	I think the price of the product corresponds to its quality and value
MV3	I think the product offered has a good quality
Cost evaluation (CE) Chang et al. (2020); Götz et al. (2010); Kim et al. (2016)	
CE1	I can easily make a decision to buy the offered product
CE2	I can easily convince myself to choose the product that suits me
CE3	I think the price of the product is still affordable and makes sense
Product/vendor reputation (PR) Keh and Xie, (2009); Lai, (2019); Sengupta et al. (2015)	
PR1	I think the product has high value and good
PR2	I think the product and service has a good image
PR3	I think e-marketplace has recently become a part of lifestyle
Customer trust (CST) Cui et al. (2020); Sirdeshmukh et al. (2018); Wang et al. (2016)	
CST1	I believe that providers and e-marketplace can provide service and need to the customer
CST2	I think the providers are trusty to every transaction that I make in e-marketplace
CST3	I think the vendors in the e-marketplace have integrity
Customer commitment (CSC) Bilgihan and Bujisic, (2015); Cui et al. (2020); Wang et al. (2016); Zhou et al. (2012)	
CSC1	Shopping in e-marketplace currently becomes a lifestyle
CSC2	I cannot stop shopping in e-marketplace
CSC3	E-marketplace can make shopping easier and more convenient for me
Sustainable purchasing (STP) Baron and Kenny, (1986); Cui et al. (2020)	
STP1	I think I will shop every month in the e-marketplace
STP2	If it is accumulated, I buy a product more than once in every 3 months
STP3	I will shop in an e-marketplace soon
Product knowledge (PK) Yoon et al. (2013); Zhang et al. (2018)	
PK1	Product information displayed on e-marketplace is detailed and helpful to learn about the product
PK2	Information in a product is detailed so that it is beneficial for me as a customer
PK3	Information of a product and service is detailed and informative and provides review from other customers, and it is helpful for me
Marketplace knowledge (MK) Yoon et al. (2013); Zhang et al. (2018)	
MK1	I can easily find the product because of its detailed information and complete features
MK2	I use e-marketplace almost every day
MK3	I have used e-marketplace for many times to do online shopping

TABLE 3 Construct reliability and validity of the model AVE, average variance extracted.

Variable/Construct	Factor loading/weight	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Customer learning value (CLV)				
PK	0.518 (Weight)	n/a (Formative construct)	n/a (Formative construct)	n/a (Formative construct)
MK	0.562 (Weight)			
Product knowledge (PK)				
PK1	0.843	0.801	0.883	0.715
PK2	0.855			
PK3	0.838			
Marketplace knowledge (MK)				
MK1	0.865	0.815	0.890	0.730
MK2	0.842			
MK3	0.856			
Monetary value (MV)				
MV1	0.883	0.801	0.884	0.718
MV2	0.759			
MV3	0.893			
Cost evaluation (CE)				
CE1	0.913	0.870	0.921	0.794
CE2	0.879			
CE3	0.881			
Product/vendor reputation (PR)				
PR1	0.766	0.798	0.882	0.714
PR2	0.897			
PR3	0.867			
Customer trust (CST)				
CST1	0.775	0.803	0.884	0.718
CST2	0.886			
CST3	0.877			
Customer commitment (CSC)				
CSC1	0.876	0.900	0.937	0.833
CSC2	0.927			
CSC3	0.935			
Sustainable purchasing (STP)				
STP1	0.817	0.786	0.870	0.691
STP2	0.819			
STP3	0.857			

other variable elements, which have been referred to in previous studies. Customer learning value (formative construct) has two basic variables: product (four-item variables) (Yoon et al., 2013; Zhang et al., 2018) and marketplace knowledge (four-item variables) (Zhang et al., 2018). The customer purchasing value (reflective construct) has three elements: monetary value (three-item variables) (Kim et al., 2016), cost evaluation (three-item variables), and product/vendor reputation (three-item variables) (Götz et al., 2010; Kim et al., 2016; Chang et al., 2020).

For variables of customer trust and commitment, this study uses four-item variables for each, which is based on previous studies (Wang et al., 2016; Zhang et al., 2018; Punyatoya, 2019; Cui et al., 2020). In addition, four-item variables are used to measure the value of sustainable customer purchases (Cui et al., 2020).

3.2 Data collection

An online survey using Google Forms was administered to the targeted respondents. Data collection was conducted from January 2022 to April 2022. It is then distributed via email, social media, group-group online, WhatsApp, and online. Respondents

TABLE 4 Discriminant validity.

Items construct	CE	CSC	CST	MK	MV	PK	PR	STP
CE1	0.913	0.503	0.609	0.852	0.712	0.680	0.611	0.674
CE2	0.879	0.512	0.635	0.861	0.735	0.632	0.642	0.707
CE3	0.881	0.429	0.542	0.691	0.696	0.819	0.545	0.658
CSC1	0.404	0.876	0.717	0.350	0.364	0.390	0.718	0.616
CSC2	0.501	0.927	0.757	0.489	0.524	0.372	0.751	0.768
CSC3	0.559	0.935	0.782	0.532	0.547	0.469	0.788	0.842
CST1	0.523	0.601	0.775	0.576	0.458	0.420	0.772	0.608
CST2	0.660	0.742	0.886	0.583	0.623	0.562	0.789	0.747
CST3	0.511	0.744	0.877	0.467	0.560	0.455	0.766	0.717
MK1	0.792	0.442	0.533	0.865	0.643	0.647	0.537	0.613
MK2	0.661	0.347	0.455	0.842	0.553	0.573	0.462	0.484
MK3	0.853	0.511	0.640	0.856	0.722	0.604	0.646	0.697
MV1	0.757	0.515	0.598	0.740	0.883	0.614	0.598	0.751
MV2	0.559	0.423	0.490	0.465	0.759	0.398	0.491	0.675
MV3	0.706	0.413	0.560	0.674	0.893	0.572	0.564	0.741
PK1	0.557	0.362	0.455	0.584	0.427	0.843	0.458	0.427
PK2	0.553	0.349	0.448	0.510	0.436	0.855	0.450	0.430
PK3	0.780	0.428	0.533	0.699	0.716	0.838	0.537	0.664
PR1	0.517	0.600	0.765	0.572	0.447	0.422	0.766	0.587
PR2	0.662	0.751	0.895	0.585	0.626	0.563	0.897	0.767
PR3	0.519	0.733	0.860	0.478	0.568	0.457	0.867	0.702
STP1	0.691	0.524	0.615	0.599	0.606	0.539	0.614	0.817
STP2	0.726	0.469	0.596	0.694	0.692	0.570	0.597	0.819
STP3	0.547	0.629	0.783	0.510	0.539	0.446	0.778	0.857

MV, Monetary value; CE, Cost evaluation; PR, Product/vendor reputation; CST, Customer trust; CSC, Customer commitment; STP, Sustainable purchasing; PK, Product knowledge; MK, Marketplace knowledge.

are users of e-marketplaces from any platform, such as Shopee, Tokopedia, Lazada, and Blibli. There were 512 distributed Google Forms; however, only 442 data were successfully collected. Data were sorted to check their completeness. Of the 442 data points, 13 were removed because of their incompleteness. Thus, valid data were obtained from 428 respondents (n-428). Table 1 presents the respondents' demographic characteristics. The variables used in this study are presented in Table 2. Descriptive statistics were used to assess each variable.

3.3 Data measurement techniques

To sort the collected data from respondents, we used Microsoft Excel software. The demographic results are presented in Table 1. The data were analyzed using Smart-PLS 3. The structural equation model partial least squares (SEM-PLS) was used to measure the reliability, validity, and hypotheses. Overall, there are two mechanisms for data measurement. The first measured the path coefficient, average variance extracted (AVE), Cronbach's alpha, and R2 values. The second was to test the hypothesis using a bootstrapping algorithm with a sample size of 1,000. The Sobel test was used to assess the mediating effect (Ringle et al., 2015).

Based on the data classification, 72.1% of the respondents were women, with 32% having ages ranging from 20 to 25 years, 42% from 26 to 35 years, and 36% from 36 to 45 years. Based on the experience of respondents using the e-marketplace platform, 10% of them had used the platform for less than a year, 35% for one to 3 years, and 55% for more than 3 years.

TABLE 5 Inner VIF result.

Construct	VIF value
CLV → CSC	4.045
CLV → CST	4.045
CPV → CSC	4.045
CPV → CST	4.045
CSC → STP	3.126
CST → STP	3.126

Customer trust (CST); Customer commitment (CSC); Sustainable purchasing (STP); Customer learning value (CLV).

4 Results

4.1 Reliability and validity

First, we assess reliability and discriminant validity. It is standardized using Cronbach's alpha, composite reliability, and the AVE value (Hair et al., 2017). Cronbach's alpha should have a value greater than 0.6; composite reliability, greater than 0.7; and AVE, at least or greater than 0.55 (Götz et al., 2010; Hair et al., 2017). Another benchmark comes from the value of the loading factor, and the value of each item in the loading factors should be at least or greater than 0.5 (Hair et al., 2017). From the computation results using SmartPLS 3, Cronbach's alpha is 0.7–0.9; composite reliability, 0.8–0.9; AVE, 0.6–0.8; and loading factor, 0.7–0.9. Discriminant validity was assessed by comparing the value of the measurement item construct to latent variance. If the value of the latent variance is greater than that of the measurement item construct, it meets the criteria of good discriminant validity. Table 3 and Table 4 present the results of reliability and discriminant validity measurements.

This study used VIF analysis to assess the multicollinearity of a construct or variable. The computation was conducted using SmartPLS 3, with the value of VIF for each variable less than 5.0 (Kline, 1998; Hair et al., 2016; Dospinescu et al., 2019). Based on the results of the computation, the value of the inner VIF in this research was 3.1–4.0 (Table 5). Therefore, it can be concluded that there was no multicollinearity for the latent construct or variable in this study (Insert Table 5 here).

TABLE 6 Summary of hypothesis testing.

Hypothesis	Construct relationship	Path coefficient	t-value	Result
H1	CLV → CST	0.384***	4.575	Supported
H2	CLV → CSC	0.377***	3.301	Supported
H3	CPV → CST	0.198**	18.687	Supported
H4	CPV → CSC	0.136**	10.498	Supported
H5	CST → STP	0.439***	5.249	Supported
H6	CSC → STP	0.460***	5.625	Supported

CST, Customer trust; CSC, Customer commitment; STP, Sustainable purchasing; CLV, Customer learning value.
**p-value < 0.01; ***p-value < 0.001.

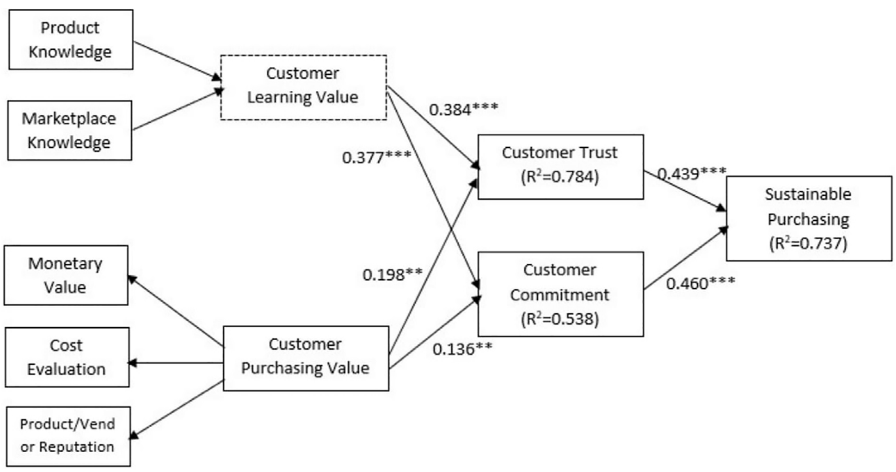

FIGURE 2
Results of the research model.

4.2 Structural model

In a structural model (SmartPLS refers to it as an inner model), the assessment is applied to path coefficients and hypotheses. Two construct models, the formative (customer learning value) and reflective constructs (customer purchasing value), are used simultaneously. Table 6 shows the results of the hypotheses, including the path coefficient and t-values. The results of the computation using bootstrapping show that the ix hypotheses have met the standard. This is acceptable and has a positive value and significant effect.

Figure 2 shows the research model of the study.

Customer learning value is positive and has a significant effect on customer trust and commitment. This corresponds to Hypotheses 1 and 2: H1 (CLV → CST: β = 0.198, t-value = 4.575, $p < 0.001$) and H2 (CLV → CSC: β = 0.377, t-value = 3.301, $p < 0.001$).

Customer purchasing value is positive and significantly affects customer trust and commitment. This corresponds to Hypotheses 3 and 4: H3 (CPV → CST: β = 0.384, t-value = 18.687, $p < 0.01$) and H4 (CPV → CSC: β = 0.136, t-value = 10.498, $p < 0.01$).

Customer trust is positive and has a significant effect on sustainable customer purchases. This corresponds to Hypothesis 5: H5 (CST → STP: β = 0.439, t-value = 5.249, $p < 0.001$).

Customer commitment is positive and significantly affects sustainable customer purchases. This corresponds to Hypothesis 6: H6 (CSC → STP: β = 0.460, t-value = 5.625, $p < 0.001$).

The endogenous variable in this study was also assessed using R^2. The R^2 value of customer trust was 0.784. This means that customer learning and purchasing values are variants of customer trust. The R^2 for customer commitment was 0.538. This means that customer learning and purchasing values are variants of customer commitment. The R^2 for sustainable customer purchase was 0.737. This means that customer trust and commitment are variants of sustainable customer purchase.

4.3 Mediating effects

The value of the path analysis and Sobel test become the benchmark to determine the mediator variables that possibly

TABLE 7 Mediation test result.

Construct	Construct relationship	t-value	z-value	*p*-value
CLV → CST → STP	CLV → CST	4.575	3.448	0.000
	CST → STP	5.249		
CLV → CSC → STP	CLV → CSC	3.301	2.846	0.004
	CSC → STP	5.625		
CPV → CST → STP	CPV → CST	18.687	5.053	0.000
	CST → STP	5.249		
CPV → CSC → STP	CPV → CSC	10.498	4.958	0.000
	CSC → STP	5.625		

CST, Customer trust; CSC, Customer commitment; STP, Sustainable purchasing; CLV, Customer learning value.

have a significant impact. If the Z value in the Sobel test is greater than 1.96, the mediator variable is accepted (Sobel, 1982). In this study, four hypotheses had a mediator. These are H1a, H2a, H3a, and H4a. The results of the mediation effects are presented in Table 7.

(Insert Table 7 here)The analysis using the Sobel test shows that customer learning value is positive and has a significant impact on sustainable customer purchases, which is mediated by customer trust. This means that Hypothesis 1a is accepted: H1a (CLV → CST → STP: β = 0.384; 0.439, z-value = 3.448, $p < 0.000$). Similarly, customer learning value is positive and has a significant impact on sustainable customer purchases, which is mediated by customer commitment. Thus, Hypothesis 2a is accepted: H2a (CLV → CSC → STP: β = 0.377; 0.460, z-value = 2.846, $p < 0.004$).

In addition, the Sobel test proves that customer purchasing value is positive and has a significant impact on sustainable purchasing, which is mediated by customer trust. This means that Hypothesis 3a is accepted: H3a (CPV → CST → STP: β = 0.198; 0.439, z-value = 5.053, $p < 0.000$). Customer purchasing value is positive and has a significant impact on sustainable customer purchases, which is mediated by customer commitment. This means that Hypothesis 4a is accepted: H4a (CPV → CSC → STP: β = 0.136; 0.460, z-value = 4.958, $p < 0.000$).

5 Research implications and conclusion

5.1 Theoretical implications

The results of this study provide several findings and implications that can serve as a reference for future research. First, from the viewpoint of theoretical issues, this study becomes a discourse of research in e-business, particularly in e-commerce transactions. This study provides a complete description of the integration of one variable and other variables to contribute to achieving sustainable customer purchases in transactions in the e-marketplace. This study has become a part of customer life. The use of two variables—customer trust and commitment—to achieve sustainable customer purchases has been used several times to prove that transactions in e-business run well when they are supported by trust and commitment, as confirmed by previous studies (Zhou et al., 2012). By assessing these two variables, this study confirms the findings of previous studies with a similar understanding (Cui et al., 2020).

Second, it was found that customer purchasing value is positive and significant for customer trust and commitment. In addition, it has an indirect positive value and significant impact on the strength of sustainable customer purchases. It builds a pattern of relationships between customers and vendors in product or service transactions in the e-marketplace. This study considers the customer purchasing value as a variable of a second-order reflective construct that is supported by monetary value, cost evaluation, and product/vendor reputation. Previous studies have confirmed that utilitarian and hedonic values support customer purchasing value. Both factors can be positive or negative for customer satisfaction and purchase intention in e-commerce transactions (Zhou et al., 2012). Another study explained that customer purchasing value has supporting factors that can build relationships with customer loyalty, trust, and purchasing intention (Atulkar and Kesari, 2017).

The third finding reveals that customer learning value is positive and has a direct significant impact on the other two variables: customer trust and commitment. Meanwhile, sustainable customer purchase is positive and has an indirect significant effect. Customer learning value is a second-order formative construct with two supporting variables: product and marketplace knowledge. This shows that the present study differs from the previous (Zhou et al., 2012; Yoon et al., 2013; Zhang et al., 2018). Product and marketplace knowledge become part of customer learning value (second-order formative construct).

This study strongly proves that customer learning value is an antecedent of customer trust and commitment in e-marketplace transactions. This is contrary to previous studies, which state that customer learning value does not have a significant effect on customer commitment but has a significant effect on sustainable customer purchases (Cui et al., 2020).

Finally, customer demography provides knowledge from a strategic viewpoint. Customer sex demography is dominated by women (72%) in conducting e-marketplace transactions, with ages ranging from 20 to 35 years (66%). This means that young women are the targeted consumers with more than 3 years of experience (55%). This suggests that vendors prepare strategies for organizing their customers, and the marketplace can provide tools that are helpful and user-friendly to the users of the e-marketplace.

5.2 Practical implications

The study contains practical value and implications for the decision-making of vendors or e-marketplaces. It also provides value to customer learning, purchasing, trust, and commitment, which affect sustainable customer purchases.

To strengthen the endurance and sustainability of e-marketplace vendors, they should also strengthen customer trust and commitment. Both variables are basic elements of the antecedent, such as customer learning and purchasing values, similar to the variable of sustainable customer purchases. This means that H1, H2, H3, and H4 directly provide positive values and have a significant impact. H1a, H1b, H2a, and H2b had positive values and indirect significant impact on the consequent variables. This means that vendors and marketplaces should improve and strengthen their quality of customer trust and the role of customers in their commitment. Vendors must be concerned with the quality of their services and products. For example, vendors provide customers the opportunity to choose delivery services. In terms of payment, vendors should provide various methods of payment and convince them that the payment is safe. If there is a technical error, the vendor should make a refund within a short time. It must be supported by the features provided in the e-marketplace to guarantee customer security and convenience.

Vendors and e-marketplaces should make an effort to improve and maintain sustainable customer purchases by evaluating the following aspects:

Based on the evaluation of customer purchasing value, the elements that should be focused on are the offered price and features for skipping advertisements. These features should function interactively and provide detailed information based on the customer's desire. Algorithms in the e-marketplace should function well. In terms of cost evaluation, the assessment focuses on minimizing risk. A gallery that provides product information and price and corresponds to quality provides a positive value from the customer to the vendor. The consistency of the offered price is important to customers because it helps them understand and review the product. In terms of product and vendor reputation, the function of two-way communication between customers and vendors should run well. One way is to activate the features of product reviews and direct chatting. Not all visitors engage in the transaction at all times. Some are only a part of the community and are observers of a product. Vendors should pay attention to the quality of their products and services, while e-marketplaces should guarantee and provide features that enable them to operate smoothly.

Another aspect that should be considered is customer learning value. The elements are the product and marketplace knowledge. Both are helpful for improving the productivity and performance of customers in e-marketplace transactions. E-marketplace providers play the dominant role in this process. These features should correspond to customer needs that are easy to use, safe, and validated in every transaction—fast process, shopping history, and checkout. All these features should be understandable and easy to learn.

The final focus is on customer trust and commitment. Both should be strengthened by improving and convincing customers about the security of using e-marketplaces, accessible features, and non-stop services. Therefore, these two factors can guarantee that customers improve their desire for sustainable purchases.

5.3 Limitations and future study

This study integrates customer learning and purchasing values with customer trust and commitment to assess sustainable customer purchases. However, it lacks several aspects. First, the respondent demographics used in this study were young individuals. Future studies could involve respondents of various ages. Second, this study uses an e-marketplace platform that is used in Indonesia; therefore, the range of the respondents is limited. In the future, researchers could choose an e-marketplace with a wider range of customers. Finally, this study uses a small sample size. This could be increased in future studies.

6 Conclusion

This study contributes to the literature on academic and professional e-marketplace transactions. Customer trust and commitment play crucial roles in the performance of e-marketplace platforms. After conducting a holistic assessment, it was confirmed that this study has different findings compared to those of previous studies (Zhou et al., 2012). It was found that customer trust and commitment have a strong effect on sustainable customer purchases. It was also confirmed that customer trust and commitment antecedents have a significant impact on sustainable customer purchases. Furthermore, this supports the findings of previous studies (Cui et al., 2020).

This is an integration of variables from several studies. They were elaborated upon and adapted to the needs of constructing a framework. Customer trust and commitment are the elements used to analyze the effects based on the antecedent and consequent. These variables are concepts and are regarded as part of customer viewpoints on products and services. This is brought into the customer's real life. Trust is a factor that gives customers a feeling of security, and commitment is the strength of customers to express their satisfaction in e-marketplace transactions. The antecedents of customer trust and commitment consist of two variables: customer learning value as a formative construct and customer purchasing value as a reflective construct. This study classifies customer learning value into two variables: product and marketplace knowledge, while customer purchasing value consists of three variables: monetary value, cost evaluation, and product/vendor reputation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

THa and THo conceived and designed the research, provided guidance throughout the entire research process, and wrote the main part of the manuscript. KMA collected the data and wrote the methods section. THa and OTA wrote the hypothesis development and methodology sections and offered modification suggestions. THo and KMA participated in the online survey and helped analyze the data. All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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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References

Abhishek, V., Jerath, K., and Zhang, Z. J. (2016). Agency selling or reselling? Channel structures in electronic retailing. *Manage. Sci.* 62, 2259–2280. doi:10.1287/mnsc.2015.2230

Akrout, H., and Nagy, G. (2018). Trust and commitment within a virtual brand community: The mediating role of brand relationship quality. *Inf. Manag.* 55, 939–955. doi:10.1016/j.im.2018.04.009

Albayrak, T., Karasakal, S., Kocabulut, Ö., and Dursun, A. (2020). Customer loyalty towards travel agency websites: The role of trust and hedonic value. *J. Qual. Assur. Hosp. Tour.* 21, 50–77. doi:10.1080/1528008x.2019.1619497

Atulkar, S., and Kesari, B. (2017). Satisfaction, loyalty and repatronage intentions: Role of hedonic shopping values. *J. Retail. Consumer Serv.* 39, 23–34. doi:10.1016/j.jretconser.2017.06.013

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51, 1173–1182. doi:10.1037/0022-3514.51.6.1173

Beatty, S. E., Reynolds, K. E., Noble, S. M., and Harrison, M. P. (2012). Understanding the relationships between commitment and voice: Hypotheses, empirical evidence, and directions for future research. *J. Serv. Res.* 15, 296–315. doi:10.1177/1094670512440835

Benn, Y., Webb, T. L., Chang, B. P., and Reidy, J. (2015). What information do consumers consider, and how do they look for it, when shopping for groceries online? *Appetite* 89, 265–273. [CrossRef] [PubMed]. doi:10.1016/j.appet.2015.01.025

Bhati, R., and Verma, H. V. (2020). Antecedents of customer brand advocacy: A meta-analysis of the empirical evidence. *J. Res. Interact. Mark.* 26.

Bilgihan, A., and Bujisic, M. (2015). The effect of website features in online relationship marketing: A case of online hotel booking. *Electron. Commer. Res. Appl.* 14, 222–232. doi:10.1016/j.elerap.2014.09.001

Bui, M., and Kemp, E. (2013). E-tail emotion regulation: Examining online hedonic product purchases. *Int. J. Retail Distribution Manag.* 41, 155–170. doi:10.1108/09590551311304338

Chang, Y.-Y., Lin, S.-C., Yen, D. C., and Hung, J.-W. (2020). The trust model of enterprise purchasing for B2B e-marketplaces. *Comput. Stand. Interfaces* 70, 103422. doi:10.1016/j.csi.2020.103422

Chen, A., Lu, Y., and Gupta, S. (2017). Enhancing the decision quality through learning from the social commerce components. *J. Glob. Inf. Manag.* 25, 66–91. doi:10.4018/jgim.2017010104

Chen, X., Huang, Q., and Davison, R. M. (2017). The role of website quality and social capital in building buyers' loyalty. *Int. J. Inf. Manage.* 37, 1563–1574. doi:10.1016/j.ijinfomgt.2016.07.005

Cui, Y., Mou, J., Cohen, J., Liu, Y., and Kurcz, K. (2020). Understanding consumer intentions toward cross-border m-commerce usage: A psychological distance and commitment-trust perspective. *Electron. Commer. Res. Appl.* 39, 100920. doi:10.1016/j.elerap.2019.100920

Dimoka, A. (2010). What does the brain tell us about trust and distrust? Evidence from a functional neuroimaging study. *MIS Q.* 34, 373–396. doi:10.2307/20721433

Dospinescu, O., Anastasiei, B., and Dospinescu, N. (2019). Key factors determining the expected benefit of customers when using bank cards: An analysis on millennials and generation Z in Romania. *Symmetry* 11, 1449. doi:10.3390/sym11121449

Götz, O., Liehr-Gobbers, K., and Krafft, M. (2010). "Evaluation of structural equation models using the partial least squares (PLS) approach," in *Handbook of partial least squares* (Berlin/Heidelberg, Germany: Springer), 691–711.

Gupta, S., and Kim, H. W. (2010). Value-driven Internet shopping: The mental accounting theory perspective. *Psychol. Mark.* 27, 13–35. doi:10.1002/mar.20317

Hair, J. F., Jr., Hult, G. T. M., Ringle, C., and Sarstedt, M. (2016). *A primer on partial least squares structural equation modeling (PLS-SEM)*. Los Angeles, CA, USA: Sage.

Hair, J. F., Jr., Matthews, L. M., Matthews, R. L., and Sarstedt, M. (2017). PLS-SEM or CB-SEM: Updated guidelines on which method to use. *Int. J. Multivar. Data Anal.* 1, 107–123. doi:10.1504/ijmda.2017.10008574

Hair, J. F., Sarstedt, M., Ringle, C. M., and Mena, J. A. (2012). An assessment of the use of partial least squares structural equation modeling in marketing research. *J. Acad. Mark. Sci.* 40, 414–433. doi:10.1007/s11747-011-0261-6

Hoffman, D. L., Novak, T. P., and Peralta, M. (1999). Building consumer trust online. *Commun. ACM* 42, 80–85. doi:10.1145/299157.299175

Huang, Z., and Benyoucef, M. (2013). "User-centered investigation of social commerce design," in *Proceedings of the international conference on online communities and social computing* (NV, USA: Las Vegas), 21–26, 287–295.

Huré, E., Picot-Coupey, K., and Ackermann, C.-L. (2017). Understanding omni-channel shopping value: A mixed-method study. *J. Retail. Consum. Serv.* 39, 314–330. doi:10.1016/j.jretconser.2017.08.011

Keh, H. T., and Xie, Y. (2009). Corporate reputation and customer behavioral intentions: The roles of trust, identification and commitment. *Ind. Mark. Manag.* 38, 732–742. doi:10.1016/j.indmarman.2008.02.005

Kim, C., Galliers, R. D., Shin, N., Ryoo, J.-H., and Kim, J. (2012). Factors influencing Internet shopping value and customer repurchase intention. *Electron. Commer. Res. Appl.* 11, 374–387. doi:10.1016/j.elerap.2012.04.002

Kim, H.-W., Kankanhalli, A., and Lee, H.-L. (2016). Investigating decision factors in mobile application purchase: A mixed-methods approach. *Inf. Manag.* 53, 727–739. doi:10.1016/j.im.2016.02.011

Kline, R. B. (1998). *Principles and practice of structural equation modeling*. New York, NY, USA: Guilford Press.

Lai, I. K. W. (2019). Hotel image and reputation on building customer loyalty: An empirical study in Macau. *J. Hosp. Tour. Manag.* 38, 111–121. doi:10.1016/j.jhtm.2019.01.003

McKnight, D. H., Lankton, N. K., Nicolaou, A., and Price, J. (2017). Distinguishing the effects of B2B information quality, system quality, and service outcome quality on trust and distrust. *J. Strategic Inf. Syst.* 26, 118–141. doi:10.1016/j.jsis.2017.01.001

Meyer, J. P., Stanley, D. J., Herscovitch, L., and Topolnytsky, L. (2002). Affective, continuance, and normative commitment to the organization: A meta-analysis of antecedents, correlates, and consequences. *J. Vocat. Behav.* 61, 20–52. doi:10.1006/jvbe.2001.1842

Noor, N. A. M. (2013). Trust and commitment: Do they influence e-customer relationship performance? *ijecs.* 3, 281–296. doi:10.7903/ijecs.1096

Pennington, R., Wilcox, H. D., and Grover, V. (2003). The role of system trust in business-to-consumer transactions. *J. Manag. Inf. Syst.* 20, 197–226. doi:10.1080/07421222.2003.11045777

Punyatoya, P. (2019). Effects of cognitive and affective trust on online customer behavior. *Mark. Intell. Plan.* 37, 80–96. doi:10.1108/mip-02-2018-0058

Ringle, C. M., Wende, S., and Becker, J.-M. (2015). *SmartPLS 3. Boenningstedt: SmartPLS GmbH*. Available online: http://www.smartpls.com (accessed on June 5, 2015).

Sarkar, A. (2011). Impact of utilitarian and hedonic shopping values on individual's perceived benefits and risks in online shopping. *Int. Manag. Rev.* 7, 58–65.

Sengupta, A. S., Balaji, M., and Krishnan, B. C. (2015). How customers cope with service failure? A study of brand reputation and customer satisfaction. *J. Bus. Res.* 68, 665–674. doi:10.1016/j.jbusres.2014.08.005

Shin, J. I., Chung, K. H., Oh, J. S., and Lee, C. W. (2013). The effect of site quality on repurchase intention in Internet shopping through mediating variables: The case of University students in South Korea. *Int. J. Inf. Manage.* 33, 453–463. doi:10.1016/j.ijinfomgt.2013.02.003

Sirdeshmukh, D., Ahmad, N. B., Khan, M. S., and Ashill, N. J. (2018). Drivers of user loyalty intention and commitment to a search engine: An exploratory study. *J. Retail. Consumer Serv.* 44, 71–81. doi:10.1016/j.jretconser.2018.06.002

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociol. Methodol.* 13, 290–312. doi:10.2307/270723

Sullivan, Y. W., and Kim, D. J. (2018). Assessing the effects of consumers' product evaluations and trust on repurchase intention in e-commerce environments. *Int. J. Inf. Manage.* 39, 199–219. doi:10.1016/j.ijinfomgt.2017.12.008

Wang, W.-T., Wang, Y.-S., and Liu, E.-R. (2016). The stickiness intention of group-buying websites: The integration of the commitment–trust theory and e-commerce success model. *Inf. Manag.* 53, 625–642. doi:10.1016/j.im.2016.01.006

Wang, X., and Yang, Z. (2010). The effect of brand credibility on consumers' brand purchase intention in emerging economies: The moderating role of brand awareness and brand image. *J. Glob. Mark.* 23, 177–188. doi:10.1080/08911762.2010.487419

Wang, Y., and Yu, C. (2017). Social interaction-based consumer decision-making model in social commerce: The role of word of mouth and observational learning. *Int. J. Inf. Manage.* 37, 179–189. doi:10.1016/j.ijinfomgt.2015.11.005

Wei, K., Li, Y., Zha, Y., and Ma, J. (2019). Trust, risk and transaction intention in consumer-to-consumer e-marketplaces. *Ind. Manag. Data Syst.* 119, 331–350. doi:10.1108/imds-10-2017-0489

Yoon, V. Y., Hostler, R. E., Guo, Z., and Guimaraes, T. (2013). Assessing the moderating effect of consumer product knowledge and online shopping experience on using recommendation agents for customer loyalty. *Decis. Support Syst.* 55, 883–893. doi:10.1016/j.dss.2012.12.024

Zhang, H., Zhao, L., and Gupta, S. (2018). The role of online product recommendations on customer decision making and loyalty in social shopping communities. *Int. J. Inf. Manage.* 38, 150–166. doi:10.1016/j.ijinfomgt.2017.07.006

Zhang, Y., Fang, Y., Wei, K.-K., Ramsey, E., McCole, P., and Chen, H. (2011). Repurchase intention in B2C e-commerce—a relationship quality perspective. *Inf. Manag.* 48, 192–200. doi:10.1016/j.im.2011.05.003

Zhou, Z., Fang, Y., Vogel, D. R., Jin, X.-L., and Zhang, X. (2012). Attracted to or locked in? Predicting continuance intention in social virtual world services. *J. Manag. Inf. Syst.* 29, 273–306. doi:10.2753/mis0742-1222290108

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Sustainable AI in environmental economics and management: Current trends and post-COVID perspective

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Introduction

Environmental economics and management in the modern market economy is largely determined by context. The COVID-19 pandemic has shifted priorities from environmental protection to social programs and measures to stimulate economic growth (Almars et al., 2022; Balakesava Reddy et al., 2022; Lim and Abdul Ghani, 2022; Liu et al., 2022; Soomro et al., 2022). The problem is that insufficient attention and lack of funding threaten an environmental crisis, which implies the high relevance of studying as well as finding ways to prevent the latter today (Chen et al., 2022; Congjuan et al., 2022; Popkova, 2022; Robinson et al., 2022; Wang et al., 2022).

The important role of artificial intelligence (AI) theory in studying its impact on the ecological economics of management is emphasized in the works of Bartmann (2022), Bolton et al. (2021), Ghermandi et al. (2022), Gooroochurn et al. (2022), Hernandez et al. (2022), Ligozat et al. (2022), Mao et al. (2022), Nost and Colven (2022), Tuia et al. (2021), and Zhang (2022).

The existing interpretation of sustainable AI defines it as smart technology for maintaining stable and balanced development of economic systems (Popkova et al., 2020; Sætra, 2021; Minkkinen et al., 2022; Osipov et al., 2022). Threats to healthcare have become more acute in the context of a pandemic; therefore, based on the existing interpretation, medicine has become the main area of application of sustainable AI (Astobiza et al., 2021; Bolton et al., 2021; Choi et al., 2021; Visvizi, 2022; Wilson and van der Velden, 2022). The advantage of the current interpretation is that it allows flexibly rebuilding a stable AI, applying it in the most demanded areas (Popkova et al., 2022a; Popkova et al., 2022b; Popkova and Sergi, 2022).

But a serious drawback of the existing interpretation is that it directs sustainable AI to combat only current threats, which does not prevent future threats. From the point of view of environmental protection, reliance on the existing interpretation causes high risks of an environmental crisis and does not allow us to unlock the potential of sustainable AI in overcoming it (Su et al., 2021; Aman et al., 2022; Yu et al., 2022; Zhou et al., 2022).

Consequently, the existing interpretation of sustainable AI does not correspond to the development priorities of environmental economics and management and needs to be revised.

The article attempts to solve the problem of environmental crisis management through the increasing use of artificial intelligence (AI) in environmental economics and management. The motivation of the article and its relevance lies in the fact that the article seeks to most fully and reliably determine the potential of AI to protect the environment. Eco-efficiency is an important and integral criterion for any modern innovation, which includes AI. The purpose of the article is related to the study of current trends and post-COVID prospects for the development of environmental economics and management based on sustainable AI. The article consistently solves the following three tasks:

→ To rethink the essence of sustainable AI from the perspective of environmental economics and management;
→ To identify current trends in environmental economics and management and determine the features of its development both before the pandemic and in the conditions of the COVID-19 pandemic;
→ To determine the advantages and identify the post-COVID perspective of using sustainable AI in environmental economics and management based on international experience.

The contribution of the article to the literature consists of rethinking AI from the standpoint of environmental economics and management and revealing the ecological nature of AI. The novelty and originality of the article consist of the authors' concept of sustainable AI, under which it is offered to understand the use of AI in the interests of environmental protection. Based on the new concept, the contribution of sustainable AI to environmental economics and management is clarified. The article also takes into account the unique experience of sustainable AI's contribution to environmental economics and management in the context of the COVID-19 pandemic.

Sustainable AI: Rethinking from the perspective of environmental economics and management

This article is based on the theory of environmental economics and management and the latest research which has been published by Astadi et al. (2022), Cui et al. (2022), Fontoura and Coelho (2022), He et al. (2022), Li et al. (2022), Rathore et al. (2022), Su (2022), and Yaoteng and Xin (2022).

The existing interpretation aims AI at combating crisis phenomena in economic systems; therefore, it is most appropriate to call it anti-crisis AI (Benaben et al., 2020; De Nicola et al., 2020; Wang et al., 2020; Prahl and Goh, 2021; Shakira Fathima and Dilshad Begum, 2021; Hernandez et al., 2022; Simeonovski et al., 2022; Wang, 2022). The concept of "sustainability," in turn, is rooted in environmental protection, to which most of the UN SDGs are devoted (Buonomano et al., 2022; Carayannis et al., 2022; Maheshwari et al., 2022; Úbeda et al., 2022). Therefore, from the standpoint of environmental economics and management, a new interpretation of sustainable AI as a "smart" environmental protection technology is proposed.

The advantage of the authors' interpretation is that, first, it clarified the classification of the directions of AI usage; in particular, it clearly identified the socio-economic (anti-crisis AI) and environmental (sustainable AI) directions. Second, the new interpretation considers the use of AI in environmental economics and management as a preventive measure to combat the environmental crisis, allowing preventing it from arising.

Current trends in environmental economics and management and features of its development both before the pandemic and in the conditions of the COVID-19 pandemic

The applied use of AI reflects the number of academic-corporate peer-reviewed AI publications. Figure 1 shows the current (over the past 10 years) trends in the development of environmental economics and management in the world's leading countries by the number of these publications in 2021. The sample was formed based on the works of Aqeel et al. (2022), Li et al. (2021), Moradi et al. (2021), and Rahmat et al. (2022).

The sample is sufficient to reflect the target (considered on the scale of the world economic system) population, as it covers both developed and developing countries from different parts of the world. America in the sample is represented by the United States and Canada (developed countries); Asia—China and India (developing countries); Japan and South Korea (developed countries); Europe—Great Britain, Germany, France, the Netherlands, Switzerland, Spain, and Italy (developed countries).

The methodology of the study is based on the application of the trend analysis method, which is used to study the ten-year trend in the environmental efficiency of the economy. The choice of methodology is based on the works of Farzadfar et al. (2022), Local Burden of Disease (2021), and Paulson et al. (2021).

Figure 1 shows wide variations in AI sustainability even among the leading countries in its development in 2021. The ten-year trend of the Environmental Performance Index is positive in most countries and is most pronounced in China (+8.4%) and Switzerland (+8.6%). In India, it is zero, and in Japan, it is negative (−0.5%). According to the calculations of the World Bank (2022), total natural resource rent has demonstrated

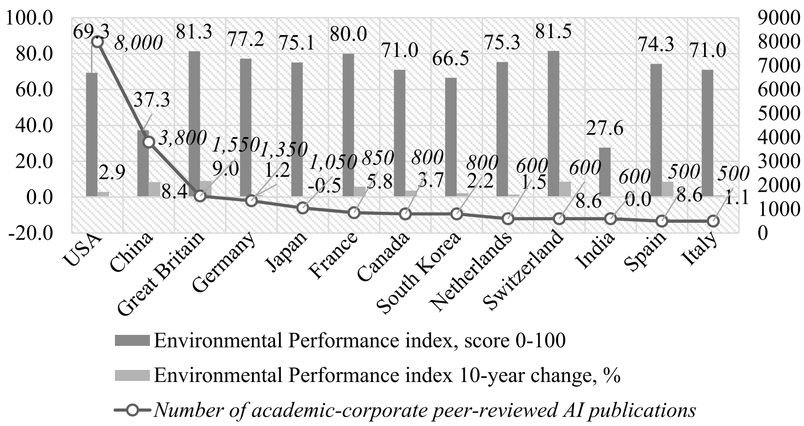

FIGURE 1
The Environmental Performance Index in 2020, its ten-year trend, and the number of educational and corporate peer-reviewed AI publications in 2021. Source: OECD AI Policy observatory (2022), Yale Center for Environmental Law and Policy, Center for International Earth Science Information Network, The McCall MacBain Foundation (2022).

great volatility over the past years. In 2009, it was 2.8%; in 2011, it increased to 4.9%; in 2016, it decreased to 1.5%; in 2019, it was 2%; and in 2020, it decreased to 1.9%. In this regard, the COVID-19 pandemic did not lead to an aggravation of the environmental crisis, but it also did not make a significant contribution to overcoming it, as it diverted attention from environmental economics and management.

Advantages and post-COVID perspective of using sustainable AI in environmental economics and management based on international experience

In 2020–2021, in the context of the COVID-19 pandemic, artificial intelligence was widely used in healthcare around the world. In China and Australia, AI has been used to diagnose COVID-19; in the United States, Apple has launched an application for "smart" screening of COVID-19; and in Germany, DOCYET has created a chatbot for remote "smart" support for consultations of COVID-19 patients (Roscongress, 2022). According to the Institute of Statistical Research and Knowledge Economics of the National Research University Higher School of Economics (HSE) (2022), AI has become the core of digital solutions of the COVID-19 era: in 2020, 17.9% of digital practical solutions in the OECD countries in COVIDTech were realized through the use of AI. In the context of the COVID-19 pandemic in 2020 in Russia, the demand for AI increased by 30.5%, and the supply increased by 23.9%.

New technological contours of the implementation of the federal project "Artificial Intelligence" of the national program "Digital Economy" have already been planned in Russia in the post-COVID perspective. Preparations are already underway to use sustainable AI for automatic ("smart") analysis of satellite images to identify violations of environmental legislation. In particular, control and monitoring of changes in the movement of objects in the environment will be carried out: identification in real-time of facts of illegal economic activity (development of the territory of specially protected natural areas, logging outside the provided cutting area, mining outside the boundaries of the approved mining allotment, etc.); identification of potentially fire-hazardous areas and fires; soil bonification; identification of categories and habitat classes according to Earth remote sensing data (Rospatent, 2022).

Based on the works of KPMG (2022), the following promising areas of application of sustainable AI and the advantages that it can provide for environmental economics and management in the post-COVID perspective (in the period up to 2030) are identified:

→ Development of green finance through the connection of the availability and cost of credit resources with the ESG initiatives of loan recipients using smart analytics (following the example of the German Landesbank Baden-Wuerttemberg);
→ Using sustainable AI for automated (more complete, transparent, efficient, and mass) standardized disclosure of financial information on combating climate change based on the experience of France (based on CDP, CDSP, IIRC, GRI, and SASB standards), as well as on the experience of Russia (Moscow Exchange: TCFD-reporting for the utility sector);
→ Automated (fair, efficient, and open) allocation of emission quotas (production and consumption waste) according to the experience of the European Union;
→ Smart environmental monitoring and automated calculation of ESG indices, as well as the compilation of sustainable development ratings.

The proposed directions are not exhaustive, but they demonstrate the great contribution that sustainable AI can and should make to environmental economics and management from the post-COVID perspective.

Discussion

The article contributes to the development of the concept of environmental economics and management by substantiating the new role that AI should play in its framework. Unlike Astobiza et al. (2021), Bolton et al. (2021), Choi et al. (2021), Minkkinen et al. (2022), Osipov et al. (2022), Popkova et al. (2020), Sætra (2021), Visvizi (2022), and Wilson and van der Velden (2022), it has been proved that the existing interpretation of sustainable AI does not allow to unlock the potential of AI to fight new global challenges and therefore needs to be revised. Distinctive features of the proposed new authors' interpretation are:

→ The transition from the practice of flexible redirection of AI from one industry to another (for example, in healthcare, in the context of the COVID-19 pandemic) to a fixed, stable, and long-term application of sustainable AI in environmental economics and management;
→ Sustainable AI should be given a new role related to preventive environmental crisis management (as opposed to dealing with current threats, which is a characteristic of the existing interpretation).

The authors' interpretation of sustainable AI clearly defined the boundaries of the ecological direction (in environmental economics and management) and separated it from the anti-crisis direction, and thereby, it clarified the classification of the directions of AI usage. The new interpretation made it possible to classify the types of AI more precisely, as it identified anti-crisis AI and sustainable AI.

The contribution of this study is that it allowed us to reconsider the experience of the pandemic from the standpoint of environmental economics and management. Environmental implications of COVID-19 in contrast to Aqeel et al. (2021), Ge et al. (2022), and NeJhaddadgar et al. (2020) turned out to be neutral. The value of the obtained results for academic purposes lies in the fact that they showed that even in the context of a pandemic and lockdown, humanity continued to inflict damage on the environment and did not advance in decarbonization issues.

In this regard, radical measures are needed, among which an important place is occupied by the development of sustainable AI recommended in the article in environmental economics and management. The post-COVID perspective of combating climate change and developing sustainable communities and territories is associated with the full-scale implementation of AI and its active use for sustainable development.

Conclusion

Thus, the article revealed the current trends in the development of environmental economics and management related to the increase in environmental performance and the reduction of total natural resource rents and also pointed to the insignificant role of sustainable AI in achieving these results. The main conclusion obtained in the article is related to the fact that sustainable AI has a significant potential for the development of environmental economics and management, but this potential has not yet been discovered. Also, the post-COVID perspective of environmental economics and management is associated with a fuller disclosure of the potential of sustainable AI.

The main results of the study are as follows: first, sustainable AI is rethought from the standpoint of environmental economics and management, and its new interpretation is proposed as smart technology for protecting the environment.

Second, modern trends in environmental economics and management have been identified: 1) a positive ten-year trend in the Environmental Performance Index and 2) high volatility of total natural resource rents. Because of this, in contrast to Chen et al. (2022), Congjuan et al. (2022), Popkova (2022), Robinson et al. (2022), and Wang et al. (2022), substantiated that the COVID-19 pandemic did not have a critical impact on the environment due to ecological AI economics and management.

Third, based on the international experience of the OECD countries and Russia, the advantages and post-COVID prospects of using sustainable AI in environmental economics and management are substantiated: 1) development of ESG initiatives of loan recipients using smart analytics; 2) disclosure of financial information on combating climate change; 3) automated allocation of carbon credits; and 4) smart environmental monitoring and automated calculation of ESG indices.

The theoretical significance of the article is that it offers the authors' interpretation of sustainable AI, which allows for increasing its role and importance in environmental economics and management. The practical significance of the results of the study is that the authors' recommendations allow us to fully reveal the potential of sustainable AI in the field of environmental crisis management from the post-COVID perspective. Policy implications lie in the usefulness of expanding the use of AI in the interests of protecting the environment in such areas as AI-green finance, smart climate reporting, intelligent support for the allocation of emission quotas, as well as smart environmental monitoring.

Restrictions

Although the article reveals the successful international experience of using sustainable AI in the practice of environmental economics and management, the proposed recommendations are general in nature and require more detailed analysis before applying them practically. In future scientific research, it is advisable to provide an in-depth study of each proposed promising direction of using sustainable AI separately in environmental economics and management.

The limitation of the current study is also the isolated consideration of AI for the most in-depth study of its environmental nature in support of sustainable development of the economy and management. A promising direction for future research is a comprehensive study of the experience and prospects for using advanced digital technologies—not only AI but also the Internet of Things (IoT), robots, etc.—in environmental economics and management to achieve a "synergy effect" in the form of accelerating the pace of sustainable development.

