

Environmental innovations in the Context of the Formation of the Sustainable Development Concept

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Abstract: The article is devoted to studying aspects of environmental innovations in the context of the formation of the sustainable development concept. The aim of the article is a thorough analysis of the development process of the environmental innovation concept within the context of the emerging paradigm of sustainable development of that time. Examples of transformations in production approaches that occurred due to the intensification of the environmental movement, the emergence of the first environmental standards and legislative initiatives are provided. Conceptual features of environmental innovations in the context of the emerging sustainability paradigm of that time are formulated. A thorough analysis of the contribution of environmental innovations to achieving sustainable development goals is conducted. The contribution of environmental innovations to the development of renewable energy sources, improved energy efficiency, as well as support for the circular economy and "clean" production technologies is investigated. The role of environmental innovations in biodiversity conservation and ecosystem restoration through biotechnology, sustainable land use, and monitoring of natural resource conditions is defined. The analysis showed how environmental innovations can become an important tool for implementing sustainable development strategy, promoting environmentally responsible production and the conservation of planetary resources.

1 INTRODUCTION


In the context of exacerbating global environmental challenges, growing anthropogenic pressure on the environment and depletion of natural resources, there is an urgent need to rethink economic growth models. Traditional management approaches should focus not only on the trend of increasing profits, but also take into account environmental consequences in order to overcome the destabilization of ecosystems.


The adoption of the UN Sustainable Development Goals until 2030, the intensification of climate policy and other international initiatives require states and businesses to take decisive steps towards integrating environmental innovations into production activities and development strategies.


All of the above highlights the relevance of environmental innovations and modern practices that


help reduce environmental risks while ensuring social responsibility in business. Research into the development of environmental innovations within