Author contributions

SL and AB contributed to the conception and design of the study. AA organized the database. SL wrote the first draft of the manuscript. AB and AA wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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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References

Almars, A. M., Gad, I., and Atlam, E.-S. (2022). Applications of AI and IoT in COVID-19 vaccine and its impact on social life. *Stud. Comput. Intell.* 1005, 115–127. doi:10.1007/978-3-030-91103-4_7

Aman, J., Shi, G., Ain, N. U., and Gu, L. (2022). Community wellbeing under China-Pakistan economic corridor: Role of social, economic, cultural, and educational factors in improving residents' quality of life. *Front. Psychol.* 12, 816592. doi:10.3389/fpsyg.2021.816592

Aqeel, M., Rehna, T., Shuja, K. H., and Abbas, J. (2022). Comparison of students' mental wellbeing, anxiety, depression, and quality of life during COVID-19's full and partial (smart) lockdowns: A follow-up study at a 5-month interval. *Front. Psychiatry* 13, 835585. doi:10.3389/fpsyt.2022.835585

Aqeel, M., Shuja, K. H., Rehna, T., Ziapour, A., Yousaf, I., Karamat, T., et al. (2021). The influence of illness perception, anxiety and depression disorders on students mental health during COVID-19 outbreak in Pakistan: A web-based cross-sectional survey. *Int. J. Hum. Rights Healthc.* 14, 17–30. doi:10.1108/ijhrh-10-2020-0095

Astadi, P., Kristina, S., Retno, S., Yahya, P., and Agni Alam, A. (2022). The long path to achieving green economy performance for micro small medium enterprise. *J. Innov. Entrep.* 11 (1), 16. doi:10.1186/s13731-022-00209-4

Astobiza, A. M., Toboso, M., Aparicio, M., and Lopez, D. (2021). AI ethics for sustainable development goals. *IEEE Technol. Soc. Mag.* 40 (29445792), 66–71. doi:10.1109/MTS.2021.3056294

Balakesava Reddy, P., Ramasubbareddy, S., and Govinda, K. (2022). AI-based medical voice assistant during COVID-19. *Innovations Comput. Sci. Eng.* 385, 119–126. doi:10.1007/978-981-16-8987-1_13

Bartmann, M. (2022). The ethics of AI-powered climate nudging—how much AI should we use to save the planet? *Sustain. Switz.* 14 (9), 5153. doi:10.3390/su14095153

Benaben, F., Fertier, A., Montarnal, A., Jiang, Z., Truptil, S., Bidoux, L., et al. (2020). An AI framework and a metamodel for collaborative situations: Application to crisis management contexts. *J. Contingencies Crisis Manag.* 28 (3), 291–306. doi:10.1111/1468-5973.12310

Bolton, M., Raven, R., and Mintrom, M. (2021). Can AI transform public decision-making for sustainable development? An exploration of critical Earth system governance questions. *Earth Syst. Gov.* 9, 100116. doi:10.1016/j.esg.2021.100116

Buonomano, A., Barone, G., and Forzano, C. (2022). Advanced energy technologies, methods, and policies to support the sustainable development of energy, water and environment systems. *Energy Rep.* 8, 4844–4853. doi:10.1016/j.egyr.2022.03.171

Carayannis, E. G., Dezi, L., Gregori, G., and Calo, E. (2022). Smart environments and techno-centric and human-centric innovations for industry and society 5.0: A quintuple helix innovation system view towards smart, sustainable, and inclusive solutions. *J. Knowl. Econ.* 13 (2), 926–955. doi:10.1007/s13132-021-00763-4

Chen, J., Wang, Q., and Li, Q. (2022). A quantitative assessment on ecological compensation based on water resources value accounting: A case study of water Source area of the middle route of south-to-north water transfer project in China. *Front. Environ. Sci.* 10, 854150. doi:10.3389/fenvs.2022.854150

Choi, S.-W., Lee, E.-B., and Kim, J.-H. (2021). The engineering machine-learning automation platform (emap): A big-data-driven ai tool for contractors' sustainable management solutions for plant projects. *Sustain. Switz.* 13 (18), 10384. doi:10.3390/su131810384

Congjuan, L., Abulimiti, M., Jinglong, F., and Haifeng, W. (2022). Ecologic service, economic benefits, and sustainability of the man-made ecosystem in the taklamakan desert. *Front. Environ. Sci.* 10, 813932. doi:10.3389/fenvs.2022.813932

Cui, L., Mu, Y., Shen, Z., and Wang, W. (2022). Energy transition, trade and green productivity in advanced economies. *J. Clean. Prod.* 361, 132288. doi:10.1016/j.jclepro.2022.132288

De Nicola, A., Karray, H., Kejriwal, M., and Matta, N. (2020). Knowledge, semantics and AI for risk and crisis management. *J. Contingencies Crisis Manag.* 28 (3), 174–177. doi:10.1111/1468-5973.12322

Farzadfar, F., Naghavi, M., Sepanlou, S. G., Saeedi Moghaddam, S., Dangel, W. J., Davis Weaver, N., et al. (2022). Health system performance in Iran: A systematic analysis for the global burden of disease study 2019. *Lancet* 399, 1625–1645. doi:10.1016/s0140-6736(21)02751-3

Fontoura, P., and Coelho, A. (2022). How to boost green innovation and performance through collaboration in the supply chain: Insights into a more sustainable economy. *J. Clean. Prod.* 359, 132005. doi:10.1016/j.jclepro.2022.132005

Ge, T., Ullah, R., Abbas, A., Sadiq, I., and Zhang, R. (2022). Women's entrepreneurial contribution to family income: Innovative technologies promote females' entrepreneurship amid COVID-19 crisis. *Front. Psychol.* 13, 828040. doi:10.3389/fpsyg.2022.828040

Ghermandi, A., Depietri, Y., and Sinclair, M. (2022). In the AI of the beholder: A comparative analysis of computer vision-assisted characterizations of human-nature interactions in urban green spaces. *Landsc. Urban Plan.* 217, 104261. doi:10.1016/j.landurbplan.2021.104261

Gooroochurn, M., Mallet, D., Jahmeerbacus, I., Shamachurn, H., and Sayed Hassen, S. Z. (2022). A framework for AI-based building controls to adapt passive measures for optimum thermal comfort and energy efficiency in tropical climates. *Lect. Notes Netw. Syst.* 359 LNNS, 526–539. doi:10.1007/978-3-030-89880-9_39

He, R., Baležentis, T., Štreimikienė, D., and Shen, Z. (2022). Sustainable green growth in developing economies: An empirical analysis on the belt and road countries. *J. Glob. Inf. Manag.* 30 (6), 1–15. doi:10.4018/JGIM.20221101.oa1

Hernandez, D., Cano, J.-C., Silla, F., Calafate, C. T., and Cecilia, J. M. (2022). AI-enabled autonomous drones for fast climate change crisis assessment. *IEEE Internet Things J.* 9 (10), 7286–7297. doi:10.1109/JIOT.2021.3098379

Institute of Statistical Research and Knowledge Economics of the National Research University Higher School of Economics (HSE) (2022). *Artificial intelligence is the core of digital solutions of the COVID-19 era*. Available at: https://issek.hse.ru/news/457149916.html (data accessed 05 18, 2022).

KPMG (2022). *KPMG digest: Operational risks and sustainable development*. Issue #7, January 19, 2021. Available at: https://assets.kpmg/content/dam/kpmg/ru/pdf/2021/04/ru-ru-ors-digest-07-19012021.pdf (data accessed 05 18, 2022).

Li, C., Sampene, A. K., Agyeman, F. O., Brenya, R., and Wiredu, J. (2022). The role of green finance and energy innovation in neutralizing environmental pollution: Empirical evidence from the MINT economies. *J. Environ. Manag.* 317, 115500. doi:10.1016/j.jenvman.2022.115500

Li, Z., Wang, D., Hassan, S., and Mubeen, R. (2021). Tourists' health risk threats amid COVID-19 era: Role of technology innovation, transformation, and recovery implications for sustainable tourism. *Front. Psychol.* 12, 769175. doi:10.3389/fpsyg.2021.769175

Ligozat, A.-L., Lefevre, J., Bugeau, A., and Combaz, J. (2022). Unraveling the hidden environmental impacts of AI solutions for environment life cycle assessment of AI solutions. *Sustain. Switz.* 14 (9), 5172. doi:10.3390/su14095172

Lim, W. J., and Abdul Ghani, N. M. (2022). COVID-19 Mandatory self-quarantine wearable device for authority monitoring with edge AI reporting & flagging system. *Health Technol. Berl.* 12 (1), 215–226. doi:10.1007/s12553-021-00631-w

Liu, M., Lv, W., Yin, B., Ge, Y., and Wei, W. (2022). The human-AI scoring system: A new method for CT-based assessment of COVID-19 severity. *Technol. Health Care* 30 (1), 1–10. doi:10.3233/THC-213199

Local Burden of Disease, H. I. V. C. (2021). Mapping subnational HIV mortality in six Latin American countries with incomplete vital registration systems. *BMC Med.* 19 (1), 4. doi:10.1186/s12916-020-01876-4

Maheshwari, N., Thakur, I. S., and Srivastava, S. (2022). Role of carbon-dioxide sequestering bacteria for clean air environment and prospective production of biomaterials: A sustainable approach. *Environ. Sci. Pollut. Res.* 29 (26), 38950–38971. doi:10.1007/s11356-022-19393-7

Mao, B., Tang, F., Kawamoto, Y., and Kato, N. (2022). AI models for green communications towards 6G. *IEEE Commun. Surv. Tutorials* 24 (1), 210–247. doi:10.1109/COMST.2021.3130901

Minkkinen, M., Niukkanen, A., and Mäntymäki, M. (2022). *What about investors? ESG analyses as tools for ethics-based AI auditing*. Springer: AI and Society. doi:10.1007/s00146-022-01415-0

Moradi, F., Tourani, S., Ziapour, A., Hematti, M., Moghadam, E. J., and Soroush, A. (2021). Emotional intelligence and quality of life in elderly diabetic patients. *Int. Q. Community Health Educ.* 42 (1), 15–20. doi:10.1177/0272684X20965811

NeJhaddadgar, N., Ziapour, A., Zakkipour, G., Abolfathi, M., and Shabani, M. (2020). Effectiveness of telephone-based screening and triage during COVID-19 outbreak in the promoted primary healthcare system: A case study in ardabil province, Iran. *J. Public Health* 29, 1301–1306. doi:10.1007/s10389-020-01407-8

Nost, E., and Colven, E. (2022). Earth for AI: A political ecology of data-driven climate initiatives. *Geoforum* 130, 23–34. doi:10.1016/j.geoforum.2022.01.016

OECD AI Policy observatory (2022). *AI index report 2021*. Available at: https://oecd.ai/en/wonk/documents/ai-index-report-2021-chapter-1 (data accessed 05 18, 2022).

Osipov, V. S., Vorozheykina, T. M., Bogoviz, A. V., Lobova, S. V., and Yankovskaya, V. V. (2022). Innovation in agriculture at the junction of technological waves: Moving from digital to smart agriculture. *Smart Innovation, Syst. Technol.* 264, 21–27. doi:10.1007/978-981-16-7633-8_3

Paulson, K. R., Kamath, A. M., Alam, T., Bienhoff, K., Abady, G. G., Abbas, J., et al. (2021). Global, regional, and national progress towards sustainable development goal 3.2 for neonatal and child health: All-cause and cause-specific mortality findings from the global burden of disease study 2019. *Lancet* 398, 870–905. doi:10.1016/s0140-6736(21)01207-1

Popkova, E. (2022). *Advanced issues in the green economy and sustainable development in emerging market economies (elements in the economics of emerging markets)*. Cambridge: Cambridge University Press. doi:10.1017/9781009093408

Popkova, E., Alekseev, A. N., Lobova, S. V., and Sergi, B. S. (2020). The theory of innovation and innovative development. AI scenarios in Russia. *Technol. Soc.* 63, 101390. doi:10.1016/j.techsoc.2020.101390

Popkova, E. G., Bogoviz, A. V., Lobova, S. V., Sozinova, A. A., and Sergi, B. S. (2022a). Changing entrepreneurial attitudes for mitigating the global pandemic's social drama. *Humanit. Soc. Sci. Commun.* 9 (1), 141. doi:10.1057/s41599-022-01151-2

Popkova, E. G., De Bernardi, P., Tyurina, Y. G., and Sergi, B. S. (2022b). A theory of digital technology advancement to address the grand challenges of sustainable development. *Technol. Soc.* 68, 101831. doi:10.1016/j.techsoc.2021.101831

Popkova, E. G., and Sergi, B. S. (2022). Digital public health: Automation based on new datasets and the Internet of Things. *Socio-Economic Plan. Sci.* 80, 101039. doi:10.1016/j.seps.2021.101039

Prahl, A., and Goh, W. W. P. (2021). Rogue machines" and crisis communication: When AI fails, how do companies publicly respond? *Public Relat. Rev.* 47 (4), 102077. doi:10.1016/j.pubrev.2021.102077

Rahmat, T. E., Raza, S., Zahid, H., Mohd Sobri, F., and Sidiki, S. (2022). Nexus between integrating technology readiness 2.0 index and students' e-library services adoption amid the COVID-19 challenges: Implications based on the theory of planned behavior. *J. Educ. Health Promot.* 11 (1), 50. doi:10.4103/jehp.jehp_508_21

Rathore, S. S., Babu, S., Shekhawat, K., Yadav, S., Singh, V. K., Singh, C., et al. (2022). Designing energy cum carbon-efficient environmentally clean production system for achieving green economy in agriculture. *Sustain. Energy Technol. Assessments* 52, 102190. doi:10.1016/j.seta.2022.102190

Robinson, N., Barnett, D. T., Jones, K. D., Stanish, L. F., and Parker, S. M. (2022). Multiple dimensions of resilience: How NEON supports ecology and the research community in the face of compounding disasters. *Front. Environ. Sci.* 10, 653666. doi:10.3389/fenvs.2022.653666

Roscongress (2022). *Robots, AI, 3D printing, blockchain and digital tourism – what new business niches have emerged in the world during the pandemic*. Available at: https://roscongress.org/news/roboty-ii-3d-pechat-blokchejn-i-tsifrovoj-turizm-kakie-novye-nishi-dlja-biznesa-voznikli-v-mire-vo-v/ (data accessed: 05 18, 2022).

Sætra, H. S. (2021). A framework for evaluating and disclosing the esg related impacts of ai with the SDGs. *Sustain. Switz.* 13 (15), 8503. doi:10.3390/su13158503

Shakira Fathima, H., and Dilshad Begum, M. (2021). The role of AI in battling against COVID-19 crisis n India. *Adv. Parallel Comput.* 39, 127–132. doi:10.3233/APC210132

Simeonovski, K., Fidanoski, F., Petkovski, M., and Sergi, B. S. (2022). Debt-growth link after an economic crisis: The case of Central and Southeast Europe. *Post-Communist Econ.* 34, 409–422. doi:10.1080/14631377.2021.2006492

Soomro, T. A., Zheng, L., Afifi, A. J., Yin, M., and Gao, J. (2022). Artificial intelligence (AI) for medical imaging to combat coronavirus disease (COVID-19): A detailed review with direction for future research. *Artif. Intell. Rev.* 55 (2), 1409–1439. doi:10.1007/s10462-021-09985-z

Su, L. (2022). The impact of coordinated development of ecological environment and technological innovation on green economy: Evidence from China. *Int. J. Environ. Res. Public Health* 19 (12), 6994. doi:10.3390/ijerph19126994

Su, Z., McDonnell, D., Cheshmehzangi, A., Abbas, J., Li, X., and Cai, Y. (2021). The promise and perils of Unit 731 data to advance COVID-19 research. *BMJ Glob. Health* 6 (4), e004772. doi:10.1136/bmjgh-2020-004772

Tuia, D., Roscher, R., Wegner, J. D., Zhu, X., and Camps-Valls, G. (2021). Toward a collective agenda on AI for earth science data analysis. *IEEE Geosci. Remote Sens. Mag.* 9 (29456877), 88–104. doi:10.1109/MGRS.2020.3043504

Úbeda, F., Forcadell, F. J., Aracil, E., and Mendez, A. (2022). How sustainable banking fosters the SDG 10 in weak institutional environments. *J. Bus. Res.* 146, 277–287. doi:10.1016/j.jbusres.2022.03.065

Visvizi, A. (2022). Artificial intelligence (AI) and sustainable development goals (SDGs): Exploring the impact of AI on politics and society. *Sustain. Switz.* 14 (3), 1730. doi:10.3390/su14031730

Wang, B., Yang, Z., Xuan, J., and Jiao, K. (2020). Financial crisis prediction model of listed companies based on statistics and AI. *Sci. Program.* 1, 1–10. doi:10.1155/2022/1118023

Wang, M., Li, Y., and Liao, G. (2022). Spatial spillover and interaction between high-tech industrial agglomeration and urban ecological efficiency. *Front. Environ. Sci.* 10, 829851. doi:10.3389/fenvs.2022.829851

Wang, Y. (2022). *Financial Crisis Prediction Model of Listed Companies Based on Statistics and AI*, 2022, 1118023. doi:10.1016/j.egyai.2020.100013*Sci. Program.*

Wilson, C., and van der Velden, M. (2022). Sustainable AI: An integrated model to guide public sector decision-making. *Technol. Soc.* 68, 101926. doi:10.1016/j.techsoc.2022.101926

World Bank (2022). *Total natural resources rents (% of GDP)*. Available at: https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS?view=chart (data accessed 05 18, 2022).

Yale Center for Environmental Law & Policy (Yale University), Center for International Earth Science Information Network (Columbia University), The McCall MacBain Foundation (The Mullion Group) (2022). *Environmental Performance Index 2020 Global metrics for the environment: Ranking country performance on sustainability issues*. Available at: https://epi.yale.edu/downloads/epi2020report20210112.pdf (data accessed: 05 18, 2022).

Yaoteng, Z., and Xin, L. (2022). Research on green innovation countermeasures of supporting the circular economy to green finance under big data. *J. Enterp. Inf. Manag.* 35 (4-5), 1305–1322. doi:10.1108/JEIM-01-2021-0039

Yu, S., Draghici, A., Negulescu, O. H., and Ain, N. U. (2022). Social media application as a new paradigm for business communication: The role of COVID-19 Knowledge, social distancing, and preventive attitudes. *Front. Psychol.* 13, 903082. doi:10.3389/fpsyg.2022.903082

Zhang, H. (2022). AI and big data in water environments. *ACS Est. Water* 2, 904–906. doi:10.1021/acsestwater.2c00203

Zhou, Y., Draghici, A., Mubeen, R., Boatca, M. E., and Salam, M. A. (2022). Social media efficacy in crisis management: Effectiveness of non-pharmaceutical interventions to manage COVID-19 challenges. *Front. Psychiatry* 12 (1099), 626134. doi:10.3389/fpsyt.2021.626134

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Improving environmental decision-making in environmental business-management using big data and AI

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Introduction

Environmental business management is a special direction in the management of entrepreneurship within the framework of environmental legislation and corporate environmental responsibility. Despite the high importance for society (determines the contribution of business to the implementation of the SDGs) and business (forms loyalty to it), there are some difficulties in the area of environmental business management for two reasons, both of which (according to the hypothesis put forward in this article) can be overcome through the use of Big Data and AI (Lubis et al., 2019; Colvin et al., 2020).

The first reason is due to the fact that enterprises face a shortage of information about current ecological problems, ongoing initiatives to protect the environment and available opportunities to join them. Big Data make it possible to automatically collect, systematize and provide enterprises with all the necessary information (Popkova et al., 2020; Lamolinara et al., 2022; Mikac et al., 2022).

The second reason is that information about the state and protection of the environment has a large volume and is subject to constant changes. Processing and analysis of this information is not available for most enterprises, especially small and medium-sized ones. Artificial intelligence allows to quickly and accurately process a large amount of information and provide intelligent support for environmental decision-making in environmental business management (Parvathi Sangeetha et al., 2022; Popkova et al., 2022; Tian, 2022).

The purpose of the article is to substantiate the prospects and develop recommendations for improving environmental decision-making in environmental business-management using Big Data and AI. The originality of the article lies in providing clear justifications for the key role of technologies in the optimization of environmental decision-making in environmental business management in the AI era.

Environmental decision-making in environmental business-management

In their publications, Oteng et al. (2022), Pullin et al. (2022), and Tang et al. (2022) cite numerous advantages of using high technologies, in particular, AI and Big Data when making environmental decisions in environmental business management in industry. Among these advantages, it is necessary to indicate the possibility to fully take into account the totality of environmental parameters when making management decisions, as well as to search for the most optimal solutions from both an economic and environmental point of view.

The existing literature also reveals in sufficient detail the essence and features of agriculture in the era of artificial intelligence, embodied in the practice of AgroTech. In the works of Dai et al. (2022), Deng et al. (2022), Dupla et al. (2022), and Parmar et al. (2022), it is noted that as technological modernization strengthens, the gap between the economy and ecology increases. If this gap is quite large and obvious in industry, then in agriculture it has been most clearly manifested only in the process of the Fourth Industrial Revolution. Although high technologies make it possible to increase the volume of food production, achieve its climatic stability and other advantages, which is realized through the transition of the agro-industrial complex from an agrarian economy (based on agriculture producing eco-products) to an industrial economy (producing synthetic food with GMOs, food additives, etc.).

The works of Li et al. (2022), Ren et al. (2022), and Yew et al. (2022) indicate that high technologies require serious financial costs. Therefore, even with the support of the state, these technologies are either inaccessible to small and medium-sized businesses, or dictate the need to optimize costs. This hinders environmental decision-making in environmental business-management.

In this regard, a research question (RQ) arises about whether high technologies (Big data and AI) contribute to the improvement of processes of developing and making environmental decisions, and how this contribution can be maximized for the optimization of environmental business-management. Based on works by [FULL NAME], which point out the advantages of high technologies for environmental business-management, this article makes a hypothesis that high technologies (Big Data and AI) are instrumental in the optimality of environmental decision-making.

In industry, environmental decision-making is associated only with reducing the environmental costs of economic growth, but in agriculture, the prospects for environmental business-management are broader and also include the production of organic (natural) products and positive impact on the environment (for example, from planting plants and forests). Therefore, in order to find an answer to the RQ, this article pays special attention to the experience of AgroTech.

The role of technology in the optimization of environmental decision-making in environmental business-management in the AI era on the example of AgroTech

To determine the role of technologies in the optimization of environmental decision-making in environmental business-management in the AI era, the dynamics of startup financing in AgroTech in 2012–2020 and its contribution to the development of food production are analyzed using the example of AgroTech (based on Biotech, Robotics, AI and Big Data technologies) (Figure 1).

As shown in Figure 1, AgroTech is actively financing startups, which increased more than 11 times in 2020 ($30.50 billion) compared to 2012 ($2.68 billion). The presented regression curves showed that as the amount of funding for startups in AgroTech increases, for every $1 billion, agriculture, forestry, and fishing value added increases by 0.0032% of GDP (correlation of 6.19%), and the food production index (2014–2016 = 100) increases by 0.0053 (correlation 86.60%).

According to the forecasts of Intellias (2022), by 2023, the amount of funding for startups in AgroTech will double by 2023, that is, it will amount to about $ 60 billion. Taking into account the established dependencies, it can be expected that this will ensure an increase in agriculture, forestry, and fishing value added by 2.26 of GDP and an increase in the food production index (2014–2016 = 100) by 14.02%. The obtained results indicate that high technologies (Big Data and AI) already play an important role in the optimization of environmental decision-making in environmental business-management in AgroTech.

Interindustry review of environmental decision-making using big data and AI: Advanced international case experience of companies

Significant results of the use of Big Data and the use of AI in environmental decision-making were demonstrated in 2021 in Russia within the Year of Science and Technology. Application solutions that have been successfully implemented in the practice of Russian companies include smart forecasting of adverse climate change (forecasting weather and natural disasters)—in environmental science; automated search for new oil and gas fields, Smart Grid development—in the energy sector; creation of new materials and technologies, quality control—in materials science; optimization of urban space, control and intelligent support of sustainable and environmentally friendly management of natural resources—in the regional management (Ministry of Science and Higher Education of the Russian Federation, 2022).

The successfully implemented projects of using AI and Big Data for the improvement of environmental decision-making

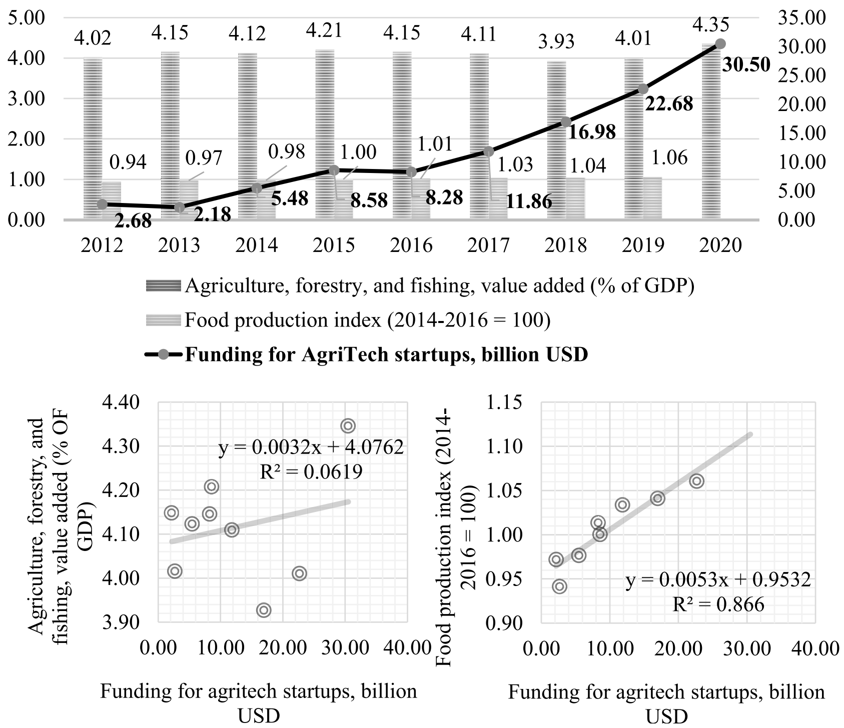

FIGURE 1
Financing of startups in AgroTech and its contribution to the development of food production in 2012–2020. Source: calculated and constructed by the authors based on the materials of the Queen (2022), Intellias (2022), and World Bank (2022).

(Ministry of Science and Higher Education of the Russian Federation, 2022) in environmental science include: 1) Whirlwind forecasting based on Big Data and AI by the researchers of the laboratory of climate theory of the Obukhov Institute of Atmospheric Physics, RAS; 2) Fire forecasting by the research and information center of the Ministry of Emergency Situations of the Russian Federation based on the Thermal Points mobile application; 3) Flood forecasting by Sber in cooperation with the Moscow Aviation Institute and Ministry of Emergency Situations using online satellite images; 4) Reduction of the carbon footprint by the Research Center for Artificial Intelligence based on the Skolkovo Institute of Science and Technology, and carbon landfills.

In addition, many smart projects in the energy sector are being implemented in Russia (Ministry of Science and Higher Education of the Russian Federation, 2022): 1) Reducing energy consumption using the application developed by the PREDICT team from Mail. Ru Group; 2) Accounting for seismic activity in the development of Gazprom Neft fields; 3) Improving the safety of Rosatom’s alternative energy through the introduction of a system for monitoring the provision of employees with personal protective equipment at nuclear power plants based on computer vision algorithms.

Moreover, AI and Big Data are abundantly used in retail sales, ensuring the reduction of the environmental footprint of the economy. Thus, the Russian retail store network Lenta creates an environmentally-friendly (biodegradable) package, while the retail store network Rossmann in the Czech Republic and Germany has introduced the “filling stations” with detergents under the trademark Love Nature, an affiliated company of Henkel (Corporate accelerator GenerationS, 2022).

AI and Big Data help to combat climate change: 1) PJSC FGC UES (Russia) launched the process of development of main power transmission lines based on Artificial Intelligence technologies; 2) Conservation of land and marine biodiversity based on monitoring and control of ecosystems, e.g. using NASA Blue River Technology in the World ocean; 3) Water saving: Valor Water Analytics allows detecting leakages, analyzing water flows in real-time mode, and tracking utility meter malfunctions; 4) Improvement of the air quality: The IBM Green Horizons project brings together machine learning and the Internet of Things for the air quality forecasting. IBM and Microsoft tools combine conventional physical models of atmospheric and weather chemistry with machine learning models. Atmospheric air pollution monitoring stations are already operating in Moscow, Moscow Oblast, and several other regions. 5) Recycling development: Nevlabs waste sorting equipment based on Artificial Intelligence (recycling kiosks and smart waste bins), produced by WinBin and TrashBack (Softline, 2022).

Recommendations for improving environmental decision-making in environmental business-management using big data and AI

To improve environmental decision-making in environmental business-management using Big Data and AI, the following recommendations are proposed. Firstly, consideration of sectoral characteristics of the use of high technologies in environmental decision-making to fully realize the development potential of environmental business management in each industry. So, in industry, the options of using Big Data and AI are being worked out in different aspects (both in theory and in practice) to improve economic production efficiency (for example, automation to increase production capacity and to benefit from the economies of scale), as well as environmental production efficiency (for example, "green" AI innovations).

In other industries, in particular, in agriculture, the focus is on the economic efficiency (for example, HRM or sales optimization) of the use of high technologies in entrepreneurship. The issues of environmental decision-making need independent and in-depth study in each industry, taking into account its characteristics. For example, in AgroTech, it is recommended to consider sustainable (responsible) environmental management as a separate economic practice and a separate area of environmental business management. In this area, independent automation of environmental decision-making can be carried out, while other areas (production and sales) may be less automated. This will reduce the costs of technological modernization of the business.

Secondly, the transition from individual to collective use of Big Data and AI in the practice of environmental decision-making in environmental business-management. Agriculture is strongly tied to the territory in which it is conducted. The planting of forests by one business structure will not noticeably improve the air quality in the territory, but if all enterprises join efforts and plant a large number of trees together, a serious contribution to the fight against climate change will be achieved.

In this regard, it is proposed to separate environmental business-management from other areas of corporate governance and separately automate environmental decision-making processes. This will help enterprises maintain economic independence and at the same time gain access to advanced technologies (Big Data and AI) for environmental business management, both acquired collectively and provided by local public authorities as a measure for the development of the ecological economy.

Discussion

The contribution of the article to the literature consists in overcoming sectoral restrictions on the use of high technologies (Big Data and AI) when making environmental decisions in environmental business-management. Unlike Oteng et al. (2022), Pullin et al. (2022), and Tang et al. (2022), it has been proved that high technologies can be used in environmental business-management not only in industry, but also in agriculture (AgroTech). Thanks to this, a much greater potential for using Big Data and AI in environmental decision-making has been revealed, which is not limited to reducing the environmental costs of economic growth, but also includes improving the ecological balance.

In contrast to Dai et al. (2022), Deng et al. (2022), Dupla et al. (2022), and Parmar et al. (2022), it has been proved that technological modernization does not necessarily lead to a gap between the economy and ecology, but on the contrary, can help to bridge this gap. So, for example, the development of AgroTech simultaneously increases the added value created in the agro-industrial complex (economic advantage) and increases the productivity of natural (organic) agriculture (environmental advantage).

Unlike Li et al. (2022), Ren et al. (2022), and Yew et al. (2022), it has been demonstrated that high technologies (Big Data and AI) can (proved by the example of startups in AgroTech) and should be available to small and medium-sized businesses in various sectors of the AI economy. Authors' framework practice-oriented recommendations have been proposed, which are universal and applicable in various sectors of the AI economy, aimed at diffusing high technologies (increasing accessibility) and increasing the efficiency of their use in environmental decision-making in environmental business management.

Conclusion

The result of the study was the confirmation of the correctness of the hypothesis put forward in the article, the justification of prospects, as well as the development of recommendations for improving environmental decision-making in environmental business-management using Big Data and AI. The key role of technologies in the optimization of environmental decision-making in environmental business-management in the AI era is revealed, associated with the harmonization and balancing of economic and environmental interests of business in decision-making, which has been proved in the example of AgroTech.

The uniqueness of the article and its contribution to the literature consist in the fact that it has bridged the gap between theory and practice, having demonstrated that high technologies (AI and Big Data) can be and are successfully used for the optimization of environmental decision-making in various sectors of the economy. For the first time, the article has proved through numerous empirical examples and the case experience of Russian companies, that high technologies have significant potential to improve the decision-making efficiency not only in the production sector but also in AgroTech and other sectors. To fulfill the identified potential to the fullest extent possible, it is recommended to take into account the industry specificity and make a transition from individual to shared use of Big Data and AI in the practice of environmental decision-making in environmental business-management.

The theoretical significance of the results obtained in the study is that they clarified organizational (in comparison with other areas of management) and industry (using the example of comparing industry and agriculture) features of technological modernization (automation based on Big data and AI) environmental business-management. The practical contribution of the conclusions and recommendations is due to the fact that the authors' proposals for improving environmental decision-making using Big Data and AI can significantly expand the range of practical applications of environmental business-management from reducing environmental damage to maximizing the contribution of business to environmental protection and improving the environment by involving all sectors of the economy in environmental business-management.

Author contributions

SV, VK, and ZT contributed to conception and design of the study. ZT and TA performed the statistical analysis. SV wrote the first draft of the manuscript. SV, VK, ZT, and TA wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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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References

Colvin, R. M., Witt, G. B., and Lacey, J. (2020). Power, perspective, and privilege: The challenge of translating stakeholder theory from business management to environmental and natural resource management. *J. Environ. Manag.* 271, 110974. doi:10.1016/j.jenvman.2020.110974

Corporate accelerator GenerationS, (2022). How Artificial Intelligence makes life more natural. Available at: https://new-retail.ru/tehnologii/kak_iskusstvennyy_intellekt_delaet_zhizn_estestvenney6681/(Accessed date: 09.08.2022).

Dai, X., Chen, Y., Wu, X., He, Y., and Wang, F. (2022). Are the agro-ecosystems sustainable? Measurement and evaluation: A case study of sichuan province, China. *Front. Environ. Sci.* 25. doi:10.3389/fenvs.2022.862740

Deng, X., Wang, G., Yan, H., Zheng, J., and Li, X. (2022). Spatial–temporal pattern and influencing factors of drought impacts on agriculture in China. *Front. Environ. Sci.* 31. doi:10.3389/fenvs.2022.820615

Dupla, X., Lemaître, T., Grand, S., Gondret, K., Charles, R., Verrecchia, E., et al. (2022). On-farm relationships between agricultural practices and annual changes in organic carbon content at a regional scale. *Front. Environ. Sci.* 24. doi:10.3389/fenvs.2022.834055

Intellias (2022). How to implement Big data Analytics in agriculture: 5 business use cases. Available at: https://intellias.com/how-to-encourage-farmers-to-use-big-data-analytics-in-agriculture/ (Accessed date: 17.05.2022).

Lamolinara, B., Pérez-Martínez, A., Guardado-Yordi, E., Dieguez-Santana, K., Diéguez-Santana, K., and Ruiz-Mercado, G. J. (2022). Anaerobic digestate management, environmental impacts, and techno-economic challenges. *Waste Manag.* 140, 14–30. doi:10.1016/j.wasman.2021.12.035

Li, B., Huang, Y., Guo, D., Liu, Z., Han, J. C., Wang, Z., et al. (2022). Environmental risks of disposable face masks during the pandemic of COVID-19: Challenges and management. *Sci. Total Environ.* 825, 153880. doi:10.1016/j.scitotenv.2022.153880

Lubis, Y., Nguyen, P. T., ThuyTo Nguyen, Q. L. H., Bich Huynh, V. D., and Fitrio, T. (2019). Study of green marketing: An environmentally friendly approach of business management. *Test Eng. Manag.* 81, 1080–1085.

Mikac, B., Abbiati, M., Adda, M., Desiderato, A., Pellegrini, M., Turicchia, E., et al. (2022). The environmental effects of the innovative ejectors plant technology for the eco-friendly sediment management in harbors. *J. Mar. Sci. Eng.* 10 (2), 182. doi:10.3390/jmse10020182

Ministry of Science and Higher Education of the Russian Federation (2022). Monthly digest within the year of science and technology in Russia – november 2021: Artificial intelligence. Available at: https://Годнауки.рф/upload/iblock/336/5pxu3rd0i88mzxxpjc69soqbil7bd44v/11.2021.pdf (Accessed date: 09.08.2022).

Oteng, D., Zuo, J., and Sharifi, E. (2022). Environmental emissions influencing solar photovoltaic waste management in Australia: An optimised system network of waste collection facilities. *J. Environ. Manag.* 314, 115007. doi:10.1016/j.jenvman.2022.115007

Parmar, B., Vishwakarma, A., Padbhushan, R., Kumar, R., Kumari, R., Kaviraj, M., et al. (2022). Hedge and alder-based agroforestry systems: Potential interventions to carbon sequestration and better crop productivity in Indian sub-himalayas. *Front. Environ. Sci.* 10, 858948. doi:10.3389/fenvs.2022.858948

Parvathi Sangeetha, B., Kumar, N., Ambalgi, A. P., Thilagam, K., and Vijayakumar, P. (2022). IOT based smart irrigation management system for environmental sustainability in India. *Sustain. Energy Technol. Assessments* 52, 101973. doi:10.1016/j.seta.2022.101973

Popkova, E. G., Bogoviz, A. V., and Krivtsov, A. I. (2020). "Conclusions: Economic and legal management of modern economic systems' innovative development: A view into the future," in *The economic and legal foundations of managing innovative development in modern economic systems*, 203–204. doi:10.1515/9783110643701-022

Popkova, E. G., De Bernardi, P., Tyurina, Y. G., and Sergi, B. S. (2022). A theory of digital technology advancement to address the grand challenges of sustainable development. *Technol. Soc.* 68, 101831. doi:10.1016/j.techsoc.2021.101831

Pullin, A. S., Cheng, S. H., Jackson, J. D. U., Envall, I., Fada, S. J., Twardek, W. M., et al. (2022). Standards of conduct and reporting in evidence syntheses that could inform environmental policy and management decisions. *Environ. Evid.* 11 (1), 16. doi:10.1186/s13750-022-00269-9

Queen, G. (2022). Total agri-food tech funding in 2020 to reach US$30.5 billion, new data shows. Available at: https://www.greenqueen.com.hk/total-agri-food-tech-funding-in-2020-to-reach-us30-5-billion-new-data-shows/ (Accessed date: 17.05.2022).

Ren, C., Zhang, X., Reis, S., and Gu, B. (2022). Socioeconomic barriers of nitrogen management for agricultural and environmental sustainability. *Agric. Ecosyst. Environ.* 333, 107950. doi:10.1016/j.agee.2022.107950

Softline (2022). Artificial Intelligence on guard of environment protection. Available at: https://slddigital.com/article/iskusstvennyj-intellekt-na-strazhe-ekologii/ (Accessed date: 09.08.2022).

Tang, Y. M., Chau, K. Y., Fatima, A., and Waqas, M. (2022). Industry 4.0 technology and circular economy practices: Business management strategies for environmental sustainability. *Environ. Sci. Pollut. Res.* 29, 49752–49769. doi:10.1007/s11356-022-19081-6

Tian, Y. (2022). The heterogeneous dynamic effect of financial development and environmental regulation on Chinese urban green technology management efficiency. *Environ. Sci. Pollut. Res.* 29 (21), 32032–32053. doi:10.1007/s11356-021-18320-6

World Bank (2022). Indicators: Agriculture & rural development. Available at: https://data.worldbank.org/indicator (Accessed date: 17.05.2022).

Yew, M. H., Molla, A., and Cooper, V. (2022). Behavioural and environmental sustainability determinants of residential energy management information systems use. *J. Clean. Prod.* 356, 131778. doi:10.1016/j.jclepro.2022.131778

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Environmental management of companies in the oil and gas markets based on AI for sustainable development: An international review

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The purpose of the article is to study the current international experience and determine the prospects for improving the environmental management of companies in the oil and gas markets based on AI in the interests of sustainable development. Relying on variation analysis and correlation analysis methods, it has been substantiated that environmental management have significant impact on companies from the perspective of social LCA, which has an impact on the competitive ability of companies. Relying on the IPAT-method, it has been proven that technology is a key factor which determines this impact. As a result, it has been proved on the example of the case experience of the largest energy companies in Russia in 2022 that the environmental management of oil and gas companies creates advantages not only for the environment but also for financial efficiency and stability (break-even operation) of these companies (implementation of SDG 8). Using the example of the international experience of energy companies (from the UAE, Sweden, the UK, the USA and Japan), it has been proved that AI can play a much greater role in the oil and gas markets, contributing not only to ensuring a deficit-free energy economy (the implementation of SDG 7) but also to environmental protection (the implementation of SDGs 13-15). The best practices of using AI in each selected sector of the oil and gas industry were studied and a quantitative and qualitative assessment of the benefits of AI was carried out. Thirdly, the most promising use of AI in the sector of environmental management for environmental economics and management is substantiated. It is proven that the options for environmental management can be different and specific to a particular object. Thanks to the results obtained in the course of the study, a systematic view of the prospects for the sustainable development of oil and gas markets has been formed, and the importance of AI for this process has been demonstrated. The theoretical significance of the study consists in expanding the existing understanding of the use of AI in the practice of environmental management of energy companies and clarifying its contribution to the implementation of the SDGs.

KEYWORDS

environmental management, energy companies, oil and gas markets, AI, sustainable development, international review

Introduction

The attention of the world community is currently focused on the oil and gas markets. The criteria for the sustainability of these markets are, firstly, the environmental friendliness of oil and gas. Environmental protection is a modern priority in all sectors of the economy, but it is especially important in the oil and gas industry.

This is explained by the fact that oil and gas production leads to the depletion of natural resources, therefore, it must be economical in order to preserve resources for future generations. Also, oil and natural gas extraction and transportation are associated with waste that needs to be reduced to prevent environmental disasters (for example, gas leaks and oil spills) (Popkova et al., 2021; Liu and Luo, 2022; Zhang et al., 2022).

Secondly, the balance of supply and demand in the oil and gas markets: energy scarcity. Oil and gas are critically needed for the state (for example, to maintain the stable operation of public infrastructure and public institutions), households and businesses. The sustainability of the oil and gas markets is to fully meet the demand, but this is becoming increasingly difficult every year, as the "clean" energy industry is actively developing, and the demand for oil and gas seems to be increasingly unpredictable (Popkova and Sergi, 2021; Marcon et al., 2022).

The barrier to meeting this criterion is that "clean" energy in the current technological mode is not able to constitute a robust alternative to fossil fuels. Even the world's most environmentally friendly economies are characterized by hybrid energy systems which combine "clean" and fossil energy in varying proportions (Yang et al., 2022). The technological origins of the problem under consideration appear in the low and unstable productivity of "clean" energy, as well as in the complexity of its storage and distribution (Maka and Alabid, 2022; Qamar et al., 2022).

As commercial entities, oil and gas companies must cover their expenses, recover their investments and produce profits for shareholders and investors. In addition to this, many oil and gas companies are large employers and even city-forming enterprises. Therefore, society (especially their employees) and the state are also interested in maintaining a stable financial position (break-even operation) of energy companies (Habeşoğlu et al., 2022; Hunt et al., 2022).

Simultaneous compliance with these three criteria is a difficult task and is an urgent scientific and practical problem. This article offers a look at the problem from the positions of fuel and energy companies in the oil and gas markets. The basic idea which forms the basis of this research and ensures its contribution to literature is that the observance of criteria of sustainability of companies in the oil and gas markets is greatly determined by technology.

This idea is based on existing contemporary literature, which points out considerable contribution of the leading technologies of the AI era to the development of the energy economy (David et al., 2022; Guzović et al., 2022; Liu et al., 2022; Santillan et al., 2022). A promising technology for intelligent support of complex decision-making is artificial intelligence (AI).

Therefore, the purpose of this article is to study the current international experience and determine the prospects for improving the environmental management of companies in the oil and gas markets based on AI in the interests of sustainable development. The originality of this article is based on the scientific study of artificial intelligence as a new and promising source of stability for fuel and energy companies in the oil and gas markets.

AI in the environmental management of companies in the oil and gas markets: a literature review and gap analysis.

As a result of the structural-functional analysis of value chains in the oil and gas industry, three sectors were identified: 1) product and market supply (energy distribution, efficiency and energy supply), 2) financial management (investment, recovery and stakeholders' profit including employment and society welfare) and 3) environmental management that makes the oil and gas business sustainable.

Due to the allocation of three designated sectors, a comprehensive understanding of the oil and gas industry has been formed, which opens up the possibility for its systematic study. In this regard, in this article, it is advisable to conduct a study in each of the identified three sectors of the oil and gas industry and reveal the features of the use of AI in various sectors.

In the existing literature, the essence of environmental management of oil and gas companies is disclosed in detail. Ibrahim et al. (2020), Margheritini et al. (2020), Wu et al. (2020), Basile et al. (2021) note in their works that the environmental management of oil and gas companies makes an important contribution to environmental protection and improvement the environmental friendliness of the energy economy. At the same time, the financial consequences of environmental management for the energy companies themselves remain poorly studied and poorly understood.

The role of AI in the oil and gas markets is also discussed in sufficient detail in the available publications. Blumenthal et al. (2020), Agbaji (2021), Desai et al. (2021), Di et al. (2021) in their works point to the significant role of AI in energy distribution and energy efficiency improvement of the economy, that is, in the implementation of SDG 7. At the same time, the role of AI in the environmental management of oil and gas companies is not defined. An assessment of the existing literature showed that, despite a significant number of publications, the problem of sustainable development of oil and gas markets has been only partially studied.

The experience and prospects of using AI in selected sectors of the oil and gas industry are poorly understood and unclear. In this regard, the prospects for the systemic (in the unity of the criteria of environmental friendliness, lack of scarcity and break-even operation) sustainable development of oil and gas markets, as well as the importance of AI to achieve it, have not been determined.

Along with the assessment of sustainable development, it is expedient to perform the life cycle assessment of technology as the factor of production of power resources in the oil and gas markets–the expert evaluation of the environmental impact. Life cycle assessment that has been performed based on existing literature, has shown the close relationship between AI and environmental management. At the first life cycle stage involved with oil and gas production, AI allows optimizing exploration and using them in the most efficient way to preserve untapped oil and gas fields for the future generations (Li et al., 2021).

At the second life cycle stage, AI helps to optimize logistics and increase safety of oil and gas transportation and storage (Ligozat et al., 2022). At the third life cycle stage, in the use of oil and gas, AI contributes to the more efficient and money-saving "smart" consumption of oil and gas resources in the energy economy (Sulistyawati et al., 2020).

Life cycle assessment has shown that there is a close relationship between environmental management of energy companies in the oil and gas markets and the role of AI. Nevertheless, given the fact that the real-life experience of energy companies is understudied, the actual closeness of this relationship is yet to be clarified and is still only potential.

The gap analysis has revealed the first gap in literature which is involved with the uncertainty of causal relationships of environmental management of companies in the oil and gas markets. Thus, despite the abundance of existing literature, it remains unclear how environmental management was implemented in the activities of energy companies. While sustainability is assessed at the general market level, the business practices of environmental responsibility are deficiently covered and are not adequately investigated.

Due to the mentioned gap, environmental management in the oil and gas markets is a "black box", where state environmental regulations (from regulation of the volume of oil and gas production to environmental taxation of energy companies) and industry-specific environmental standards are at the entry, and the achieved level of environmental performance of markets under consideration is at the output.

The need to fill the mentioned gap is due to the fact that it is a barrier on the way to the management of environmental performance of oil and gas markets. Existing literature reveals the status quo, but prevents from changing a take on it. From the research and practice perspective, it is extremely important to study the actual practices of environmental management of energy companies, because it opens up possibilities and prospects to manage and improve the environmental performance of oil and gas markets.

The second gap in literature consists in the ambiguous role of AI in the environmental management of companies in the oil and gas markets. Thus, available literature points to the active digital modenization of the energy economy; however, it remains unclear how exactly high technologies of the AI era are used in the activities of energy companies.

The importance of filling the identified gap is attributable to the fact that it prevents from determining the degree of fulfillment of potential of using AI in the environmental management of energy companies. The existing view from the standpoint of oil and gas markets in general only shows their general level of digitalization, which is fairly high. That said, the rate of active use of AI in the environmental management of energy companies, which remains outside the existing view, can be either high or low.

Based on the existing works of Yu et al. (2020), Zhu et al. (2022), revealing the advantages of using AI for environmental management of energy companies, this article hypothesizes that this management in the oil and gas markets in the interests of sustainable development should be carried out based on AI since this will ensure simultaneous compliance with all the specified criteria.

In this regard, this article raises the research question on how the environmental management of companies in the oil and gas markets for the sustainable development should be performed. Relying on existing works by Yu et al. (2020), Zhu et al. (2022), which reveal the benefits of using AI for the environmental management of energy companies, the authors of this article put forward a hypothesis that this management in the oil and gas markets for the sustainable development must be performed through the use of AI, since this will ensure simultaneous observance of all abovementioned criteria.

The contribution of this article to literature consists in filling the two identified gaps which ensures, first, the disclosure of contents of the "black box" of environmental management of companies in the oil and gas markets. As a result, the article opens up possibilities to manage the environmental performance of oil and gas markets through the adjustment of the practices of environmental management of energy companies.

Second, the detected degree of involvement of the potential to use AI in the environmental management of companies in the oil and gas markets, as well as identifying the prospects for a more perfect fulfillment of this potential. The mentioned academic contribution is made and the identified gaps are filled in this article through a fresh approach to the oil and gas markets–from the standpoint of environmental management of energy companies, which means the study of these markets at the corporate (micro-) level.

Methodology and materials

This article uses the Impact, Population, Affluence, and Technology (IPAT) method to clarify the factors that have an impact on renewable energy sources. Reliable and authoritative official statistics from the World Bank (2022) at the global level serves as the empirical basis of the research of international practices.

In accordance with the selected method, the "I" variable in the "I=PAT" equation is reflective of the result of environmental management of companies in the oil and gas markets, whose indicator is renewable energy consumption (% of total final energy consumption), which increased from 16.86% in 2010 to 17.54% (the most up-to-date statistics) (World Bank, 2022). Hence, the Impact in recent years decreased by 4.03%.

Population, despite a significant increase in the world population in the period under consideration, demonstrated a responsibility towards the environment in terms of energy use. In this article, it is assessed in terms of fossil fuel energy consumption (% of total), which decreased from 80.8% in 2010 to 79.7% (the most up-to-date statistics) (World Bank, 2022). Hence, the Population in recent years decreased by 1.36%.

Affluence, even with intensive economic growth, also decreased due to the environmental responsibility of society and the economy. In this article, it is assessed in terms of total natural resources rents (% of GDP), which decreased from 3.7% in 2010 to 2% (the most up-to-date statistics) (World Bank, 2022). Hence, the Affluence in recent years decreased by 45.95%.

Technology gained momentum thanks to the Fourth Industrial Revolution, as a result of which the world entered the AI era in the period under consideration. In this article, it is assessed in terms of alternative and nuclear energy (% of total energy use), which increased from 8.3% in 2010 to 13.4% (the most up-to-date statistics) (World Bank, 2022). Hence, the Technology in recent years decreased by 61.45%.

Thus, technology has made the most significant contribution to the minimization of detrimental effect of the energy economy on environment over the period from 2010 to the present day. In this regard, the technological progress is a key factor in improving the efficiency of environmental management of energy companies in the oil and gas markets. Therefore, it is expedient to focus further research in this paper on the in-depth study of the selected technology factor.

Use of AI in various sectors of the oil and gas industry

Based on the results of the structural and functional analysis of value chains in the oil and gas industry conducted in this article, we will analyze the practical experience of using AI in various sectors of the oil and gas industry.

In the production and market supply sector (energy distribution, efficiency and supply), the analysis of seismic data and exploration drilling data using AI allows drilling fewer wells and doing less testing in exploration, which saves both money and time. The return on smart fields, even due to the introduction of AI, has increased by 2–10%.

Chevron has invested more than $6 billion in the i-Field "Connected fields" project and is now generating about $1 billion in additional revenue per year. Productivity of production facilities increased by 4%, and oil recovery factor by six p. p. At Gazprom Neft, the time for interpreting geological data due to the work of AI was reduced by 6 times, and the amount of useful information extracted from them increased by 30% (Vedomosti, 2022).

In the financial management sector (investment, recovery and stakeholders' profit including employment and society welfare), the implementation of AI increases the return on investment. In this regard, C3. ai is a good example - it is an applied artificial intelligence company that has created several commercial platforms for introducing machine intelligence into business processes, including in the field of oil and gas.

The company was founded in 2009 by billionaire and tech investor Thomas Siebel, a native of Oracle. Clients (about 30 in total) include oil and gas companies such as Shell and Baker Hughes. The company's revenue has been growing exponentially over the last 5 years: in 2017 it was estimated at $33 million, and in 2021 at $183 million. Oil and gas investors can invest in projects involving the implementation of AI in the activities of oil and gas enterprises, both through the acquisition of C3. ai shares (indirectly) and through financing the development of applied solutions for expanding the use of AI in the activities of oil and gas enterprises (BCS-express, 2021).

In the environmental management sector that makes the oil and gas business sustainable, due to the introduction of AI, Gazprom's environmental performance has increased, which is reflected in corporate sustainability reports for 2021. In particular, a 6% reduction in waste was achieved. Due to the optimization of logistics with the help of AI, the frequency of accidents during the transportation of oil has decreased - this has ensured savings in fuel and energy resources in the implementation of energy supply programs by 24.6%.

The data presented on whether AI has been used in this oil and gas industry showed that AI provides significant benefits in all sectors of the oil and gas industry. In the first two sectors (product development and financial management), AI improves only the economic efficiency of oil and gas companies. In the third sector (environmental management), both the economic (saving of oil and gas resources) and environmental (environmental protection) efficiency of oil and gas companies are simultaneously increasing.

In this regard, the most promising and should be carried out as a matter of priority is the expansion of the use of AI in the third sector (environmental management). Therefore, in this article, it is advisable to focus on the third sector (environmental management) of the oil and gas industry as the most promising from the standpoint of environmental economics and management.

The activities of oil and gas companies in the environmental management sector can differ in terms of their site-specific operations, environmental issues, and waste generation and disposal. Options for environmental management can be different and specific to a particular facility.

AI can be useful for the environmental management of oil and gas companies, firstly, for planning oil and gas production, the most efficient use of fields and slowing down the depletion of oil and gas resources - their conservation for future generations. In this case, oil and gas fields act as an object of environmental management, and as an option for environmental management based on AI, intellectual support for planning and development of fields. The successful experience of Chevron can serve as an example.

Secondly, to reduce production waste: optimize logistics and prevent accidents (natural disasters) during the transportation of oil and gas. In this case, the object of environmental management is the transportation of oil and gas, and the environmental management option based on AI is environmentally responsible optimization of logistics. The successful experience of Gazprom can serve as an example.

International experience in environmental management of companies in the oil and gas markets based on AI

In order to get the most complete, accurate and reliable picture of the global prospects of environmental management companies in the oil and gas markets based on AI in the interests of sustainable development, we will conduct an international review of the experience of the largest fuel and energy companies operating in these markets.

As a result of the systematization of international experience (based on the materials of What Next, 2022), the following areas of environmental management of companies in the oil and gas markets based on AI in the interests of sustainable development have been identified, firstly, reduction of greenhouse gas emissions and freshwater consumption (for example, Abu Dhabi National Oil Company (ADNOC), the UAE).

Secondly, prediction of production waste (for example, Swedish multinational corporation, ABB, Sweden). Thirdly, decarbonization and achieving zero carbon emissions (for example, British Petroleum, the UK). Fourthly, optimization of oil and gas production (for example, Baker Hughes, the United States) and their processing (for example, JXTG Holdings, Japan).

The international review of best practices conducted in the study allows us to propose a universal recommendation to expand the range of AI use in the oil and gas markets from the achievement of SDG seven to the implementation of environmental management–the achievement of SDGs 13–15–in the interests of sustainable development. Nevertheless, international experience does not reveal the prospect for compliance with the third (financial) criterion of stability of markets and gas with the help of AI, which requires an in-depth (case) study.

Case study of sustainable development of oil and gas companies in Russia with the help of AI-based environmental management

The methodology of this study is based on the application of a systematic approach. The empirical basis of the study is the materials of Global 2000 (Forbes, 2022). Further, the article presents a quantitative and qualitative study on the example of Russia, which allows us to obtain the most objective results. The top five Russian oil and gas companies in 2022 (with the industry affiliation "Energy: Oil & Gas Operations") were selected for the study (based on the results of 2021), according to the Forbes rating (2022).

Table 1 shows their financial indicators (based on the results of 2021) from the Forbes Global-500 rating (2022), as well as their weight in the Moscow Exchange (2022) "Vector of Sustainable Development" (as of 18 May 2022).

The variation analysis in Table 1 has shown that the rank of TOP five Russian oil and gas companies in 2022 in the Global-500 Forbes ranking (2022) is highly differentiated (the variation is 104.36%). The market value of their assets (the variation is 95.65%), the volume of sales (the variation is 75.22%) and the amount of profit (the variation is 59.47%) vary highly as well.

This being said, the market capitalization (the variation is 38.35%) and weighting coefficient in the Index "Sustainable development vector" (the variation is 29.55%) are moderately differentiated and fairly uniform. This is indicative of potential relation between the market value of energy companies in the oil and gas markets and their environmental management. To prove the existence of this relation, we shall turn to the results of the correlation analysis.

Correlation analysis of statistics in Table 1 showed that environmental management (reflected in the index "Vector of Sustainable Development") contributes to improving the position of companies in the global ranking (correlation -57.09%), increasing sales (48.46%), profit (88.46%), asset value (91.26%) and market share (78.63%) of oil and gas companies. As a result of studying the applied experience of oil and gas companies in Russia, it was revealed that they actively

TABLE 1 Financial indicators and weight in the index "Vector of sustainable development" of the top five Russian oil and gas companies in 2022.

Company	Rank (the less, the better)	Sales, billions of dollars	Profit, billions of dollars	Assets, billions of dollars	Market value, billions of dollars	Weight in the index "vector of sustainable development"
Rosneft	53	126.9	10.9	208.5	48.1	3.93
Gazprom	32	122.6	22.7	331.7	60.8	5.6
LukOil	99	116.3	9.9	95.7	41.2	2.87
Novatek	316	13.2	13.4	32.5	42.6	3.43
Tatneft	539	14.8	3.0	19.9	16.7	2.97
Average for the top 5	207.8	78.76	11.98	137.66	41.88	3.76
Variation, %	104.36	75.22	59.47	95.65	38.35	29.55
Correlation with weight in the "Vector of Sustainable Development" index", %	−57.09	48.46	88.46	91.26	78.63	-

Source: Compiled by the authors based on materials.

carry out AI-based environmental management in the interests of sustainable development.

Since 2020, Tatneft has been implementing a project to use AI in field development (in drilling, that is, in production management). This energy company also creates and actively uses digital twins of drilling rigs in order to minimize the environmental costs of its operation (Energy Land, 2022). Novatek uses AI to prevent accidents during oil production (drilling) and prevent environmental disasters (ComNews, 2022b).

LukOil uses AI to monitor serviceability, predict and prevent equipment breakdowns for reducing environmental costs (Perm Oil, 2022). Gazprom (2022a) applies AI in oil engineering. Rosneft uses AI for oil exploration and production, which makes it possible to ensure eco-friendly drilling and use it most effectively to preserve untouched oil fields for future generations (ComNews, 2022a).

Thus, the prospects for improving the environmental management of companies in the oil and gas markets based on AI in the interests of sustainable development are associated with its use for the systematic implementation of SDGs seven to eight and SDGs 13–15.

Discussion

The article contributes to the development of the concept of environmental management of oil and gas companies, revealing the role of AI in its improvement in support of sustainable development. In contrast to the works of Ibrahim et al. (2020), Margheritini et al. (2020), Wu et al. (2020), Basile et al. (2021) the article substantiates (by the example of the case experience of the largest energy companies in Russia in 2022) that the environmental management of oil and gas companies creates advantages not only for the environment but also for the financial efficiency and stability (break-even operation) of these companies (implementation of SDG 8).

The obtained results also contradict the existing works of Blumenthal et al. (2020), Agbaji (2021), Desai et al. (2021), Di et al. (2021), as it has been proved (using the example of the international experience of energy companies from the UAE, Sweden, the UK, the United States and Japan) that AI can play an important role in the oil and gas markets, contributing not only to ensuring a deficit-free energy economy (implementation of SDG 7) but also to environmental protection (implementation of SDGs 13–15). Thanks to the results obtained in the course of the study, a systematic view of the prospects for the sustainable development of oil and gas markets has been formed, and the importance of AI for this process has been demonstrated.

Conclusion

Thus, the following results have been obtained in the course of research. First, the structural and functional analysis of value chains in the oil and gas industry has made it possible to distinguish between three sectors: 1) production and supply on the market (energy distribution, energy efficiency and energy supply), 2) financial management (investment, recovery of investment, and the benefit of parties concerned, including employment and welfare of the community) and 3) environmental management, which makes oil and gas business socially responsible.

Second, the advanced experience of using AI in each identified sector of oil and gas industry has been studied, and the quantitative and qualitive assessment of advantages of AI has been performed. Third, the maximum potential of using AI in the environmental management sector has been substantiated, since it ensures the growth of both economic and environmental performance at the same time, and, accordingly, is the most beneficial to environmental economics and management.

Fourth, it has been substantiated that the options of environmental management can be diverse and characteristic of a particular object. It has been shown how AI can be useful to environmental management of oil and gas companies in such an object as oil and gas fields (intelligent support of reservoir planning and development by AI based on Chevron's experience for resource conservation), as well as in such an object as oil and gas transportation (environmentally responsible optimization of logistics using AI based on Gasprom's experience).

Practical significance of the research, academic contribution and future research

So, the hypothesis put forward in the article has been confirmed and it has been revealed that management in the oil and gas markets in the interests of sustainable development should be carried out based on AI since this ensures simultaneous compliance with all the criteria for the sustainability of these markets: environmental friendliness, energy scarcity and financial efficiency of oil and gas companies. The theoretical significance of the study consists in expanding the existing understanding of the use of AI in the practice of environmental management of energy companies and clarifying its contribution to the implementation of the SDGs.

The practical significance of the article is that the progressive international experience illustrated and systematized in it can become more widespread around the world in support of the sustainable development of oil and gas markets. Management implications are related to the fact that the authors' conclusions and recommendations make it possible to increase the efficiency of using AI in the activities of oil and gas companies and provide them with an application guide for the practical implementation of the SDGs. Social implications consist in the fact that the article has formed scientific and methodological support and revealed the applied perspective of a more complete (systemic) support of the SDGs in the oil and gas markets with the help of AI.

This article uses reliance on the experience of individual energy companies as the limitation of results obtained. This is attributable to the goal setting of this article and the intention to study the real-life experience of environmental management of companies in the oil and gas markets in the most thorough and deep way possible. Nevertheless, the focus on the case experience of Russia as an energy exporting country is the limitation of this article.

It appears that in other countries, especially in the energy importing countries, sustainability of energy companies, although being heavily dependent on of the AI era, still implies some other role of these technologies in the environmental management. While the exporting countries mainly use AI in oil and gas extraction and transportation, it is obvious that the use of AI to increase sustainability of oil and gas storage and consumption is dominant in the importing countries–it is expedient to engage in the study of relevant practices during further research following this article.

Recommendations and solution

To solve the raised problem of ensuring sustainability of energy companies in the oil and gas markets, it is suggested to increase the rate of active use of AI in the environmental management. The case experience of Russia has shown that despite diversification and success rate, the practices of using AI in the environmental management are fragmented and are implemented by individual separate companies. In this regard, the solution is involved with the institutionalization of the most advanced practices.

It is recommended, first, to use AI in the exploration and development of oil and gas fields. Second, in the "smart" oil production for the lean drilling, as well as for the prevention of accidents during oil production and prevention of environmental disasters. Third, for the monitoring of working order and equipment failure prediction and prevention to reduce environmental costs in oil engineering.

The proposed recommendations ensure the consistent use of AI throughout the life cycle in the oil and gas markets and allow for the maximum possible fulfillment of the potential of AI to support sustainable development of companies in these markets.

Conclusion and policy implications

Hence, it may be concluded that the article has filled both identified gaps in literature, having formed a new approach to the oil and gas markets–from the standpoint of environmental management of energy companies, that is, after the study of these markets at the corporate (micro-) level.

First, this article revealed the contents of the "black box" of environmental management of companies in the oil and gas markets, having demonstrated the modern real-life experience of using AI in the environmental management at each stage of life cycle in the oil and gas markets. As a result, the article has opened up possibilities to manage the environmental performance of oil and gas markets through the adjustment of the practices of environmental management of energy companies.

Second, this article has demonstrated that there is a substantial potential of using AI in the environmental management of companies in the oil and gas markets; however, the experience of Russian companies has shown that this potential has not been fully unlocked. Each company focuses on using AI at a certain life cycle stage. The prospects for the better fulfillment of this potential are involved with the consistent use of AI at all life cycle stages in the oil and gas markets.

Policy implications are involved with the need to support the institutionalization of practices of using AI in the environmental management of energy companies in the oil and gas markets. In order to have an impact on environmental management, it is expedient to promote tax and subsidiary encouragement of investments to "smart" innovations of energy companies.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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References

Agbaji, A. L. (2021). "Leadership and managerial decision-making in an AI-enabled oil and gas industry," in Society of Petroleum Engineers - Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi. ADIP 2021. doi:10.2118/207613-MS

Basile, V., Capobianco, N., and Vona, R. (2021). The usefulness of sustainable business models: Analysis from oil and gas industry. *Corp. Soc. Responsib. Environ. Manag.* 28 (6), 1801–1821. doi:10.1002/csr.2153

BCS-express (2021). Investments in artificial intelligence: A new tool at st. Petersburg. Available at: https://bcs-express.ru/novosti-i-analitika/2022088850-investitsii-v-iskusstvennyi-intellekt-novyi-instrument-na-spb (Accessed 07 07, 2022).

Blumenthal, R., El Naser, A., and Blug, C. (2020). "Generating green value from data: Applying AI-based analytics to monitor and manage energy usage across oil and gas operations," in Society of Petroleum Engineers - Abu Dhabi International Petroleum Exhibition and Conference 2020, Abu Dhabi. ADIP 2020.

ComNews (2022a). Artificial intelligence helps Rosneft in drilling. Available at: https://www.comnews.ru/content/202453/2019-10-18/2019-w42/iskusstvennyy-intellekt-pomogaet-rosnefti-burenii (Accessed 05 18, 2022).

ComNews (2022b). NOVATEK reduced drilling accident rate with the help of AI. Available at: https://www.comnews.ru/content/219388/2022-03-23/2022-w12/novatek-snizil-avariynost-bureniya-pri-pomoschi-ai (Accessed: 05 18, 2022).

David, L. O., Nwulu, N. I., Aigbavboa, C. O., and Adepoju, O. O. (2022). Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis. *J. Clean. Prod.* 363, 132522. doi:10.1016/j.jclepro.2022.132522

Desai, J. N., Pandian, S., and Vij, R. K. (2021). Big data analytics in upstream oil and gas industries for sustainable exploration and development: A review. *Environ. Technol. Innov.* 21, 101186. doi:10.1016/j.eti.2020.101186

Di, S., Cheng, S., Cao, N., Gao, C., and Miao, L. (2021). AI-based geo-engineering integration in unconventional oil and gas. *J. King Saud Univ. - Sci.* 33 (6), 101542. doi:10.1016/j.jksus.2021.101542

Energy Land (2022). Tatneft implements artificial intelligence in field development. Available at: http://energyland.info/news-show–neftegaz-196196 (Accessed 05 18, 2022).

Forbes (2022). Global 500 – 2021. Available at: https://www.forbes.com/lists/global2000/?sh=4e4a20275ac0 (Accessed 05 18, 2022).

Gazprom (2022a). Artificial intelligence in petroleum engineering: Opportunities and prospects. Available at: https://www.oil-industry.net/SD_Prezent/2021/04/Часанов%20MM.pdf (Accessed 05 18, 2022).

Guzović, Z., Duic, N., Piacentino, A., Mathiesen, B. V., and Lund, H. (2022). Recent advances in methods, policies and technologies at sustainable energy systems development. *Energy* 245, 123276. doi:10.1016/j.energy.2022.123276

Habeşoğlu, O., Samour, A., Tursoy, T., Abdullah, L., and Othman, M. (2022). A study of environmental degradation in Turkey and its relationship to oil prices and financial strategies: Novel findings in context of energy transition. *Front. Environ. Sci.* 10, 876809. doi:10.3389/fenvs.2022.876809

Hunt, J. D., Nascimento, A., Nascimento, N., Vieira, L. W., and Romero, O. J. (2022). Possible pathways for oil and gas companies in a sustainable future: From the perspective of a hydrogen economy. *Renew. Sustain. Energy Rev.* 160, 112291. doi:10.1016/j.rser.2022.112291

Ibrahim, Y. M., Hami, N., and Abdulameer, S. S. (2020). Assessing sustainable manufacturing practices and sustainability performance among oil and gas industry in Iraq. *Int. J. Energy Econ. Policy* 10 (4), 60–67. doi:10.32479/ijeep.9228

Li, H., Yu, H., Cao, N., Tian, H., and Cheng, S. (2021). Applications of artificial intelligence in oil and gas development. *Arch. Comput. Methods Eng.* 28, 937–949. doi:10.1007/s11831-020-09402-8

Ligozat, A.-L., Lefevre, J., Bugeau, A., and Combaz, J. (2022). Unraveling the hidden environmental impacts of AI solutions for environment life cycle assessment of AI solutions. *Sustainability* 14, 5172. doi:10.3390/su14095172

Liu, P., and Luo, Z. (2022). A measurement and analysis of the growth of urban green total factor productivity – based on the perspective of energy and Land elements. *Front. Environ. Sci.* 10, 838748. doi:10.3389/fenvs.2022.838748

Liu, Y., Li, Z., and Huang, L. (2022). The application of blockchain technology in smart sustainable energy business model. *Energy Rep.* 8, 7063–7070. doi:10.1016/j.egyr.2022.05.002

Maka, A. O. M., and Alabid, J. M. (2022). Solar energy technology and its roles in sustainable development. *Clean. Energy* 6 (3), 476–483. doi:10.1093/ce/zkac023

Marcon, L., Sotiri, K., Bleninger, T., Mannich, M., Männich, M., and Hilgert, S. (2022). Acoustic mapping of gas stored in sediments of shallow aquatic systems linked to methane production and ebullition patterns. *Front. Environ. Sci.* 10, 876540. doi:10.3389/fenvs.2022.876540

Margheritini, L., Colaleo, G., Contestabile, P., Simonsen, M. E., Lanfredi, C., Dell'Anno, A., et al. (2020). Development of an eco-sustainable solution for the second life of decommissioned oil and gas platforms: The mineral accretion technology. *Sustain. Switz.* 12 (9), 3742. doi:10.3390/su12093742

Moscow Exchange (2022). Index "vector of sustainable development": Database of values as of 05/18/2022. Available at: https://www.moex.com/ru/index/MRSV/constituents/(Accessed 05 18, 2022).

Perm oil (2022). Artificial intelligence in action – Lukoil. Available at: https://permneft-portal.ru/newspaper/articles/iskusstvennyy-intellekt-v-deystvii/ (Accessed 05 18, 2022).

Popkova, E. G., Inshakova, A. O., Bogoviz, A. V., and Lobova, S. V. (2021). Energy efficiency and pollution control through ICTs for sustainable development. *Front. Energy Res.* 9, 735551. doi:10.3389/fenrg.2021.735551

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Qamar, S., Ahmad, M., Oryani, B., and Zhang, Q. (2022). Solar energy technology adoption and diffusion by micro, small, and medium enterprises: Sustainable energy for climate change mitigation. *Environ. Sci. Pollut. Res.* 29 (32), 49385–49403. doi:10.1007/s11356-022-19406-5

Santillan, M. R., Syn, J. W., Charani Shandiz, S., Pires de Lacerda, M., Pires de Lacerda, M., and Rismanchi, B. (2022). A technology assessment approach for achieving sustainable communities: An energy master plan for a new urban development. *Appl. Sci. Switz.* 12 (8), 3860. doi:10.3390/app12083860

Sulistyawati, S., Iswara, A. P., and Boedisantoso, R. (2020). Impacts assessment of crude oil exploration using life cycle assessment (LCA). *IOP Conf. Ser. Earth Environ. Sci.* 506, 012025. doi:10.1088/1755-1315/506/1/012025

Vedomosti (2022). Robots are here. Available at: https://www.vedomosti.ru/partner/articles/2018/11/21/786829-roboti-zdes (Accessed 0707, 2022).

What Next (2022). Artificial intelligence and oil & gas industry – partnership towards sustainable future. Available at: https://www.whatnextglobal.com/post/artificial-intelligence-and-oil-gas-industry-partnership-towards-sustainable-future (Accessed: 05 19, 2022).

World Bank (2022). Indicators: Energy & mining. Available at: https://data.worldbank.org/indicator (Accessed 0808, 2022).

Wu, L., Yang, Y., Yan, T., Zheng, L., Qian, K., Hong, F., et al. (2020). Sustainable design and optimization of co-processing of bio-oil and vacuum gas oil in an existing refinery. *Renew. Sustain. Energy Rev.* 130, 109952. doi:10.1016/j.rser.2020.109952

Yang, X., Guo, Y., Liu, Q., and Zhang, D. (2022). Dynamic Co-evolution analysis of low-carbon technology innovation compound system of new energy enterprise based on the perspective of sustainable development. *J. Clean. Prod.* 349, 131330. doi:10.1016/j.jclepro.2022.131330

Yu, K.-H., Jaimes, E., and Wang, C.-C. (2020). "Ai based energy optimization in association with class environment," in ASME 2020 14th International Conference on Energy Sustainability, June 17–18, 2020, V001T16A004. doi:10.1115/ES2020-1696

Zhang, H., Sun, X., Ahmad, M., Lu, Y., and Xue, C. (2022). A step towards a green future: Does sustainable development policy reduce energy consumption in resource-based cities of China? *Front. Environ. Sci.* 10, 901721. doi:10.3389/fenvs.2022.901721

Zhu, S., Ota, K., and Dong, M. (2022). Green AI for IIoT: Energy efficient intelligent edge computing for industrial internet of things. *IEEE Trans. Green Commun. Netw.* 6 (1), 79–88. doi:10.1109/TGCN.2021.3100622

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AI's contribution to combating climate change and achieving environmental justice in the global economy

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Introduction

This article focuses on the category of environmental justice, the achievement of which involves reducing the inequality of the world's countries in the state of the environment and climate. Although climate change is a global problem, it manifests itself, to varying degrees, in the countries of the world. In the existing literature, in particular, in the works of Filho et al. (2022), Martín-Arias et al. (2022), Peng and Huang (2022), and Tu et al. (2022), much attention is paid to the problem of climate change and combating it (the implementation of SDG 13).

The concept of environmental justice was formed in the era of colonialism and was supplemented in the subsequent period in connection with the division of the countries of the world into developed and developing countries. At that time, environmental inequality was evident in the limited capacity of developing countries and colonies to protect the environment. The most harmful industries were located on their territory. They also acted as exporters of resources for the developed countries, depleting their mineral wealth. This implied high environmental costs of economic growth in developing countries.

In this regard, the concept of environmental justice has taken shape as equal opportunities for countries to protect the environment (Budolfson et al., 2021; Cappelli et al., 2021; Dagdeviren et al., 2021; Gazzotti et al., 2021; Pérez-Peña et al., 2021; Yang and Tang, 2022). Based on this concept, an approach to ensuring environmental justice through responsible production (corporate social responsibility) and consumption has developed (Ali et al., 2016; Anantharajah and Setyowati, 2022; Furlan and Mariano, 2022; He et al., 2022; Islam, 2022). The problem is that the concept and approach to ensuring environmental justice based on experience do not correspond to the new realities.

Over the past decades, all countries have received equal opportunities to protect the environment thanks to the coordinated efforts of the entire world community to implement the Millennium Development Goals, and then their successor, the Sustainable Development Goals (SDGs), under the auspices of the UN. Social progress and the strengthening of priorities of environmental values have contributed to the formation of sustainable communities and territories in each country and the achievement of a high level of development of responsible production and consumption. Nevertheless, there remains a noticeable gap in the "green" economy and the implementation of SDG 13 between developed and developing countries and between countries within these categories.

Thus, the new essence of environmental justice in the "Decade of Action" is not revealed in modern scientific literature, which is a research gap. Another gap is connected with the fact that the potential of scientific and technological progress, in particular, artificial intelligence (AI) as advanced technology of Industry 4.0 in terms of combating climate change, is insufficiently studied. This article is intended to fill the noted gaps in the literature and aims to analyze AI's contribution to the fight against climate change and the achievement of environmental justice in the global economy. The goal is achieved with the help of a set of the following fundamental and applied tasks:

– To rethink the meaning of environmental justice in the "Decade of Action."
– To study the current level, trends, and causes of inequality in countries in the state of the environment and climate.
– To identify the prospects for achieving environmental justice in the global economy based on the most optimal use of the potential of artificial intelligence in contributing to the fight against climate change.

The originality of the article lies in developing a new approach to achieving environmental justice in the global economy through the use of artificial intelligence as a tool to combat climate change.

Literature review

The problem of country inequality is well recognized and reflected in SDG10 and disclosed in detail in the existing literature (Goyal et al., 2021; Chia et al., 2022; Cojocaru et al., 2022). In the available publications, the difference in natural and climatic conditions is mainly considered from the standpoint of the country's wealth in natural resources for economic growth and the standpoint of the favorable climate for the development of certain sectors of the economy (e.g., agriculture) (Rahman et al., 2022; Shimada, 2022).

Thus, by now, the economic perspective of studying the environmental inequality of countries has developed and prevails (Adom and Amoani, 2021; Duan et al., 2022; Sahin and Ayyildiz, 2022). Decarbonization carried out in support of sustainable development in the current interpretation is considered a factor that limits (slows down) economic growth (Sisodia et al., 2020; Zhao et al., 2022).

The exacerbation of climate change phenomena in the "Decade of Action" highlighted a new, much less studied component of the environmental inequality of countries from the standpoint of differences in the favorable climatic conditions for human life and health (Mupedziswa and Kubanga, 2017; Štreimikienė et al., 2022).

The COVID-19 pandemic has demonstrated the dangers of climate change as a factor in disrupting ecosystems, reducing biodiversity, and spreading zoonotic diseases (Harjoto et al., 2021; Sergi et al., 2021; Popkova et al., 2022; Stuart et al., 2022). Climate anomalies (abnormal frosts and droughts) that have become more frequent during the "Decade of Action" have focused attention on climate change as a factor in the quality of life and sustainable development of society (Mocuta, 2017; Ptak-Wojciechowska et al., 2021).

The review of the literature revealed the insufficient development of the social perspective of the environmental inequality of countries. In particular, the theoretical and methodological basis for assessing climate inequality has not been formed, which is a gap in the literature. The prospects for reducing environmental inequality and achieving environmental justice in the global economy are also unclear, which is another gap in the literature.

This raises a research question (RQ) about how to achieve environmental justice in the global economy. This study hypothesizes that the fight against climate change based on artificial intelligence (AI) will achieve environmental justice in the global economy. In order to fill in the identified gaps, search for an answer to the set RQ and test the hypothesis put forward, this article conducts a quantitative and qualitative study: based on quantitative methodology (method of analysis of variation), environmental inequality of countries is monitored, and based on qualitative analysis (method of a case study), it defines the contribution of AI to the fight against climate change and the achievement of environmental justice in the global economy.

Environmental justice: A new meaning in the "decade of action"

The theoretical foundation of this research is the concept of social justice. Forsyth and McDermott (2022) identified the effects of alienation and deep co-production in transformative environmental science and policy, through which they described the signs of a violation of climate justice and justified ways to restore it. Zeng et al. (2022) showed a strong relationship between environmental justice and health risks (using the example of Shanghai, China).

Du and Sun (2022a) developed a benefit-sharing model for cooperative air pollution prevention and control in China and also offered recommendations for using this model to achieve environmental justice. Smith and Wodajo (2022) substantiated the relationship between climate justice and environmental

TABLE 1 Climate index in the G7 and the BRICS countries in 2018–2022.

Category	Country	Climate index, score 0-200				
		2018	2019	2020	2021	2022
The G7 countries	Canada	52.82	52.55	50.57	56.75	55.98
	France	89.80	88.25	90.25	89.94	89.70
	Germany	82.53	82.51	83.00	82.97	82.44
	Italy	91.38	91.25	92.27	91.48	91.45
	Japan	84.82	84.79	84.79	85.27	85.27
	United Kingdom	87.92	87.82	87.62	88.04	88.06
	United States	78.23	77.51	77.54	77.28	76.78
The BRICS countries	Brazil	94.23	95.35	97.16	92.39	97.15
	China	78.81	78.91	79.19	80.15	78.41
	India	65.68	65.74	64.87	65.30	65.13
	Russia	44.70	46.53	40.36	38.46	48.95
	South Africa	95.98	95.97	95.25	95.25	95.25
Analytics	Average for the G7 countries (points)	81.07	80.67	80.86	81.68	81.38
	Variation on the G7 countries (%)	16.33	16.33	17.58	14.66	15.03
	Average for the BRICS countries (points)	75.88	76.50	75.37	74.31	76.98
	Variation on the BRICS countries (%)	28.15	27.37	31.26	31.31	26.53
	The percentage ratio of the average for the G7 countries to the average for the BRICS countries	6.84	5.45	7.29	9.91	5.72
	Variation across the entire sample of 12 countries	20.77	20.38	22.77	21.64	19.41

justice. Martín (2022) identified the evolution of climate action in the environmental justice movement, 2010–2020.

Medina et al. (2022) proved the need for an environmental justice approach to wastewater epidemiology for rural and disadvantaged communities (California, United States). Reeder et al. (2022) argued for the key role of environmental justice organizations and the spread of conflict over mining in Latin America. In turn, Gouveia et al. (2022) proved the connection between air pollution and environmental justice in Latin America.

Du and Sun (2022b) argued the need for collaborative air pollution prevention and control from a global community environmental justice perspective (based on a two-stage dynamic game model). Hope (2022) identified the phenomenon of globalization of sustainable development using the example of decolonial destruction and environmental justice in Bolivia. Jiang and Yang (2022) argued for the significant impact of spatial and ethnic factors on the socioeconomic status, health of residents, and environmental justice in Greater Los Angeles. Carvalho et al. (2022) proposed inequality scales to determine the role of spatial extent in environmental justice analysis.

In the 21st century, the world has entered the era of global equality of opportunities and freedoms, supported by globalization. This requires a revision of the concept of environmental justice because, despite the same opportunities for countries in the fight against climate change, they achieve significantly different results in implementing SDG 13. Therefore, equality of opportunity does not guarantee the same progress for countries in the fight against climate change and, therefore, is not identical to environmental justice.

In the “Decade of Action,” results come to the fore—it is in the light of the results of the implementation of the SDGs that the sustainability of each country and the world economy as a global system is assessed. Therefore, a new interpretation of environmental justice is proposed as the degree of environmental inequality (i.e., uniformity of results in the fight against climate change). Clarification of this concept makes it possible to reliably quantify environmental justice in the global economy.

Inequality of countries in the state of the environment and climate: current level, trends, and reasons

In order to quantify the inequality of countries in the state of the environment and climate, the authors used the Numbeo (2022) statistics for 2018–2022 in developed countries (using the example of the G7) and in developing countries (using the example of the BRICS), as shown in Table 1.

Source: calculated and compiled by the authors based on the materials of Numbeo (2022).

As calculated in Table 1, global environmental inequality (variation across the entire sample) is quite large: in 2018, it was 20.77%; in 2020, against the background of the COVID-19 pandemic, it increased to 22.77%; and in 2022, it decreased to 19.41%. Overall, it remained at a high level. Among the BRICS countries (26.53% in 2022), environmental inequality is higher than among the G7 countries (15.03% in 2022). The percentage ratio of the average for the G7 countries (81.38 points in 2022) to the average for the BRICS countries (76.98 points in 2022) is also very high −26.53% in 2022, although it has decreased compared to 2021, when it was 31.31%. The causes of environmental inequality are the following:

– Limited opportunities for climate change forecasting;
– Insufficient awareness of climate change risks and opportunities to reduce them;
– The complexity of introducing innovations (e.g., "clean" energy and "green" transport) in the fight against climate change.

Responsible production and consumption cannot fully eliminate the above reasons. Consequently, ensuring environmental justice in the "Decade of Action" lies beyond social progress. In this regard, it is advisable to determine whether technological progress (AI) can overcome this limitation and provide instrumental support for environmental justice.

Prospects for achieving environmental justice in the global economy based on the optimal use of the potential of artificial intelligence to contribute to the fight against climate change

To determine AI's contribution to the fight against climate change, which was partially considered only in separate works by Bartmann (2022), Gooroochurn et al. (2022), and Popkova et al. (2020), a review of international experience was conducted. This made it possible to identify the prospects for achieving environmental justice in the global economy based on the optimal use of the potential of artificial intelligence to contribute to the fight against climate change.

These prospects are connected, firstly, with high-precision forecasting (short-, medium-, and long-term) and scenario analysis of climate change using AI. As demonstrated by the best experience of the American startup "Terrafuse AI," the advantages of using AI in the fight against climate change can be the detection of climatic anomalies (forest fires, changes in the natural habitat of various species on land and the sea) and predicting their occurrence (Share America, 2022).

Secondly, AI can provide automated information support to the broad masses of the population (and business) on climate change issues, measures taken to slow down this process, and practical climate solutions available to everyone. This will involve the whole society in the fight against climate change. A successful example is the AI system "LaMDA," launched by Google as a chatbot for users (Davis, 2022).

Thirdly, AI can generate applied innovations, considering the sectoral characteristics of the economy. For example, the World Meteorological Organization uses AI to prevent natural disasters, reduce greenhouse gas emissions, and develop "clean" energy and "green" transport in the international fight against climate change (Federal Service for Hydrometeorology and Environmental Monitoring(Roshydromet), 2022).

Discussion

The contribution of the article to the literature consists of clarifying the essence of environmental justice as a criterion and target of environmental economics and management. The scientific novelty of the research and the results obtained in the article consist of rethinking the concept and essence of environmental justice, considering the new, modern realities of the "Decade of Action." In contrast to existing works (Budolfson et al., 2021; Cappelli et al., 2021; Dagdeviren et al., 2021; Gazzotti et al., 2021; Pérez-Peña et al., 2021; Yang and Tang, 2022), the authors proposed to define environmental justice not from the standpoint of equality of opportunities, but equality of results in protecting the environment and combating climate change. The author's definition provides new opportunities for determining (in particular, for quantitative measurement) and studying changes in environmental justice.

According to the updated definition, a new approach to ensuring environmental justice using high technologies of industry 4.0, and first of all AI, has been proposed. In contrast to the existing publications (Ali et al., 2016; Anantharajah and Setyowati, 2022; Furlan and Mariano, 2022; He et al., 2022; Islam, 2022), the article proposes to combat climate change based not on social but technological progress. In addition, the article determines the causes of climate change and demonstrates that social factors only indirectly affect them, while technological factors make it possible to eliminate these causes. The proposed new approach is based on international best practices and therefore opens up wide opportunities for highly effective practical use of AI in the integrated fight against climate change.

Conclusion

Rethinking the meaning of environmental justice in the "Decade of Action" and comparing the results in the field of environmental protection and combating climate change to measure environmental inequality are the results of the study. Guided by the new meaning of environmental justice, its assessment was made, which revealed that the degree of environmental inequality is high (climate variation: 19.41%), it increased in the conditions of the COVID-19 pandemic in 2020–2021; and in 2022, it began to decrease but remained high.

Quantitative analysis of ecological inequality in the state of the environment and climate in the dynamics of 2018–2022 in developed (on the example of the G7) and in developing (on the example of the BRICS) countries is supplemented by a qualitative analysis showing that the way to achieve environmental justice lies not in the field of social progress but the field of technological progress.

Prospects have been identified, and recommendations have been proposed to achieve environmental justice in the global economy based on the most optimal use of the potential of artificial intelligence to contribute to the fight against climate change. In particular, 1) high-precision forecasting, 2) automated increase in environmental awareness of the population, and 3) the creation of applied innovations specific to each sector of the economy using AI are proposed.

The theoretical significance of the article (the contribution of the article to the literature) is to clarify the essence of environmental justice in the global economy and reveal the potential of artificial intelligence to help combat climate change in the interests of ensuring environmental justice in the global economy. The practical significance of the results obtained in the article is that they have formed an instrumental apparatus for achieving environmental justice in the world economy.

The authors' recommendations are of interest and value to the state and supranational (e.g., the UN) environmental regulators, as they offer a new promising solution to the problem of achieving environmental justice in the global economy. The social significance of the article is that its results make it possible to increase the effectiveness of the fight against climate change and accelerate the achievement of environmental justice in the global economy.

The novelty of the article and its contribution to the existing literature is that the results obtained have strengthened the theory and methodology for assessing and analyzing environmental justice in the global economy. The concept of environmental justice is rethought in the article from the standpoint of sustainable development in the "Decade of Action." In the updated concept, environmental justice has received a more accurate and reliable measurement from the standpoint of the results of SDG13 in the field of combating climate change.

The consequences of the results for practice are related to the fact that clarifying the cause-and-effect relationships of environmental inequality, achieved in the article, opens up opportunities for its identification, systematic monitoring, and overcoming. The author's theoretical interpretation and improved methodology for assessing environmental inequality make it possible to monitor environmental inequality based on annual reports on the SDGs, in particular, complete, transparent, and open UN reports on sustainable development.

The practical value and significance of the results obtained in the article also lie in the fact that they proved the limitations of existing technologies in measuring and overcoming environmental inequality. AI is proposed as a promising technology for combating climate change and achieving environmental justice in the global economy, as well as the current directions for its use.

As a result, the article has formed a clear vision and offered practical recommendations for improving the current practice of combating environmental inequality in the global economy. The practical management implications of the article are to substantiate the need for systematic implementation of SDG10 and SDG13, reveal the prospects, and develop applied recommendations for achieving this based on combating climate change based on AI.

The limitation of the research is the isolated consideration of technological progress in the AI era as a source of environmental justice in the global economy. While this allowed for the most accurate and reliable characterization of the potential of this source, it left other sources unconsidered. As shown in the article, social progress alone is insufficient to fully achieve environmental justice in the global economy.

Nevertheless, a combination of social and technological progress may help achieve more significant results due to the synergistic effect of socioeconomic development. In this regard, the role of social progress in the fight against climate change, if it is systematically achieved, together with technological progress, deserves to be studied. The prospects for future academic pursuits are related to the systematic study of the sources of environmental justice in the global economy, in particular, technological and social progress.

Author contributions

Idea: VO and TS. Abstract: VO and TS. Keywords: TS. Introduction: TV. Methodology: VO and TS. Research: VO and TS. Discussion: VO and TS. Conclusion: VO and TS. References: TS.

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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References

Adom, P. K., and Amoani, S. (2021). The role of climate adaptation readiness in economic growth and climate change relationship: An analysis of the output/ income and productivity/institution channels. *J. Environ. Manag.* 293, 112923. doi:10.1016/j.jenvman.2021.112923

Ali, H., Dumbuya, B., Hynie, M., Keil, R., and Perkins, P. (2016). The social and political dimensions of the ebola response: Global inequality, climate change, and infectious disease. in *Climate change management*, (Cham: Springer), 151–169. doi:10.1007/978-3-319-24660-4_10

Anantharajah, K., and Setyowati, A. B. (2022). Beyond promises: Realities of climate finance justice and energy transitions in Asia and the Pacific. *Energy Res. Soc. Sci.* 89, 102550. doi:10.1016/j.erss.2022.102550

Bartmann, M. (2022). The ethics of AI-powered climate nudging—how much AI should we use to save the planet? *Sustain. Switz.* 14 (9), 5153. doi:10.3390/su14095153

Budolfson, M., Dennig, F., Errickson, F., Ferranna, M., Fleurbaey, M., Wagner, F., et al. (2021). Climate action with revenue recycling has benefits for poverty, inequality and well-being. *Nat. Clim. Chang.* 11 (12), 1111–1116. doi:10.1038/ s41558-021-01217-0

Cappelli, F., Costantini, V., and Consoli, D. (2021). The trap of climate change-induced "natural" disasters and inequality. *Glob. Environ. Change* 70, 102329. doi:10.1016/j.gloenvcha.2021.102329

Carvalho, C., Del Campo, A. G., and de Carvalho Cabral, D. (2022). Scales of inequality: The role of spatial extent in environmental justice analysis. *Landsc. Urban Plan.* 221, 104369. doi:10.1016/j.landurbplan.2022.104369

Chia, P. S., Law, S. H., Trinugroho, I., Damayanti, S. M., and Sergi, B. S. (2022). Dynamic linkages among transparency, income inequality and economic growth in developing countries: Evidence from panel vector autoregressive (PVAR) model. *Res. Int. Bus. Finance* 60, 101599. doi:10.1016/j.ribaf.2021.101599

Cojocaru, T. M., Ionescu, G. H., Firoiu, D., Oțil, M. D., Oțil, M. D., and Toma, O. (2022). Reducing inequalities within and among EU countries—assessing the achievement of the 2030 agenda for sustainable development targets (SDG 10). *Sustain. Switz.* 14 (13), 7706. doi:10.3390/su14137706

Dagdeviren, H., Elangovan, A., and Parimalavalli, R. (2021). Climate change, monsoon failures and inequality of impacts in South India. *J. Environ. Manag.* 299, 113555. doi:10.1016/j.jenvman.2021.113555

Davis, A. (2022). The race to understand the exciting and dangerous world of language and AI. URL: https://ru.print-it-online.at/race-understand-exhilarating (data accessed: 19.05.2022).

Du, J., and Sun, L. (2022a). A benefit allocation model for the joint prevention and control of air pollution in China: In view of environmental justice. *J. Environ. Manag.* 315, 115132. doi:10.1016/j.jenvman.2022.115132

Du, J., and Sun, L. (2022b). Reflection on the joint prevention and control of air pollution from the perspective of environmental justice—insights from a two-stage dynamic game model. *Environ. Sci. Pollut. Res.* 29 (27), 40550–40566. doi:10.1007/ s11356-021-17911-7

Duan, H., Yuan, D., Cai, Z., and Wang, S. (2022). Valuing the impact of climate change on China's economic growth. *Econ. Analysis Policy* 74, 155–174. doi:10. 1016/j.eap.2022.01.019

Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) (2022). Climate change: Newsletter, No. 89 february-march 2021 URL: https://meteoinfo.ru/images/misc/izmenenie_klimata-h/izmenenie_klimata_n89.pdf (data accessed: 19.05.2022).

Filho, W. L., Hickmann, T., Nagy, G. J., Sharifi, A., Minhas, A., García Vinuesa, A., et al. (2022). The influence of the corona virus pandemic on sustainable development goal 13 and united nations framework convention on climate change processes. *Front. Environ. Sci.* 10, 784466. doi:10.3389/fenvs.2022.784466

Forsyth, T., and McDermott, C. L. (2022). When climate justice goes wrong: Maladaptation and deep co-production in transformative environmental science and policy. *Polit. Geogr.* 98, 102691. doi:10.1016/j.polgeo.2022.102691

Furlan, M., and Mariano, E. (2022). A confirmatory factor model for climate justice: Integrating human development and climate actions in low carbon economies. *Environ. Sci. Policy* 133, 17–30. doi:10.1016/j.envsci.2022.03.004

Gazzotti, P., Emmerling, J., Marangoni, G., Wijst, K. I. v. d., Hof, A., Tavoni, M., et al. (2021). Persistent inequality in economically optimal climate policies. *Nat. Commun.* 12 (1), 3421. doi:10.1038/s41467-021-23613-y

Gooroochurn, M., Mallet, D., Jahmeerbacus, I., Shamachurn, H., and Sayed Hassen, S. Z. (2022). A framework for AI-based building controls to adapt passive measures for optimum thermal comfort and energy efficiency in tropical climates. *Lect. Notes Netw. Syst.* 359, 526–539. doi:10.1007/978-3-030-89880-9_39

Gouveia, N., Slovic, A. D., Kanai, C. M., and Soriano, L. (2022). Air pollution and environmental justice in Latin America: Where are we and how can we move forward? *Curr. Environ. Health Rep.* 9 (2), 152–164. doi:10.1007/s40572-022-00341-z

Goyal, S., Agrawal, A., and Sergi, B. S. (2021). Social entrepreneurship for scalable solutions addressing sustainable development goals (SDGs) at BoP in India. *Qual. Res. Organ. Manag. Int. J.* 16 (3-4), 509–529. doi:10.1108/qrom-07-2020-1992

Harjoto, M. A., Rossi, F., Lee, R., and Sergi, B. S. (2021). How do equity markets react to COVID-19? Evidence from emerging and developed countries. *J. Econ. Bus.* 115, 105966. doi:10.1016/j.jeconbus.2020.105966

He, B.-J., Zhao, D., Dong, X., Feng, C., Qi, Q., Sharifi, A., et al. (2022). Perception, physiological and psychological impacts, adaptive awareness and knowledge, and climate justice under urban heat: A study in extremely hot-humid chongqing, China. *Sustain. Cities Soc.* 79, 103685. doi:10.1016/j.scs.2022.103685

Hope, J. (2022). Globalising sustainable development: Decolonial disruptions and environmental justice in Bolivia. *Area* 54 (2), 176–184. doi:10.1111/area.12626

Islam, M. M. (2022). Distributive justice in global climate finance – recipients' climate vulnerability and the allocation of climate funds. *Glob. Environ. Change* 73, 102475. doi:10.1016/j.gloenvcha.2022.102475

Jiang, Y., and Yang, Y. (2022). Environmental justice in greater Los angeles: Impacts of spatial and ethnic factors on residents' socioeconomic and health status. *Int. J. Environ. Res. Public Health* 19 (9), 5311. doi:10.3390/ijerph19095311

Martín, C. E. (2022). The evolution of climate action in the environmental justice movement, 2010-2020. *Environ. Justice* 15 (3), 170–178. doi:10.1089/env.2021.0062

Martín-Arias, V., Evans, C., Griffin, R., Lee, C. M., Mishra, D. R., Jay, J. A., et al. (2022). Modeled impacts of LULC and climate change predictions on the hydrologic regime in Belize. *Front. Environ. Sci.* 10, 848085. doi:10.3389/fenvs. 2022.848085

Medina, C. Y., Kadonsky, K. F., Roman, F. A., Sinclair, R. G., D'Aoust, P. M., Bischel, H. N., et al. (2022). The need of an environmental justice approach for wastewater based epidemiology for rural and disadvantaged communities: A review in California. *Curr. Opin. Environ. Sci. Health* 27, 100348. doi:10.1016/j.coesh.2022. 100348

Mocuta, D. N. (2017). Influence of the climate changes on the human life quality, in rural areas. *Rev. Chim.* 68 (6), 1392–1396. doi:10.37358/rc.17.6.5680

Mupedziswa, R., and Kubanga, K. P. (2017). Climate change, urban settlements and quality of life: The case of the Southern African Development Community region. *Dev. South. Afr.* 34 (2), 196–209. doi:10.1080/0376835x.2016.1231057

Numbeo (2022). Climate index by country 2018-2022. URL: https://www.numbeo.com/quality-of-life/rankings_by_country.jsp?title=2022&displayColumn=8 (data accessed: 19.05.2022).

Peng, M., and Huang, H. (2022). The synergistic effect of urban canyon geometries and greenery on outdoor thermal comfort in humid subtropical climates. *Front. Environ. Sci.* 10, 851810. doi:10.3389/fenvs.2022.851810

Pérez-Peña, M. C., Jiménez-García, M., Ruiz-Chico, J., and Peña-Sánchez, A. R. (2021). Analysis of research on the sdgs: The relationship between climate change, poverty and inequality. *Appl. Sci. Switz.* 11 (19), 8947. doi:10.3390/app11198947

Popkova, E., Alekseev, A. N., Lobova, S. V., and Sergi, B. S. (2020). The theory of innovation and innovative development. AI scenarios in Russia. *Technol. Soc.* 63, 101390. doi:10.1016/j.techsoc.2020.101390

Popkova, E. G., Bogoviz, A. V., Lobova, S. V., Sozinova, A. A., and Sergi, B. S. (2022). Changing entrepreneurial attitudes for mitigating the global pandemic's social drama. *Humanit. Soc. Sci. Commun.* 9 (1), 141. doi:10.1057/s41599-022-01151-2

Ptak-Wojciechowska, A., Januchta-Szostak, A., Gawlak, A., and Matuszewska, M. (2021). The importance of water and climate-related aspects in the quality of urban life assessment. *Sustain. Switz.* 13 (12), 6573. doi:10.3390/su13126573

Rahman, S., Anik, A. R., and Sarker, J. R. (2022). Climate, environment and socio-economic drivers of global agricultural productivity growth. *Land* 11 (4), 512. doi:10.3390/land11040512

Reeder, B. W., Arce, M., and Siefkas, A. (2022). Environmental justice organizations and the diffusion of conflicts over mining in Latin America. *World Dev.* 154, 105883. doi:10.1016/j.worlddev.2022.105883

Sahin, G., and Ayyildiz, F. V. (2022). An investigation of climate change within the framework of a schumpeterian economic growth model. in *Palgrave studies in sustainable business in association with future earth*, London: Palgrave Macmillian, 185–213. doi:10.1007/978-3-030-86803-1_9

Sergi, B. S., Harjoto, M. A., Rossi, F., and Lee, R. (2021). Do stock markets love misery? Evidence from the COVID-19. *Finance Res. Lett.* 42, 101923. doi:10.1016/j.frl.2021.101923

Share America (2022). On land and in the oceans: American innovative startup helps protect the environment. URL: https://share.america.gov/ru/на-суше-и-в-океанач-американский-иннов/(data accessed: 19.05.2022).

Shimada, G. (2022). The impact of climate-change-related disasters on africa's economic growth, agriculture, and conflicts: Can humanitarian aid and food assistance offset the damage? *Int. J. Environ. Res. Public Health* 19 (1), 467. doi:10.3390/ijerph19010467

Sisodia, G. S., Awad, E., Alkhoja, H., and Sergi, B. S. (2020). Strategic business risk evaluation for sustainable energy investment and stakeholder engagement: A proposal for energy policy development in the Middle East through khalifa funding and land subsidies. *Bus. Strategy Environ.* 29 (6), 2789–2802. doi:10.1002/bse.2543

Smith, M. D., and Wodajo, T. (2022). New perspectives on climate equity and environmental justice. *Bull. Am. Meteorol. Soc.* 103 (6), E1522–E1530. doi:10.1175/BAMS-D-22-0032.1

Štreimikienė, D., Samusevych, Y., Bilan, Y., Vysochyna, A., and Sergi, B. S. (2022). Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security. *Environ. Sci. Pollut. Res.* 29 (5), 7917–7935. doi:10.1007/s11356-021-16239-6

Stuart, D., Petersen, B., and Gunderson, R. (2022). Shared pretenses for collective inaction: the economic growth imperative, COVID-19, and climate change. *Globalizations* 19 (3), 408–425. doi:10.1080/14747731.2021.1943897

Tu, C., Ma, H., Li, Y., You, Z. J., Newton, A., Luo, Y., et al. (2022). Transdisciplinary, Co-designed and adaptive management for the sustainable development of rongcheng, a coastal city in China in the context of human activities and climate change. *Front. Environ. Sci.* 10, 670397. doi:10.3389/fenvs.2022.670397

Yang, X., and Tang, W. (2022). Climate change and regional inequality: The effect of high teperatures on fiscal stress. *Urban Clim.* 43, 101167. doi:10.1016/j.uclim.2022.101167

Zeng, P., Sun, F., Shi, D., Zhang, R., Tian, T., Che, Y., et al. (2022). Integrating anthropogenic heat emissions and cooling accessibility to explore environmental justice in heat-related health risks in Shanghai, China. *Landsc. Urban Plan.* 226, 104490. doi:10.1016/j.landurbplan.2022.104490

Zhao, Y., Su, Q., Li, B., Wang, X., Zhao, H., Guo, S., et al. (2022). Have those countries declaring "zero carbon" or "carbon neutral" climate goals achieved carbon emissions-economic growth decoupling? *J. Clean. Prod.* 363, 132450. doi:10.1016/j.jclepro.2022.132450

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The role of education and social policy in the development of responsible production and consumption in the AI economy

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university education, social policy, responsible production and consumption, environmental AI economy, SDG 12, Kyrgyz Republic

Introduction

Responsible production and consumption is one of the key mechanisms of the environmental economy. The advantage of this mechanism is its market nature. An alternative (or complementary) mechanism of state regulation involves, for example, the introduction of environmental norms and standards, taking into account the strategic priorities of the economic system (Peng and Jiang, 2021). Its disadvantage is a certain disconnection from economic reality and generalization, as a result of which the environmental practices provided by this mechanism may be formal and limited due to the narrow framework outlined by the state.

In contrast, responsible production and consumption is associated with increased flexibility and includes a much wider range of eco practices. And these practices are based on the actual current opportunities of business and society, providing fertile ground for the implementation of their "green" initiatives. Voluntary environmental protection based on altruism implies a more thoughtful and serious approach, as well as a strict focus on achieving concrete outcomes, thereby eliminating formality and false results (Liu et al., 2021; Ravina-Ripoll et al., 2021; Smith et al., 2021; Whitson and French, 2021; Vecchi, 2022).

The formation of the environmental AI economy in the context of industry 4.0 has endowed "smart" technologies (automation tools controlled by artificial intelligence) with a key role in responsible production and consumption. Advanced production and consumption technologies really contribute to the introduction of "green" innovations in many ways, increasing the degree of control over the consumption of natural resources and production waste, as well as providing intellectual support for their reduction (Schwartz et al., 2020; Bianchet et al., 2021; König et al., 2022).

The problem is that the high level of digital competitiveness of the AI economy does not guarantee its great contribution to environmental protection. For example, the global leaders of responsible production and consumption according to the *UNDP, (2022)* on the countries' progress towards achieving SDG 12 in 2021 are Ethiopia (96.1588 points, 1st place), Mozambique (96.1192 points, 2nd place), Benin (96.0360 points, 3rd place) and other countries that are not even included the IMD World Digital Competitiveness ranking (2022), while the SDG 12 Index of the AI economies leading the *IMD (2022)* is low. For example, Singapore ranks 178th (16.3123 points), Iceland—175th (28.5343 points), Switzerland—173rd (39.4245 points) in the UNDP ranking (2022).

In the existing literature, Amos and Lydgate (2020), Cappelen and Ognedal (2017), Jacob-John et al. (2021), Palakshappa and Dodds (2021) the issues of responsible and consumption are covered in sufficient detail. Digital competitiveness as the basis for the development of the AI economy is considered in the publications of Anisha et al. (2022), Cheng et al. (2022), Vekaria et al. (2021). The importance of the development of responsible and consumption in the environmental AI economy is noted and emphasized in the works of Fraga-Lamas et al. (2021), Ruffolo (2022), Wilson et al. (2022). However, the cause-and-effect relationships and features of the development of responsible production and consumption in the AI economy remain poorly understood and insufficiently developed in the available literature.

Consequently, there is a gap in the logical chain of development of responsible production and consumption in the environmental AI economy. The originality of this study lies in the fact that it critically re-examines the scientific concept of the economy of artificial intelligence and the essence of the Fourth Industrial Revolution. The article substantiates that the main source of development of responsible production and consumption in the environmental AI economy is the increase in the level of environmental awareness in society and business. The purpose of the article is to study the role of education and social policy in the development of responsible production and consumption in the AI economy.

Case experience of the Kyrgyz republic in the development of responsible production and consumption in the artificial intelligence economy based on education and social policy

The experience of the Kyrgyz Republic, which demonstrated serious results in the practical implementation of SDG 12 (86.505 points according to the *UNDP, 2022*), is also very notable. Though the statistics of *IMD (2022)* and *Times Higher Education (2022)* are not available for the Kyrgyz Republic, its case experience shows that knowledge and its diffusion are very important for the development of the responsible production and consumption.

The Concept of the green economy of the Kyrgyz Republic "Kyrgyzstan – country of the green economy", which was adopted by the decree of the Jogorku Kenesh of the Kyrgyz Republic (2022) dated 28 June 2018, No. 2532-VI, notes the necessity and planned measures on the increase of awareness and development of environmental education as a very important direction of the green economy. "Green thinking, green upbringing, green education" were adopted as a special "green" direction of the Kyrgyz Republic. In this context, the following measures of stimulating the domestic production and consumption through the development of education and diffusion of knowledge are implemented:

- Using the 3R principle in the development of green thinking: Reduce (consumption), Reuse, and Recycle;
- Multiple courses on the foundations of environmental knowledge in the educational establishments of all levels of the educational system;
- Environmental upbringing and education for sustainable development;
- Large-scale training of specialists on the issues of ecology, nature protection, and the green economy;
- Training programs on the development of green entrepreneurship;
- Dissemination of traditional folk knowledge in nature used, reflected in national epic, sagas, legends, and literary works of Kyrgyz writers, which foster humans' caring attitude toward nature, flora, and fauna;
- 'Environmental informational and educational centres, which are oriented at the work with the population based on specially protected areas;
- Green PR in mass media, publication of popular scientific literature on the issues of preservation of biodiversity, regular preparation and publication of annual overview on biological resources and biodiversity, publication of school and university study guides in view of the specifics of the biodiversity of the Kyrgyz Republic.

The report on the course of achievement of the Sustainable Development Goals in Kyrgyzstan, prepared by the UN interdepartmental task force within the MAPS mission (2022), notes that the basis of the provision of transitioning to the rational models of consumption and production (achievement of SDG 12) includes the increase in the level of education and awareness of the current problems of environment and the opportunities to solve them in the practice of business and households.

Literature review and gap analysis

The fundamental basis of this study is the Theory of Ecological Economics, according to which the ecological economy is defined as a set of economic practices and economic systems that support and contribute to sustainable development: the implementation of sustainable development goals (SDGs) (Ali et al., 2022; Singh et al., 2022; Li et al., 2022; Zhou et al., 2022). Artificial intelligence (AI) is treated in the existing literature as an end-to-end Industry 4.0 technology (Patel et al., 2018; Hayhoe et al., 2019; Jin, 2019; Mhlanga, 2020; Paynabar and Callicott, 2021; Spanaki et al., 2021).

The concept of an ecological AI economy interprets it as an economy in which artificial intelligence (AI) is widespread and actively used to support sustainable development and the implementation of the SDGs (Cao et al., 2021; Khan et al., 2021; Dragomir, 2022; Dwivedi and Paul, 2022; Howe et al., 2022; Jia et al., 2022; Xu et al., 2022).

In their works, Pan et al. (2020) define social policy as a direction of state economic policy designed to improve the quality of life of the population through support for employment and social adaptation to changes (economic crises, scientific and technological progress). So that social policy does not undermine the population's initiatives to improve the quality of life, it is necessary to preserve the market mechanism. In this regard, the development of education is a promising tool of social policy, as it expands employment opportunities and increases the income of the population while maintaining market relations in the labour market.

In the existing literature, Dimitropoulos et al. (2021), Wearn et al. (2019), the Fourth Industrial Revolution is interpreted as a path to automation—the replacement of humans with machines. Artificial intelligence is considered a non-human subject of management, which ensures responsible (more economical use of natural resources) production and consumption through strict measures and total control. From the standpoint of responsible production and consumption, the environmental AI economy is interpreted as a cyber-ecological system in which artificial intelligence acts as the controlling entity and the environment is the controlled object (Pan et al., 2020; Zhang et al., 2020).

Although the potential of artificial intelligence to protect the environment (for example, through automated waste sorting, high-tech circular production, and monitoring of waste disposal through AI-controlled machine vision) is well known and high, it remains unclear how this potential is realized in practice. The uncertainty of the causal relationships between the development of responsible production and consumption in the environmental AI economy is a gap in the literature, which this article aims to fill.

The works of (Fai Pun 2006), Pérez et al. (2021), Rezaei et al. (2021) (Singh et al., 2022), note that the subject of responsible production and consumption is a human being. Studies by Dzindolet et al. (2006), Karim et al. (2022) indicate that there are two subjects in automated production and consumption processes at once—although artificial intelligence performs command functions, as well as execution and control ones, the decision-making function is performed by a human. This means that responsibility is human property, not artificial intelligence.

The works of D'Souza et al. (2022), Li and Wang (2022), Mamzer et al. (2021) indicate that environmental responsibility is rooted in human nature (a part of a human being). In terms of practice, it can be seen that the ecological economy develops as knowledge about the environment and ways to protect it is gained. "Green" innovations are created purposefully in response to identified and widely publicized environmental problems and are implemented only if they have benefits for the environment. That is, the environmental economy is rooted in social progress.

Based on this, the article raises a research question (RQ) about the role of education and social policy in the development of responsible production and consumption in the AI economy, and also puts forward the hypothesis that responsible production and consumption are achieved by increasing the level of public consciousness, diffusion of new knowledge and technologies. The hypothesis states that responsible production and consumption act as humanity's initiative to protect the environment, which is based on the knowledge gained.

Methodology

The basis of the research conducted in this article is an empirical analysis of the role of education and social policy in the development of responsible production and consumption in the AI economy. To obtain the most accurate and reliable results, the article relies on econometric methodology, as it allows using the mathematical apparatus in the study.

To take into account the special context of the era of artificial intelligence, *IMD (2022)* is chosen as a source of data on social policy. Education in the era of artificial intelligence is specific and involves the training of digital personnel - this feature is taken into account and reflected by IMD statistics (2022). "Knowledge" and "knowledge transfer" are chosen as indicators of social policy, since they collectively represent the creation and dissemination of knowledge in the AI economy.

Times Higher Education (2022) "Impact Rankings 2021: responsible consumption and production" was chosen as an indicator of the development of education for responsible production and consumption since this indicator most accurately reflects the contribution of higher education to responsible production and consumption and allows us to quantify this contribution.

As a result in the field of responsible production and consumption in the AI economy, the progress achieved in the implementation of SDG12 is assessed by *UNDP (2022)* as the most reliable and authoritative source of statistics in the field of sustainable development and the implementation of the SDGs.

To form a representative sample, it includes developed and developing countries that show the best values in the *Times Higher Education (2022)*, from different geographical regions of the world: Europe (United Kingdom, Ireland, Russia), America (United States, Canada, Mexico) and Asia (Thailand, Indonesia, Saudi Arabia), Oceania (Australia). To take into account the characteristics of developed and developing countries, their experience is studied separately. The study is based on data for 2021.

To determine the relationship between responsible production and consumption and its support in society and university education, the method of correlation analysis was chosen. The choice of this method is explained by the fact that it allows establishing relationships between variables without the need to separate them into factor and result variables. This is valuable for this article since from a qualitative point of view it is impossible to state categorically what is primary (and what is secondary): the development of education and social policy or responsible production and consumption.

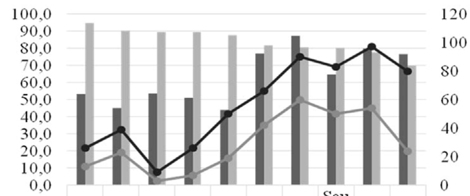
The regression analysis method, which uses equations of type Y = a + bX to predict the value of dependent variable Y according to the known value of independent variable X, serves as a potential alternative in this paper. In contrast to it, the statistical concept of correlation measures the direction and intensity of the relation between the two number variables.

Since all the variables under consideration are social in nature, they are closely interrelated in a cohesive way. Thus, a preliminary qualitative analysis shows that, on the one hand, the implementation of social policy through the development of education is based on the current level of progressiveness of society, which characterizes and ensures responsible production and consumption in the AI economy. On the other hand, the implementation of social policy through the development of education is instrumental in social progress and promotes responsible production and consumption in the AI economy.

The above-described two-way relation between variables in the continuous cycle of social progress is indicative of a consistent interrelation between the indicators under consideration. As a result, it is difficult and even incorrect to divide them into factor variables and resulting variables, since all of them are equivalent. Therefore, the correlation analysis is preferred in this paper, which has constituted a ground for choosing this method for the research.

Empirical analysis of the role of education and social policy in the development of responsible production and consumption in the artificial intelligence economy

To test the hypothesis put forward, the role of knowledge (the "knowledge" indicator calculated by *IMD, 2022*), its



	UK	Ireland	USA	Canada	Australia	Thailand	Indonesia	Saudi Arabia	Mexico	Russia
Goal 12 Score, 0-100	53,3	45,2	53,6	51,0	44,1	77,1	87,2	64,7	80,0	76,7
THE World University Rankings "Impact Rankings 2021: responsible consumption and production", score 0-100	94,9	90,3	89,7	89,5	87,6	81,9	80,7	80,1	77,5	69,9
Knowledge transfer, places 1-64	13	16	6	19	31	24	30	33	43	56
Knowledge, places 1-64	13	23	3	7	19	42	60	50	54	24

FIGURE 1
Responsible production and consumption and its support in society and university education in 2021.

dissemination (the "knowledge transfer" indicator calculated by *IMD, 2022*), as well as universities [based on the materials of the *Times Higher Education (2022)* World University Rankings "Impact Rankings 2021: responsible consumption and production"] in achieving results in the field of responsible production and consumption in the AI economy [implementation of SDG 12 according to the *UNDP (2022)*]. The international experience is studied and the peculiarities of developed and developing countries are identified.

To conduct the study, a sample of five developed and five developing countries were formed, demonstrating the best values in the *Times Higher Education (2022)*. The sample contains data on the university from each country that occupies the best position in the ranking. The list of universities is as follows: the United Kingdom: University of Manchester; Ireland: University College Cork; the United States: Arizona State University (Tempe); Canada: University of British Columbia; Australia: University of Wollongong; Thailand: King Mongkut's University of Technology Thonburi; Indonesia: Institut Teknologi Sepuluh Nopember; Saudi Arabia: Prince Mohammad Bin Fahd University; Mexico: Metropolitan Autonomous University; Russia: Altai State University. The factual basis of the study is shown in Figure 1.

Source: systematized and constructed by the authors based on materials from *IMD (2022)*, *Times Higher Education (2022)*, and *UNDP (2022)*.

Using the method of correlation analysis based on statistics from Figure 1, the relationships of indicators are established. It should be noted that there is a positive correlation between SDG12 and its support by universities, and a negative correlation with knowledge (*IMD, 2022*), since the higher the score, the better, and the lower the values in places, the better. In developed countries, the link between the implementation of SDG 12 and the "knowledge society" is very close (correlation −84.47%), as well as with the diffusion of knowledge (correlation −77.46%) and with the support of universities (correlation 58.16%).

In developing countries, the relationship between the implementation of SDG 12 and the diffusion of knowledge is moderate (correlation −2.95%), as well as with the support of universities (correlation 2.13%). And the connection with the "knowledge society" is contradictory (correlation 27.58%).

The results obtained are consistent with the existing literature by D'Souza et al. (2022), Li and Wang (2022), Mamzer et al. (2021) that the environmental economy is rooted in social progress and developed through social policies with a focus on education.

The difference between the obtained results and the available publications (Jiang et al., 2020; Zhang et al., 2020) is that the environmental AI economy includes not only a cybernetic (artificial intelligence, AI) and physical (environment) but also a social component that plays a connecting role and largely determines achievements in the field of responsible production and consumption.

Differences in results between developed and developing countries indicate that, in contrast to Dimitropoulos et al. (2021), Wearn et al. (2019) responsible (environment-friendly) production and consumption are not a guaranteed result of the Fourth Industrial Revolution, that is, not a property of artificial intelligence (AI), but an achievement of humanity through social policy and education.

The obtained results confirm the hypothesis put forward by the authors and indicate that factors such as knowledge, increasing environmental awareness and university support contribute to the development of responsible production and consumption in the economy of environmental AI, but their role differs significantly between countries—it is more pronounced in developed countries, but insignificant in developing countries.

Case experience of the Kyrgyz republic in the development of responsible production and consumption in the artificial intelligence economy based on education and social policy

The experience of the Kyrgyz Republic, which demonstrated serious results in the practical implementation of SDG 12 (86.505 points according to the *UNDP, 2022*), is also very notable. Though the statistics of *IMD (2022)* and *Times Higher Education (2022)* are not available for the Kyrgyz Republic, its case experience shows that knowledge and its diffusion are very important for the development of the responsible production and consumption. The Concept of the green economy of the Kyrgyz Republic "Kyrgyzstan—country of the green economy", which was adopted by the decree of the Jogorku Kenesh of the Kyrgyz Republic (2022) dated 28 June 2018, No. 2532-VI, notes the necessity and planned measures on the increase of awareness and development of environmental education as a very important direction of the green economy. "Green thinking, green upbringing, green education" were adopted as a special "green" direction of the Kyrgyz Republic. In this context, the following measures of stimulating the domestic production and consumption through the development of education and diffusion of knowledge are implemented:

– Using the 3R principle in the development of green thinking: Reduce

(consumption), Reuse, and Recycle;

– Multiple courses on the foundations of environmental knowledge in the

educational establishments of all levels of the educational system;

Recommendations for the development of education and improvement of social policy for responsible production and consumption in the artificial intelligence economy

Based on the established evidence base, a new approach to managing responsible production and consumption in the economy of artificial intelligence, based on the development of knowledge and technology, is proposed. The central role in the authors' approach is assigned to universities as drivers of AI-economy development. Based on the recommended approach, the following recommendations are proposed for public administration aimed at developing education and improving social policy in support of responsible production and consumption in the AI economy:

– Inclusion of the SDG 12 support factor in the organization of universities' activities and their scientific research when distributing state (e.g., grant, subsidiary) funding among them;
– Inclusion of knowledge about the problems of environmental AI economics, as well as skills and abilities for the implementation of SDG 12 in the practice of responsible production and consumption in the requirements for the competencies of university graduates and their consolidation in state educational standards;

- Increasing the accessibility of higher education, as well as encouraging young people to obtain higher education and advanced training in university educational programs that provide for the development of competencies of responsible production and consumption.

Discussion

The review and empirical analysis of international experience revealed the significant role of education and social policy in the development of responsible production and consumption in the AI economy. In developed countries, this role is more pronounced as they have already finally entered the era of artificial intelligence (AI) and are characterized by a larger and more effective social policy and a higher level of competitiveness in universities.

Unlike the existing studies of Dimitropoulos et al. (2021), artificial intelligence in this article is endowed not with a direct, but an intermediary function in the environmental AI economy and is considered as a technology to support decision-making by people who are subjects of management in the implementation of responsible production and consumption practices. In this regard, a new interpretation of the Fourth Industrial Revolution is proposed as a new stage in the development of the "knowledge economy"—the evolution of man (with the secondary role of machines).

Unlike (Jiang et al., 2020; Zhang et al., 2020) responsible production and consumption in the environmental AI economy are represented in the form of cyber-socio-ecological systems. The added new (social) component clarified the causal relationships between the development of responsible production and consumption in the environmental AI economy. Unlike D'Souza et al. (2022), Li and Wang (2022), Mamzer et al. (2021), the authors reasoned that environmental responsibility is not natural, but a human property acquired through education, a competence that should be mastered and developed.

Conclusion

So, as a result of the study, its goal has been achieved—the role of education and social policy in the development of responsible production and consumption in the AI economy has been studied. The hypothesis put forward was confirmed based on econometric methodology (correlation analysis method) and it was proved that knowledge, environmental awareness and university support contribute to the development of responsible production and consumption in the environmental AI economy has been confirmed and proven. At the same time, it was revealed that the role of knowledge and universities is more significant in developed countries, while in developing countries it is not so pronounced and contradictory. One of the possible explanations for this fact may be the reduced effectiveness of institutions in developing countries—it is proposed to devote future scientific research to test this assumption.

The following are proposed as recommendations for the development of education and the improvement of social policy in support of responsible production and consumption in the AI economy. Firstly, taking into account support for SDG12 in the activities of universities and their scientific research when distributing public funding among them. Secondly, the inclusion of knowledge about the problems of environmental AI-economics, the skills and abilities to implement SDG12 in the practice of responsible production and consumption in the competencies of university graduates and their consolidation in state educational standards. Thirdly, increasing accessibility and stimulating the acquisition of higher education and advanced training in university education programs that provide for the development of the competencies of responsible production and consumption.

The novelty of the article is connected with the development of a new approach to the management of responsible production and consumption in the economy of artificial intelligence, based on the development of knowledge and technology. The contribution of the article to the literature is to substantiate the central role of universities in the development of responsible production and consumption in the environmental AI economy.

The theoretical significance of the results and the conclusions of this study lies in the disclosure of the essence and explanation of subject-object relations, as well as the relations of responsible production and consumption in the environmental AI economy. The practical significance of the authors' recommendations is that they make it possible to achieve increased flexibility and efficiency of state incentives for responsible production and consumption in the economy of ecological AI by shifting from direct to indirect (based on a market mechanism) regulation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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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References

Ali, Q., Parveen, S., Yaacob, H., Rani, A. N., and Zaini, Z. (2022). Environmental beliefs and the adoption of circular economy among bank managers: Do gender, age and knowledge act as the moderators? *J. Clean. Prod.* 361, 132276. doi:10.1016/j.jclepro.2022.132276

Amos, R., and Lydgate, E. (2020). Trade, transboundary impacts and the implementation of SDG 12. *Sustain. Sci.* 15 (6), 1699–1710. doi:10.1007/s11625-019-00713-9

Anisha, P. R., Reddy, C. K. K., and Nguyen, N. G. (2022). *Blockchain technology: A boon at the pandemic times – a solution for global economy upliftment with AI and IoT*. Switzerland: EAI/Springer Innovations in Communication and Computing, 227–252. doi:10.1007/978-3-030-70501-5_11

Bianchet, R. T., Provin, A. P., Beattie, V. I., and de Andrade Guerra, J. B. S. O. (2021). COVID-19 and sustainable development goal 12: What are the impacts of the pandemic on responsible production and consumption? *Environ. Footprints Eco-Design Prod. Process.*, 35–71. doi:10.1007/978-981-16-3860-2_2

Cao, S., Nie, L., Sun, H., Sun, W., and Taghizadeh-Hesary, F. (2021). Digital finance, green technological innovation and energy-environmental performance: Evidence from China's regional economies. *J. Clean. Prod.* 327, 129458. doi:10.1016/j.jclepro.2021.129458

Cappelen, A. W., and Ognedal, T. (2017). Certification and socially responsible production. *Econ. Gov.* 18 (1), 71–84. doi:10.1007/s10101-016-0184-2

Cheng, X., Zhang, X., Yang, B., and Fu, Y. (2022). An investigation on trust in AI-enabled collaboration: Application of AI-Driven chatbot in accommodation-based sharing economy. *Electron. Commer. Res. Appl.*, 101164. doi:10.1016/j.elerap.2022.101164

D'Souza, C., Ahmed, T., Khashru, M. A., Ratten, V., and Jayaratne, M. (2022). The complexity of stakeholder pressures and their influence on social and environmental responsibilities. *J. Clean. Prod.* 358, 132038. doi:10.1016/j.jclepro.2022.132038

Dimitropoulos, N., Togias, T., Michalos, G., and Makris, S. (2021). Operator support in human–robot collaborative environments using AI enhanced wearable devices. *Procedia CIRP* 97, 464–469. doi:10.1016/j.procir.2020.07.006

Dragomir, D.-A. (2022). Research on data analysis (environmental, social and economic) in the context of implementing the circular economy. *Smart Innovation, Syst. Technol.* 276, 133–147. doi:10.1007/978-981-16-8866-9_12

Dwivedi, A., and Paul, S. K. (2022). A framework for digital supply chains in the era of circular economy: Implications on environmental sustainability. *Bus. Strategy Environ.* 31 (4), 1249–1274. doi:10.1002/bse.2953

Dzindolet, M. T., Beck, H. P., and Pierce, L. G. (2006). "Adaptive automation: Building flexibility into human-machine systems," in *Understanding adaptability: A prerequisite for effective performance within Complex environments advances in human performance and cognitive engineering research*. Editors C. Shawn Burke, L. G. Pierce, and E. Salas (Bingley: Emerald Group Publishing Limited), 6, 213–245. doi:10.1016/S1479-3601(05)06007-8

Fai Pun, K. (2006). Determinants of environmentally responsible operations: A review. *Int. J. Qual. Reliab. Manag.* 23 (3), 279–297. doi:10.1108/02656710610648233

Fraga-Lamas, P., Lopes, S. I., and Fernández-Caramés, T. M. (2021). Green IoT and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: An industry 5.0 use case. *Sensors* 21 (17), 5745. doi:10.3390/s21175745

Hayhoe, T., Podhorska, I., Siekelova, A., and Stehel, V. (2019). Sustainable manufacturing in industry 4.0: Cross-sector networks of multiple supply chains, cyber-physical production systems, and ai-driven decision-making. *J. Self-Governance Manag. Econ.* 7 (2), 31–36. doi:10.22381/JSME7220195

Howe, B. M., Angove, M., Aucan, J., Barros, J. S., Bayliff, N., Weinstein, S., et al. (2022). SMART subsea cables for observing the earth and ocean, mitigating environmental hazards, and supporting the blue economy. *Front. Earth Sci. (Lausanne).* 9, 775544. doi:10.3389/feart.2021.775544

IMD (2022). World digital competitiveness ranking 2021. Available at: https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/ (Accessed 04 20, 2022).

Jacob-John, J., D'souza, C., Marjoribanks, T., and Singaraju, S. (2021). Synergistic interactions of SDGs in food supply chains: A review of responsible consumption and production. *Sustain. Switz.* 13 (16), 8809. doi:10.3390/su13168809

Jia, L., Hu, X., Zhao, Z., He, B., and Liu, W. (2022). How environmental regulation, digital development and technological innovation affect China's green economy performance: Evidence from dynamic thresholds and system GMM panel data approaches. *Energies* 15 (3), 884. doi:10.3390/en15030884

Jiang, C., Ma, Y., Chen, H., Zheng, Y., Gao, S., and Cheng, S. (2020). Cyber physics system: A review. *Libr. Hi Tech.* 38 (1), 105–116. doi:10.1108/LHT-11-2017-0256

Jin, A. (2019). Digital innovations, AI, industrie 4.0. *Control Eng.* 66 (4), 5.

Karim, M., Swart-Opperman, C., and Bick, G. (2022). Robotics at dimension data: Friend or foe of the human in process automation? *Emerald Emerg. Mark. Case Stud.* 12 (1)–40. doi:10.1108/EEMCS-03-2021-0075

Khan, S. A. R., Ponce, P., Thomas, G., Al-Ahmadi, M. S., and Tanveer, M. (2021). Digital technologies, circular economy practices and environmental policies in the era of Covid-19. *Sustain. Switz.* 13 (22), 12790. doi:10.3390/su132212790

König, P. D., Wurster, S., and Siewert, M. B. (2022). Consumers are willing to pay a price for explainable, but not for green AI. Evidence from a choice-based conjoint analysis. *Big Data Soc.* 9 (1), 205395172110696. doi:10.1177/20539517211069632

Li, C., Sampene, A. K., Agyeman, F. O., Brenya, R., and Wiredu, J. (2022). The role of green finance and energy innovation in neutralizing environmental pollution: Empirical evidence from the MINT economies. *J. Environ. Manag.* 317, 115500. doi:10.1016/j.jenvman.2022.115500

Li, D., and Wang, L. F. S. (2022). Does environmental corporate social responsibility (ECSR) promote green product and process innovation? *MDE. Manage. Decis. Econ.* 43 (5), 1439–1447. doi:10.1002/mde.3464

Liu, F., Lai, K., and Cai, W. (2021). Responsible production for sustainability: Concept analysis and bibliometric review. *Sustain. Switz.* 13 (3), 12751–12827. doi:10.3390/su13031275

Mamzer, H., Skedsmo, P. W., and Węsławski., J. M. (2021). Attitudes towards the polar regions as a reflection of the Sense of responsibility for the environment. *Theor. Backgr. Furth. Study. Front. Environ. Sci.* 9. doi:10.3389/fenvs.2021.610926

Mhlanga, D. (2020). Industry 4.0 in finance: The impact of artificial intelligence (ai) on digital financial inclusion. *Int. J. Financial Stud.* 8 (345), 45–14. doi:10.3390/ijfs8030045

Palakshappa, N., and Dodds, S. (2021). Mobilising SDG 12: Co-creating sustainability through brands. *Mark. Intell. Plan.* 39 (2), 265–283. doi:10.1108/MIP-08-2018-0360

Pan, Y., Sun, H., and Taghizadeh-Hesary, F. (2020). Can environmental corporate social responsibility Reduce Firms' idiosyncratic Risk? Evidence from China. *Front. Environ. Sci.* doi:10.3389/fenvs.2020.608115

Patel, P., Ali, M. I., and Sheth, A. (2018). From raw data to smart manufacturing: AI and semantic web of things for industry 4.0. *IEEE Intell. Syst.* 33 (4), 849701279–849701286. doi:10.1109/MIS.2018.043741325

Paynabar, K., and Callicott, M. (2021). AI-Based analytics for industry 4.0: Opportunities and challenges for manufacturing improvement. *TAPPICon LIVE* 2021 (2), 1128–1135.

Peng, C., and Jiang, H. (2021). The influence of Host Country's environmental regulation on Enterprises' Risk preference of multinational investment. *Front. Environ. Sci.* doi:10.3389/fenvs.2021.667633

Pérez, A., Collado, J., and Liu, M. T. (2021). Social and environmental concerns within ethical fashion: General consumer cognitions, attitudes and behaviours. *J. Fash. Mark. Manag.* doi:10.1108/JFMM-04-2021-0088

Ravina-Ripoll, R., Nunez-Barriopedro, E., Almorza-Gomar, D., and Tobar-Pesantez, L.-B. (2021). Happiness management: A culture to explore from brand orientation as a sign of responsible and sustainable production. *Front. Psychol.* 12, 727845. doi:10.3389/fpsyg.2021.727845

Rezaei, A., Ahmadi, S., and Karimi, H. (2021). The role of online social networks in University students' environmentally responsible behavior. *Int. J. Sustain. High. Educ.* doi:10.1108/IJSHE-05-2020-0168

Ruffolo, M. (2022). The role of ethical AI in fostering harmonic innovations that support a human-centric digital transformation of economy and society. *Lect. Notes Netw. Syst.* 282, 139–143. doi:10.1007/978-3-030-81190-7_15

Schwartz, R., Dodge, J., Smith, N. A., and Etzioni, O. (2020). Green AI. *Commun. ACM* 63 (12), 54–63. doi:10.1145/3381831

Singh, E., Mishra, R., Kumar, A., Lo, S.-L., and Kumar, S. (2022a). Circular economy-based environmental management using biochar: Driving towards sustainability. *Process Saf. Environ. Prot.* 163, 585–600. doi:10.1016/j.psep.2022.05.056

Singh, S., Sharma, P., Garg, N., and Bala, R. (2022b). Groping environmental sensitivity as an antecedent of environmental behavioural intentions through perceived environmental responsibility. *J. Enterprising Communities People Places Glob. Econ.* 16 (2), 299–319. doi:10.1108/jec-09-2020-0169

Smith, R. D. J., Kamwendo, Z. T., Berndt, A., and Parkin, J. (2021). Taking knowledge production seriously in responsible research and innovation. *J. Responsible Innovation* 8 (2), 199–208. doi:10.1080/23299460.2021.1935584

Spanaki, K., Karafili, E., and Despoudi, S. (2021). AI applications of data sharing in agriculture 4.0: A framework for role-based data access control. *Int. J. Inf. Manag.* 59, 102350. doi:10.1016/j.ijinfomgt.2021.102350

Times Higher Education (2022). THE world university rankings "impact rankings 2021: Responsible consumption and production". Available at https://www.timeshighereducation.com/rankings/impact/2021/responsible-consumption-and-production#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/undefined (Accessed 04 20, 2022).

UNDP (2022). Sustainable development report 2021: The decade of action for the sustainable development goals. Available at https://www.sdgindex.org/reports/sustainable-development-report-2021/(Accessed 04 20, 2022).

Vecchi, M. (2022). Groups and socially responsible production: An experiment with farmers. *J. Econ. Behav. Organ.* 196, 372–392. doi:10.1016/j.jebo.2022.01.020

Vekaria, D., Kumari, A., Tanwar, S., and Kumar, N. (2021). ξboost: An AI-based data analytics scheme for COVID-19 prediction and economy boosting. *IEEE Internet Things J.* 8 (21), 15977–15989. doi:10.1109/JIOT.2020.3047539

Wearn, O. R., Freeman, R., and Jacoby, D. M. P. (2019). Responsible AI for conservation. *Nat. Mach. Intell.* 1, 72–73. doi:10.1038/s42256-019-0022-7

Whitson, J., and French, M. (2021). Productive play: The shift from responsible consumption to responsible production. *J. Consumer Cult.* 21 (1), 14–33. doi:10.1177/1469540521993922

Wilson, M., Paschen, J., and Pitt, L. (2022). The circular economy meets artificial intelligence (AI): Understanding the opportunities of AI for reverse logistics. *Manag. Environ. Qual. Int. J.* 33 (1), 9–25. doi:10.1108/MEQ-10-2020-0222

Xu, S., Yang, C., Huang, Z., and Failler, P. (2022). Interaction between digital economy and environmental pollution: New evidence from a spatial perspective. *Int. J. Environ. Res. Public Health* 19 (9), 5074. doi:10.3390/ijerph19095074

Zhang, C., Xu, X., and Chen, H. (2020). Theoretical foundations and applications of cyber-physical systems: A literature review. *Libr. Hi Tech.* 38 (1), 95–104. doi:10.1108/LHT-11-2017-0230

Zhou, X., Jia, M., Altuntaş, M., Kirikkaleli, D., and Hussain, M. (2022). Transition to renewable energy and environmental technologies: The role of economic policy uncertainty in top five polluted economies. *J. Environ. Manag.* 313, 115019. doi:10.1016/j.jenvman.2022.115019

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Challenges and prospects of decarbonization of the economy in the age of AI

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Introduction

Decarbonization is on the agenda of most countries of the world (Lau, 2022; Luo et al., 2022; Mathur et al., 2022; Obrist et al., 2022; Zhao et al., 2022). The global GHG emission reduction agenda was launched in November 2021 at the UN (2022) Climate Change Conference in Glasgow (COP26). At this conference, environmental degradation and the importance of decarbonization were recognized by 120 world leaders (Adebayo, 2022a; Adebayo et al., 2022; Adebayo, 2022b).

The problem is that, despite the significant progress made in decarbonizing the economy by individual countries, their results are contradictory (Doğan et al., 2022; Li et al., 2022; Nasir et al., 2022). On the one hand, the benefits of reducing the carbon footprint of the economy for the environment and quality of life are obvious (the tip of the iceberg) (Murshed et al., 2021; Hamid et al., 2022a; Alam et al., 2022; Hamid et al., 2022b; Murshed et al., 2022; Popkova, 2022).

On the other hand, deep contradictions of decarbonization remain undisclosed, but gradually are coming to the surface (Ratner et al., 2022), since the existing technological structure does not allow for completely replacing natural energy resources with "green" analogues (Sisodia et al., 2020; Teichmann et al., 2020). A vivid manifestation of these contradictions is that the countries that are leaders in the field of decarbonization of the economy—the United States, Japan, the European Union and the United Kingdom—are experiencing energy crises (Gallo et al., 2020; Ratner et al., 2021; Štreimikienė et al., 2022).

This contradiction is becoming more acute in the era of artificial intelligence. In the works of Kovacova and Lăzăroiu (2021), Popkova et al. (2021), Sergi and Popkova (2022), the AI era is defined as a modern period of world history, the distinctive feature of which is the gap between people and automation tools. For the first time in the history of industrial revolutions, automation does not improve the human use of means of production but completely isolates and excludes him from economic processes.

As noted in the works of Chen et al. (2021), Faheem and Butt (2022), Matsunaga et al. (2022), Oks et al. (2022), the systematic nature of cyber-physical systems achieved in the AI era reflects the revolutionary communications of inanimate objects (digital technology) with each other, with physical objects (for example, buildings, equipment) and even with wildlife (for example, natural resources in various industries or plants and animals in agriculture). But this integration does not apply to a man who is outside of Industry 4.0 systems.

This article uses a broad interpretation of the AI era, which is not limited to AI alone and covers the whole set of disruptive (subversive) technological innovations of Industry 4.0, in particular, robots, Big Data and data analytics, as well as the Internet of Things (IoT). All technologies of the AI era are characterized by high energy intensity, which was the criterion for their generalization in the works of Hao et al. (2022), Miśkiewicz et al. (2021), Reshetnikova and Pugacheva (2022), Wang et al. (2022).

Full automation, taking place in the AI era, brings the energy intensity of the economy to a critical level even with the use of energy-saving technologies (Berner et al., 2022; Chen et al., 2022; Muhammad et al., 2022). And "clean" energy today is not able to cover the growing demands of the economy in energy, which does not allow reduction and may even lead to a forced growth in carbon emissions. In this regard, in the works of Doroshuk (2021), Maggiore et al. (2021), Parmar et al. (2022), Qi et al. (2022), the AI era is considered an unfavourable time and an unfriendly technological landscape for decarbonization.

Thus, the relevance of the study is explained by the fact that the era of artificial intelligence associated with total automation creates increased risks of climate change and, at the same time, opens up high-tech opportunities for energy saving. The main reason for conducting this study is the need to form a systematic understanding of the special context of decarbonization, which consists in the era of artificial intelligence, taking into account its advantages and disadvantages, as well as the formation of a balanced (providing both deficit-free and environmentally friendly energy) approach to the development of an ecological AI-economy in support of decarbonisation.

The research question of this article is as follows: "How to achieve a reduction in carbon emissions and decarbonization of the economy and at the same time avoid an energy crisis (energy shortage)?" To answer the research question posed in this article, the hypothesis H_0 is put forward that artificial intelligence allows achieving a reduction in carbon emissions and decarbonization of the economy and at the same time avoid an energy crisis (energy shortage).

The purpose of the article is to reveal the features of the decarbonization of the economy in the era of artificial intelligence, taking into account the challenges of developing "clean" energy and the prospects for reducing carbon emissions using robots, Big Data, IoT and AI. After the above introduction, this article reveals the challenges of the AI era for "clean" energy and decarbonization of the economy. Using the regression analysis method, the impact of robot density on CO_2 emissions and the share of renewable energy in the leading countries in industrial robotization in 2021 is modelled, according to the International Federation of Robotics (2022b). Then describes the prospects and recommendations for decarbonization of the AI economy. Further, the results obtained are discussed in comparison with the existing literature, and a conclusion is made at the end of the article.

The contribution of the study to the literature consists of a systematic analysis and rethinking of the consequences of the spread and use of disruptive innovations of Industry 4.0 for "clean" energy in the era of artificial intelligence. The author's systematization and classification of these innovations made it possible to identify and clearly distinguish between the innovations of the era of artificial intelligence that contribute to the reduction of carbon emissions (AI, IoT and Big Data), as well as the innovations of this era that slow down decarbonization (robots). In this way, the article opens up opportunities for more environmentally responsible dissemination and application of the disruptive innovations of Industry 4.0, as well as their flexible combination in support of decarbonization.

Theoretical mechanism and hypothesis built-up

The fundamental research framework in this article is the Theory of decarbonization of the economy. Comparison and contrast of different studies within the limits of this theory has revealed the controversial aspects of decarbonization as a scientific and economic category. Camarasa et al. (2022), Lau (2022), Luo et al. (2022) in their writings point out that decarbonization is essential since it is one of the most important vectors of development of ecological economics.

As opposed to them, Fulzele et al. (2022), Pilloni et al. (2022), Vatsa and Miljkovic (2022) in their writings point out the increasingly growing need for energy resources and, in particular, fossil fuel energy, to accelerate the recovery of the global economy from the COVID-19 crisis. Gargallo et al. (2022), Ram and Webler (2022), Tan et al. (2021), Zhang et al. (2022) in their publications maintain that the world community is not ready to completely abandon fossil fuel energy and that clean energy involves certain constraints that are associated with its incomplete coverage of economic entities (constraints of infrastructure), high cost (financial constraints), as well as low and unpredictable performance (natural and climatic constraints of renewable energy sources).

The literature review has identified its main gaps that need to be worked upon. The first gap is the contradiction of decarbonization as a catalyst for sustainable development while also an obstacle to economic growth. The second gap is that while the existing literature by Favi et al. (2022), Mastrocinque et al. (2022), Matsunaga et al. (2022), Morelli et al. (2022), Vitiello et al. (2022), Wachnik et al. (2022) points out the special context of energy development that has formed at present in the context of the AI economy, this context has been left out of consideration in decarbonization planning.

This allows defining the study's problem statement as the uncertainty of the prospects for achieving decarbonization of the economy in the AI era. The significance of this research is attributable the fact that decarbonization is declared as an official priority of the countries across the world, most of which have already approved their national decarbonization strategies by now. However, given acute energy deficiency and unprecedentedly high global energy prices, these strategies have been jeopardized. In this respect, the potential of various factors to support decarbonization strategies should be identified. Among these factors, the AI economy is of paramount importance, since it allows taking advantage of the opportunities created by the new technological mode (Industry 4.0).

The research question of the article consists in methods of achieving carbon reduction and decarbonization of the economy while also avoiding an energy crisis (energy shortage). Based on the writings by Ahmed et al. (2022), Dimou and Vakalis (2022), Ragulina et al. (2022), Xuan and Ocone (2022) which point out the benefits of AI-based energy automation, this article puts forward the H0 hypothesis that carbon reduction and decarbonization of the economy while avoiding an energy crisis (energy shortage) can be achieved through the use of Artificial Intelligence.

The contribution of the article to the systematic research literature in this area of investigation consists in precise definition of the features—challenges and prospects—of the decarbonization of the economy in the new context of modernity, that has formed in the era of Artificial Intelligence. The theoretical mechanism for testing the hypothesis advanced in this article is involved with a qualitative-quantitative analysis analysis of the cause-and-effect relationships of the development of clean energy and carbon reduction using robots, Big Data, IoT and AI based on the systematic approach.

Challenges of the AI era for "clean" energy and decarbonization of the economy

To test the proposed hypothesis H_0, the Systematic Approach methodology is used, based on which a quantitative and qualitative analysis of the impact of disruptive technological innovations of the era of artificial intelligence on reducing carbon emissions and decarbonizing the economy is carried out. The quantitative analysis includes econometric modelling of the impact of the spread of robots as the advanced technology of the AI era on climate change. The qualitative analysis is related to expert analytics on the contribution of the Internet of Things (IoT) and Big Data as disruptive technological innovations in the era of artificial intelligence to the decarbonization of the economy.

The quantitative analysis has used such variables as Robot Density according to the International Federation of Robotics (2022a) as a factor in the AI economy, as well as CO_2 emissions and the share of renewable energy according to the UNDP (2022) as results in the field of decarbonization (development of clean energy and carbon reduction).

The choice of indicators is explained by the fact that industrial robots are the technology of the AI era, which is the most widespread and used in practice today. Also, thanks to the global efforts of the UN, serious progress has been made today in the development of "clean" energy and the decarbonization of the economy (Figure 1).

A simple linear regression allowed us to obtain models (carb = 0.93 + 0.0001*rb and renew = 27.01–0.03rb), according to which, with an increase in robot density by 1 robot per 10,000 employees, CO_2 emissions from fuel combustion for electricity and heating per total electricity output increase by 0.0001 $MtCO_2$/TWh (correlation 11.43%), and the share of renewable energy in total primary energy supply is reduced by 0.03% (correlation 44.42%).

According to the International Federation of Robotics (2022b), the global average in 2021 robot density is 435 robots per 10,000 employees, and by 2024 it will increase to 518 robots per 10,000 employees, that is, by 19.08%. Based on the regression models obtained above, it can be expected that this will increase CO_2 emissions from fuel combustion for electricity and heating per total electricity output by 1% and reduce the share of renewable energy in the total primary energy supply by 9.68%.

Consequently, robotization represents a serious challenge in the AI era for "clean" energy and decarbonization of the economy. At the same time, other disruptive technological innovations are also actively developing. Thus, according to Mordor Intelligence (2022), IoT active connections will increase from 2.65 million units in 2022 to 3.09 million units by 2025—and this is only in retail. According to IDC Corporate USA (2022), global spending on Big Data in 2021-2025 will increase by 12.8% annually. This opens up favourable opportunities for "smart" analytics of "clean" energy with the help of artificial intelligence.

Thus, the obtained results revealed the challenges of the era of artificial intelligence for "clean" energy and the decarbonization of the economy. The first one is related to the fact that as robotization increases, CO_2 emissions increase and the share of renewable energy decreases. The second challenge is that as the Internet of Things (IoT) advances and Big Data spreads, new opportunities for decarbonization are opening up that need to be exploited to mitigate and offset the negative impact of robots on energy and the environment.

A systematic look at the identified challenges showed that the era of artificial intelligence opens up new opportunities for decarbonization to a greater extent than increases its risks. This is explained by the fact that robotization is a factor of energy and environmental risks developing at a slower pace (6.36% per year) than two factors for the development of

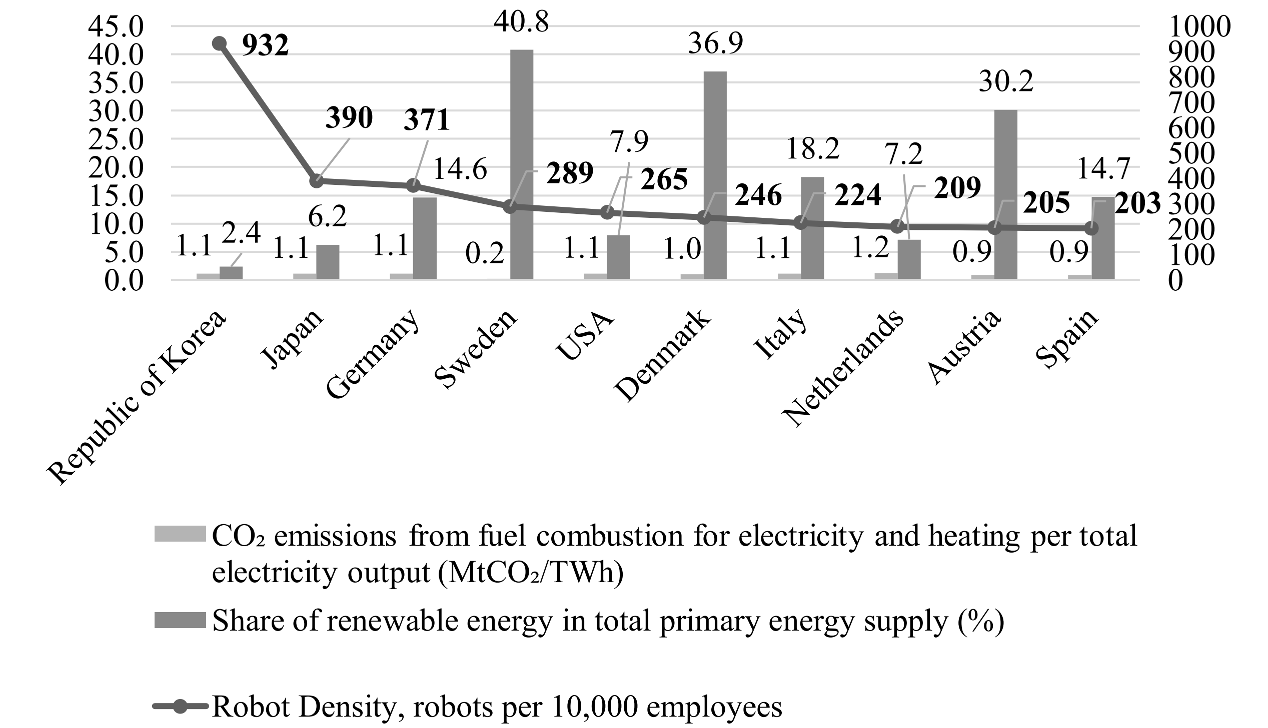

FIGURE 1
Robot density (rb), CO_2 emissions (carb) and the share of renewable energy sources (renew) in the leading countries in the robotics industry in 2021. Source: Compiled by the authors based on materials from the International Federation of Robotics (2022a), UNDP (2022).

"clean" energy and reducing greenhouse gas emissions: IoT (5.53% per year) and Big Data (12.8% per year).

Prospects and recommendations for the decarbonization of the AI economy

Recommendations for standard business regulation policies include stimulating entrepreneurial innovation and supporting high-tech economic growth. In the field of innovation policy, it is recommended to stimulate the balanced development of disruptive technological innovations - robots, the Internet of Things (IoT), Big Data and artificial intelligence (AI). In the field of energy policy, it is proposed to tighten the requirements for energy efficiency of disruptive technological innovations in support of energy saving. In the field of environmental policy, it is recommended to expand the use of high technology opportunities in the implementation of economic decarbonization strategies.

Big Data and IoT form the information base for "smart" AI-enabled analytics. The promising role that artificial intelligence can play in the transition to "clean" and alternative energy, as well as in improving the energy efficiency of the economy, is associated with the identification of the potential of disruptive innovations of the AI economy to support decarbonization. That is, artificial intelligence is designed to become an intermediary, a mediator between the Fourth Industrial Revolution and the decarbonization of the economy.

Many advanced solutions in the field of decarbonization of low-tech economic processes have already been found and are successfully practised, but in the field of high technology, there is a shortage of environmentally friendly solutions. Artificial intelligence is able (unlike humans) to take into account the subtleties of Industry 4.0 technologies and therefore offer non-standard and revolutionary solutions for their use in order to decarbonize the economy. The following applied recommendations are proposed for managing the decarbonization of the AI-based economy to perform the role described above in practice:

→ Automated statistical monitoring of the contribution of high technologies of Industry 4.0 (for example, robots) to the decarbonization of the economy. The "smart" AI-enabled analytics allows identifying individual contributions to the decarbonization of each technology and technical device. This will demonstrate the strengths and weaknesses of decarbonization in the context of enterprises and markets;

→ Highly detailed decarbonization planning in Industry 4.0. Artificial intelligence will be able to select unique decarbonization solutions for each enterprise and market, as well as offer highly detailed plans for their transition to clean energy and reduction of carbon emissions;

→ Search for solutions to complex optimization problems to correspond to the specified decarburization criteria using high technologies of Industry 4.0 (for example, robots). Artificial intelligence, thanks to its high-performance and record-fast analytics, can find optimal solutions for decarbonization, for example, when saving the required number of jobs or a given amount of required profit in case of a limited budget.

The advantages of reducing carbon emissions and decarbonizing the AI-based economy include, firstly, support for decarbonization by high-tech sectors of the economy, which, without the use of artificial intelligence, make a small or zero contribution to decarbonization and may even hinder it. Secondly, they involve system solutions for decarbonization, covering the entire set of processes for the production of "clean" energy, its distribution and optimal consumption, if necessary in combination with fossil energy.

Discussion

The contribution of the article to the literature consists in rethinking the prospects of decarbonization, taking into account the peculiarities of the AI era. Following the research results, it has been revealed that new challenges arise for "clean" energy and decarbonization of the economy in the era of Artificial Intelligence. On the one hand, there is an increasing energy intensity of housekeeping and a growing need for fossil fuels for the maintenance of robots. This gives rise to a challenge associated with the need to increase the energy intensity of robotic production works.

On the other hand, other disruptive technological innovations of the era of Artificial Intelligence, including Artificial Intelligence as such, as well as the Internet of Things (IoT) and Big Data, open up new opportunities for decarbonization, supporting the development of "clean" energy and carbon reduction.

The prospects for decarbonization of the AI economy are involved with the use of a systematic approach to the national economic policy. This systematic approach should comprise and ensure the integrated management of the development of disruptive technological innovations, energy and environmental economics. The advantage of the proposed systematic approach will consist in the support of the balanced and sustainable development, as well as consistent progress in the implementation of SDG7 and SDG13.

The contribution of the paper to the improvement of scientific knowledge in the field of decarbonization and combating climate change is as follows. Unlike Hao et al. (2022), Miśkiewicz et al. (2021), Reshetnikova and Pugacheva (2022), Wang et al. (2022), it has been proved that disruptive technological innovations are not homogeneous, but are characterized by serious differences in terms of energy efficiency. A new classification of these innovations according to the criterion of consequences for decarbonization has been proposed; technologies with high energy intensity (for example, robots) and technologies that support decarbonization (for example, IoT, Big Data and AI) have been identified. The advantage of the author's classification is that it allows flexible use of technologies of the AI era, achieving the best practical results in decarbonization.

Unlike Doroshuk (2021), Maggiore et al. (2021), Parmar et al. (2022), Qi et al. (2022), it has been proven that in the era of artificial intelligence there are no obstacles to decarbonization, but on the contrary, new opportunities have been created for this. Using only disruptive innovations of industry 4.0 (for example, only robots) can hinder the reduction or even increase the number of carbon emissions, as well as slow down the transition to "clean" energy. But with the complex use of technologies in the AI era, the disadvantages of some technologies are compensated by the advantages of others. And artificial intelligence can play a system-forming role in this process, providing intellectual support for maximizing the cumulative contribution of disruptive innovations of Industry 4.0 to the decarbonization of the AI economy.

The contribution of the findings to the growth of scientific knowledge lies in the fact that they allow us to take a fresh look at the process and prospects for the decarbonization of the economy in the era of artificial intelligence, taking into account both the advantages and disadvantages of the disruptive innovations of Industry 4.0. This allows robots, Big Data and AI to spread more consciously, with clear control and high-precision prediction of their impact on carbon emissions and clean energy. Due to this, the article more deeply revealed the cause-and-effect relationships of the development of ecological economics and management in the AI era, showing the place of the disruptive innovations of Industry 4.0 in this process.

Conclusion

The results of the study revealed the challenges of the AI era for "clean" energy and decarbonization of the economy, associated, on the one hand, with an increase in carbon emissions and a reduction in the share of "clean" energy as robotics develops, and, on the other hand, with support for the decarbonization of the AI economy based on Big Data, IoT and AI. The author's conclusions that the disruptive innovations of Industry 4.0 can both accelerate and slow down the processes of reducing carbon emissions and the transition to "clean" energy allow a more objective and systematic look at the AI era as a decarbonization context and take into account the peculiarities of this context in the state and corporate managing the development of ecological economics and management.

The theoretical significance of the study consists in revealing the consequences of the spread of disruptive innovations of Industry 4.0 for environmental AI economics and management through the author's classification based on the criteria of contribution to decarbonization. The article develops and complements the scientific strategies of decarbonization, presented in the writing by Hamid et al. (2022). The practical significance of the author's conclusions and proposed recommendations on the use of artificial intelligence for the decarbonization of the economy makes it possible to accelerate the transition to "clean" energy and increase the scale of carbon emissions reduction through the involvement of high-tech sectors of the AI economy, which were previously considered inaccessible for decarbonization.

The social significance of the research results is that they support the systematic practical implementation of SDG 7 and SDG 13 in environmental AI economics and management. Suggestions for policy makers include flexible use of the disruptive innovations of Industry 4.0: increased use of IoT, Big Data and AI as catalysts for carbon reduction and clean energy transition, and more thoughtful, careful and responsible distribution of robots as potential inhibitors of these processes.

A limitation of the results obtained is that this study focuses on decarbonization, while there are many other promising areas for the development of environmental economics and management. Among these areas is the reduction of production and consumption waste, recycling, reducing the consumption of natural resources and increasing the resource efficiency of the economy, etc. Each of these areas needs an independent in-depth study of the prospects for its implementation in the AI era. In this regard, Future directions of research are related to the disclosure of the consequences (both challenges and prospects) of the spread of disruptive innovations of Industry 4.0 for other areas of development of ecological economics and management, as well as to identify the prospects for more responsible and sustainable use of these innovations.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The author declares 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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References

Adebayo, T. S., Oladipupo, S. D., Kirikkaleli, D., and Adeshola, I. (2022). Asymmetric nexus between technological innovation and environmental degradation in Sweden: An aggregated and disaggregated analysis. *Environ. Sci. Pollut. Res.* 29, 36547–36564. doi:10.1007/s11356-021-17982-6

Adebayo, T. S., Oladipupo, S. D., Rjoub, H., Kirikkaleli, D., and Adeshola, I. (2022b). Asymmetric effect of structural change and renewable energy consumption on carbon emissions: Designing an SDG framework for Turkey. *Environ. Dev. Sustain.*, 1–29. doi:10.1007/s10668-021-02065-w

Adebayo, T. S. (2022a). Renewable energy consumption and environmental sustainability in Canada: Does political stability make a difference? *Environ. Sci. Pollut. Res. Int.* doi:10.1007/s11356-022-20008-4

Ahmed, Q. W., Garg, S., Rai, A., Jhanjhi, N. Z., Masud, M., Baz, M., et al. (2022). AI-based resource allocation techniques in wireless sensor internet of things networks in energy efficiency with data optimization. *Electron. Switz.* 11 (13), 2071. doi:10.3390/electronics11132071

Alam, M., Alam, M., Murshed, M., Mahmood, H., and Alam, R. (2022). Pathways to securing environmentally sustainable economic growth through efficient use of energy: A bootstrapped ARDL analysis. *Environ. Sci. Pollut. Res.* 29, 50025–50039. doi:10.1007/s11356-022-19410-9

Berner, A., Bruns, S., Moneta, A., and Stern, D. I. (2022). Do energy efficiency improvements reduce energy use? Empirical evidence on the economy-wide rebound effect in europe and the United States. *Energy Econ.* 110, 105939. doi:10.1016/j.eneco.2022.105939

Camarasa, C., Mata, É., Navarro, J. P. J., Bezerra, P., Angelkorte, G. B., Wanemark, J., et al. (2022). A global comparison of building decarbonization scenarios by 2050 towards 1.5–2 °C targets. *Nat. Commun.* 13 (1), 3077. doi:10.1038/s41467-022-29890-5

Chen, H., Shi, Y., Xu, M., and Zhao, X. (2022). Investment in renewable energy resources, sustainable financial inclusion and energy efficiency: A case of us economy. *Resour. Policy* 77, 102680. doi:10.1016/j.resourpol.2022.102680

Chen, M., Sinha, A., Hu, K., and Shah, M. I. (2021). Impact of technological innovation on energy efficiency in Industry 4.0 era: Moderation of shadow economy in sustainable development. *Technol. Forecast. Soc. Change* 164, 120521. doi:10.1016/j.techfore.2020.120521

Dimou, A., and Vakalis, S. (2022). Technoeconomic analysis of green energy transitions in isolated grids: The case of Ai Stratis – green Island. *Renew. Energy* 195, 66–75. doi:10.1016/j.renene.2022.06.039

Doğan, B., Ferraz, D., Gupta, M., Duc Huynh, T. L., and Shahzadi, I. (2022). Exploring the effects of import diversification on energy efficiency: Evidence from the OECD economies. *Renew. Energy* 189, 639–650. doi:10.1016/j.renene.2022.03.018

Doroshuk, H. (2021). Prospects and efficiency measurement of artificial intelligence in the management of enterprises in the energy sector in the era of Industry 4.0. *Polityka Energetyczna –. Energy Policy J.* 24 (4), 61–76. doi:10.33223/epj/144083

Faheem, M., and Butt, R. A. (2022). Big Datasets of optical-wireless cyber-physical systems for optimizing manufacturing services in the internet of things-enabled Industry 4.0. *Data Brief* 42, 108026. doi:10.1016/j.dib.2022.108026

Favi, C., Marconi, M., Mandolini, M., and Germani, M. (2022). Sustainable life cycle and energy management of discrete manufacturing plants in the industry 4.0 framework. *Appl. Energy* 312, 118671. doi:10.1016/j.apenergy.2022.118671

Fulzele, R., Fulzele, V., and Dharwal, M. (2022). Mapping the impact of COVID-19 crisis on the progress of sustainable Development Goals (SDGs) - a focus on global environment and energy efficiencies. *Mater. Today Proc.* 60, 873–879. doi:10.1016/j.matpr.2021.09.517

Gallo, E., Wu, Z., and Sergi, B. S. (2020). China's power in its strategic energy partnership with the Eurasian economic union. *Communist Post-Communist Stud.* 53 (4), 200–219. doi:10.1525/j.postcomstud.2020.53.4.200

Gargallo, P., Lample, L., Miguel, J., and Salvador, M. (2022). Dynamic comparison of portfolio risk: Clean vs dirty energy. *Finance Res. Lett.* 47, 102957. doi:10.1016/j.frl.2022.102957

Hamid, I., Alam, M. S., Kanwal, A., Jena, P. K., Murshed, M., and Alam, R. (2022a). Decarbonization pathways: The roles of foreign direct investments, governance, democracy, economic growth, and renewable energy transition. *Environ. Sci. Pollut. Res.* 29, 49816–49831. doi:10.1007/s11356-022-18935-3

Hamid, I., Alam, M. S., Murshed, M., Jena, P. K., and Sha, N. (2022b). The roles of foreign direct investments, economic growth, and capital investments in decarbonizing the economy of Oman. *Environ. Sci. Pollut. Res.* 29, 22122–22138. doi:10.1007/s11356-021-17246-3

Hao, A., Tan, J., Ren, Z., and Zhang, Z. (2022). A spatial empirical examination of the relationship between agglomeration and green total-factor productivity in the context of the carbon emission peak. *Front. Environ. Sci.* 10, 829160. doi:10.3389/fenvs.2022.829160

IDC Corporate USA (2022). Global spending on Big data and analytics solutions will reach $215.7 billion in 2021, according to a new IDC spending guide. Available at: https://www.idc.com/getdoc.jsp?containerId=prUS48165721.

International Federation of Robotic (2022a). World robot report: Robot density nearly doubled globally. Available at: https://ifr.org/ifr-press-releases/news/robot-density-nearly-doubled-globally#:~:text=This%20is%20according%20to%20the,Japan%2C%20Germany%2C%20and%20Sweden (Accessed 05 15, 2022).

International Federation of Robotics (2022b). IFR presents World Robotics 2021 reports. Available at: https://ifr.org/ifr-press-releases/news/robot-sales-rise-again.

Kovacova, M., and Lăzăroiu, G. (2021). Sustainable organizational performance, cyber-physical production networks, and deep learning-assisted smart process planning in Industry 4.0-based manufacturing systems. *Econ. Manag. Financial Mark.* 16 (3), 41–54. doi:10.22381/emfm16320212

Lau, H. C. (2022). Decarbonization roadmaps for ASEAN and their implications. *Energy Rep.* 8, 6000–6022. doi:10.1016/j.egyr.2022.04.047

Li, G., Luo, T., and Song, Y. (2022). Climate change mitigation efficiency of electric vehicle charging infrastructure in China: From the perspective of energy transition and circular economy. *Resour. Conservation Recycl.* 179, 106048. doi:10.1016/j.resconrec.2021.106048

Luo, S., Hu, W., Liu, W., Bai, C., Huang, Q., Chen, Z., et al. (2022). Study on the decarbonization in China's power sector under the background of carbon neutrality by 2060. *Renew. Sustain. Energy Rev.* 166, 112618. doi:10.1016/j.rser.2022.112618

Maggiore, S., Realini, A., Zagano, C., Gobbi, E., and Borgarello, M. (2021). Energy efficiency in industry 4.0: Assessing the potential of industry 4.0 to achieve 2030 decarbonisation targets. *Int. J. Eq.* 6 (4), 371–381. doi:10.2495/EQ-V6-N4-371-381

Mastrocinque, E., Ramírez, F. J., Honrubia-Escribano, A., and Pham, D. T. (2022). Industry 4.0 enabling sustainable supply chain development in the renewable energy sector: A multi-criteria intelligent approach. *Technol. Forecast. Soc. Change* 182, 121813. doi:10.1016/j.techfore.2022.121813

Mathur, S., Gosnell, G., Sovacool, B. K., Griffiths, S., Bazilian, M., Kim, J., et al. (2022). Industrial decarbonization via natural gas: A critical and systematic review of developments, socio-technical systems and policy options. *Energy Res. Soc. Sci.* 90, 102638. doi:10.1016/j.erss.2022.102638

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of energy efficiency in smart manufacturing through the application of cyber-physical systems and industry 4.0 technologies. *J. Energy Resour. Technol.* 144 (10), 102104. doi:10.1115/1.4053868

Miśkiewicz, R., Rzepka, A., Borowiecki, R., and Olesiński, Z. (2021). Energy efficiency in the Industry 4.0 era: Attributes of teal organisations. *Energies* 14 (20), 6776. doi:10.3390/en14206776

Mordor Intelligence (2022). Internet of things (iot) market - growth, trends, COVID-19 IMPACT, and forecasts. Available at: https://www.mordorintelligence.com/industry-reports/internet-of-things-moving-towards-a-smarter-tomorrow-market-industry.

Morelli, G., Magazzino, C., Gurrieri, A. R., Pozzi, C., and Mele, M. (2022). Designing smart energy systems in an industry 4.0 paradigm towards sustainable environment. *Sustain. Switz.* 14 (6), 3315. doi:10.3390/su14063315

Muhammad, S., Pan, Y., Agha, M. H., Umar, M., and Chen, S. (2022). Industrial structure, energy intensity and environmental efficiency across developed and developing economies: The intermediary role of primary, secondary and tertiary industry. *Energy* 247, 123576. doi:10.1016/j.energy.2022.123576

Murshed, M., Mahmood, H., Ahmad, P., Rehman, A., and Alam, M. S. (2022). Pathways to Argentina's 2050 carbon-neutrality agenda: The roles of renewable energy transition and trade globalization. *Environ. Sci. Pollut. Res.* 29, 29949–29966. doi:10.1007/s11356-021-17903-7

Murshed, M., Rahman, M. A., Alam, M. S., Ahmad, P., and Dagar, V. (2021). The nexus between environmental regulations, economic growth, and environmental sustainability: Linking environmental patents to ecological footprint reduction in south asia. *Environ. Sci. Pollut. Res.* 28, 49967–49988. doi:10.1007/s11356-021-13381-z

Nasir, M. H., Wen, J., Nassani, A. A., Igharo, A. E., Musibau, H. O., Waqas, M., et al. (2022). Energy security and energy poverty in emerging economies: A step towards sustainable energy efficiency. *Front. Energy Res.* 10, 834614. doi:10.3389/fenrg.2022.834614

Obrist, M. D., Kannan, R., Schmidt, T. J., and Kober, T. (2022). Long-term energy efficiency and decarbonization trajectories for the Swiss pulp and paper industry. *Sustain. Energy Technol. Assessments* 52, 101937. doi:10.1016/j.seta.2021.101937

Oks, S. J., Jalowski, M., Lechner, M., Merklein, M., Vogel-Heuser, B., Möslein, K. M., et al. (2022). Cyber-physical systems in the context of industry 4.0: A review, categorization and outlook. *Inf. Syst. Front.* doi:10.1007/s10796-022-10252-x

Parmar, B., Vishwakarma, A., Padbhushan, R., Kumar, R., Kumari, R., Kaviraj, M., et al. (2022). Hedge and alder-based agroforestry systems: Potential interventions to carbon sequestration and better crop productivity in Indian sub-himalayas. *Front. Environ. Sci.* 10, 858948. doi:10.3389/fenvs.2022.858948

Pilloni, M., Kádár, J., and Hamed, T. A. (2022). The impact of COVID-19 on energy start-up companies: The use of global financial crisis (GFC) as a lesson for future recovery. *Energies* 15 (10), 3530. doi:10.3390/en15103530

Popkova, E. (2022). *Advanced issues in the green economy and sustainable development in emerging market economies (elements in the economics of emerging markets)*. Cambridge: Cambridge University Press. doi:10.1017/9781009093408

Popkova, E., Bogoviz, A. V., and Sergi, B. S. (2021). Towards digital society management and 'capitalism 4.0' in contemporary Russia. *Humanit. Soc. Sci. Commun.* 8 (1), 77. doi:10.1057/s41599-021-00743-8

Qi, H., Sun, L., Long, F., Gao, X., and Hu, L. (2022). Does forest resource protection under the carbon neutrality target inhibit economic growth? Evidence of poverty-stricken county from China. *Front. Environ. Sci.* 10, 858632. doi:10.3389/fenvs.2022.858632

Ragulina, Y. V., Dubova, Y. I., Litvinova, T. N., and Balashova, N. N. (2022). The environmental AI economy and its contribution to decarbonization and waste reduction. *Front. Environ. Sci.* 10, 914003. doi:10.3389/fenvs.2022.914003

Ram, B., and Webler, T. (2022). Social amplification of risks and the clean energy transformation: Elaborating on the four attributes of information. *Risk Anal.* 42, 1423–1439. doi:10.1111/risa.13902

Ratner, S., Berezin, A., Gomonov, K., Serletis, A., and Sergi, B. S. (2022). What is stopping energy efficiency in Russia? Exploring the confluence of knowledge, negligence, and other social barriers in the krasnodar region. *Energy Res. Soc. Sci.* 85, 102412. doi:10.1016/j.erss.2021.102412

Ratner, S., Berezin, A., and Sergi, B. S. (2021). Energy efficiency improvements under conditions of low energy prices: The evidence from Russian regions. *Energy Sources, Part B Econ. Plan. Policy*, 1–20. doi:10.1080/15567249.2021.1966134

Reshetnikova, M. S., and Pugacheva, I. A. (2022). *The global industrial robotics market: Development trends and volume forecast. Current problems of the world economy and international trade*. Emerald Publishing Limited, 42.

Sergi, B. S., and Popkova, E. G. (2022). Towards a 'wide' role for venture capital in OECD countries' Industry 4.0. *Heliyon* 8 (1), e08700. doi:10.1016/j.heliyon.2021.e08700

Sisodia, G. S., Awad, E., Alkhoja, H., and Sergi, B. S. (2020). Strategic business risk evaluation for sustainable energy investment and stakeholder engagement: A proposal for energy policy development in the Middle East through khalifa funding and land subsidies. *Bus. Strategy Environ.* 29 (6), 2789–2802. doi:10.1002/bse.2543

Štreimikienė, D., Samusevych, Y., Bilan, Y., Vysochyna, A., and Sergi, B. S. (2022). Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security. *Environ. Sci. Pollut. Res.* 29 (5), 7917–7935. doi:10.1007/s11356-021-16239-6

Tan, X., Geng, Y., Vivian, A., and Wang, X. (2021). Measuring risk spillovers between oil and clean energy stocks: Evidence from a systematic framework. *Resour. Policy* 74, 102406. doi:10.1016/j.resourpol.2021.102406

Teichmann, F., Falker, M.-C., and Sergi, B. S. (2020). Gaming environmental governance? Bribery, abuse of subsidies, and corruption in European union programs. *Energy Res. Soc. Sci.* 66, 101481. doi:10.1016/j.erss.2020.101481

UN (2022). UN climate change conference in Glasgow (COP-26). Available at: https://www.un.org/ru/climatechange/cop26 (Accessed 06 29, 2022).

UNDP (2022). Sustainable development report 2021: Explore data. Available at: https://dashboards.sdgindex.org/(Accessed 05 15, 2022).

Vatsa, P., and Miljkovic, D. (2022). Energy and crop price cycles before and after the global financial crisis: A new approach. *J. Agric. Econ.* 73 (1), 220–233. doi:10.1111/1477-9552.12454

Vitiello, S., Andreadou, N., Ardelean, M., and Fulli, G. (2022). Smart metering roll-out in europe: Where do we stand? Cost benefit analyses in the clean energy package and research trends in the green deal. *Energies* 15 (7), 2340. doi:10.3390/en15072340

Wachnik, B., Kłodawski, M., and Kardas-Cinal, E. (2022). Reduction of the information gap problem in industry 4.0 projects as a way to reduce energy consumption by the industrial sector. *Energies* 15 (3), 1108. doi:10.3390/en15031108

Wang, J., Hui, W., Liu, L., Du, Y., and Li, J. (2022). Estimation and influencing factor Analysis of carbon emissions from the entire production cycle for household consumption: Evidence from the urban communities in beijing, China. *Front. Environ. Sci.* 10, 843920. doi:10.3389/fenvs.2022.843920

Xuan, J., and Ocone, R. (2022). The equality, diversity and inclusion in energy and AI: Call for actions. *Energy AI* 8, 100152. doi:10.1016/j.egyai.2022.100152

Zhang, L., Chen, Z., Yang, C., and Xu, Z. (2022). Global supply risk assessment of the metals used in clean energy technologies. *J. Clean. Prod.* 331, 129602. doi:10.1016/j.jclepro.2021.129602

Zhao, X., Huning, A. J., Burek, J., Kropaczek, D. J., and Pointer, W. D. (2022). The pursuit of net-positive sustainability for industrial decarbonization with hybrid energy systems. *J. Clean. Prod.* 362, 132349. doi:10.1016/j.jclepro.2022.132349

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ESG investing in the AI era: Features of developed and developing countries

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Introduction

The era of artificial intelligence (AI) is a period when automation for the first time goes beyond the century-old practice of production and covers a wide range of organizational processes in which intellectual support for managerial decision making is provided (Dudukalov et al., 2021; Ivanov et al., 2022; Popkova, 2022). At the same time, the Sustainable Development Goals (SDGs) have become widespread in the global economic system. In their practical implementation, business practices are reviewed from the point of view of ESG principles and transformed in accordance with them. This process is called ESG investing, including environmental, social, and governance investing on a systemic basis (Gao et al., 2021; Popkova et al., 2021; Popkova and Sergi, 2021; Rehman and Noman, 2022).

ESG is a systemic approach to business management, which covers and reconsiders through the lens of the SDGs (orients toward their support) environmental (E: with the focus on corporate environmental responsibility), social (S: with the focus on corporate social responsibility), and corporate (G: with the focus on financial management, maximization of profit and increase in economic effectiveness of business) management. Thus, ESG investment is a process of financing sustainable development (Aldowaish et al., 2022; Ge et al., 2022).

The concept of "ESG performance" means that a company is evaluated (by shareholders and investors, government, and society) by the ESG criterion when making decisions on management and interaction with the company (Inampudi and Macpherson, 2020). For this purpose, corporate reporting is used, reports on sustainable development, reports on corporate social and environmental responsibility, financial reports, and ESG reports (Breedt et al., 2019). In the works of Fafaliou et al. (2022), Zhang et al. (2022), and Zhang et al. (2021), the scholars note a strong influence of ESG on companies in developed and developing countries: ESG determines the effectiveness of companies, their sustainability to economic crises, investment attractiveness, and strategic perspectives for the development of business.

In the age of AI, ESG practices are based on smart technology automatization means (robots, unmanned transport) under the control of AI, which are united in cyber-physical systems with the help of the Internet of Things (IoT). ESG investment in the age of AI acquires two specific features (Selim, 2020; Sætra, 2021). The first one is that ESG investments imply the financing of smart technologies which systemically improve the environmental, social, and financial characteristics of business activities (Minkkinen et al., 2022a). The second one is that ESG investment is performed based on smart technologies, for example, blockchain (Alkaraan et al., 2022).

The AI era opens up wide opportunities for the development of ESG investments thanks to technological support for improving decision making by all stakeholders (Teichmann et al., 2022). Investors get access to "smart" analytics of investment projects grouped, sorted, and ranked according to the criterion of the degree of compliance with ESG principles, contribution to the implementation of the SDGs, and the correlation between risk and profitability (Aroul et al., 2022; Popkova et al., 2020; Popkova and Sergi, 2022). A business can establish stable AI communications with the external environment, attracting a larger volume of ESG investments and achieving greater payback (Shahzad et al., 2020). Intelligent and automated state–public monitoring of ESG investments is also becoming available to identify and encourage the most responsible market agents (Andersson et al., 2022).

The established approach to the development of ESG investments in the AI era is focused on technology, and therefore it can be called technological. This approach is described in the works of Ielasi et al. (2020), Tong et al. (2022), and Yasmine and Kooli (2022) and involves stimulating scientific and technological progress for AI support of ESG investments. The disadvantage of the existing approach is that it does not take into account the possibility of using advanced "smart" technologies in practice, and the degree of use of their potential.

As practice shows, the availability of advanced technologies is not enough for their application. Based on the technological approach, the works of Li et al. (2022), Minkkinen et al. (2022b), Abdur Rehman Khan et al. (2022), and Sætra (2021) indicate the feasibility of developing "smart" technologies to increase the volume of ESG investments. Focusing on the existing concept of "smart" ESG investments, the AI economy is progressing, but despite the similar level of development of advanced "smart" technologies, there are serious differences in the intensity of automation of ESG investments in developed and developing countries (Jonsdottir et al., 2022). The available publications (Chen et al., 2022; Sharma et al., 2022) do not explain these differences, which is a gap in the literature. The set of conditions necessary and sufficient for the development of the AI economy is more fully reflected in UNCTAD (2022), which highlights the following:

– ICT ranking, showing the level of development, availability, and quality of advanced telecommunications infrastructure required for the application of "smart" technologies
– Skills ranking, demonstrating the availability of highly qualified personnel with digital competencies necessary for the use of "smart" technologies
– R and D ranking, characterizing the direct accessibility of "smart" technologies and the degree of their innovation
– Industry ranking, revealing the degree of high-tech production and international trade
– Finance ranking, demonstrating the adequacy of funding allocations to "smart" technologies and flexibility of financial instruments to achieve this goal

Systematic consideration of the abovementioned conditions reveals the AI economy in a new light–from the standpoint of social institutes. Since it is the differences in institutional support that form the basis for categorizing the countries of the world with the division of developed and developing countries, this article, based on the works of Shkalenko et al. (2022), Yankovskaya et al. (2021), hypothesizes that the AI economy institutes to determine the features of ESG investments in developed and developing countries.

The purpose of this article is to identify prospects and offer recommendations for the development of ESG investing in the AI era, taking into account the characteristics of developed and developing countries. To achieve this goal, the following tasks are set and solved:

– To identify the features of the impact of digital technologies of the AI era on the existing ESG investing practices in developed and developing countries
– To identify the prospects for the development of ESG investing in the AI era, as well as to offer authors' recommendations, separately for developed and developing countries

A theory for the relationship between ESG and artificial intelligence: A literature review and gap analysis

The central scientific category of this article is the age of artificial intelligence (AI). It is treated as a new, modern stage of the development of society and economy, in which smart technologies, which are based on AI, are widely applied in practice (Kukushkina et al., 2022; Ragulina et al., 2022).

The age of AI began due to the fourth Industrial Revolution, the essential difference of which from previous industrial revolutions is the systemic coverage of technological modernization (Wilson et al., 2022). While in the past, industrial revolutions improved only production technologies, now–under the conditions of the fourth Industrial Revolution–management technologies are also improved. AI ensures the intellectual support for decision making, in particular investment decisions (Luitse and Denkena, 2021; Som, 2021).

This article is based on the theory of the relationship between ESG and artificial intelligence (AI). ESG performance is the evaluation of the company's effectiveness from the position of sustainable development with the systemic coverage of environmental (E: with the focus on corporate environmental responsibility), social (S: with the focus on corporate social responsibility) effectiveness, and effectiveness of corporate governance (G: with the focus on profitability) (Avramov et al., 2022; Pedersen et al., 2021). ESG seriously influences companies in developed and developing countries (Cardillo et al., 2022; Chen et al., 2022; Lööf et al., 2022).

Fritz-Morgenthal et al. (2022), Minkkinen et al. (2022b), and Nauck (2019) point out in their works that AI allows (based on the Internet of Things, IoT) to collecting and analyzing Big Data on the topic of green innovation and corporate social and environmental responsibility. This data can be used as a basis for drawing much more complete and reliable internal and external corporate sustainability reporting (Maas, 2018). In addition, smart reporting on the implementation of ESG investment projects can be drawn (Vetrò et al., 2019).

Viriato (2019) and Wang et al. (2021) in their works hold that AI allows investors to make the most justified (coordinated) decisions on the location of ESG investments thanks to automated market analysis and intelligent support for decision making. In particular, corporate reporting can be processed by AI at a rapid pace and serve as a milestone for investment decisions (Cornforth, 2018). Furthermore, AI allows for building up the most efficient investment portfolios with a consistent risk-return ratio, as well as the ratio of economic, social, and environmental efficiency of capital investment projects (Auer and Schuhmacher, 2016; In et al., 2019).

Thus, the literature review has shown that both from the standpoint of demand (ESG investors) and the standpoint of supply (companies implementing ESG investment projects), AI contributes to benchmarking and ensures the balance of ESG investment markets. On the other hand, the gap analysis has revealed somewhat poor elaboration of the causal relationships of the development of ESG investments in the AI era, which is a gap in the literature. Since market patterns have their specific character in developed and developing countries, the causal relationships of the development of ESG investments in the AI era are studied and modeled individually in these categories of countries to fill the identified gap in this article.

Materials and methods

The initial point of this research is the following proposed hypothesis: institutes of the AI economy determine the specifics of ESG investment in developed and developing countries. The logic of the research consists of the following: at the qualitative level of the research, a potential connection between ESG analyses and principles of responsible AI is seen. This connection is manifested in the fact that responsible AI allows for high precision forecasting of the environmental consequences of the activities of companies and planning of the projects of corporate environmental responsibility (E).

Responsible AI ensures the growth of corporate social responsibility through smart monitoring of the safety of workplaces, remote execution of manipulations that are dangerous for employees' health, creation of knowledge-intensive jobs, and expansion of opportunities for advanced training based on remote corporate training (S); responsible AI also stimulates the rationalization of the use of resources, optimization of all business processes, especially production and logistics, and increase in the scale effect and profitability of the business (G).

The methodology of testing the hypothesis is based on regression analysis, as a reliable method of economic statistics. The research is performed in two successive stages. In the first stage, we determine the specifics of the influence of digital technologies of the age of AI on the existing practices of ESG investing in developed and developing countries. For this, we perform the economic and mathematical modeling of the influence of the factors of Readiness for frontier technologies according to the UNCTAD (2022) on ESG score according to Morningstar (2021). The research model has the following form:

$$ESG = a + b_1 * ict + b_2 * skl + b_3 * r\&d + b_4 * ind + b_5 * fin, \quad (1)$$

where ESG: ESG score, the rest: factors of readiness for frontier technologies; skl: skill ranking; r&d: R&D ranking; ind: industry ranking; fin: finance ranking; ict: ICT ranking.

To check the reliability of the econometric models, we use significance F and t-Stat. We formed a sample of developed countries (Denmark, Italy, the United States, Canada, Austria, Belgium, Australia, Norway, New Zealand, and the Czech Republic) and a sample of developing countries (China, India, Colombia, Malaysia, Chile, Brazil, Indonesia, Qatar, Russia, and Saudi Arabia). The samples contain countries with the highest level of development of ESG investment, according to the ranking by Morningstar (2021).

In the second stage, we determine the prospects and offer recommendations for the development of ESG investment in the age of AI in developed and developing countries. For this, we use the least squares method based on the obtained regression models. We also use the method of SWOT analysis to perform a quantitative-qualitative study of strengths and weaknesses, opportunities, and threats to the development of ESG investment in the age of AI in developed and developing countries.

Features of the impact of digital technologies of the AI era on the existing ESG investing practices in developed and developing countries

To determine the specifics of the development of ESG investments in the AI era in developed and developing countries (to test the hypothesis put forward in the article), an

TABLE 1 ESG investments and readiness for frontier technologies in developed and developing countries in 2021.

Country		ESG score (ESG)	Readiness for frontier technologies				
			ICT ranking (ict)	Skill ranking (skl)	R&D ranking (r&d)	Industry ranking (ind)	Finance ranking (fin)
Developed countries	Denmark	21,42	2	4	25	21	5
	Italy	22,35	52	32	10	30	44
	United States	22,56	14	17	2	20	2
	Canada	23,43	13	21	9	27	17
	Austria	23,77	26	26	23	26	36
	Belgium	23,87	10	3	24	17	48
	Australia	24,03	31	1	12	61	12
	Norway	24,27	5	5	28	50	10
	New Zealand	26,38	8	8	41	70	7
	Czech	30,34	30	23	32	18	72
Developing countries	China	27,47	99	96	1	7	6
	India	27,73	93	108	4	28	76
	Colombia	28,26	88	79	53	99	77
	Malaysia	28,56	29	65	33	12	19
	Chile	29,50	61	45	45	109	20
	Brazil	30,01	73	53	17	42	60
	Indonesia	30,31	47	98	88	83	121
	Qatar	32,18	42	100	57	137	42
	Russia	33,42	39	28	11	66	45
	Saudi Arabia	34,79	56	41	26	129	69

Source: compiled by the authors based on materials from Morningstar (2021) and UNCTAD (2022).

empirical study based on the available official statistics of Morningstar (2021), reflects the level of development of ESG investments in various countries was conducted. Readiness for frontier technologies is also taken into account, reflecting the quantitative measurement of the level of development of the institutes of the AI economy. The study was conducted based on 10 developed and 10 developing countries from different parts of the world with the highest level of development of ESG investment in 2021 (Table 1).

The benefit of the ranking of developing and developed countries shown in Table 1 is that it has revealed a significant discrepancy between the existing boundaries of these categories of countries based on the criterion of market freedom and the efficiency of institutes (the integration of countries into the OECD defines them as developed countries) and on the criterion of income level (according to the World Bank classification, countries with a high level of income are considered as developed countries, while all other countries are considered as developing countries) with the criteria of ESG investments and readiness for frontier technologies.

For example, China is one of the most active users of artificial intelligence (AI) on the international scale, although it ranks among the developing countries. On the other hand, Austria is classified as a developed country by the OECD and the World Bank, while Table 1 shows that this country is classified as a country that is lagging behind in many respects. Standard boundaries of categories of countries have been stored in Table 1 to make the results comprehensible, easily interpretable, reproducible, and comparable with other studies on the topic of distinctions between developed and developing countries.

As a result of processing the data from Table 1 using regression and correlation analysis methods, the following two economic and mathematical models of the contribution of the institutes of the AI economy to the development of ESG investments were obtained:

– Model for developed countries: ESG = 18.91 − 0.12ict + 0.07skl-0.02r&d + 0.11ind + 0.13fin. The resulting model means that in developed countries, the development of ESG investments is positively influenced by such institutes of the AI economy as ICT and R&D. The cumulative correlation of ESG investments with the institutes of the AI economy is estimated at 83.86% (high). Because of the mentioned inconsistency of the sample of developed countries (reduced volume of ESG investments and readiness for frontier technologies despite the high-income level, high market freedom, and high efficiency of institutes), the model for developed countries is only reliable at a significance level of 0.3 (Significance F = 0 .27746), although the standard error is relatively small and is equal to 2.06. The t-statistics for the factor variables were as follows: for ICT ranking (ict): −1.04, for Skills ranking (skl): 0.73, for R&D ranking (r&d): −0.16, for Industry ranking (ind): 1.38, for Finance ranking (fin): 1.76;

– Model for developing countries: ESG = 32.86–0.07ict-0.01skl-0.07r&d + 0.04ind + 0.03fin. The resulting model means that in developed countries, the development of ESG investments is positively influenced by such institutes of the AI economy as ICT, Skills, and R&D. The cumulative correlation of ESG investments with the institutes of the AI economy is estimated at 94.56% (very high). The model for developing countries proved to be more reliable–it is reliable at a significance level of 0.05 (Significance F = 0.0440), and the standard error is small and equals 1.22. The t-statistics for the factor variables were as follows: for ICT ranking (ict): −2.91, for Skills ranking (skl): −0.32, for R&D ranking (r&d): −2.73, for Industry ranking (ind): 4.49, for Finance ranking (fin): 1.91.

Prospects and recommendations for the development of ESG investments in the AI era in developed and developing countries

To determine the prospects for the development of ESG investments in the AI era in developed and developing countries, based on the obtained economic and mathematical models, it was found that in developed countries, due to the progress of ICT institutes (+94.76% compared to the level of 2021) and R&D (+95.15%), the level of development of ESG investments may increase up to 26.80 points, that is, by 10.55% compared to 2021 (24.24 points).

To clarify the quantitative results, they were supplemented with a qualitative study using the SWOT analysis method, as a result of which (based on statistics from Table. 1) it was revealed that the strengths (S) of the AI economy in developed countries are the high level of development of such institutes as ICT (on average, in the sample of developed countries, 19.10 position) and R&D (20.60 positions).

The weaknesses (W) are the small contribution of skills to the development of ESG investments, despite the high level of development of this institute of the AI economy (14th place), as well as the moderate level of development and a small contribution to the development of ESG investments of such institutes as Industry (34th position) and Finance (25.30 positions). Opportunities (O) are associated with the further development of ICT and R&D institutes, as well as with the transformation of skills, industry, and finance institutes towards greater support for the SDGs and achieving their more significant contribution to the development of ESG investments. Threats (T) consist of the slow pace of development of ICT and R&D institutes as well as difficulties in the transformation of the Skills institute.

In developing countries, due to the progress of ICT institutes (+98.41%), Skills (+98.60%) and R&D (+97.01%), the level of development of ESG investment may increase up to 37.05 points, that is, by 22.57% compared to 2021 (30.22 points). The SWOT analysis showed that the strength (S) of the AI economy in developing countries is a moderate level of development of R&D institute (33.50 positions).

Weaknesses (W) is the low level of development of such institutes as ICT (62.70 positions) and Skills (71.30 positions), as well as a small contribution to the development of ESG investments in Industry and Finance institutes. Opportunities (O) are associated with the further development of R&D institutes, with accelerated progress in the development of ICT and Skills institutes, as well as with the transformation of Industry and Finance institutes towards greater support for the SDGs and achieving their more significant contribution to the development of ESG investments. Threats (T) consist in the slow pace of development of the R&D institute, as well as in difficulties in the transformation of the finance institute.

Discussion

The article contributed to the development of the concept of "smart" ESG investments by clarifying the causal relationships of the development of ESG investments in the AI economy. In contrast to Ielasi et al. (2020), Tong et al. (2022); Yasmine and Kooli (2022), it has been proved that the contribution of the AI economy to the development of ESG investments is related not so much to institutes but technologies. This allows us to propose a new (alternative) approach to the development of ESG investments in the AI era, involving the systematic development of institutes of the AI economy.

However, standard institutes (freedom of international trade, protection of investors, common "rules of the game" in industry markets) are not enough. Special institutes are required and are coming to the fore to ensure the movement of ESG investment flows in the AI era. Corporate social and environmental responsibility, green finance, corporate management, etc. serve as these special institutes. This is because ESG investments in the AI era, despite the traditional leadership of developed countries in most rankings, are more pronounced in developing countries.

It is suggested that a new classification of countries, in which the boundaries of developed and developing countries will be determined with due account for the level of development of the mentioned institutes of ESG investments in the AI era, could serve as a basis for the proposed approach. This will provide a means for a more reliable definition of the positions of countries in the world economic system from the standpoint of environmental economics and management, as well as for a more objective and accurate assessment of their progress in the development of ESG investments in the AI era.

The advantage of the new approach is, first, that it more accurately and reliably describes the regularities of development of ESG investments in the AI era. Second, the new approach explains the differences in the development of ESG investments in the AI economy of developed and developing countries, and also allows us to find unique application solutions for them, taking into account their specifics.

Also, as a result of the study, unlike Li et al. (2022), Minkkinen et al. (2022b), Rehman Khan et al. (2022); Sætra (2021), it has been proved that the development of "smart" technologies alone are not enough to increase the volume of ESG investments - the development of institutes of the AI economy is also required. This served as an argument for a clear division of the AI economies of developed and developing countries, whose institutes contribute differently (among institutes and categories of countries) to the development of ESG investments.

Conclusion

The result of the study is proof of the hypothesis put forward in the article. A review of international experience in 2021 showed that the institutes of the AI economy determine the features of ESG investments in developed (where ICT and R&D institutes are the most significant and highly developed) and developing countries (where ICT, Skills, and R&D institutes are the most significant, but only R&D institute is moderately developed). The obtained models, reasonable prospects, and proposed recommendations outlined the priorities for the development of institutes in the AI economy for the most effective support for ESG investments, taking into account the characteristics of each category of countries.

The contribution of the article to the improvement of scientific knowledge consists of the fact that the article has provided a new basis for the classification of countries, which enables a more exact definition of their modern boundaries in the AI era. It is suggested that the level of development and institutes of ESG investments could serve as this new basis. The article has made its contribution to the literature through the development of the theory for the relationship between ESG and artificial intelligence (AI), showing that this relationship can be observed at the level of institutes, not technologies, as in the previous opinion.

The theoretical significance of the results obtained in the article is related to the fact that the proposed new institutional approach to the development of ESG investments in the AI era takes into account the possibilities of using advanced "smart" technologies in practice, as well as the degree of use of their potential, and therefore bridges the gap between theory and practice. The applied significance of the authors' conclusions and recommendations is that they take into consideration the characteristics of developed and developing countries and allow for the most effective management of the AI economy (through the development of its target institutes proposed in the article) in support of the development of ESG investments.

Recommendation and solution

As a prospective solution to the problem of the development of ESG investing in the age of AI, we propose a transition from the isolated development of technologies to the systemic development of institutes. Due to this, the process of development of ESG investing in the age of AI transforms from linear into cyclical, for institutes in society and the economy initiate the creation and implementation of new technologies, which, in its turn, strengthens the institutes and causes repetition of the cycle.

In developed countries, for the development of ESG investment in the age of AI, it is recommended to focus on the development of the institute of ICT and institute of R&D, and in developing countries–also the institute of Skills. That is, technologies play an important role, and for this, it is recommended to improve the telecommunication infrastructure and disseminate ICT. However, the progress of technologies only is not enough in both categories of countries.

A mandatory condition for the development of ESG investment in the age of AI is the growth of innovative activity in the economy. For this, it is recommended to increase the volume of financing of R&D and the share of science-intensive, high-tech, and innovative products. In developing countries, an important role belongs to social adaptation. For this, it is recommended to fill in the gaps in competencies, train digital personnel, create knowledge-intensive jobs and implement corporate training.

The advantage of the proposed solution is the comprehensive development of society, economy, and technologies, as well as consideration of the specifics and offering of the authors' applied recommendations for developed and developing countries. This will allow reaching the mass character of ESG investing and an increase in scale in the age of AI, as well as ensure the reliable support for the implementation of the SDGs in the Decade of Action from society and business based on the technologies of the age of AI and ESG investing.

Economic policy implications

The results obtained allow concluding that the models of development of ESG investment in the age of AI are different in developed and developing countries. Based on the compiled econometric models and results of the SWOT analysis, the following recommendations for economic policy are offered for developed countries: 1) supporting the achieved high level of development of the institute of ICT and the institute of R&D through the improvement of the legal regulation of these institutes; 2) stimulating the growth of the contribution of skills to ESG investments through the development of the "knowledge economy"; 3) raising the level of the development of the institutes of industry and finance and increasing their contribution to ESG investments through the stimulation of support for the SDGs.

The following recommendations for economic policy are offered for developing countries: 1) supporting the achieved high level of the development of the institute of R&D through further development of the innovative economy; 2) raising the level of the development of the institutes of ICT and skills through accelerated digital modernization of society and economy; 3) stimulating the growth of the contribution to ESG investments by the institutes of industry and finance through stimulating corporate social responsibility. The proposed recommendations allow focusing the national economic policy on the key spheres, thus facilitating the increase in its effectiveness.

Limitations and prospects for future research

Summing up the research, it should be noted that the institutional approach to studying the influence of the AI economy on ESG investments, which is offered and used in this article, has demonstrated its high effectiveness. The advantage of the institutional approach is the possibility to combine qualitative and quantitative research methods, as well as to take into account the specifics of developed and developing countries.

A limitation of this research is the generalized consideration of developed and developing countries at the level of categories, while in each country, institutes of the AI economy are specific, similar to the practices of ESG investment. To deal with this limitation, it is recommended to perform a range of case studies, to identify the national models of development of ESG investment based on the institutes of the AI economy and with the use of the institutional approach.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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References

Aldowaish, A., Kokuryo, J., Almazyad, O., and Goi, H. C. (2022). Environmental, social, and governance integration into the business model: Literature review and research agenda. *Sustainability* 14, 2959. doi:10.3390/su14052959

Alkaraan, F., Albitar, K., Hussainey, K., and Venkatesh, V. G. (2022). Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG). *Technol. Forecast. Soc. Change* 175, 121423. doi:10.1016/j.techfore.2021.121423

Andersson, E., Hoque, M., Rahman, M. L., Uddin, G. S., and Jayasekera, R. (2022). ESG investment: What do we learn from its interaction with stock, currency and commodity markets? *Int. J. Fin. Econ.* 27 (3), 3623–3639. doi:10.1002/ijfe.2341

Aroul, R. R., Sabherwal, S., and Villupuram, S. V. (2022). ESG, operational efficiency and operational performance: evidence from real estate investment trusts. *Manag. Finance* 48 (8), 1206–1220. doi:10.1108/MF-12-2021-0593

Auer, B. R., and Schuhmacher, F. (2016). Do socially (ir)responsible investments pay? New evidence from international ESG data. *Q. Rev. Econ. Finance* 59, 51–62. doi:10.1016/j.qref.2015.07.002

Avramov, D., Cheng, S., Lioui, A., and Tarelli, A. (2022). Sustainable investing with ESG rating uncertainty. *J. Financial Econ.* 145 (2), 642–664. doi:10.1016/j.jfineco.2021.09.009

Breedt, A., Ciliberti, S., Gualdi, S., and Seager, P. H. (2019). Is ESG an equity factor or just an investment guide? *J. Invest.* 28 (2), 32–42. doi:10.3905/joi.2019.28.2.032

Cardillo, G., Bendinelli, E., and Torluccio, G. (2022). COVID-19, ESG investing, and the resilience of more sustainable stocks: Evidence from European firms. *Bus. Strategy Environ.*, 10.1002/bse.3163. doi:10.1002/bse.3163

Chen, G., Wei, B., and Dai, L. (2022). Can ESG-responsible investing attract sovereign wealth funds' investments? Evidence from Chinese listed firms. *Front. Environ. Sci.* 10, 935466. doi:10.3389/fenvs.2022.935466

Cornforth, M. (2018). UK AI gets investment and advisory board. *IoTex* 2018 (1), 50–51.

Dudukalov, E. V., Terenina, I. V., Perova, M. V., and Ushakov, D. (2021). Industry 4.0 readiness: The impact of digital transformation on supply chain performance. *E3S Web Conf.* 244, 08020. doi:10.1051/e3sconf/202124408020

Fafaliou, I., Giaka, M., Konstantios, D., and Polemis, M. (2022). Firms' ESG reputational risk and market longevity: A firm-level analysis for the United States. *J. Bus. Res.* 149, 161–177. doi:10.1016/j.jbusres.2022.05.010

Fritz-Morgenthal, S., Hein, B., and Papenbrock, J. (2022). Financial risk management and explainable, trustworthy, responsible AI. *Front. Artif. Intell.* 5, 779799. doi:10.3389/frai.2022.779799

Gao, Y., Li, Y., and Wang, Y. (2021). The dynamic interaction between investor attention and green security market: an empirical study based on baidu index. *China Finance Rev. Int.* doi:10.1108/CFRI-06-2021-0136

Ge, G., Xiao, X., Li, Z., and Dai, Q. (2022). Does ESG performance promote high-quality development of enterprises in China? The mediating role of innovation input. *Sustainability* 14, 3843. doi:10.3390/su14073843

Ielasi, F., Ceccherini, P., and Zito, P. (2020). Integrating ESG analysis into smart beta strategies. *Sustain. Switz.* 12 (22), 93511–93522. doi:10.3390/su12229351

In, S. Y., Rook, D., and Monk, A. (2019). Integrating alternative data (also known as ESG data) in investment decision making. *Glob. Econ. Rev.* 48 (3), 237–260. doi:10.1080/1226508X.2019.1643059

Inampudi, K., and Macpherson, M. (2020). "The impact of AI on environmental, social and governance (ESG) investing: Implications for the investment value chain," in *The artificial intelligence handbook for investors, entrepreneurs and FinTech visionaries*. Editors S. Chishti, I. Bartoletti, A. Leslie, and M. M. Shân (New Jersey: John Wiley & Sons). doi:10.1002/9781119551966.ch35

Ivanov, A. A., Ivanov, A. A., and Ivashchenko, Y. S. (2022). Digital technologies of the self: Instrumental rationality or creative integrity? *Lect. Notes Netw. Syst.* 345, 139–147.

Jonsdottir, B., Sigurjonsson, T. O., Johannsdottir, L., and Wendt, S. (2022). Barriers to using ESG data for investment decisions. *Sustain. Switz.* 14 (9), 5157. doi:10.3390/su14095157

Kukushkina, A. V., Mursaliev, A. O., Krupnov, Y. A., and Alekseev, A. N. (2022). Environmental competitiveness of the economy: Opportunities for its improvement with the help of AI. *Front. Environ. Sci.* 10, 953111. doi:10.3389/fenvs.2022.953111

Li, S., Yu, Y., Jahanger, A., Usman, M., and Ning, Y. (2022). The impact of green investment, technological innovation, and globalization on CO2 emissions: Evidence from MINT countries. *Front. Environ. Sci.* 10, 868704. doi:10.3389/fenvs.2022.868704

Lööf, H., Sahamkhadam, M., and Stephan, A. (2022). Is corporate social responsibility investing a free lunch? The relationship between ESG, tail risk, and upside potential of stocks before and during the COVID-19 crisis. *Finance Res. Lett.* 46, 102499. doi:10.1016/j.frl.2021.102499

Luitse, D., and Denkena, W. (2021). The great transformer: Examining the role of large language models in the political economy of AI. *Big Data Soc.* 8 (2), 205395172110477. doi:10.1177/20539517211047734

Maas, M. M. (2018). "Regulating for 'normal AI accidents': Operational lessons for the responsible governance of artificial intelligence deployment," in AIES - Proceedings of the 2018 AAAI/ACM Conference on AI, Ethics, and Society, New Orleans La, USA, Feb 2-3, 223–228.

Minkkinen, M., Niukkanen, A., and Mäntymäki, M. (2022a). What about investors? ESG analyses as tools for ethics-based AI auditing. *AI Soc.* doi:10.1007/s00146-022-01415-0

Minkkinen, M., Zimmer, M. P., and Mäntymäki, M. (2022b). Co-shaping an ecosystem for responsible AI: Five types of expectation work in response to a technological frame. *Inf. Syst. Front.* doi:10.1007/s10796-022-10269-2

Morningstar (2021). Sustainability atlas assesses the ESG profile of countries across the globe. URL: https://www.morningstar.co.uk/uk/news/211424/which-countries-lead-on-esg.aspx (data accessed: 13.05.2022).

Nauck, D. (2019). Responsible AI. *J. Inst. Telecommun. Prof.* 13, 14–19.

Pedersen, L. H., Fitzgibbons, S., and Pomorski, L. (2021). Responsible investing: The ESG-efficient frontier. *J. Financial Econ.* 142 (2), 572–597. doi:10.1016/j.jfineco.2020.11.001

Popkova, E. (2022). *Advanced issues in the green economy and sustainable development in emerging market economies (elements in the economics of emerging markets)*. Cambridge: Cambridge University Press.

Popkova, E., Alekseev, A. N., Lobova, S. V., and Sergi, B. S. (2020). The theory of innovation and innovative development. AI scenarios in Russia. *Technol. Soc.* 63, 101390. doi:10.1016/j.techsoc.2020.101390

Popkova, E. G., Oudah, A.-M. M. Y., Ermolina, L. V., and Sergi, B. S. (2021). Financing sustainable development amid the crisis of 2020. A research note. *Lect. Notes Netw. Syst.* 198, 773–780. doi:10.1007/978-3-030-69415-9_88

Popkova, E. G., and Sergi, B. S. (2021). Dataset modelling of the financial risk management of social entrepreneurship in emerging economies. *Risks* 9 (12), 211. doi:10.3390/risks9120211

Popkova, E. G., and Sergi, B. S. (2022). High-tech economic growth from the standpoint of the theory of economic time: Modelling and reducing space–time inequality. *Smart Innovation, Syst. Technol.* 287, 15–22. doi:10.1007/978-981-16-9804-0_2

Ragulina, Y. V., Dubova, Y. I., Litvinova, T. N., and Balashova, N. N. (2022). The environmental AI economy and its contribution to decarbonization and waste reduction. *Front. Environ. Sci.* 10, 914003. doi:10.3389/fenvs.2022.914003

Rehman, F. U., and Noman, A. A. (2022). China's outward foreign direct investment and bilateral export sophistication: a cross countries panel data analysis. *China Finance Rev. Int.* 12 (1), 180–197. doi:10.1108/cfri-04-2020-0040

Rehman Khan, S. A., Hassan, S., Khan, M. A., Godil, D. I., and Tanveer, M. (2022). Nexuses between energy efficiency, renewable energy consumption, foreign direct investment, energy consumption, global trade, logistics and manufacturing industries of emerging economies: In the era of COVID-19 pandemic. *Front. Environ. Sci.* 10, 880200. doi:10.3389/fenvs.2022.880200

Sætra, H. S. (2021). A framework for evaluating and disclosing the esg related impacts of ai with the SDGs. *Sustain. Switz.* 13 (15), 8503. doi:10.3390/su13158503

Selim, O. (2020). "ESG and AI: The beauty and the beast of sustainable investing," in *Sustainable investing: A path to a new horizon*. Editors Herman Bril, Georg Kell, and Andreas Rasche (England: Routledge), 227–243. doi:10.4324/9780429351044-12

Shahzad, F., Hussain Baig, M., Rehman, I. U., Latif, F., and Sergi, B. S. (2020). What drives the impact of women directors on firm performance? Evidence from intellectual capital efficiency of US listed firms. *J. Intellect. Cap.* 21 (4), 513–530. doi:10.1108/JIC-09-2019-0222

Sharma, U., Gupta, A., and Gupta, S. K. (2022). The pertinence of incorporating ESG ratings to make investment decisions: a quantitative analysis using machine learning. *J. Sustain. Finance Invest.*, 1–15. doi:10.1080/20430795.2021.2013151

Shkalenko, A. V., Inshakova, A. O., and Inshakova, E. I. (2022). "The digital economy in action: Integration of institutional economy paradigms and law in the neo-industrialization period," in *Advances in research on Russian business and management* (North Carolina: Information Age Publishing), 99–116.

Som, T. (2021). Sustainability in energy economy and environment: Role of AI based techniques. *Model. Optim. Sci. Technol.* 18, 647–682. doi:10.1007/978-3-030-72929-5_31

Teichmann, F., Boticiu, S. R., and Sergi, B. S. (2022). Compliance risks for crowdfunding. A neglected aspect of money laundering, terrorist financing and fraud. *J. Financ. Crime.* doi:10.1108/JFC-05-2022-0116

Tong, L., Yan, W., and Manta, O. (2022). Artificial intelligence influences intelligent automation in tourism: A mediating role of Internet of Things and environmental, social, and governance investment. *Front. Environ. Sci.* 10, 853302. doi:10.3389/fenvs.2022.853302

UNCTAD (2022). Technology and innovation report 2021. URL: https://unctad.org/page/technology-and-innovation-report-2021 (data accessed: 13.05.2022).

Vetrò, A., Santangelo, A., Beretta, E., and De Martin, J. C. (2019). AI: from rational agents to socially responsible agents. *Digital Policy, Regul. Gov.* 21 (3), 291–304. doi:10.1108/DPRG-08-2018-0049

Viriato, J. C. (2019). AI and machine learning in real estate investment. *J. Portfolio Manag.* 45 (7), 43–54. doi:10.3905/jpm.2019.45.7.043

Wang, X., Butt, A. H., Zhang, Q., Ahmad, H., and Shafique, M. N. (2021). Intention to use AI-powered financial investment robo-advisors in the M-banking sector of Pakistan. *Inf. Resour. Manag. J.* 34 (4), 1–27. doi:10.4018/IRMJ.2021100101

Wilson, M., Paschen, J., and Pitt, L. (2022). The circular economy meets artificial intelligence (AI): understanding the opportunities of AI for reverse logistics. *Manag. Environ. Qual. Int. J.* 33 (1), 9–25. doi:10.1108/MEQ-10-2020-0222

Yankovskaya, V. V., Osipov, V. S., Zeldner, A. G., Panova, T. V., and Mishchenko, V. V. (2021). Institutional matrix of social management in region's economy: stability and sustainability vs innovations and digitalization. *Int. J. Sociol. Soc. Policy* 41 (1-2), 178–191. doi:10.1108/IJSSP-03-2020-0088

Yasmine, B., and Kooli, M. (2022). Smart beta ESG disclosure. *J. Asset Manag.* doi:10.1057/s41260-022-00257-1

Zhang, D., Zhao, Z., and Lau, C. K. M. (2022). Sovereign ESG and corporate investment: New insights from the United Kingdom. *Technol. Forecast. Soc. Change* 183, 121899. doi:10.1016/j.techfore.2022.121899

Zhang, X., Zhao, X., and Qu, L. (2021). Do green policies catalyze green investment? Evidence from ESG investing developments in China. *Econ. Lett.* 207, 110028. doi:10.1016/j.econlet.2021.110028

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Environmental taxation: Contribution to sustainable development and AI prospects

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Introduction

The Sustainable Development Goals (WEH) are the embodiment of sustainable development, therefore, it is advisable to evaluate its progress based on their results. Due to the diversity of the SDGs, integrated management of them should be combined with initiatives in the implementation of certain areas of sustainable development. In the direction of social progress, serious progress has been made to date both in improving living standards and in reducing gender and income inequality.

In the direction of economic growth, the results are also impressive. The COVID-19 crisis, although rightly considered the deepest since the beginning of the XXI century, was limited to 1 year (2020) and has now been replaced by a rapid recovery of the world economic system. Thus, according to the World Bank (2022), the reduction of world GDP was 3.3% in 2020, but as soon as 2021 the growth rate of the world economy was 5.8%, which is much higher than the 2019 level when it was 2.6%.

The ecological direction deserves special attention since it demonstrates more limited results. Despite the unprecedented efforts of the world community, the problem of biodiversity reduction remains critical, and the COVID-19 pandemic (which, according to a common hypothesis, is caused by the above problem) continues to this day and threatens new waves of morbidity. The World Health Organization (2022) informed (as of the end of October 2022) of 162,207 new cases in the last 24 h (as of 5:43 p.m. CEST, 28 October 2022). In this regard, the growth of the ecological economy is a priority for sustainable development, the success in the implementation of which determines the prospects for a balanced achievement of the SDGs in the Decade of Action.

The shortage of financial resources is considered in the existing literature among the key barriers to the sustainable development of the ecological economy. Private investments in environmental protection, responsible production and consumption practices remain at the discretion of market agents (business structures and households) and therefore provide a pronounced effect for sustainable development only in progressive societies (mainly in developed countries) (Congjuan et al., 2022;

Cordova-Buiza et al., 2022; Huang et al. al., 2022; Tu et al., 2022; Yang et al., 2022). Consequently, regulatory financial mechanisms require the most attention (because of their universality, i.e., accessibility for developing countries), among which environmental taxation occupies an important place.

The essence and experience of applying environmental taxation are considered in the works of Lei et al. (2022), Liu et al. (2022), Matti et al. (2022), Zhao et al. (2022). But the contribution of environmental taxation to the sustainable development of the ecological economy has not been sufficiently studied and defined, which is a gap in the literature. In the works of Barbanti et al. (2022), Barik et al. (2022), Giuliani et al. (2020), Xu et al. (2022), it is noted that lagging countries (for example, in Africa) have a much higher level of development of the ecological economy and, in particular, more pronounced success in preserving biodiversity than in developed countries due to a lower level of industrial development and greater dependence of the society on the environment in terms of livelihood.

This is presented as an argument in favour of the insignificant role of environmental taxation in the sustainable development of the ecological economy, which is mainly determined by industrial development. Recognizing the high priority of industrial development, attention should be paid to the consistency of the SDGs and the need to find a common solution that allows preserving biodiversity without limiting industrial development. In this regard, environmental taxation can be very important, which requires research.

The general advantages of the formation of the AI economy for environmental protection and sustainable development are noted in the works of Lobova et al. (2022), Popkova et al. (2022), and Popkova et al. (2021). The available publications of Li and Zhu (2021), Zackrisson et al. (2020) indicate the advantages of using advanced "smart" technologies of the AI economy for modernization and optimization of taxation. However, the features of the use of "smart" technologies in environmental taxation are poorly understood, which is another gap in the literature. To fill both identified gaps, this article aims to study the contribution of environmental taxation to the sustainable development of the ecological economy, as well as substantiate the prospects for increasing this contribution with the use of AI. The goal is achieved by using the following set of research tasks:

→ Analysis of international best practices and econometric modelling of the contribution of environmental taxation to sustainable development;
→ Case study of Russia's progressive experience in the field of environmental taxation;
→ Development of recommendations for improving environmental taxation based on artificial intelligence to ensure sustainable development.

The originality of this article lies in the identification of new prospects for improving environmental taxation, which are provided by the introduction of artificial intelligence.

Methodology

We have selected the corresponding methodology for each task. Analysis of the leading international experience and econometric modelling of the environmental taxation's contribution to sustainable development is performed with the help of regression analysis. We also perform the econometric modelling of the connection between the ecosystems protection and preservation of biodiversity (result on SDG 15) and environmentally related tax revenue, in % of GDP and in monetary units per capita. The reliability of regression equations is determined with the help of an F-test, *t*-test, coefficients of correlation and standard errors.

The sample contains the top 10 developed and the top 10 developing countries with the highest level of environmental taxation (leaders of the ranking Compare your country, 2022), which ensures the representativeness of the sample and allows applying the research results to the world economy. The size of the sample is sufficient for the correct reflection of the leading experience, while this paper is not aimed at representing the entire population of the planet, which would require larger studies in the future.

The case research of the progressive experience of Russia in the sphere of environmental taxation is performed with the help of the method of the case study. As a result, we develop a range of authors' recommendations on the improvement of environmental taxation based on artificial intelligence, in the interests of sustainable development.

Contribution of environmental taxation to sustainable development: Modelling based on a review of international experience

To determine the contribution of environmental taxation to sustainable development, its modelling is carried out by regression analysis. The dependence of the results of biodiversity conservation (according to SDG 15 based on the assessment report of the UNDP, 2022) in 2021 on environmental taxation in 2019 (having a delayed effect) is determined. To analyze international best practices, the study is conducted on a sample of the top 10 developed and top 10 developing countries with the highest level of environmental taxation (which are the leaders of the "Compare your country" ranking, 2022), for which data on SDG 15 are available (Table 1, in additional materials).

As a result of econometric modelling based on the data from Table 1, the following regression equations are obtained:

TABLE 1 Environmental taxation in 2019 and the results of the implementation of SDG 15 in 2021 in developed and developing countries.

Country category	Country	Environmentally related tax revenue, % GDP	Environmentally related tax revenue per capita, USD	Goal 15, score 0–100
		ET_{GDP}	ETpc	SDG 15
Developing countries	Guyana	4.01	521.64	55.69
	Mauritius	3.05	671.91	26.43
	South Africa	2.94	359.21	58.99
	Costa Rica	2.31	441.26	61.59
	Honduras	2.3	120.5	60.68
	Kenya	2.12	85.36	59.29
	Turkey	2.09	584.42	53.26
	Argentina	1.82	337.63	60.67
	Uruguay	1.67	346.94	58.81
	Chile	1.38	319.48	59.09
Developed countries	Slovenia	4.01	1466.62	88.46
	Greece	3.87	1113.18	81.09
	Estonia	3.73	1278.41	96.26
	Netherlands	3.68	2009.74	84.13
	Latvia	3.33	971.06	97.86
	Italy	3.29	1272.19	80.22
	Denmark	3.29	1757.82	90.64
	Bulgaria	2.99	637.34	90.65
	Israel	2.55	1024.6	50.9
	South Korea	2.66	989.5	54.5

Source: compiled by the authors based on materials from Compare your country (2022), UNDP (2022).

$$SDG15 = 41.64 + 5.02*ET_{GDP} + 0.01*ET_{pc} \quad (1)$$

$$ET_{GDP} = 2.03 + 0,001*ET_{pc} \quad (2)$$

To obtain Eqs 1, 2, we use the method of regression analysis to determine the regression dependence of SDG 15 on factor variables ETGDP and ETpc and then the dependence ETGDP (which in this case is a resulting variable) on the factor variable ETpc. The described mathematical steps are performed automatically in Microsoft Excel, using the built-in function of regression analysis.

To check the reliability of the regression equations, we perform an F-test. For Eq. 1, the automatically found significance F equals 0.01961. Therefore, Eq. 1 conforms to the significance level of 0.05. At two factor variables (m = 2) and 20 observations (n = 20), i.e., at the number of degrees of freedom k1 = m = 2 and k2 = n − m − 1 = 20 − 2 − 1 = 17, the table value of F is 3.59. The observed value of F equals 4.999, exceeding the table value.

Therefore, the F-test has been passed. This means that the regression equation is reliable at the significance level of 0.05. The correlation coefficient in Eq. 1 equals 0.6085. Therefore, the change in results in the sphere of preservation of ecosystems of land and protection of biodiversity, manifested in SDG 15, is by 60.85% explained by the environmental taxation factors.

For Eq. 2, the automatically found significance F equals 0.000877. Therefore, Eq. 2 conforms to the significance level of 0.01. At one factor variable (m = 1) and 20 observations (n = 20), i.e., at the number of degrees of freedom of k1 = m = 1 and k2 = n − m − 1 = 20 − 1 − 1 = 18, the table value of F is 8.29. The observed value of F equals 15.846, exceeding the table value. Therefore, the F-test has been passed.

We also performed a t-test. At 19 degrees of freedom at the set level of significance of 0.05, the table value of t equals 2.86. The observed value of t for the factor variable equals 3.98, exceeding the table value. This means that the regression equations is reliable at the level of significance of 0.01. The correlation coefficient in Eq. 2 equals 0.6842. Therefore, the environmentally related tax revenue in % of GDP is by 68.42% explained by the change in environmentally related tax revenue per capita.

Based on the modelling results, it was found that for the most complete conservation of biodiversity (maximizing the result according to SDG 15: 100 points, +46.07% compared to the average value in 2021), an increase in environmentally related tax revenue by 189.37% is necessary (from $815.44 per capita to $2359.63 per capita). This will lead to an increase in environmentally related tax revenue by 54.92% (from 2.85% of GDP to 4.425% of GDP).

Standard errors are moderate in Eq. 1, equalling 6.18 and 0.0009 for the first and second factor variables, accordingly. In Eq. 2, the standard error is 0.60, i.e., it is small. The limitation of the proposed model is that it reflects the influence of environmental taxation on one Sustainable Development Goal only, namely SDG 15, while there might be a connection also with other SDGs, which are not necessarily connected with environmental protection but have socioeconomic nature. For example, there might be clear or hidden consequences—expressed to varying degrees—consequences for green employment and green growth of the economy (SDG 8).

The advantage of the created econometric model is the precise quantitative reflection of the regularities of protection of land ecosystems and preservation of biodiversity in the course of an increase in environmental taxation. Due to this, the model specified the causal connections and allows compiling high-precision forecasts for the achievement of SDG 15. A drawback of the model is the generalisation of the experience of developed and developing countries, while their specific features could determine the specifics of the change in the level of land ecosystems protection and preservation of biodiversity in the course of an increase in environmental taxation.

Case experience of Russia in the field of environmental taxation

Additionally, the case experience of Russia in the field of environmental taxation has been studied, which makes it possible to highlight successful practical examples and consider them both from the positions of enterprises and the positions of the state and society. In Russia, the environmental tax is a mandatory payment (compensation) for the negative impact on the environment, which covers pollution of atmospheric air, water, subsoil, soil with noise, heat, electromagnetic ionizing and other types of physical actions, production and consumption waste (stationary and mobile objects) (Aero-Soft Information Technology Bureau, 2022).

It is important to note that the payment of the environmental tax does not exempt economic entities from the obligation to protect the environment and fully compensate for damage caused to the environment and the health of interested persons. Environmental taxation has been practised in Russia since 2002 (for 20 years). The amount of the environmental tax is calculated by taxpayers (all those who pollute the environment) independently, taking into account the established tax rates for the amount of pollution exceeding the statutory standards, as well as increasing coefficients (Aero-Soft Information Technology Bureau, 2022).

Traditional (used over the course of 20 years) environmental taxes in Russia include, first, a fee for use of fauna objects and water biological resources (tax rates are determined in rubles per one animal or one ton of biological resource). Second, water tax (a large list of tax rates in rubles per 1,000 cubic meters of water). Third, tax on minerals extraction (% rate in rubles per one ton or 1,000 cubic meters of extracted minerals).

Fourth, transport tax (tax rates in rubles per horsepower; the values are changed depending on the horsepower, varying among regions). Fifth, land tax (up to 0.3% and up to 1.5%—depending on the land category) (Taxation in the Russian Federation, 2022). In 2022, a new environmental tax was introduced—a fee for direct violation of environmental laws and harm to the ecology. The tax base is determined as the volume of produced production waste minus the weight of waste that was recycled (Accounting in the Russian Federation, 2022).

The result of the case study showed that environmental taxation in Russia makes a great contribution to environmental protection and biodiversity conservation, as it forms a reliable regulatory framework for responsible environmental management. At the same time, the shortcomings of environmental taxation in Russia have been identified, including a rather complex, knowledge-intensive and time-consuming procedure for calculating and paying environmental tax, insufficient control (administration) over the payment of environmental tax and high risks of environmental tax evasion.

Due to the reformation of the tax law, there is no quantitative view of the value of environmental taxation in Russia yet. However, there is the quantitative value of the achieved serious results in the sphere of sustainable development of the environmental economy in Russia. The result on SDG 13 in 2022 was assessed at 73.441 points, the result on SDG 14–52.321 points and the result on SDG 15–66.183 points (UNDP, 2022). This is a sign of the successful fight against climate change, protection of ecosystems and preservation of biodiversity in Russia. Improvement (addition with a new tax) of the tax law will allow increasing and multiplying the achieved results in the sphere of the sustainable development of the environmental economy in Russia in the Decade of Action.

Recommendations for improving environmental taxation based on artificial intelligence to ensure sustainable development

The AI economy opens up new opportunities for improving environmental taxation, allowing us to overcome all its shortcomings identified in Russia. To do this, we propose a set of the following practice-oriented recommendations for improving environmental taxation based on artificial intelligence to achieve sustainable development:

→ Automation of the taxing process and tax optimization using AI, which allows simplifying and speeding up the process of calculating and paying environmental taxes;
→ Transition to "smart" tax administration based on electronic document management. This transition will ensure full-scale control of the correctness of the calculation and payment of environmental tax by all taxpayers;
→ Monitoring of environmental tax evasion based on "machine vision", which allows timely detection of facts of environmental pollution exceeding the standards and prevention of environmental tax evasion.

The proposed recommendations will be useful for all countries of the world—both developing and developed, as they will contribute to improving the efficiency of environmental taxation and maximizing its contribution to environmental protection and biodiversity conservation.

Discussion

The contribution of the article to the literature is to clarify the role of environmental taxation in the sustainable development of the ecological economy, as well as to substantiate the prospects for improving environmental taxation based on "smart" technologies of the AI economy. The results obtained in this study are different from the results received in similar studies.

Unlike Barbanti et al. (2022), Barik et al. (2022), Giuliani et al. (2020), Xu et al. (2022), it has been proved that environmental taxation plays an important role in ensuring the sustainable development of the ecological economy. The advantage of environmental taxation is that it is a widely accessible tool for environmental protection and biodiversity conservation, while the limitation of industrial development is available only to lagging countries and has a contradictory interpretation from the standpoint of socio-economic development.

Unlike Congjuan et al. (2022), Cordova-Buiza et al. (2022), Huang et al. (2022), Tu et al. (2022), Yang et al. (2022), it has been justified that state intervention in market processes in the ecological economy (through environmental taxation) does not reduce, but increases its effectiveness. Environmental taxation makes it possible to overcome "market failures" associated with the insufficient motivation of economic entities to protect the environment and preserve biodiversity, especially clearly manifested in developing countries. The "smart" AI economy technologies make it possible to significantly improve environmental taxation.

The results obtained and the authors' conclusions are shown—in a systemic and representative manner—by the framework model of the research (Figure 1).

The framework model of the research (Figure 1) demonstrates that results in the sphere of ecosystems protection and preservation of biodiversity (SDG 15) are by 60.85% explained by environmental taxation, and in the remaining—by errors (E2) or other factors, which are not included in the model. The share of environmental taxation in GDP is by 68.42% explained by its value in the monetary expression, and in the remaining—by errors (E2) or other factors, which are not included in the model. Errors are factors of the social environment, economy and institutions.

The authors' recommendations on the improvement of environmental taxation based on AI in the interest of sustainable development ensure, first, the strengthening of the connection and growth of collection and effectiveness of environmental taxation. Second, an increase in the contribution and the synergetic effect from environmental taxation in the form of increased growth of results in the sphere of ecosystem protection and preservation of biodiversity (SDG 15).

This study is consistent with findings from past and recent studies in other country settings: Chawla et al. (2022), Ghosh et al. (2022), Wang et al. (2022), Xie and Jamaani (2022). It strengthens the evidence base that economic tools, such as environmental taxation, could make (in practice) a significant contribution to the environmental protection and development of the environmental economy. The paper has advanced our understanding on the previous work on the existing theories of the environmental economy (Nita, 2019; Adebayo et al., 2022; Borojo et al., 2022; Hassan et al., 2022; Nita et al., 2022; Nwani et al., 2022; Pinheiro et al., 2022; Rani et al., 2022), proving the existence of a close direct connection between the collection of environmental taxes, protection of ecosystems and preservation of biodiversity.

The authors' contribution in the political context consists in substantiating the necessity for the joint development and systemic implementation of state economic and environmental policy in the Decade of Action; in the economic context—in proving high environmental (not only economic) effectiveness of environmental taxation; in the social context—in supporting the practical implementation of SDG 15; in the technological context—in the strengthening of the technological provision of environmental taxation through proving the necessity for the active use of smart technologies during its application in the AI economy.

The obtained results demonstrated the universal character of environmental taxation as a prospective tool for stimulating the sustainable development of the environmental economy in all countries of the world—developed and developing.

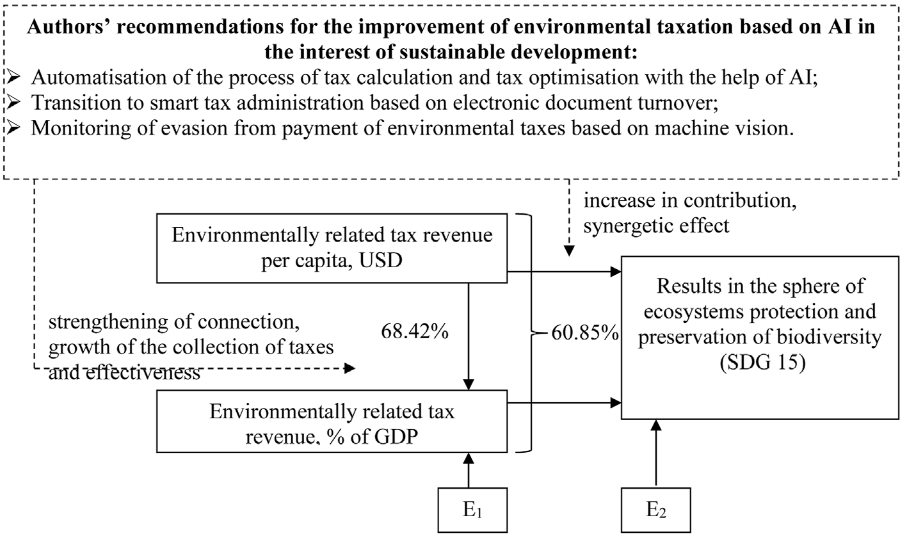

FIGURE 1
Framework model of the research, Source: authors.

Environmental taxation already significantly (by 60.85%) facilitates the protection of land ecosystems and the preservation of biodiversity. In the future of the AI economy, the contribution of environmental taxation to the achievement of SDG 15 might be increased.

This will take place due to an increase in the collection of environmental taxes—an increase in the level of tax responsibility, simplification of the process of calculation and payment of environmental tax and inclusion of the information on the payment in corporate reporting on sustainable development, as well as the limitation of the opportunities for evasion from payment of environmental taxes. The proposed authors' recommendations are universal since they are based on a wide analysis of the international experience and generally accessible technologies of the AI economy. They will be suitable for all countries of the world.

Conclusion

The set goal was achieved as a result of the performed research. We substantiated the contribution of environmental taxation to the sustainable development of the environmental economy in developed and developing countries around the world—the share of environmentally related tax revenue in GDP by 60.85% explains and ensures the results of implementing SDG 15. We also substantiated the prospects for an increase in this contribution with the help of AI. For this, we offered a set of authors' recommendations, which include the following: 1) automatization of the process of tax calculation and tax optimisation with the help of AI; 2) transition to smart tax administration based on electronic document turnover; 3) monitoring of evasion from payment of environmental taxes based on machine vision.

As a result of the conducted research, both gaps in the literature are filled. Firstly, a serious contribution of environmental taxation to the sustainable development of the ecological economy associated with the support of biodiversity conservation has been identified—SDG 15 can be fully and successfully implemented solely through environmental taxation. Secondly, the advantages of using advanced "smart" technologies of the AI economy for modernization and optimization of taxation have been determined, including simplification and expediting of the process of calculating and paying environmental tax, full-scale administration of environmental tax, as well as prevention of environmental tax evasion.

The theoretical significance of the results obtained is because they allowed us to offer a universal tool for environmental protection and biodiversity conservation (accessible and effective in all countries of the world), overcoming the limitations of existing alternative tools: limitations of industrial development (practiced in lagging countries) and responsible production and consumption practices (characteristic of developed countries). The empirical significance of the proposed authors' recommendations makes it possible to fully and effectively use the new opportunities provided by the AI economy to maximize the contribution of environmental taxation to environmental protection and biodiversity conservation.

The results obtained contribute to the development of the theory and practice of the environmental economy since they elaborated on the deeply rooted and poorly studied causal connection between taxation, which has been traditionally regarded as a purely economic tool, and environmental protection, which traditionally belonged to the sphere of economy. Based on the obtained results, environmental taxation should be considered a prospective and highly-effective tool of state management for the development of the environmental economy.

The authors' results and conclusion made will benefit production and society on the whole through the support of green economic growth. Digital technologies of the AI economy will contribute to the development of the environmental economy through the improvement of environmental taxation, which, in its turn, will strengthen the protection of ecosystems and increase the results in the sphere of biodiversity preservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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.

Publisher's note

References

Accounting in the Russian Federation (2022). New environmental tax in 2022. available at: https://online-buhuchet.ru/novyj-ekologicheskij-nalog-v-2019-godu/ (data accessed 10 30, 2022).

Adebayo, T. S., Altuntaş, M., Goyibnazarov, S., Zawbaa, H. M., and Kamel, S. (2022). Dynamic effect of disintegrated energy consumption and economic complexity on environmental degradation in top economic complexity economies. *Energy Rep.* 8, 12832–12842. doi:10.1016/j.egyr.2022.09.161

Aero-Soft Information Technology Bureau (2022). Environmental payments: Payment for negative impact on the environment. available at: https://www.airsoft-bit.ru/stati-po-ekologii/188-ekologicheskie-platezhi (data accessed 05 11, 2022).

Barbanti, A., Blumenthal, J. M., Broderick, A. C., Pascual, M., Carreras, C., Turmo, M., et al. (2022). The architecture of assisted colonisation in sea turtles: Building new populations in a biodiversity crisis. *Nat. Commun.* 13 (1), 1580. doi:10.1038/s41467-022-29232-5

Barik, S., Saha, G. K., and Mazumdar, S. (2022). Influence of land cover features on avian community and potential conservation priority areas for biodiversity at a Ramsar site in India. *Ecol. Process.* 11 (1), 25. doi:10.1186/s13717-022-00369-x

Borojo, D. G., Yushi, J., and Miao, M. (2022). The effects of COVID-19 on trade, production, environmental quality and its implications for green economy. *J. Econ. Stud.* 49 (8), 1340–1359. doi:10.1108/JES-06-2021-0307

Chawla, S., Varghese, B. S., Chithra, A., Keçili, R., and Hussain, C. M. (2022). Environmental impacts of post-consumer plastic wastes: Treatment technologies towards eco-sustainability and circular economy. *Chemosphere* 308, 135867. doi:10.1016/j.chemosphere.2022.135867

Compare your country (2022). Environmentally related tax revenue in 2019. available at: https://www.compareyourcountry.org/environmental-taxes (data accessed 05 11, 2022).

Congjuan, L., Abulimiti, M., Jinglong, F., and Haifeng, W. (2022). Ecologic service, economic benefits, and sustainability of the man-made ecosystem in the taklamakan desert. *Front. Environ. Sci.* 10, 813932. doi:10.3389/fenvs.2022.813932

Cordova-Buiza, F., Paucar-Caceres, A., Quispe-Prieto, S. C., de León-Panduro, C. V. P., Burrowes-Cromwell, T., Valle-Paucar, J. E., et al. (2022). Strengthening collaborative food waste prevention in Peru: Towards responsible consumption and production. *Sustain. Switz.* 14 (3), 1050. doi:10.3390/su14031050

Ghosh, S., Balsalobre-Lorente, D., Doğan, B., Paiano, A., and Talbi, B. (2022). Modelling an empirical framework of the implications of tourism and economic complexity on environmental sustainability in G7 economies. *J. Clean. Prod.* 376, 134281. doi:10.1016/j.jclepro.2022.134281

Giuliani, G., Chatenoux, B., Benvenuti, A., Santoro, M., and Mazzetti, P. (2020). Monitoring land degradation at national level using satellite Earth Observation time-series data to support SDG15–exploring the potential of data cube. *Big Earth Data* 4 (1), 3–22. doi:10.1080/20964471.2020.1711633

Hassan, T., Khan, Y., He, C., Chen, J., Alsagr, N., Song, H., et al. (2022). Environmental regulations, political risk and consumption-based carbon emissions: Evidence from OECD economies. *J. Environ. Manag.* 320, 115893. doi:10.1016/j.jenvman.2022.115893

Huang, X., Chau, K. Y., Tang, Y. M., and Iqbal, W. (2022). Business ethics and irrationality in SME during COVID-19: Does it impact on sustainable business resilience? *Front. Environ. Sci.* 10, 870476. doi:10.3389/fenvs.2022.870476

Lei, Z., Huang, L., and Cai, Y. (2022). Can environmental tax bring strong porter effect? Evidence from Chinese listed companies. *Environ. Sci. Pollut. Res.* 29 (21), 32246–32260. doi:10.1007/s11356-021-17119-9

Li, H., and Zhu, D. (2021). "AI technology and tax administration: An analysis of tax services technology in China," in Proceedings of the Conference Proceedings of the 9th International Symposium on Project Management (ISPM 2021), Beijing, China, July 2021, 1194–1199.

Liu, G., Yang, Z., Zhang, F., and Zhang, N. (2022). Environmental tax reform and environmental investment: A quasi-natural experiment based on China's environmental protection tax law. *Energy Econ.* 109, 106000. doi:10.1016/j.eneco.2022.106000

Lobova, S. V., Bogoviz, A. V., and Alekseev, A. N. (2022). Responsible smart agriculture and its contribution to the sustainable development of modern economic and environmental systems. *Smart Innovation, Syst. Technol.* 264, 287–293. doi:10.1007/978-981-16-7633-8_32

Matti, S., Nässén, J., and Larsson, J. (2022). Are fee-and-dividend sche (1mes the savior of environmental taxation? Analyses of how different revenue use alternatives affect public support for Sweden's air passenger tax. *Environ. Sci. Policy* 132, 181–189. doi:10.1016/j.envsci.2022.02.024

Nita, A. (2019). Empowering impact assessments knowledge and international research collaboration – A bibliometric analysis of environmental impact assessment review journal. *Environ. Impact Assess. Rev.* 78, 106283. doi:10.1016/j.eiar.2019.106283

Nita, A., Fineran, S., and Rozylowicz, L. (2022). Researchers' perspective on the main strengths and weaknesses of Environmental Impact Assessment (EIA) procedures. *Environ. Impact Assess. Rev.* 92, 106690. doi:10.1016/j.eiar.2021.106690

Nwani, C., Alola, A. A., Omoke, C. P., Adeleye, B. N., and Bekun, F. V. (2022). Responding to the environmental effects of remittances and trade liberalization in net-importing economies: The role of renewable energy in sub-saharan Africa. *Econ. Change Restruct.* 55 (4), 2631–2661. doi:10.1007/s10644-022-09403-6

Pinheiro, A. B., Oliveira, M. C., and Lozano, M. B. (2022). The mirror effect: Influence of national governance on environmental disclosure in coordinated economies. *J. Glob. Responsib.* 13 (4), 380–395. doi:10.1108/JGR-01-2022-0009

Popkova, E. G., De Bernardi, P., Tyurina, Y. G., and Sergi, B. S. (2022). A theory of digital technology advancement to address the grand challenges of sustainable development. *Technol. Soc.* 68, 101831. doi:10.1016/j.techsoc.2021.101831

Popkova, E. G., Oudah, A.-M. M. Y., Ermolina, L. V., and Sergi, B. S. (2021). Financing sustainable development amid the crisis of 2020. A research note. *Lect. Notes Netw. Syst.* 198, 773–780. doi:10.1007/978-3-030-69415-9_88

Rani, T., Amjad, M. A., Asghar, N., and Rehman, H. U. (2022). Revisiting the environmental impact of financial development on economic growth and carbon emissions: Evidence from south asian economies. *Clean. Technol. Environ. Policy* 24 (9), 2957–2965. doi:10.1007/s10098-022-02360-8

Taxation in the Russian Federation (2022). Environmental tax in 2021-2022 — Terms of payment and rates. available at: https://nalog-nalog.ru/ekologicheskij_nalog/#more (data accessed 10 30, 2022).

Tu, C., Ma, H., Li, Y., You, Z., Newton, A., Luo, Y., et al. (2022). Transdisciplinary, Co-designed and adaptive management for the sustainable development of rongcheng, a coastal city in China in the context of human activities and climate change. *Front. Environ. Sci.* 10, 670397. doi:10.3389/fenvs.2022.670397

UNDP (2022). Sustainable development report 2021. available at: https://dashboards.sdgindex.org/ (data accessed 05 11, 2022).

Wang, Q., Wang, L., and Li, R. (2022). Does the energy transition alleviate environmental degradation? Evidence from the high income, upper and lower middle income economies. *Energy Strategy Rev.* 44, 100966. doi:10.1016/j.esr.2022.100966

World Bank (2022). GDP growth (annual %). available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?view=chart (data accessed 10 30, 2022).

World Health Organization (2022). WHO coronavirus (COVID-19) dashboard: Globally, as of 5:43pm CEST, 28 october 2022. available at: https://covid19.who.int/?gclidCj0KCQjwrIf3BRD1ARIsAMuugNsIqvk ZsmIoto8RJ964Wv1YdYllaCbKloYu2Z9HLeUkZuatNROZyzgaAvEiEALw_wcB (data accessed 10 30, 2022).

Xie, P., and Jamaani, F. (2022). Does green innovation, energy productivity and environmental taxes limit carbon emissions in developed economies: Implications for sustainable development. *Struct. Change Econ. Dyn.* 63, 66–78. doi:10.1016/j.strueco.2022.09.002

Xu, K., Wang, X., Wang, J., Zhang, X., Fu, L., Tian, R., et al. (2022). Effectiveness of protection areas in safeguarding biodiversity and ecosystem services in Tibet Autonomous Region. *Sci. Rep.* 12 (1), 1161. doi:10.1038/s41598-021-03653-6

Yang, F., Choi, Y., Lee, H., and Debbarma, J. (2022). Sustainability of overlapped emission trading and command-and-control CO2 regulation for Korean coal power production: A DEA-based cost-benefit analysis. *Front. Environ. Sci.* 10, 877823. doi:10.3389/fenvs.2022.877823

Zackrisson, M., Bakker, A., and Hagelin, J. (2020). AI and tax administrations: A good match. *Bull. Int. Tax.* 74 (10), 619–625.

Zhao, A., Wang, J., Sun, Z., and Guan, H. (2022). Environmental taxes, technology innovation quality and firm performance in China—a test of effects based on the porter hypothesis. *Econ. Analysis Policy* 74, 309–325. doi:10.1016/j.eap.2022.02.009

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Ecological behaviour in the AI economy and its impact on biodiversity: Lessons from the COVID-19 pandemic and a post-COVID perspective

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Introduction

The problem of biodiversity conservation is formulated by the UN Sustainable Development Goals (SDGs): SDG 14 (conservation of marine ecosystems) and SDG 15 (conservation of terrestrial ecosystems) (Mehmood et al., 2022; Sobieraj et al., 2022; Wang et al., 2022). The relevance of this problem is particularly high at present against the background of the global increase in the number of zoonotic diseases, as well as against the background of the COVID-19 pandemic, which, according to many scientists (Khetan, 2020; Codeço et al., 2021; Fernández et al., 2021; Lawler et al., 2021; Morand and Lajaunie, 2021; Tsantopoulos et al., 2021), is a new zoonotic disease directly or indirectly caused by the destruction of the natural habitat of animals and the unsafe neighbourhood of people with them.

In the existing literature, Dick et al. (2022), McLaughlin et al. (2022), Xie et al. (2022), the reduction of biodiversity is interpreted as an environmental problem. The main attention is paid to natural and climatic threats to biodiversity. In their works, Marques et al. (2019), Meng et al. (2019), Otero et al. (2020), and Usman Mirza et al. (2020) also point to the significant role of economic factors of biodiversity, the reduction of which is perceived as the environmental costs of economic growth. At the same time, the role of social factors is insufficiently developed and not defined, which is a research gap.

In this article, the study is based on the Noospheric model of economic systems, according to which these systems are considered as a unity of all constituent elements aiming at a balance of economic, social and environmental development. However, the role of social factors is not elaborated sufficiently nor determined in developing countries, which is a research gap. It is important to take into account the modern high-tech context of society's development. The transition to an AI economy in the works of Alvarez Leon (2021), Buhvald et al. (2021), Popkova et al. (2020) and Popkova (2022) is associated with the formation of a technogenic (information) society in which knowledge and technology are the driving forces.

In this regard, the economy is perceived as a socio-economic environment that is separated from environmental problems and, in particular, unfavourable for solving the problem of biodiversity conservation, since it contradicts the interests of accelerating high-tech economic growth. Nevertheless, the connection of the AI economy with biodiversity has remained largely unexplored, which is another research gap filled in this article.

This article aims to explore a change in ecological behaviour in the AI economy and biodiversity against the background of the COVID-19 pandemic, as well as to determine the post-COVID perspective of biodiversity conservation through improving ecological behaviour in the AI economy.

The originality of this paper consists in its elaborating on the little-studied experience of developing countries in the sphere of the change of ecological behaviour amid the COVID-19 pandemic by the example of Russia and describing its consequences for biodiversity and the post-COVID perspective in the AI economy. The paper's contribution to the literature consists in strengthening the evidential base of the hypothesis on the popularisation of responsible ecological behaviour in the AI economy under the conditions of the COVID-19 pandemic, supplementing the extensively researched experience of developed countries with insufficiently researched in the literature the experience of developing countries, by the example of Russia.

Literature review

The important role of ecological behaviour in the preservation of biodiversity has been studied in detail and described in multiple works by Chaigneau and Schill (2022), Deng et al. (2016), Luengo-Valderrey et al. (2022), Sullivan et al. (2017), Tang et al. (2022) and Toppi et al. (2016). The specifics of ecological behaviour under the conditions of the AI economy are described in the works of Ligozat et al. (2022), Nost and Colven (2022), Sarmento and Loureiro (2021), Skiter et al. (2022) and Yankovskaya et al. (2022).

Content analysis of the above literature demonstrated that these specific features are contradictory. On the one hand, smart technologies of the AI economy provide new opportunities for environmental protection and, in particular, the preservation of biodiversity. On the other hand, the dissemination of smart technologies in the AI economy leads to new ecological risks, i.e., an increase in the economy's energy intensity. Aubry et al. (2021), Guo and Lee (2022), Li et al. (2021), Naseer et al. (2022) and Tagliacozzo et al. (2021) provide many proofs from developed countries and propose a hypothesis on the increase in the level of ecological responsibility of population and business amid the COVID-19 pandemic.

While the main attention in these publications is focused on the leading experience of developed countries, the experience of developing countries remains poorly studied, the same as the role of smart technologies in the AI economy. Thus, there remains uncertainty as to whether the proposed hypothesis can be used for developing countries. This is a literature gap.

This allows formulating the research question (RQ) of this paper. RQ: How did the ecological behaviour of developing countries change under the conditions of the COVID-19 pandemic and what are its consequences for biodiversity and the post-COVID perspective in the AI economy? In this paper, the research is performed based on the model of 3Ps of sustainability (3 principles of sustainability & sustainable development), according to which these systems are considered in their unity, striving toward the balance of the economic, social and ecological development. This allows filling the discovered gap and studying the connection between social factors (ecological behaviour) and biodiversity.

Materials and methods

This research is performed in two consecutive stages. The first stage includes the determination of the lessons of the COVID-19 pandemic for ecological behaviour and biodiversity. The research is performed based on the 3P sustainability model: people, profit and planet. For this, the method of case study is used for an overview of the leading experience of Russia in the sphere of the use of ecological behaviour of population and business amid the COVID-19 pandemic. The information and empirical materials of RBC (2022) are used.

To reveal how the COVID-19 pandemic influenced ecological behaviour and biodiversity, we use the method of trend analysis. As the indicator of ecological behaviour, we use social inclusion according to Global Green Growth Institute (2022). As the indicators of protection of ecosystems and preservation of biodiversity, we use Goal 14 Score and Goal 15 Score according to the UNDP (2022). The growth of these indicators over 2019–2021 is assessed.

The second stage implies the determination of the post-COVID perspective of improving the ecological behaviour in the AI economy to preserve biodiversity. We propose recommendations for the fullest development of the potential of the preservation of biodiversity in the post-COVID period and perform an overview of the prospects for improving ecological behaviour based on the leading technologies of the AI economy.

Lessons of the COVID-19 pandemic for ecological behaviour and biodiversity: An overview of the leading experience of Russia

To determine the lessons of the COVID-19 pandemic for ecological behaviour and biodiversity, let us perform an overview of the leading experience of Russia based on the 3P sustainability model: people, profit and planet.

P1: People. RBC (2022) notes the growth of the popularity of green technologies and ESG initiatives in Russia amid the COVID-19 pandemic. Based on the "Zero waste" project of Greenpeace in Russia, Procter & Gamble performed a representative study of buyer preferences. It demonstrated a large interest of the Russians in the "green agenda." The survey's results showed that 90% of Russians are ready to sort household garbage, and 69% are ready to pay the extra price for eco-products. Also, 55% of the respondents express interest in the ecological standards of manufacturers before purchasing their products.

P2: Profit. From the position of the government, there are government programmes for the development of the green economy in Russia. One of the programmes envisages the expanded responsibility of manufacturers–the use of the mechanisms of economic regulation, according to which the manufacturer and importer of goods have to dispose of the manufactured or imported products at the end of their life cycle, after their losing consumer properties. There is also a national project "Ecology," which is aimed at the effective treatment of production and consumption waste. Another important program is the one that supports projects on the construction of infrastructure for waste treatment in Russia's regions.

The government's initiatives are actively supported by business, which implements multiple ESG initiatives. The Russian branch of Danone declares ideas and implements the principles of packaging eco production and control. By 2019–2020, the company's share of recycled plastic in the production of packaging reached 25%.

Rockwool factory in Vyborg, which manufactures heat-insulating materials that are used in construction, works in the regime of the circular economy. In 2020, the company started working on the project of return of façade and roof heat-insulating boards from the construction sites of St. Petersburg and the Leningrad Region, according to the "Vtoraya Zhizn" ("Second life") project. State concern Galaktika (dairy products) implements a dairy organic campaign on the production of the environmentally friendly product in organic packaging.

Rosseti Lenenergo PJSC implements a program of creation of a network of electric charging stations, which will allow using more electric cars. Sberbank offers green crediting: the transition from physical carriers to a digital card in 2020 alone allowed saving more than 1.3 tons of plastic in the North-Western Federal District of Russia. In Murmansk Region, Sberbank supports the campaign "Clean Arctic" in the implementation of environmental projects on the replacement of equipment at polluting companies in the region.

P3: Planet. Trend analysis allowed revealing that social inclusivity in Russian society grew by 3.16% in 2020 (77.88 points) compared to 2019 (73.36 points) (Global Green Growth Institute, 2022). This provided serious results for the preservation of biodiversity. Despite the modest result by the Goal 15 Score (-0.04%), the Goal 14 Score grew by 23.14% in 2021 (52.3205 points) compared to 2019 (42.4900 points) (UNDP, 2022).

The results that were obtained by the example of Russia demonstrate a large value of ecological behaviour for the preservation of biodiversity in developing countries. We also revealed a substantial potential for the preservation of biodiversity through the improvement of ecological behaviour in developing countries, by the example of Russia.

The post-COVID perspective of improving ecological behaviour in the AI economy for biodiversity conservation

To determine the prospects for unlocking the potential of biodiversity conservation in the post-COVID period, we will consider the prospects for improving ecological behaviour based on advanced technologies of the AI economy:

- Artificial intelligence (AI) can provide intelligent decision support in the field of biodiversity conservation. This will allow finding flexible solutions for the development of urban and rural areas with minimal damage to biodiversity;
- Ubiquitous computing (UC) will allow to track the number and habitats of animals and, based on this, conduct continuous monitoring of biodiversity;
- Big data will make it possible to study biodiversity trends and select the most effective practices of ecological behaviour for the conservation of biodiversity;
- Machine vision will enable us to identify practices of ecological behaviour that are prohibited and negatively affect biodiversity and to stop them in a timely manner.

The implementation of the mentioned prospects for improving ecological behaviour in the AI economy will serve the interests of biodiversity conservation to prevent future epidemics and pandemics.

Discussion

The paper's contribution to literature consists in strengthening the evidential base of the existing hypothesis in developing countries–specifying the role of ecological behaviour in the AI economy in the preservation of biodiversity by the example of Russia, amid the COVID-19 pandemic. The results showed that biodiversity is determined not only by natural and climatic factors [unlike Dick et al. (2022), McLaughlin et al.

(2022), Xie et al. (2022)] and not only by economic factors [unlike Marques et al. (2019), Meng et al. (2019), Otero et al. (2020), Usman Mirza et al. (2020)] but also by social factors. Ecological behaviour is a significant social factor that largely determines success in preserving biodiversity.

It is also shown that, unlike Alvarez Leon (2021), Buhvald et al. (2021), Popkova et al. (2020), and Popkova (2022), the AI economy is not exclusively a technogenic environment. Based on the Noospheric model of economic systems, it has been established that favourable opportunities have been created in the AI economy for the use of "smart" technologies to adjust ecological behaviour in order to preserve biodiversity. This enabled us to take a fresh look at the AI economy as an economic system with a balance of economic, social and environmental development.

Conclusion

The experience of developing countries (by the example of Russia) was taken into account, and the lessons of the COVID-19 pandemic for ecological behaviour and biodiversity were revealed. By the example of Russia's experience in the 3P sustainability model, we substantiated a large role of ecological behaviour in the preservation of biodiversity amid the COVID-19 pandemic. We also revealed a substantial potential for the preservation of biodiversity through the improvement of ecological behaviour in the post-COVID perspective, based on smart technologies of the AI economy.

The theoretical significance of the results obtained is that the key role of social factors (ecological behaviour) in the conservation of biodiversity is justified, as well as the close relationship of the AI economy with biodiversity. The practical significance of the conclusions is that they allow accelerating progress in the practical implementation of SDG 14 and SDG 15 through improving ecological behaviour in the AI economy based on the proposed recommendations.

Speaking about the limitations of this study, it should be noted that it focuses on COVID-19 and the post-pandemic period, which determines the linkage of the results obtained to this particular time period. In future scientific papers, it is advisable to expand the time frame of research and study the overall contribution of ecological behaviour in the AI economy to the conservation of biodiversity.

Author contributions

EP, TL, AK, and YP contributed to conception and design of the study. TL wrote the first draft of the manuscript. EP, AK, and YP wrote sections of the manuscript. EP prepared the final version. All authors contributed to manuscript revision, read, and approved the submitted version.

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.

Publisher's note

References

Alvarez Leon, L. F. (2021). AI and the capitalist space economy. *Space Polity* 25 (2), 220–236. doi:10.1080/13562576.2021.1985852

Aubry, L. M., Laverty, T. M., and Ma, Z. (2021). Impacts of COVID-19 on ecology and evolutionary biology faculty in the United States. *Ecol. Appl.* 31 (2), 2265. doi:10.1002/eap.2265

Buhvald, E. M., Larionova, E. I., Avkopashvili, P. T., Adamyants, S. T., and Alekseev, A. N. (2021). Information Age Publishing, 445–452.Post-economy of AI: New challenges and perspectives of sustainable development of socio-economic systems*Adv. Res. Russ. Bus. Manag.*

Chaigneau, T., and Schill, C. (2022). Environmental behaviours within ecological and social limits: Integrating well-being with behavioural research for sustainability. *Curr. Opin. Environ. Sustain.* 57, 101201. doi:10.1016/j.cosust.2022.101201

Codeço, C. T., Dal'Asta, A. P., Rorato, A. C., Neves, T. C., Andreazzi, C. S., Coelho, F. C., et al. (2021). Epidemiology, biodiversity, and technological trajectories in the Brazilian amazon: From malaria to COVID-19. *Front. Public Health* 9, 647754. doi:10.3389/fpubh.2021.647754

Deng, J., Sun, P., Zhao, F., Feng, Y., Yang, G., and Feng, Y. (2016). Analysis of the ecological conservation behavior of farmers in payment for ecosystem service programs in eco-environmentally fragile areas using social psychology models. *Sci. Total Environ.* 550, 382–390. doi:10.1016/j.scitotenv.2016.01.152

Dick, M., Abreu da Silva, M., Franklin da Silva, R. R., Maia, M. d. S., Lima, S. F. d., Paiva Neto, V. B. D., et al. (2022). Climate change and land use from Brazilian cow-calf production amidst diverse levels of biodiversity conservation. *J. Clean. Prod.* 342, 130941. doi:10.1016/j.jclepro.2022.130941

Fernández, D., Giné-Vázquez, I., Liu, I., Nai Ruscone, M., Morena, M., Pan, W., et al. (2021). Are environmental pollution and biodiversity levels associated to the spread and mortality of COVID-19? A four-month global analysis. *Environ. Pollut.* 271, 116326. doi:10.1016/j.envpol.2020.116326

Global Green Growth Institute (2022). Global green growth index reports 2019-2020 URL: https://greengrowthindex.gggi.org/?page_id=3126,

Guo, Q., and Lee, D. C. (2022). The ecology of COVID-19 and related environmental and sustainability issues. *Ambio* 51 (4), 1014–1021. doi:10.1007/s13280-021-01603-0

Khetan, A. K. (2020). COVID-19: Why declining biodiversity puts us at greater risk for emerging infectious diseases, and what we can do. *J. General Intern. Med.* 35 (9), 2746–2747. doi:10.1007/s11606-020-05977-x

Lawler, O. K., Allan, H. L., Baxter, P. W. J., Tor, M. C., Dann, L. E., Rogers, A. M., et al. (2021). The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health. *Lancet Planet. Health* 5 (11), 840–850. doi:10.1016/S2542-5196(21)00258-8

Li, Y., Shin, J., Sun, J., Yang, A., Qu, Y., and Yang, A. (2021). Organizational sensemaking in tough times: The ecology of NGOs' COVID-19 issue discourse communities on social media. *Comput. Hum. Behav.* 122, 106838. doi:10.1016/j.chb.2021.106838

Ligozat, A.-L., Lefevre, J., Bugeau, A., and Combaz, J. (2022). Unraveling the hidden environmental impacts of AI solutions for environment life cycle assessment of AI solutions. *Sustain. Switz.* 14 (9), 5172. doi:10.3390/su14095172

Luengo-Valderrey, M.-J., Emmanuel-Martínez, E., Rivera-Revilla, R., and Vicente-Molina, A. (2022). Ecological behaviour in times of crisis and economic well-being through a comparative longitudinal study. *J. Clean. Prod.* 359, 131965. doi:10.1016/j.jclepro.2022.131965

Marques, A., Martins, I. S., Kastner, T., Theurl, M. C., Eisenmenger, N., Erb, K., et al. (2019). Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nat. Ecol. Evol.* 3 (4), 628–637. doi:10.1038/s41559-019-0824-3

McLaughlin, B. C., Skikne, S. A., Beller, E., Olliff-Yang, R., Morueta-Holme, N., Brown, B. J., et al. (2022). Conservation strategies for the climate crisis: An update on three decades of biodiversity management recommendations from science. *Biol. Conserv.* 268, 109497. doi:10.1016/j.biocon.2022.109497

Mehmood, K., Bao, Y., Saifullah, (, Dahlawi, S., Yaseen, M., Fahad, S., et al. (2022). Contributions of open biomass burning and crop straw burning to air quality: Current research paradigm and future outlooks. *Front. Environ. Sci.* 10, 852492. doi:10.3389/fenvs.2022.852492

Meng, H.-H., Zhou, S.-S., Li, L., Li, J.-W., and Li, J. (2019). Conflict between biodiversity conservation and economic growth: Insight into rare plants in tropical China. *Biodivers. Conserv.* 28 (2), 523–537. doi:10.1007/s10531-018-1661-4

Morand, S., and Lajaunie, C. (2021). Biodiversity and COVID-19: A report and a long road ahead to avoid another pandemic. *One Earth* 4 (7), 920–923. doi:10.1016/j.oneear.2021.06.007

Naseer, S., Wei, Z., Aslam, M. S., and Naseer, S. (2022). A mini-review: Positive impact of COVID-19 on arial health and ecology. *Environ. Sci. Pollut. Res.* 29 (27), 40520–40530. doi:10.1007/s11356-022-19961-x

Nost, E., and Colven, E. (2022). Earth for AI: A political ecology of data-driven climate initiatives. *Geoforum* 130, 23–34. doi:10.1016/j.geoforum.2022.01.016

Otero, I., Farrell, K. N., Pueyo, S., Kehoe, L., Haberl, H., Schneider, F., et al. (2020). Biodiversity policy beyond economic growth. *Conserv. Lett.* 13 (4), 12713. doi:10.1111/conl.12713

Popkova, E., Alekseev, A. N., Lobova, S. V., and Sergi, B. S. (2020). The theory of innovation and innovative development. AI scenarios in Russia. *Technol. Soc.* 63. doi:10.1016/j.techsoc.2020.101390101390

Popkova, E.G. (2022). Vertical farms based on hydroponics, deep learning, and AI as smart innovation in agriculture. *Smart Innovation, Syst. Technol.* 264, 257–262. doi:10.1007/978-981-16-7633-8_28

Rbc (2022). Russia moves to the green economy. URL: https://spb.plus.rbc.ru/news/60c84df77a8aa9ba8b2443e3 (data accessed: 15.09.2022).

Sarmento, E. M., and Loureiro, S. M. C. (2021). Exploring the role of norms and habit in explaining pro-environmental behavior intentions in situations of use robots and AI agents as providers in tourism sector. *Sustain. Switz.* 13 (24), 13928. doi:10.3390/su132413928

Skiter, N. N., Rogachev, A. F., Ketko, N. V., Simonov, A. B., and Tarasova, I. A. (2022). Sustainable development of enterprises in conditions of smart ecology: Analysis of the main problems and development of ways to solve them, based on artificial intelligence methods and innovative technologies. *Front. Environ. Sci.* 10, 892222. doi:10.3389/fenvs.2022.892222

Sobieraj, K., Stegenta-Dąbrowska, S., Luo, G., Koziel, J. A., and Białowiec, A. (2022). Carbon monoxide fate in the environment as an inspiration for biorefinery industry: A review. *Front. Environ. Sci.* 10, 822463. doi:10.3389/fenvs.2022.822463

Sullivan, A. P., Bird, D. W., and Perry, G. H. (2017). Human behaviour as a long-term ecological driver of non-human evolution. *Nat. Ecol. Evol.* 1 (3), 0065. doi:10.1038/s41559-016-0065

Tagliacozzo, S., Albrecht, F., and Ganapati, N. E. (2021). International perspectives on COVID-19 communication ecologies: Public health agencies' online communication in Italy, Sweden, and the United States. *Am. Behav. Sci.* 65 (7), 934–955. doi:10.1177/0002764221992832

Tang, T., Zhao, M., Wang, D., Chen, W., Xie, C., Ding, Y., et al. (2022). Does environmental interpretation impact public ecological flow experience and responsible behaviour? A case study of potatso national park, China. *Int. J. Environ. Res. Public Health* 19 (15), 9630. doi:10.3390/ijerph19159630

Toppi, J., Borghini, G., Petti, M., De Giusti, V., He, B., Astolfi, L., et al. (2016). Investigating cooperative behavior in ecological settings: An EEG hyperscanning study. *PLoS ONE* 11 (4), 0154236. doi:10.1371/journal.pone.0154236

Tsantopoulos, G., Papageorgiou, A. C., and Karasmanaki, E. (2021). Covid-19: An outcome of biodiversity loss or a conspiracy? Investigating the attitudes of environmental students. *Sustain. Switz.* 13 (9), 5307. doi:10.3390/su13095307

Undp (2022). Sustainable development reports 2019-2021 .URL: https://dashboards.sdgindex.org/explorer/mean-area-that-is-protected-in-marine-sites-important-to-biodiversity/chart,

Usman Mirza, M., Richter, A., van Nes, E. H., and Scheffer, M. (2020). Institutions and inequality interplay shapes the impact of economic growth on biodiversity loss. *Ecol. Soc.* 2539 (4), art39–11. doi:10.5751/ES-12078-250439

Wang, L., Guo, J., Ahmad, M., and Khan, Y. A. (2022). Investigating the impact of monetary progress on ecological excellence in Malaysia: Employing financial maturity, and biological variation. *Front. Environ. Sci.* 10, 852379. doi:10.3389/fenvs.2022.852379

Xie, L., Bulkeley, H., and Tozer, L. (2022). Mainstreaming sustainable innovation: Unlocking the potential of nature-based solutions for climate change and biodiversity. *Environ. Sci. Policy* 132, 119–130. doi:10.1016/j.envsci.2022.02.017

Yankovskaya, V. V., Gerasimova, E. B., Osipov, V. S., and Lobova, S. V. (2022). Environmental CSR from the standpoint of stakeholder theory: Rethinking in the era of artificial intelligence. *Front. Environ. Sci.* 10, 953996. doi:10.3389/fenvs.2022.953996

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Fight against climate change and sustainable development based on ecological economy and management in the AI era

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Introduction

Fundamental changes are taking place in the modern economy and business under the influence of two global trends. The first trend is associated with the development of the digital economy based on smart technologies under the influence of the Fourth Industrial Revolution. Automation happens in all industries and encompasses all types of business processes. In the era of artificial intelligence (AI), the countries of the world set themselves the strategic task to strengthen digital competitiveness and gain unique competitive advantages in the global markets of high-tech products (Popkova, 2022; Popkova and Sergi, 2022). For this purpose, innovations are actively being introduced into the economy and business, as well as telecommunications infrastructure is being developed (Ruffolo, 2022). The significance of the described trend is emphasized by SDG 9.

The second trend is environmental protection (Calero Preciado et al., 2022). This protection is becoming ubiquitous, which clearly demonstrates the introduction of green innovations at all stages of the value chain: from the transition to renewable energy sources to biodegradable packaging and recycling (Mentzel et al., 2022). Among the wide range of environmental initiatives implemented in the economy and business, the fight against climate change occupies an important place (Dirmeyer et al., 2022). This trend is reflected in the formulation of SDG 13.

The above trends are reflected in the development of ecological economy and management in the AI era. We understand ecological economy and management as a sphere of the economy in which economic processes and business practices are conducted with strict observation of environmental principles, norms and standards and strive toward contributing to environmental protection and the fight against climate change (Badry et al., 2022; Bakkaloglu et al., 2022; Chen et al., 2022; Mohd Fuzi et al., 2022). The AI era is a new stage in the development of the global economy, which started due to the Fourth Industrial Revolution and is characterized by the formation of Industry 4.0, information society and the digital economy (Luitse and Denkena, 2021; Som, 2021; Li et al., 2022; Ruffolo, 2022; Wilson et al., 2022).

It is noteworthy that the peak of both described global trends falls on the period from 2020 to 2030, called the "Decade of Action". In the existing literature, these trends are mostly considered separately, and the subject area at the crossroads of these trends—ecological economics and management in the AI era—is a gap in the literature, since it is poorly studied. On the one hand, this makes it possible to reliably describe the theories of ecological economics and smart economics, respectively, as well as to study in detail and in-depth the existing practice within the boundaries of each trend.

On the other hand, an isolated consideration causes uncertainty about the consequences of the overlap of these trends on each other, which takes place in practice. Theoretical models compiled separately within the boundaries of each trend do not allow making reliable forecasts of economic practice, since they are limited by a narrow set of factors of the corresponding trend. The problem is that this reduces the efficiency of economic and business management, as well as hinders sustainable development.

This article seeks to solve the problem posed by filling the identified gap in the literature. The purpose of the article is to study the contribution of ecological economy and management in the AI era to the fight against climate change for sustainable development. To achieve this goal, the article sets two research tasks. The first task is to model the contribution of ecological economy and management in the AI era to the fight against climate change for sustainable development. The second task is to identify and measure the synergetic effect of the systemic development of ecological economy and management in the AI era to combat climate change from the perspective of sustainable development.

Literature review

This article is based on three concepts elaborated in detail and well-established in the scientific literature. The first is the concept of ecological economics and business management (Hassan et al., 2022; Xie and Jamaani, 2022). The second is the concept of a digital economy based on smart technologies in the AI era (Atabekova et al., 2022; Gyamfi et al., 2022). The third is climate change and the fight against climate change (Bechtel et al., 2022; Popkova and Shi, 2022; Skeirytė et al., 2022; Victor-Gallardo et al., 2022). These concepts have been studied in detail, and this indicates a high degree of elaboration of the research problem and the reliability of its theoretical basis. However, there is a scarcity of scientific research at the Intersections of these concepts, which is a gap in the literature. In this regard, the following two research questions (RQ) arise.

RQ_1: What impact does the development of the digital economy and business based on smart technologies in the AI era have on the ecological economy and management? The available literature indicates the high risks of negative consequences of the development of the digital economy and business based on smart technologies in the era of AI for the environment. Among these negative consequences are increased energy intensity of automated business (Fu et al., 2022; Kakraliya et al., 2022; Matsunaga et al., 2022), increased environmental costs of high-tech economic growth (Kong, 2021; Sun et al., 2021), as well as the limitation of the use of "clean energy" (Garriz and Domingo, 2022; Xiong et al., 2022).

Taking into account the publications of Bermeo-Ayerbe et al. (2022), Chehri et al. (2022), Farzaneh et al. (2021), Wang et al. (2021), which note the positive contribution of smart technologies to the development of the ecological economy and business, for example, Smart Grid, climate-smart agriculture, automated recycling, this article puts forward the H_1 hypothesis that the development of the digital economy and business based on smart technologies in the AI era can have a positive impact on ecological economy and management under certain conditions. The article is devoted to the verification of the proposed hypothesis and the identification of the conditions under which the hypothesis is confirmed.

RQ_2: How to manage the development of the digital economy and business based on smart technologies in the AI era to maximize their contribution to the fight against climate change in support of sustainable development? The existing literature offers separate recommendations for managing subjects of both the digital economy and business based on smart technologies in the AI era. In their papers, Fendrich et al. (2022), Xie and Jamaani (2022) consider that from the standpoint of the state, it is necessary to develop an e-government system in the direction of tightening environmental control (smart environmental taxation, automated quality and environmental certification).

In their works, Rachinsky-Spivakov (2022), Zikargae et al. (2022) express the opinion that from the standpoint of consumers and the general public, electronic participation of the population in environmental protection issues should be expanded and the information society should be developed in the direction of public environmental control. In their research, Kazancoglu et al. (2021), Mishra et al. (2022) propose to develop environmentally responsible high-tech industries from a business perspective. Taking into account the positive contribution of all these subjects separately, this article puts forward the H_2 hypothesis that in order to maximize their contribution to the fight against climate change in support of sustainable development, it is preferable to systematically manage the development of the digital economy and business based on smart technologies in the AI era.

Methodology

To obtain the most accurate and reliable results, the study relies on the mathematical apparatus. The solution of the first task, which consists in modelling the contribution of ecological economics and management in the AI era to the fight against climate change for sustainable development, is carried out using the method of correlation analysis. The choice of the correlation analysis method and its preference for the regression analysis method, which acts as its alternative, is related to the fact that the purpose of the article is to study the complex relationships of indicators, since the trends in the development of the ecological economy and the digital economy have an equal impact on each other (dependent and factor variables cannot be distinguished).

The information and empirical base of the study is statistical data for 2022 published by WIPO (2022). The indicators of the economy and management in the AI era are: 1) Government's online service; 2) E-participation; 3) High-tech manufacturing. The indicators of ecological economy and management are: 1) GDP/unit of energy use; 2) Environmental performance; 3) ISO 14001 environmental certificates/bn PPP$ GDP. The values of all indicators are expressed in points to ensure their comparability. The average correlation between groups of indicators is also determined.

The study sample includes 15 of the best countries in the world with a formed digital economy, which are active participants in the Fourth Industrial Revolution and have demonstrated the best results in combating climate change in 2022 in terms of implementing SDG 13 according to the UN (2022). The criterion for selecting countries was also the availability of the full volume of statistical data (without gaps) on the indicators selected for the study in WIPO (2022) materials. The sample structure is dominated by five East and South Asia countries (33.33%) and five OECD countries (33.33%). The sample also includes two LAC countries (13.33%), one Sub-Saharan Africa country (6.67%), one MENA country (6.67%) and 1 E. Europe and C. Asia country (6.67%).

The solution of the second task related to the identification and measurement of the synergetic effect of the systemic development of ecological economy and management in the AI era to combat climate change from the standpoint of sustainable development is carried out using the regression analysis method. The regression dependence of Goal 13 Score (according to UN, 2022) in 2022 on the totality of the six indicators of the ecological economy and digital economy listed above from UN (2022) materials is determined. The correlation coefficients of Goal 13 Score with the selected six indicators are individually compared with the multiple correlation coefficient in the regression model. Based on the obtained regression equation, a forecast is made for the system management of all six indicators to combat climate change.

Results

Modelling the contribution of ecological economy and management in the AI era to the fight against climate change for sustainable development

As part of the first task, the correlation analysis method was used to model the contribution of ecological economy and management in the AI era to the fight against climate change for sustainable development. The sample of the study, as well as the results of its processing using the selected method are shown in Table 1.

The results of modelling from Table 1 identified the significant contribution of environmental economics and management in the AI era to the fight against climate change for sustainable development. Among the indicators of economy and management in the AI era, high-tech manufacturing demonstrated the closest relationship with the indicators of ecological economy and management: 20.51%, reflecting the key contribution of business. The contribution of the state is also significant (the correlation of government's online service with indicators of ecological economy and management was 18.24%) and the contribution of society (the correlation of e-participation with indicators of ecological economy and management was 13.33%).

Indicators of environmental economics and management, in turn, have also demonstrated a close relationship with indicators of economy and management in the AI era. The correlation for GDP/unit of energy use averaged 11.92%, for environmental performance—5.90%, for ISO 14001 environmental certificates/bn PPP$ GDP—34.26%. Nevertheless, the average correlation of the considered six indicators with SDG 13 score turned out to be negative and amounted to −16.39%. This indicates an insufficient use of the potential of ecological economics and management in the era of artificial intelligence in terms of increasing the contribution to the fight against climate change in the interests of sustainable development.

The results obtained allow concluding that ecological economy and management in the AI era take new forms of e-government, information society and high-tech business. Ecological economy and management contribute to the fight against climate change for sustainable development. This is manifested in the reduction of the economy's energy intensity, increase in ecological efficiency of economic growth and development of ecological certification and quality of products. This contribution is expressed in the fight against climate change and is achieved through a combination of the institutes of the AI era and ecological economy and management.

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TABLE 1 Ecological economy, management in the AI era and the results of the fight against climate change in 2022, scores 1–100.

Country	Regions in the UN classification (2022)	Indicators of economy and management in the AI era			Ecological economy and management indicators			Goal 13 score
		Government's online service	E-participation	High-tech manufacturing, %	GDP/unit of energy use	Environmental performance	ISO 14001 environmental certificates/bn PPP$ GDP	
		x_1	x_2	x_3	x_4	x_5	x_6	y
India	East and South Asia	85.3	85.7	45.8	25.5	18.9	5.7	96.2
Brazil	LAC	87.1	75.0	49.4	26.7	43.6	5.8	93.3
Peru	LAC	75.3	76.2	15.5	43.4	39.8	11.7	92.7
Vietnam	East and South Asia	65.3	70.2	39.0	19.6	20.1	11.2	92.6
Indonesia	East and South Asia	68.2	75.0	39.0	36.9	28.2	4.5	92.1
Colombia	OECD	76.5	86.9	25.4	47.5	42.4	24.8	88.7
Turkey	OECD	85.9	89.3	41.3	45.8	26.3	7.3	85.9
China	East and South Asia	90.6	96.4	64.4	15.5	28.4	42.9	85.5
South Africa	Sub-Saharan Africa	74.7	75.0	26.8	10.0	37.2	7.6	81.7
Iran (the Islamic Republic of Iran)	MENA	58.8	46.4	50.6	7.0	34.5	2.8	78.9
Chile	OECD	85.3	85.7	30.8	28.8	46.7	13.4	78.3
Italy	OECD	82.9	82.1	52.2	43.5	57.7	44.9	76.3
Malaysia	East and South Asia	85.3	85.7	60.3	25.5	35.0	16.8	73.7
Hungary	OECD	74.7	67.9	79.7	30.1	55.1	54.8	72.4
Russian Federation	E. Europe and C. Asia	81.8	86.9	29.4	9.4	37.5	1.3	70.8
Correlation coefficients, %	Government's online service	100.00	-	-	-	-	-	−6.63
	E-participation	84.18	100.00	-	-	-	-	4.50
	High-tech manufacturing, %	15.84	−10.55	100.00	-	-	-	−34.33
	GDP/unit of energy use	20.31	31.82	−16.38	100.00	-	-	28.82
	Environmental performance	11.67	−9.94	15.97	26.43	100.00	-	−55.71
	ISO 14001 certificates/	22.73	18.11	61.94	25.32	55.23	100.00	−34.97
	Arithmetic mean	18.24[a]	13.33[a]	20.51[a]	11.92[b]	5.90[b]	34.26[b]	−16.39

[a]With indicators of ecological economy and management.
[b]With indicators of economy and management in the AI, era.
Source: compiled and calculated by the authors based on the materials of UN (2022), WIPO (2022).

The synergetic effect of the systemic development of ecological economy and management in the AI era to combat climate change from the perspective of sustainable development

As part of the second task of the study, the regression analysis method was used to identify and measure the synergetic effect of the systemic development of ecological economy and management in the AI era to combat climate change from the standpoint of sustainable development. The regression dependence of Goal 13 Score in 2022 on six indicators of the ecological economy and digital economy from Table 1 was determined, which allowed us to obtain the following equation of multiple linear regression:

$$y = 116,75 + 1,04^{*}x_1 - 0,98^{*}x_2 - 0,41^{*}x_3 + 0,32^{*}x_4 - 0,91^{*}x_5 + 0,35^{*}x_6 \quad (1)$$

To check the reliability of the regression Eq. 1, we will conduct the F-test. The significance of F was 0.0521, therefore, the equation corresponds to $\alpha = 0.10$. For 15 observations and six factor variables ($k_1 = 6$; $k_2 = 15\text{-}6\text{-}1 = 8$), the tabular F = 2.67. The observed F = 3.5215—it exceeded the tabular and, therefore, the F-test was passed.

It is also advisable to conduct a Student's t-test. At 14 degrees of freedom, the tabular t = 1.345. The observed t exceeded the tabular modulo for all variables and amounted to 6.8115 for the constant, 2.0410 for x_1, −2.2981 for x_2, −2.0893 for x_3,2,3649 for x_4, −3.5882 for x_5 and 1.6068 for x_6. Therefore, the *t*-test is also passed. Together, both tests confirmed the validity and reliability of Eq. 1 at a significance level of 0.10.

The multiple correlation coefficient in the regression model was 85.17% (R^2 = 75.54), significantly exceeding the correlation coefficients of Goal 13 Score with the selected six indicators separately (shown in Table 1 and are (modulo) from 4.50% to 55.71%, and on average, as indicated above, they are -16.39%. Based on the obtained regression Eq. 1, a forecast of the system management of all six indicators for combating climate change is made.

According to the forecast, with an increase of 15% government's online service (from 78.51 points in 2022 to 90.29 points), as well as with an increase of 15%, respectively, GDP/unit of energy use (from 27.68 points to 33.22 points) and ISO 14001 environmental certificates/bn PPP$ GDP (from 17.03 score up to 20.44 points) Goal 13 score will increase to the maximum possible 100% (+18.06% compared to 83.95 points in 2022).

The received results allow for a conclusion that the systemic development of ecological economy and management in the AI era ensures the synergetic effect for fighting climate change from the position of sustainable development. Isolated measures of the development of ecological economy and management in the AI era give a limited contribution to the fight against climate change. Thus, the development of e-government by one point leads to an increase in the result of the implementation of SDG 13 by 1.04 points. A decrease in the energy intensity of GDP by 1% leads to an increase in the results of the implementation of SDG 13 by 0.32 points. An increase in the activity of ecological certification of the quality of products by 1% leads to an increase in the result of the implementation of SDG 13 by 0.35 points.

The full-scale fight against climate change within separate directions requires their unattainable scale. Thus, to reach 100 points on SDG 13, it is necessary to raise government's online service up to 94 points or increase GDP/unit of energy use up to 80 points, or raise ISO 14001 environmental certificates/bn PPP$ GDP up to 65 points—which cannot be achieved in the mid-term. Collectively, these measures allow—in the case of a slight increase in their scale—achieving full-scale results in the fight against climate change.

Discussion

The article contributes to the literature by strengthening the systemic links between the concept of ecological economics and business management and the concept of the digital economy based on smart technologies in the AI era, as well as by filling the gap in knowledge at the intersection of these concepts. In contrast to the position of such scientists as Fu et al. (2022), Garris and Domingo (2022), Kakraliya et al. (2022), Kong (2021), Matsunaga et al. (2022), Sun et al. (2021), Xiong et al. (2022), the authors proved that the development of the digital economy and business based on smart technologies in the AI era can have a positive impact on the ecological economy and management, provided that all economic entities—the state, society and business—show high corporate environmental responsibility.

In contrast to the position of Fendrich et al. (2022), Kazancoglu et al. (2021), Mishra et al. (2022), Rachinsky-Spivakov (2022), Xie and Jamaani (2022), Zikargae et al. (2022), it has been proved that systematic management of the development of the digital economy and business based on smart technologies in the AI era is required to maximize their contribution to the fight against climate change in support of sustainable development. This will make it possible to obtain a synergistic effect in the form of achieving much better results of the implementation of SDG13 (correlation of 85.17%) compared to managing these factors separately (correlation modulo: from 4.50% to 55.71%, and on average 16.39%).

The scientific novelty and originality of the paper lie in its filling the gap at the intersection of ecological economy and business management, the concept of the digital economy and the concept of climate change and the fight against climate change. Due to this, the paper, first, revealed the influence of the development of the digital economy and business based on smart technologies in the AI era on ecological economy and management, manifested in the increase in results on SDG 3. Second, the paper offered prospective measures for managing the development of the digital economy and business based on smart technologies in the AI era to maximize their contribution to the fight against climate change, in the support of sustainable development, which include the increase in government's online service, growth of GDP/unit of energy use and increase in ISO 14001 environmental certificates.

In conclusion, it is necessary to mention the limitation of this research: the results obtained are generalized, and they would be reliable for the world economy on the whole, while the specifics of isolated economic systems are beyond the limits of this research. It is generally known that the digital economy and ecological management have vivid and significant specifics in different countries. To deal with this limitation in future studies, it is necessary to focus on the specifics of ecological economy and management in the AI era and the development of practical recommendations for the fight against climate change which would take into account the national specifics.

Conclusion

The article has formed a systematic view of environmental economics and management in the AI era, filled the identified gap in the literature and solved the problems posed. The article has answered both RQ and proved both hypotheses put forward. The development of the digital economy and business based on smart technologies in the era of AI can have a positive impact on the ecological economy and management, provided that the corporate environmental responsibility of market participants is high (the H_1 hypothesis has been proved).

Systematic management of the development of the digital economy and business based on smart technologies in the AI era, providing a synergistic effect in the form of maximizing their contribution to the fight against climate change in support of sustainable development is preferable (the H_2 hypothesis has been proved). The theoretical significance of the results obtained in the article is related to the clarification of cause-and-effect relationships in the development of ecological economy and management in the AI era. The practical significance of the authors' conclusions and recommendations lies in the fact that they will improve the efficiency of economic management and business in the "Decade of Action" and support the sustainable development of the AI economy.

Author contributions

AS, TL, and IM. contributed to conception and design of the study. AK organized the database. TL performed the statistical analysis. AS wrote the first draft of the manuscript. AS, TL, IM, and AK wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Conflict of interest

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References

Atabekova, N. K., Dzedik, V. A., Troyanskaya, M. A., and Matytsin, D. E. (2022). The role of education and social policy in the development of responsible production and consumption in the AI economy. *Front. Environ. Sci.* 10, 929193. doi:10.3389/fenvs.2022.929193

Badry, A., Slobodnik, J., Alygizakis, N., Walker, L. A., Koschorreck, J., and ClaBen, D. (2022). Using environmental monitoring data from apex predators for chemicals management: Towards harmonised sampling and processing of archived wildlife samples to increase the regulatory uptake of monitoring data in chemicals management. *Environ. Sci. Eur.* 34 (1), 1-9. doi:10.1186/s12302-022-00664-6

Bakkaloglu, S., Cooper, J., and Hawkes, A. (2022). Life cycle environmental impact assessment of methane emissions from the biowaste management strategy of the United Kingdom: Towards net zero emissions. *J. Clean. Prod.* 376, 134229. doi:10.1016/j.jclepro.2022.134229

Bechtel, M. M., Scheve, K. F., and van Lieshout, E. (2022). Improving public support for climate action through multilateralism. *Nat. Commun.* 13 (1), 6441. doi:10.1038/s41467-022-33830-8

Bermeo-Ayerbe, M. A., Ocampo-Martinez, C., and Diaz-Rozo, J. (2022). Data-driven energy prediction modeling for both energy efficiency and maintenance in smart manufacturing systems. *Energy* 238, 121691. doi:10.1016/j.energy.2021.121691

Calero Preciado, C., Soria-Carrasco, V., Boxall, J., and Douterelo, I. (2022). Climate change and management of biofilms within drinking water distribution systems. *Front. Environ. Sci.* 10, 962514. doi:10.3389/fenvs.2022.962514

Chehri, A., Saadane, R., Fofana, I., and Jeon, G. (2022). Smart Grid for sustainable cities: Strategies and pathways for energy efficiency solutions. *Smart Innovation, Syst. Technol.* 263, 317–327. doi:10.1007/978-981-16-6269-0_27

Chen, Y., Xu, Y., and Zhou, K. (2022). Cross-administrative and downscaling environmental spatial management and control system: A zoning experiment in the yangtze river delta, China. *J. Environ. Manag.* 323, 116257. doi:10.1016/j.jenvman.2022.116257

Dirmeyer, P. A., Sridhar Mantripragada, R. S., Gay, B. A., and Klein, D. K. D. (2022). Evolution of land surface feedbacks on extreme heat: Adapting existing coupling metrics to a changing climate. *Front. Environ. Sci.* 10, 949250. doi:10.3389/fenvs.2022.949250

Farzaneh, H., Malehmirchegini, L., Bejan, A., Daka, P. P., Mulumba, A., and Daka, P. P. (2021). Artificial intelligence evolution in smart buildings for energy efficiency. *Appl. Sci. Switz.* 11 (2), 7631–7726. doi:10.3390/app11020763

Fendrich, A. N., Barretto, A., Sparovek, G., da Luz Ferreira, J., de Souza Filho, C. F. M., and de Guedes, C. M. G. (2022). Taxation aiming environmental protection: The case of Brazilian Rural Land Tax. *Land Use Policy* 119, 106164. doi:10.1016/j.landusepol.2022.106164

Fu, J., Zhu, P., Hua, J., Li, J., and Wen, J. (2022). Optimization of the energy efficiency in smart internet of vehicles assisted by MEC. *EURASIP J. Adv. Signal Process.* 2022 (1), 13. doi:10.1186/s13634-022-00845-8

Garriz, C., and Domingo, R. (2022). Trajectory optimization in terms of energy and performance of an industrial robot in the manufacturing Industry. *Sensors* 22 (19), 7538. doi:10.3390/s22197538

Gyamfi, B. A., Ampomah, A. B., Bekun, F. V., and Asongu, S. A. (2022). Can information and communication technology and institutional quality help mitigate climate change in E7 economies? An environmental kuznets curve extension. *J. Econ. Struct.* 11 (1), 14. doi:10.1186/s40008-022-00273-9

Hassan, T., Khan, Y., He, C., Alsagr, N., Song, H., and khan, N. (2022). Environmental regulations, political risk and consumption-based carbon emissions: Evidence from OECD economies. *J. Environ. Manag.* 320, 115893. doi:10.1016/j.jenvman.2022.115893

Kakraliya, S. K., Jat, H. S., Singh, I., Kakraliya, M., Bijarniya, D., and Sharma, P. C. (2022). Energy and economic efficiency of climate-smart agriculture practices in a rice–wheat cropping system of India. *Sci. Rep.* 12 (1), 8731. doi:10.1038/s41598-022-12686-4

Kazancoglu, Y., Sezer, M. D., Ozkan-Ozen, Y. D., Mangla, S. K., and Kumar, A. (2021). Industry 4.0 impacts on responsible environmental and societal management in the family business. *Technol. Forecast. Soc. Change* 173, 121108. doi:10.1016/j.techfore.2021.121108

Kong, S. (2021). Environmental cost of energy consumption and economic growth: Can China shift some burden through financial development? An asymmetric analysis. *Environ. Sci. Pollut. Res.* 28 (20), 25255–25264. doi:10.1007/s11356-021-12397-9

Li, B., Jiang, F., Xia, H., and Pan, J. (2022). Under the background of AI application, research on the impact of science and technology innovation and industrial structure upgrading on the sustainable and high-quality development of regional economies. *Sustain. Switz.* 14 (18), 11331. doi:10.3390/su141811331

Luitse, D., and Denkena, W. (2021). The great transformer: Examining the role of large language models in the political economy of AI. *Big Data Soc.* 8 (2), 205395172110477. doi:10.1177/20539517211047734

Matsunaga, F., Zytkowski, V., Valle, P., and Deschamps, F. (2022). Optimization of energy efficiency in smart manufacturing through the application of cyber-physical systems and Industry 4.0 technologies. *J. Energy Resour. Technol.* 144 (10), 102104. doi:10.1115/1.4053868

Mentzel, S., Grung, M., Holten, R., Stenrod, M., Stenrød, M., and Moe, S. J. (2022). Probabilistic risk assessment of pesticides under future agricultural and climate scenarios using a bayesian network. *Front. Environ. Sci.* 10, 957926. doi:10.3389/fenvs.2022.957926

Mishra, R., Singh, R. K., and Subramanian, N. (2022). Exploring the relationship between environmental collaboration and business performance with mediating effect of responsible consumption and production. *Bus. Strategy Environ.* doi:10.1002/bse.3240

Mohd Fuzi, N., Habidin, N. F., Adam, S., and Ong, S. Y. Y. (2022). The relationship between environmental cost on organisational performance and environmental management system: A structural equation modelling approach. *Meas. Bus. Excell.* 26 (4), 496–507. doi:10.1108/MBE-03-2021-0039

Popkova, E. G. (2022). International trade in the era of neo-globalization: Disintegration vs digital partnership. *Res. Econ. Anthropol.* 42, 7–13. doi:10.1108/S0190-128120220000042001

Popkova, E. G., and Sergi, B. S. (2022). High-tech economic growth from the standpoint of the theory of economic time: Modelling and reducing space–time inequality. *Smart Innovation, Syst. Technol.* 287, 15–22. doi:10.1007/978-981-16-9804-0_2

Popkova, E. G., and Shi, X. (2022). Economics of climate change: Global trends, country specifics and digital perspectives of climate action. *Front. Env. Econ.* 1, 935368. doi:10.3389/frevc.2022.935368

Rachinsky-Spivakov, Y. (2022). The role of civil society in the Lower Mekong Region in environmental decision-making: Water management and forestry issues. *Asian Polit. Policy* 14 (2), 264–276. doi:10.1111/aspp.12639

Ruffolo, M. (2022). The role of ethical AI in fostering harmonic innovations that support a human-centric digital transformation of economy and society. *Lect. Notes Netw. Syst.* 282, 139–143. doi:10.1007/978-3-030-81190-7_15

Skeirytė, A., Krikštolaitis, R., and Liobikienė, G. (2022). The differences of climate change perception, responsibility and climate-friendly behavior among generations and the main determinants of youth's climate-friendly actions in the EU. *J. Environ. Manag.* 323, 116277. doi:10.1016/j.jenvman.2022.116277

Som, T. (2021). Sustainability in energy economy and environment: Role of AI based techniques. *Model. Optim. Sci. Technol.* 18, 647–682. doi:10.1007/978-3-030-72929-5_31

Sun, X., Ping, Z.-B., Dong, Z.-F., Zhu, X. D., Larry Li, B., and Fang, S. (2021). Resources and environmental costs of China's rapid economic growth: From the latest theoretic SEEA framework to modeling practice. *J. Clean. Prod.* 315, 128126. doi:10.1016/j.jclepro.2021.128126

UN (2022). Sustainable development report 2022 – SDG index. URL:https://dashboards.sdgindex.org/rankings (data accessed: 23.10.2022)

Victor-Gallardo, L., Roccard, J., Campos, P., Quiros-Tortos, J., Lefevre, E. N., and Quiros-Tortos, J. (2022). Identifying cross-sectoral policy synergies for decarbonization: Towards short-lived climate pollutant mitigation action in Costa Rica. *J. Clean. Prod.* 379, 134781. doi:10.1016/j.jclepro.2022.134781

Wang, C., Gu, J., Sanjuán Martínez, O., and González Crespo, R. (2021). Economic and environmental impacts of energy efficiency over smart cities and regulatory measures using a smart technological solution. *Sustain. Energy Technol. Assessments* 47, 101422. doi:10.1016/j.seta.2021.101422

Wilson, M., Paschen, J., and Pitt, L. (2022). The circular economy meets artificial intelligence (AI): Understanding the opportunities of AI for reverse logistics. *Manag. Environ. Qual. Int. J.* 33 (1), 9–25. doi:10.1108/MEQ-10-2020-0222

Wipo (2022). Explore the interactive database of the WIPO global innovation index 2021 indicators. URL: https://www.globalinnovationindex.org/analysis-indicator (data accessed: 23.10.2022)

Xie, P., and Jamaani, F. (2022). Does green innovation, energy productivity and environmental taxes limit carbon emissions in developed economies: Implications for sustainable development. *Struct. Change Econ. Dyn.* 63, 66–78. doi:10.1016/j.strueco.2022.09.002

Xiong, H., Cao, H., Diao, X., Lu, W., and Lou, Y. (2022). On the optimal energy efficiency of the multi-rotor UAVs of an aerial work platform based on an aerial cable towed robot. *Mech. Mach. Theory* 176, 105002. doi:10.1016/j.mechmachtheory.2022.105002

Zikargae, M. H., Woldearegay, A. G., and Skjerdal, T. (2022). Assessing the roles of stakeholders in community projects on environmental security and livelihood of impoverished rural society: A nongovernmental organization implementation strategy in focus. *Heliyon* 8 (10), e10987. doi:10.1016/j.heliyon.2022.e10987

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The contribution of sustainable and clean energy to the strengthening of energy security

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KEYWORDS

sustainable and clean energy, fuel and energy complex, sustainable development goals (SDGs), environmental economy, energy security

Introduction

The motivation for this research was the large importance of the development of clean energy for environmental protection and the uncertainty about the impacts of clean energy on energy security. Sustainable and clean energy includes clean and alternative energy, which is renewable and whose production does not lead to the depletion of natural resources. Although sustainable and clean energy has been in existence for a long time, its positions have significantly strengthened and it received a new impulse for development after the adoption of the Paris Agreement (the United Nations Framework Convention on Climate Change (UNFCCC), 2022) at the global level and green agendas and strategies of decarbonization at the national level.

Both existing alternatives—sustainable and clean energy (e.g., solar, wind, and water) and fossil fuel energy (e.g., oil, natural gas, and coal)—have advantages and disadvantages. A choice in favor of a certain alternative is made, given the specifics of the needs of the sectors and economies. During decision-making on the management of the fuel and energy complex, it is necessary to be guided by the interests of energy security provision.

The institutional foundations of energy security were set by international regulatory acts. The International Energy Agency treats energy security as "reliable, affordable access to all fuels and energy sources" (IEA, 2022). Sustainability, here, is treated as the stability and reliability of energy.

The UN (2022) supplements this treatment with the priority connected with the implementation of SDG 7 in the aspect of "ensuring access to affordable, reliable, sustainable, and modern energy." Here, sustainability is closer to environmental performance and is treated as energy's friendliness toward the environment. The goal of this paper is to study the contribution of sustainable and clean energy to the strengthening of energy security.

Literature review

This paper uses the scientific provisions of the concept of energy security. General issues of clean energy were studied in detail in Chen (2022), Jia et al. (2022), and Khalfaoui et al. (2022). However, the consequences of the transition to sustainable and clean energy for energy security remain insufficiently studied and unclear, which is a literature gap. According to the concept of energy security, the fuel and energy complex is a part of the core of the environmental economy. Thus, this complex is assigned two strategic functions in modern economic systems.

The first function is traditional and the most obvious function—the provision of stability (continuous work and absence of crises) and high effectiveness of the energy system (Ragulina et al., 2022). Since energy is an essential resource, which is necessary for the normal implementation of most economic processes, a deficit of energy is unacceptable because it brings the risks of a reduction in the population's living standards and quality of life and a slowdown of the economic growth rate (Chutcheva et al., 2022).

The second function is more modern and is becoming more significant due to support around the world—the protection of the environment (Vorozheykina, 2022). In the past, this function was considered additional, but today, it is the main function, together with the first function, and equally significant (Kukushkina et al., 2022). The fuel and energy complex determines natural resource rent in GDP and preservation of natural heritage for future generations. Being a part of the industry, this complex forms a substantial part of production waste and consumption in the economy. Modernization of the fuel and energy complex facilitates the implementation of the climate agenda (Yankovskaya et al., 2022).

The leading trend of the development of the fuel and energy complex, conducted by the most progressive countries of the world, consists in the transition to sustainable and environmental (i.e., clean and renewable) energy (Hongsuchon et al., 2022). The initial accumulated experience of this transition in recent decades has been contradictory. Thus, the problem consists in the uncertainty of the consequences and prospects for the fuel and energy complex, executing its two described functions with the dominance of sustainable and clean energy (Malhotra et al., 2022).

The world community's largest concerns are connected with the risks associated with the first function—energy security. Thus, it is important to study the contribution of sustainable and clean energy to the strengthening of energy security (Abotaleb et al., 2022). Considering energy security in the context of the described functions of the fuel and energy complex, this paper raises the two following research questions (RQs).

RQ1: What is the contribution of sustainable and clean energy to the provision of affordability and sufficiency of energy? Eales et al. (2020), Rybak et al. (2021), and Villavicencio Calzadilla and Mauger (2018) provide legitimate concerns regarding the transfer to clean energy, reducing the affordability of energy in the economy. This allows formulating hypothesis H1: sustainable and clean energy has a negative impact on the stability and effectiveness of the energy system. However, the existing arguments are based mainly on theoretical assumptions and general regularities and thus need rechecking.

RQ2: What is the contribution of sustainable and clean energy to the reduction of production waste and consumption and the fight against climate change? The existing literature notes that this contribution is significant since clean energy facilitates the reduction of CO_2 emissions (Ajagekar and You, 2022; Qamar et al., 2022) and is climate friendly (Chen and You, 2022; Matak et al., 2022). This allows formulating hypothesis H2: sustainable and clean energy makes a significant positive contribution to the reduction of production and consumption waste and the fight against climate change. However, here, the reasoning is also fragmented and based on separate data; thus, it needs to be strengthened.

To fill the discovered gap in the literature and ensure reliable reasoning for the answers to the raised research questions, we systemically study the contribution of sustainable and clean energy to the strengthening of energy security, taking into account both designated functions.

Results

A systemic approach to the contribution of sustainable and clean energy to the strengthening of energy security

In most of the existing sources, the two designated functions of the fuel and energy complex are acknowledged, but they are differentiated. Energy security is associated with the first function (Popkova et al., 2019; Popkova and Sergi, 2021; Wang et al., 2022), while the second function belongs to the green economy (Fouladvand, 2022; Oladeji et al., 2022).

A systemic view of these two functions in the Decade of Action shows that energy security is inextricably linked to the green economy. From the position of sustainable development of energy security, this is not just sufficiency but also environmental friendliness of energy. This is why this paper proposes a clarified treatment of energy security in the unity of the results of the fuel and energy complex executing its two functions.

It is suggested to treat energy security as the stability and high effectiveness of the energy system and its correspondence to the interest of environmental protection. The advantage of the new definition is that it allows for a comprehensive and reliable assessment of the prospects for the provision of energy security—from the position of the consequences for energy security to the position of the consequences for the environmental security of energy.

TABLE 1 Comparison of the results obtained and the literature.

Objects of comparison		Contribution of sustainable and clean energy		
		RQ1	RQ2	
		To provision of accessibility and sufficiency of energy	To the reduction of production and consumption waste	To the fight against climate change
Relevant SDG		SDG 7	SDG 12	SDG 13
Existing literature	Functions of sustainable and clean energy	Provision of stability and high effectiveness of the energy system	Environmental protection	
	Treatment	Hypothesis H1: negative impact	Hypothesis H2: significant positive contribution	
	Sources	Eales et al. (2020), Rybak et al. (2021), and Villavicencio Calzadilla and Mauger (2018)	Ajagekar and You (2022) and Qamar et al. (2022)	Chen and You (2022) and Matak et al. (2022)
Results obtained	Functions of sustainable and clean energy	Authors' specified interpretation of the unity of two functions: simultaneous provision of stability, high effectiveness of the energy system, and protection of the environment		
	Treatment	Description of the weakness of hypothesis H1 (the influence is absent or weak)	Description of the strengths of hypothesis H2, which is supported with proof	
	Considered case experience	BRICS	G7	

Source: authors.

International case experience of the contribution of sustainable and clean energy to the strengthening of energy security

Using the formed systemic view of the contribution of sustainable and clean energy to the strengthening of energy security, given both designated functions, we perform a case overview of the international experience of the execution of these functions in practice. To strengthen the evidence base of hypothesis H1, we use the experience of the countries of BRICS, all of which ratified the Paris Agreement and adopted national strategies on economic decarbonization.

As for sustainable and clean energy in Brazil, bioenergy and hydropower dominate. Among the largest economies in the world, the Russian fuel and energy balance is one of the most environmental friendly economies (low carbon): more than one-third of electric energy generation accounts for atomic energy, hydropower, and other renewable energy sources. In recent years, the share of sustainable and clean energy in India has increased, with the active development of solar and wind energy.

China became a country with the world's largest installed capacity of hydropower, wind energy, and solar energy. South Africa shows large potential for expanding the use of renewable energy sources since it possesses rich natural resources of sun and wind (BRICS Energy Research Cooperation Platform, 2022). As of now, all countries of BRICS have a high level of energy security. Therefore, sustainable and clean energy in BRICS countries strengthens the stability and raises the effectiveness of the energy system.

To strengthen the evidence base of hypothesis H2, we use the case experiences of countries in the G7, which demonstrate serious results in the development of sustainable and clean energy. The ongoing projects include forced decarbonization of sectors, systemic changes for environmental sustainability in all spheres of life, tackling extinction, and initiatives on ocean protection (SDG Knowledge Hub, 2022). Therefore, in countries of the G7, sustainable and clean energy makes a significant positive contribution to the reduction of production and consumption waste and the fight against climate change.

Discussion

This paper contributes to the literature through the development of the scientific provisions of the concept of energy security by its integration with environmental economics. The results obtained are compared to the existing literature in Table 1.

As shown in Table 1, unlike the division—which is present in the existing literature—between the function of provision of stability and high effectiveness of the energy system (Chutcheva et al., 2022; Ragulina et al., 2022) and the function of environmental protection (Kukushkina et al., 2022; Vorozheykina, 2022; Yankovskaya et al., 2022), this paper proposes addressing these functions in a comprehensive manner. Unlike Eales et al. (2020), Rybak et al. (2021), and Villavicencio Calzadilla and Mauger (2018), we determined a weakness of hypothesis H1. Using the example of the case experience of the countries of BRICS, we did not discover the negative consequences of the development of clean energy with regard to the accessibility and sufficiency of energy in the society and the economy.

We also discovered the strengths of hypothesis H2 and supported it with proof based on the case experience of the G7. We demonstrated a positive contribution of sustainable and clean energy to the reduction of production waste, which strengthened the scientific evidence of the works of Ajagekar and You (2022) and Qamar et al. (2022). We also discovered the contribution of sustainable and clean energy to the fight against climate change, which strengthened the scientific evidence of the works of Chen and You (2022) and Matak et al. (2022). This is why the transition to sustainable and clean energy should be conducted in combination with other measures for implementing SDG 12 and SDG 13.

Conclusion

This paper proved a significant, but moderate, contribution of sustainable and clean energy to the strengthening of energy security, filling a literature gap and providing answers to both raised research questions. As an answer to RQ1, it was discovered that the function of provision of stability and high effectiveness of the energy system is further successfully performed by the fuel and energy complex with the development of sustainable and clean energy. As an answer to RQ2, it is determined that the function of environmental protection is performed more successfully by the fuel and energy complex with the development of clean energy.

The originality and theoretical significance of the paper consist in, first, clarification of the notion and essence of an economic system's energy security from the position of the sustainable development goals (SDGs) through consideration of not only the function of provision of stability and high effectiveness of the energy system but also the function of environmental protection and, second, rethinking the consequences of the transition to sustainable and clean energy from the position of the fuel and energy complex performing its two functions on the provision of energy security.

The practical significance of the authors' conclusions and recommendations is that they could be used during the development and implementation of programs and strategies for energy security provision since they suggest sustainable and clean energy as a prospective management tool. Energy policy implications consist in the expedience of including the indicators and plans for the development of sustainable and clean energy in the programs for achieving SDG 12 and SDG 1 and the necessity to reconsider the programs for achieving SDG 7, given the absence of a close connection between it and clean energy.

Author contributions

YK, VKr, VKi, and AY were responsible for writing the original draft, investigation, methodology, supervision, and writing and editing.

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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References

Abotaleb, A., Almasri, D., Elrayyah, A., Al-Kuwari, M., and Amhamed, A. (2022). Sustainable energy harvesting system for roads in desert climate. *Adv. Sci. Technol. Innovation* 2022, 369–379. doi:10.1007/978-3-030-76081-6_45

Ajagekar, A., and You, F. (2022). Quantum computing and quantum artificial intelligence for renewable and sustainable energy: A emerging prospect towards climate neutrality. *Renew. Sustain. Energy Rev.* 165, 112493. doi:10.1016/j.rser.2022.112493

BRICS Energy Research Cooperation Platform (2022). Overview of the energy sphere of BRICS countries. Avaliable At: https://brics-russia2020.ru/images/114/89/1148936.pdf (data accessed 11 12, 2022).

Chen, P. (2022). Is the digital economy driving clean energy development? -New evidence from 276 cities in China. *J. Clean. Prod.* 372, 133783. doi:10.1016/j.jclepro.2022.133783

Chen, W.-H., and You, F. (2022). Sustainable building climate control with renewable energy sources using nonlinear model predictive control. *Renew. Sustain. Energy Rev.* 168, 112830. doi:10.1016/j.rser.2022.112830

Chutcheva, Y. V., Kuprianova, L. M., Seregina, A. A., and Kukushkin, S. N. (2022). Environmental management of companies in the oil and gas markets based on AI for sustainable development: An international review. *Front. Environ. Sci.* 10, 952102. doi:10.3389/fenvs.2022.952102

Eales, A., Frame, D., Coley, W., Bayani, E., and Galloway, S. (2020). Sustainable delivery models for achieving SDG7: Lessons from an energy services social enterprise in Malawi. *GHTC* 2020, 9342877. doi:10.1109/GHTC46280.2020.9342877

Fouladvand, J. (2022). Behavioural attributes towards collective energy security in thermal energy communities: Environmental-friendly behaviour matters. *Energy* 261, 125353. doi:10.1016/j.energy.2022.125353

Hongsuchon, T., Alfawaz, K. M., Hariguna, T., and Alsulami, O. A. (2022). The effect of customer trust and commitment on customer sustainable purchasing in e-marketplace, the antecedents of customer learning value and customer purchasing value. *Front. Environ. Sci.* 10, 964892. doi:10.3389/fenvs.2022.964892

International Energy Agency (IEA) (2022). Energy security: Reliable, affordable access to all fuels and energy sources. Avaliable At: https://www.iea.org/topics/energy-security (data accessed 11 23, 2022).

Jia, W., Jia, X., Wu, L., Yang, T., Wang, E., Xiao, P., et al. (2022). Research on regional differences of the impact of clean energy development on carbon dioxide emission and economic growth. *Humanit. Soc. Sci. Commun.* 9 (1), 25. doi:10.1057/s41599-021-01030-2

Khalfaoui, R., Mefteh-Wali, S., Viviani, J.-L., Lucey, B. M., Abedin, M. Z., and Lucey, B. M. (2022). How do climate risk and clean energy spillovers, and uncertainty affect U.S. stock markets? *Technol. Forecast. Soc. Change* 185, 122083. doi:10.1016/j.techfore.2022.122083

Kukushkina, A. V., Mursaliev, A. O., Krupnov, Y. A., and Alekseev, A. N. (2022). Environmental competitiveness of the economy: Opportunities for its improvement with the help of AI. *Front. Environ. Sci.* 10, 953111. doi:10.3389/fenvs.2022.953111

Malhotra, A., Mathur, A., Diddi, S., and Sagar, A. D. (2022). Building institutional capacity for addressing climate and sustainable development goals: Achieving energy efficiency in India. *Clim. Policy* 22 (5), 652–670. doi:10.1080/14693062.2021.1984195

Matak, N., Mimica, M., and Krajačić, G. (2022). Optimising the cost of reducing the CO2 emissions in sustainable energy and climate action plans. *Sustain. Switz.* 14 (6), 3462. doi:10.3390/su14063462

Oladeji, I., Zamora, R., and Lie, T. T. (2022). Security constrained optimal placement of renewable energy sources distributed generation for modern grid operations. *Sustain. Energy, Grids Netw.* 32, 100897. doi:10.1016/j.segan.2022.100897

Popkova, E. G., Inshakov, O. V., and Bogoviz, A. V. (2019). Regulatory mechanisms of energy conservation in sustainable economic development. *Lect. Notes Netw. Syst.* 44, 107–118. doi:10.1007/978-3-319-90966-0_8

Popkova, E. G., and Sergi, B. S. (2021). Energy efficiency in leading emerging and developed countries. *Energy* 221, 119730. doi:10.1016/j.energy.2020.119730

Qamar, S., Ahmad, M., Oryani, B., and Zhang, Q. (2022). Solar energy technology adoption and diffusion by micro, small, and medium enterprises: Sustainable energy for climate change mitigation. *Environ. Sci. Pollut. Res.* 29 (32), 49385–49403. doi:10.1007/s11356-022-19406-5

Ragulina, Y. V., Dubova, Y. I., Litvinova, T. N., and Balashova, N. N. (2022). The environmental AI economy and its contribution to decarbonization and waste reduction. *Front. Environ. Sci.* 10, 914003. doi:10.3389/fenvs.2022.914003

Rybak, A., Rybak, A., and Kolev, S. D. (2021). Analysis of the eu-27 countries energy markets integration in terms of the sustainable development sdg7 implementation. *Energies* 14 (21), 7079. doi:10.3390/en14217079

SDG Knowledge Hub (2022). G7 environment, climate and energy ministers meeting 2022. Avaliable At: https://sdg.iisd.org/events/g7-environment-climate-and-energy-ministers-meeting-2022/(data accessed 11 12, 2022).

The United Nations Framework Convention on Climate Change (UNFCCC) (2022). The Paris agreement. Avaliable At: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement ((data accessed 11 23, 2022).

UN (2022). SDG7: Ensure access to affordable, reliable, sustainable and modern energy. Avaliable At: https://www.un.org/sustainabledevelopment/energy/(data accessed 11 23, 2022).

Villavicencio Calzadilla, P., and Mauger, R. (2018). The UN's new sustainable development agenda and renewable energy: The challenge to reach SDG7 while achieving energy justice. *J. Energy & Nat. Resour. Law* 36 (2), 233–254. doi:10.1080/02646811.2017.1377951

Vorozheykina, T. M. (2022). Challenges and prospects of decarbonization of the economy in the age of AI. *Front. Environ. Sci.* 10, 952821. doi:10.3389/fenvs.2022.952821

Wang, J., Ghosh, S., Olayinka, O. A., Shah, M. I., and Zhong, K. (2022). Achieving energy security amidst the world uncertainty in newly industrialized economies: The role of technological advancement. *Energy* 261, 125265. doi:10.1016/j.energy.2022.125265

Yankovskaya, V., Gerasimova, E. B., Osipov, V. S., and Lobova, S. V. (2022). Environmental CSR from the standpoint of stakeholder theory: Rethinking in the era of artificial intelligence. *Front. Environ. Sci.* 10, 953996. doi:10.3389/fenvs.2022.953996

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Development of environmental economy and management in the age of AI based on green finance

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Introduction

Green finance is a set of innovative solutions in the financial sector of the economy, which have become widespread due to the adoption by the United Nations (UN) of the Sustainable Development Goals (SDGs) in 2015, which is expected to reach its peak in the Decade of Action (Tong A et al., 2022; Zhou and Tang, 2022). Green finance refers to the totality of financial transactions (including public subsidies, private investment, lending, charitable contributions, and payment for goods and services by consumers) that comply with ESG principles and are carried out with corporate environmental responsibility by all subjects of financial relations (Dong et al., 2022; Ronaldo and Suryanto, 2022; Tang M et al., 2022; Wang K et al., 2022).

There are currently all necessary institutional conditions and prerequisites for the development of green finance. Governments worldwide have ratified the SDGs and adopted national strategies to decarbonize their economies (Feng et al., 2022; Li J et al., 2022). Businesses actively publish corporate sustainability and environmental responsibility reports, following ESG principles in their operations and building green business practices to their competitive advantage (Jiang et al., 2022; Li S et al., 2022). In civil society and consumer society, environmentally responsible communities are being created and developed; entire areas (cities and regions) become environmentally sustainable, for example, by practising recycling and clean energy (Desalegn and Tangl, 2022; Guo H et al., 2022; Popkova, 2022; Sun and Chen, 2022; Wu G, 2022).

Nevertheless, green finance continues to have a limited impact on the environmental economy and management (Yang and Masron, 2022; Zhang and Liu, 2022). The causal relationships between the spread and use of green finance remain largely undefined, which is a gap in the literature. This raises the research question (RQ) of what importance green finance has for the economy and environmental management and the prospects for increasing this importance.

In seeking an answer to the posed RQ, this research considers the special context of the Decade of Action because it takes place in the era of the economy of artificial intelligence (AI). The essence of the AI economy consists in the automatization of economic processes and dissemination of smart technologies, which are based on AI. As such, green finance is undergoing a digital upgrade, in which it is becoming increasingly smart. Consideration of the context of the AI era ensures the originality of this research. This research aims to explore the importance of green finance in the AI era for economics and environmental management.

Literature review

The theoretical basis of this research is the concept of green finance. The scientific provisions of this concept are detailed and described in detail in existing publications (Guang-Wen and Siddik, 2022; Guo C Q et al., 2022; Kaginalkar et al., 2022; Li Q et al., 2022; Ma et al., 2022; Wu H, 2022), which allows us to determine the degree of elaboration of the problem of this research as a high. The conducted literature review and content analysis of existing works on the given topic showed that the existing literature notes a fragmented contribution of green finance to the economy and environmental management.

We understand the environmental economy as a sphere of the economy in which green innovations are actively implemented and sustainable economic growth is achieved. Environmental management is a process of business management with the implementation of environmentally responsible organisational models and circular business practices. Environmental economy and management facilitate the achievement of the Sustainable Development Goals (SDGs), which are connected with environment protection (development of clean energy, protection of ecosystems, fight against climate change, *etc.*) (Huang et al., 2022; Li X et al., 2022; Li Z et al., 2022; Liu and Tang, 2022; Pang et al., 2022; Tong J et al., 2022; Zhang et al., 2022).

Chang et al. (2022), Chen et al. (2022), Tang (2022), and Wang Y et al. (2022) note that the contribution of green finance to the development of the economy and environmental management is achieved through its particularity of supporting ESG principles and the dissemination of corporate environmental responsibility. However, the existing literature leaves the RQ open and does not sufficiently reveal the specifics of green finance development in the AI era. The lack of elaboration on the causal relationships between the development of green finance in the AI era and its importance to economics and environmental management is a gap in the literature that this research seeks to fill.

Based on the works of Chen and Zhou (2021), Chen (2021), and Natanelov et al. (2022), which noted the benefits of smart finance, the research hypothesizes that the development of green finance in the AI era is constrained by the lack of use of advanced smart technology capabilities; the prospects for the development of green finance are related to the increased use of these capabilities. To fill the gap, this research systemically examines the implications of green finance for the entire set of SDGs shaping the green economy and management and considers the advantages of smart green finance as a new kind of finance that has emerged in the AI era.

Materials and methodology

To solve the first research problem, the authors model the contribution of green finance to economic development and environmental management using the structural equation modelling method (SEM). For this purpose, using the methods of correlation and regression analysis, the authors determine the impact of green finance factors allocated to the Green Finance Platform, (2021) ["policy and strategy" (ps), "market and product" (mp), and "international cooperation" (ic)] in 2021 on the results of environmental economy and management from a sustainable development perspective, i.e., scores of SDGs 2–3, 6–7, and 11–15 (UNDP, 2021) in 2022.

To solve the second research problem, the authors studied the international case studies of the development of smart green finance in the AI era. The sources of information, evidence, and case studies are IDOM (2020), Vinogradova (2021), and Damianova et al. (2018). This allows specifying the role of smart technologies in the development of green finance in the age of AI and identifying the consequences of their development for traditional finance.

Results

Modelling the contribution of green finance to economic development and environmental management

In the first task of this research, the authors performed economic and mathematical modelling of the contribution of green finance to the development of the economy and environmental management (Supplementary Material).As a result, nine multiple linear regression equations were obtained, each of which was tested for reliability using Fisher's *F*-test. Detailedregression statistics are given along with the Data Table in the Microsoft Excel file that accompanies this research. To systemically reflect and comprehensively demonstrate the impact of green finance on the economy and environmental management in 2022, the authors present the results using the SEM model in Figure 1, with correlation coefficients in italics and regression coefficients in regular font.

The SEM model in Figure 1 reflects the following results: the SDG 2 Score = 73.91–0.23*ps-0.08*mp+0.01*ic. According to this equation, the SDG 2 Score increases by 0.23 points when policy and strategy increase by 1. The SDG 2 Score increases by 0.08 points if the market and product increase by 1. Correlation is high: the SDG 2 Score is influenced by green finance factors by 62.34%. The significance is F = 1.7*10–0.5; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 10.59, exceeding the tabulated F. In this regard, the F-test is passed, and the equation is reliable.

The SDG 3 Score = 96.06–0.03*ps-0.62*mp+0.15*ic. According to this equation, the SDG 3 Score increases by 0.03 points when the policy and strategy increase by 1. The SDG 3 Score increases by 0.62 points if the market and product increase by 1. Correlation is high: the SDG 3 Score is influenced by green finance factors by 60.67%. The significance is F = 3.7*10–0.5; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 9.71, exceeding the tabulated F. In this regard, the *F*-test is passed, and the equation is reliable.

The SDG 3 Score = 92.71–0.07*ps-0.41*mp-0.06*ic. According to this equation, the SDG 3 Score increases by 0.07 points when the policy and strategy increase by 1. The SDG 6 Score increases by 0.41 points if the market and product increase by 1. The SDG 6 Score increases by 0.06 points if international cooperation increases by 1. Correlation is high: the SDG six Score is influenced by green finance factors by 69.37%. The significance is F = 3*10–0.7; therefore, the equation corresponds to the highest level of significance 0.01; therefore, the equation corresponds to the highest level of

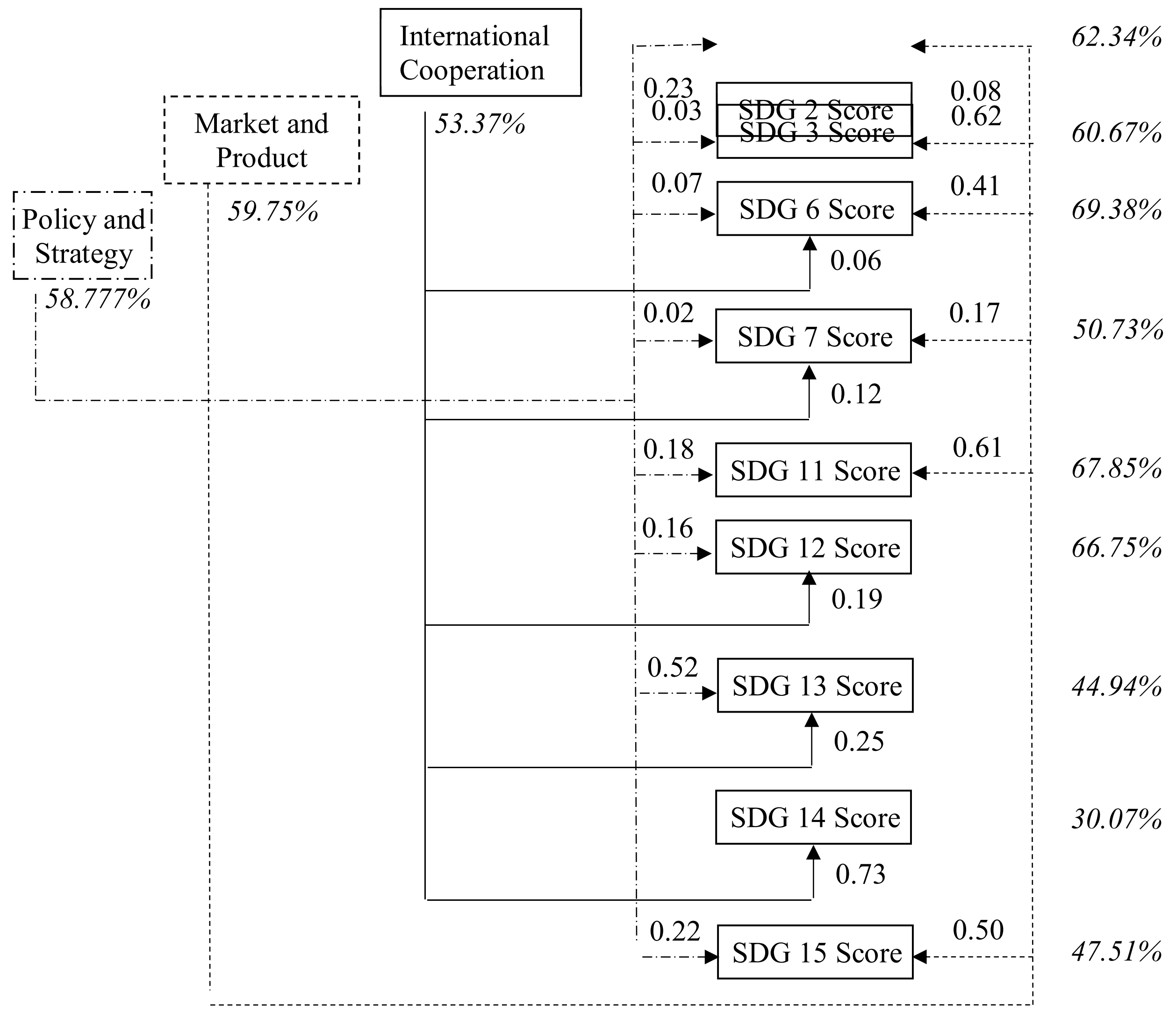

FIGURE 1
SEM model of the impact of green finance on the economy and environmental managementin 2022.

significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 15.46, exceeding the tabulated F. In this regard, the F-test is passed, and the equation is reliable.

The SDG 7 Score = 81.85–0.02*ps-0.17*mp-0.12*ic. According to this equation, the SDG 7 Score increases by 0.02 points when the policy and strategy increase by 1. The SDG 7 Score increases by 0.17 points if the market and product increase by 1. The SDG 7 Score increases by 0.12 points if international cooperation increases by 1. Correlation is moderate: the SDG 7 Score is influenced by green finance factors by 50.73%. The significance is F = 0.002; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 5.77, exceeding the tabulated F. In this regard, the *F*-test is passed, and the equation is reliable.

The SDG 11 Score = 97.28–0.18*ps-0.61*mp+0.18*ic. According to this equation, the SDG 11 Score increases by 0.18 points when the policy and strategy increase by 1. The SDG 11 Score increases by 0.61 points if the market and product increase by 1. Correlation is high: the SDG 11 Score is influenced by green finance factors by 67.85%. The significance is F = 8*10–0.7; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 14.22, exceeding the tabulated F. In this regard, the *F*-test is passed, and the equation is reliable.

The SDG 12 Score = 63.18–0.16*ps+0.84*mp-0.19*ic. According to this equation, the SDG 12 Score increases by 0.16 points when the policy and strategy increase by 1. The SDG 12 Score increases by 0.19 points if the market and product increase by 1. Correlation is high: the SDG 12 Score is influenced by green finance factors by 66.75%. The significance is F = 1.5*10–0.6; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 13.40, exceeding the tabulated F. In this regard, the F-test is passed, and the equation is reliable. The SDG 13 Score = 63.17–0.52*ps+1.04*mp-0.25*ic. According to this equation, the SDG 13 Score increases by 0.52 points when the policy and strategy increase by 1. The SDG 13 Score increases by 0.25 points if the market and product increase by 1. Correlation is moderate: the SDG 13 Score is influenced by green finance factors by 66.75%. The significance is F = 0.009; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 14.22, exceeding the tabulated F. In this regard, the *F*-test is passed, and the equationis reliable.

The SDG 14 Score = 55.75 + 0.34*ps+0.43*mp-0.73*ic. According to this equation, the SDG 14 Score increases by 0.73 points when the policy and strategy increase by 1. Correlation is moderate: The SDG 14 Score is influenced by green finance factors by 35.06%. The significance is F = 0.08; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 2.23. The observed F is 2.34, exceeding the tabulated F. In this regard, the F-test is passed, and the equation is reliable.

The SDG 15 Score = 73.13–0.22*ps-0.50*mp+0.43*ic. According to this equation, the SDG 15 Score increases by 0.22 points when the policy and strategy increase by 1. The SDG 15 Score increases by 0.50 points if the market and product increase by 1. Correlation is moderate: The SDG 14 Score is influenced by green finance factors by 47.51%. The significance is F = 0.005; therefore, the equation corresponds to the highest level of significance 0.01. At a given significance level with three factor variables (k1 = 3) and 54 observations (k2 = 54-3-1 = 50), the tabulated F is 4.126. The observed F is 4.85, exceeding the tabulated F. In this regard, the *F*-test is passed, and the equation is reliable.

The cumulative contribution of each factor of green finance (separately) to the development of ecological economy and management is defined as follows:

$$-\text{Policy and strategy:}\quad (62.34 + 60.67 + 69.38 + 50.73 + 67.85 + 66.75 + 44.94 + 47.51)/8 = 58.77\%;$$

$$-\text{Market and product:}\quad (62.34 + 60.67 + 69.38 + 50.73 + 67.85 + 47.51)/6 = 59.75\%;$$

$$-\text{International cooperation:}\quad (69.38 + 50.73 + 66.75 + 44.94 + 35.07)/5 = 53.37\%.$$

The results indicate that green finance significantly contributes to the development of the economy and environmental management, supporting the implementation of the entire set of environmental SDGs. The discovered systemic contribution of green finance to the achievement of environmental Sustainable Development Goals allows for a wider (than before) use of green finance in the interests of the development of the economy and management of the environment.

Case study of smart green finance development in the AI era

In the second task of this research, let us look at international case studies of the development of smart green finance in the AI era. In Russia, green finance is actively used to develop alternative energy and waste recycling. ROSATOM has been issuing green bonds since 2021 as an ESG tool for green financing of wind energy facilities. In the North of Russia, in the Republic of Yakutia, a comprehensive program for the development of solar energy based on green financing is being implemented. The Yakutsk solar power plant was built based on a green loan provided by "Otkritie" Bank to the "Enelt" Group for the implementation of the project of "RusHydro" Corporation. Both projects represent the Smart Grid. In the Yegoryevsk district (Moscow Region), thanks to green investments, the group of companies "Ecoline" will build the largest in Eastern Europe automated waste recycling complex on the territory of ecotechnopark "Vostok" in 2019–2020 (Vinogradova, 2021).

In 2014, China created a green finance task force to support the decarbonization of the economy. First, information systems and big data, which store information about credit histories in the field of green finance, play an essential role in this process. Second, an important role is played by smart green finance (Damianova et al., 2018). According to case studies, the development of the environmental economy and management in the AI era must be based on smart green finance.

Discussion

The research contributes to the literature by developing scientific provisions of the concept of green finance, clarifying the causal relationships of their distribution and use based on international experience. In contrast to Huang et al. (2022), Li Z et al. (2022), Liu and Tang (2022), Pang et al. (2022), Tong J et al. (2022), and Zhang et al. (2022), this research justifies that green finance makes a holistic and integrated contribution to economic and environmental management, rather than a stand-alone contribution.

In contrast to Chang et al. (2022), Chen et al. (2022), Tang (2022), and Wang Y et al. (2022), it has been proven that the spread of green finance is significantly affected by its accessibility, which is enhanced by the use of advanced automation tools. This means that the importance of green finance for the economy and environmental management in the AI era is determined not by institutions (ESG principles and attractiveness to market actors) but by technology. Due to its high-tech nature, smart green finance has become massively available and could supplant traditional finance.

Conclusion

The main contribution of this paper to the literature is the discovery and description of a complex chain of cause-and-effect relationships of the development of green finance in the age of AI. The case study of the international experience of developed and developing countries substantiates that the development of green finance in the AI era is constrained by insufficient use of advanced capabilities of smart technologies. The prospects for the development of smart technologies are associated with the expansion of the use of these capabilities.

The scientific novelty and originality of the research results lie in the fact that the composed econometric model SEM, for the first time, reflected the systemic relationship of green finance with the economy and environmental management through the prism of the set of environmental SDGs. The theoretical significance of the research is that it reveals the peculiarity of green finance in the AI era, namely that green finance can reach its full development potential only by relying on smart technology.

The practical significance of the research lies in the fact that the conclusion made about the increased use of smart technologies will increase the competitiveness of green finance and accelerate its spread in the economy and environmental management. The case studies discussed will be useful for other countries in the world. The results of this research will contribute to the ongoing discussions in the sphere of environmental science on the topic of environmental economics and management by a discovery of a new tool of the management of environmental economy and business. This tool is green finance.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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References

Chang, X., Fu, K., Jin, Y., and Liem, P. F. (2022). Sustainable finance: ESG/CSR, firm value, and investment returns. *Asia-Pacific J. Financial Stud.* 51 (3), 325–371. doi:10.1111/ajfs.12379

Chen, C., and Zhou, Y. (2021). Application of deep reinforcement learning algorithm in smart finance. *Front. Artif. Intell. Appl.* 341, 40–48. doi:10.3233/FAIA210230

Chen, Y. (2021). Framework of the smart finance and accounting management model under the artificial intelligence perspective. *Mob. Inf. Syst.* 2021 (SI), 4295191–4295211. doi:10.1155/2021/4295191

Chen, Y. P. V., Zhuo, Z., Huang, Z., and Li, W. (2022). Environmental regulation and ESG of SMEs in China: Porter hypothesis re-tested. *Sci. Total Environ.* 850, 157967. doi:10.1016/j.scitotenv.2022.157967

Damianova, A., Guttierez, E., Levitanskaya, K., Minasyan, G., and Nemova, V. (2018). *Russia green finance: Unlocking opportunities for green investments*. Moscow, Russia: World Bank Group. Available at: https://documents1.worldbank.org/curated/en/699051540925687477/pdf/131516-RUSSIAN-PN-P168296-P164837-PUBLIC-Green-finance-Note.pdf (Accessed October 22, 2022).

Desalegn, G., and Tangl, A. (2022). Enhancing green finance for inclusive green growth: A systematic approach. *Sustainability* 14 (12), 7416. doi:10.3390/su14127416

Dong, Z., Xu, H., Zhang, Z., Lyu, Y., Lu, Y., and Duan, H. (2022). Whether green finance improves green innovation of listed companies—evidence from China. *Int. J. Environ. Res. Public Health* 19 (17), 10882. doi:10.3390/ijerph191710882

Feng, H., Liu, Z., Wu, J., Iqbal, W., Ahmad, W., and Marie, M. (2022). Nexus between Government spending's and Green Economic performance: Role of green finance and structure effect. *Environ. Technol. Innovation* 27, 102461. doi:10.1016/j.eti.2022.102461

Green Finance Platform (2021). Global finance and development report. Available at: https://www.greenfinanceplatform.org/research/global-finance-and-development-report-2021 (Accessed October 22, 2022).

Guang-Wen, Z., and Siddik, A. B. (2022). Do corporate social responsibility practices and green finance dimensions determine environmental performance? An empirical study on Bangladeshi banking institutions. *Front. Environ. Sci.* 10, 890096. doi:10.3389/fenvs.2022.890096

Guo, C. -Q., Wang, X., Cao, D. -D., and Hou, Y. -G. (2022). The impact of green finance on carbon emission-analysis based on mediation effect and spatial effect. *Front. Environ. Sci.* 10, 844988. doi:10.3389/fenvs.2022.844988

Guo, H., Gu, F., Peng, Y., Deng, X., and Guo, L. (2022). Does digital inclusive finance effectively promote agricultural green development? – a case study of China. *Int. J. Environ. Res. Public Health* 19 (12), 6982. doi:10.3390/ijerph19126982

Huang, H., Mbanyele, W., Wang, F., Song, M., and Wang, Y. (2022). Climbing the quality ladder of green innovation: Does green finance matter? *Technol. Forecast. Soc. Change* 184, 122007. doi:10.1016/j.techfore.2022.122007

Jiang, Y., Guo, C., and Wu, Y. (2022). Does digital finance improve the green investment of Chinese listed heavily polluting companies? The perspective of corporate financialization. *Environ. Sci. Pollut. Res.* 29 (47), 71047–71063. doi:10.1007/s11356-022-20803-z

Kaginalkar, A., Kumar, S., Gargava, P., Kharkar, N., and Niyogi, D. (2022). SmartAirQ: A big data governance framework for urban air quality management in smart cities. *Front. Environ. Sci.* 10, 785129. doi:10.3389/fenvs.2022.785129

Li, J., Dong, X., and Dong, K. (2022). How much does financial inclusion contribute to renewable energy growth? Ways to realize green finance in China. *Renew. Energy* 198, 760–771. doi:10.1016/j.renene.2022.08.097

Li, Q., Sharif, A., Razzaq, A., and Yu, Y. (2022). Do climate technology, financialization, and sustainable finance impede environmental challenges? Evidence from G10 economies. *Technol. Forecast. Soc. Change* 185, 122095. doi:10.1016/j.techfore.2022.122095

Li, S., Yu, Y., Jahanger, A., Usman, M., and Ning, Y. (2022). The impact of green investment, technological innovation, and globalization on CO_2 emissions: Evidence from MINT countries. *Front. Environ. Sci.* 10, 868704. doi:10.3389/fenvs.2022.868704

Li, X., Shao, X., Chang, T., and Albu, L. L. (2022). Does digital finance promote the green innovation of China's listed companies? *Energy Econ.* 114, 106254. doi:10.1016/j.eneco.2022.106254

Li, Z., Wu, L., Zhang, Z., Chen, R., Jiang, Y., Peng, Y., et al. (2022). The transformative impacts of green finance governance on construction-related CO_2 emissions. *Sustainability* 14 (16), 9853. doi:10.3390/su14169853

Liu, Q., and Tang, L. (2022). Research on the accelerating effect of green finance on the transformation of energy consumption in China. *Res. Int. Bus. Finance* 63, 101771. doi:10.1016/j.ribaf.2022.101771

Ma, R., Li, F., and Du, M. (2022). How does environmental regulation and digital finance affect green technological innovation: Evidence from China. *Front. Environ. Sci.* 10, 928320. doi:10.3389/fenvs.2022.928320

Natanelov, V., Cao, S., Foth, M., and Dulleck, U. (2022). Blockchain smart contracts for supply chain finance: Mapping the innovation potential in Australia-China beef supply chains. *J. Industrial Inf. Integration* 30, 100389. doi:10.1016/j.jii.2022.100389

Pang, L., Zhu, M. N., and Yu, H. (2022). Is green finance really a blessing for green technology and carbon efficiency? *Energy Econ.* 114, 106272. doi:10.1016/j.eneco.2022.106272

Popkova, E. (2022). *Advanced issues in the green economy and Sustainable development in emerging market economies (elements in the economics of emerging markets)*. Cambridge, UK: Cambridge University Press. doi:10.1017/9781009093408

Ronaldo, R., and Suryanto, T. (2022). Green finance and sustainability development goals in Indonesian Fund Village. *Resour. Policy* 78, 102839. doi:10.1016/j.resourpol.2022.102839

Sun, H., and Chen, F. (2022). The impact of green finance on China's regional energy consumption structure based on system GMM. *Resour. Policy* 76, 102588. doi:10.1016/j.resourpol.2022.102588

Tang, H. (2022). The effect of ESG performance on corporate innovation in China: The mediating role of financial constraints and agency cost. *Sustainability* 14 (7), 3769. doi:10.3390/su14073769

Tang, M., Ding, J., Kong, H., Bethel, B. J., and Tang, D. (2022). Influence of green finance on ecological environment quality in Yangtze River Delta. *Int. J. Environ. Res. Public Health* 19 (17), 10692. doi:10.3390/ijerph191710692

Tong, A., Jiang, L., Ru, Y., Hu, Z., Xu, Z., and Wang, Y. (2022). Research on the impact of inclusive finance on agricultural green development: Empirical analysis of China's main grain producing areas. *PLoS ONE* 17 (9), e0274453. doi:10.1371/journal.pone.0274453

Tong, J., Yue, T., and Xue, J. (2022). Carbon taxes and a guidance-oriented green finance approach in China: Path to carbon peak. *J. Clean. Prod.* 367, 133050. doi:10.1016/j.jclepro.2022.133050

UNDP (2021). Sustainable development report (SDG index) 2021. Available: https://www.sdgindex.org/reports/sustainable-development-report-2021/(Accessed October 22, 2022).

Vinogradova, E. (2021). How ESG funding helps solve environmental problems. Vedomosti. Available at: https://www.vedomosti.ru/partner/articles/2021/12/10/899949-esg-finansirovanie (Accessed October 22, 2022).

Wang, K.-H., Zhao, Y.-X., Jiang, C.-F., and Li, Z.-Z. (2022). Does green finance inspire sustainable development? Evidence from a global perspective. *Econ. Analysis Policy* 75, 412–426. doi:10.1016/j.eap.2022.06.002

Wang, Y., Chen, L., and Jin, S. (2022). Environmental performance, social responsibility and corporate governance (ESG) ratings and financial risk. *Environ. Eng. Manag. J.* 21 (5), 857–868. doi:10.30638/eemj.2022.078

Wu, G. (2022). Research on the spatial impact of green finance on the ecological development of Chinese economy. *Front. Environ. Sci.* 10, 887896. doi:10.3389/fenvs.2022.887896

Wu, H. (2022). Trade openness, green finance and natural resources: A literature review. *Resour. Policy* 78, 102801. doi:10.1016/j.resourpol.2022.102801

Yang, C., and Masron, T. A. (2022). Impact of digital finance on energy efficiency in the context of green sustainable development. *Sustainability* 14 (18), 11250. doi:10.3390/su141811250

Zhang, D., Mohsin, M., and Taghizadeh-Hesary, F. (2022). Does green finance counteract the climate change mitigation: Asymmetric effect of renewable energy investment and R&D. *Energy Econ.* 113, 106183. doi:10.1016/j.eneco.2022.106183

Zhang, M., and Liu, Y. (2022). Influence of digital finance and green technology innovation on China's carbon emission efficiency: Empirical analysis based on spatial metrology. *Sci. Total Environ.* 838, 156463. doi:10.1016/j.scitotenv.2022.156463

Zhou, X., and Tang, X. (2022). Spatiotemporal consistency effect of green finance on pollution emissions and its geographic attenuation process. *J. Environ. Manag.* 318, 115537. doi:10.1016/j.jenvman.2022.115537

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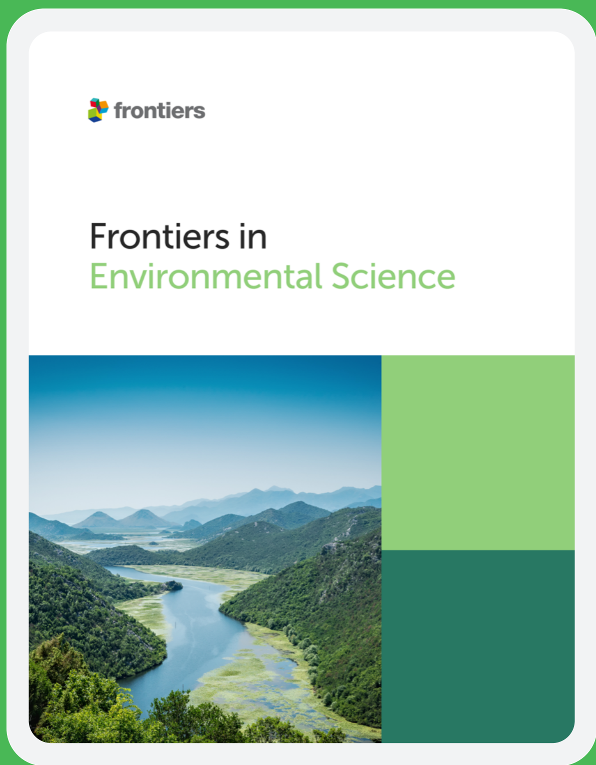

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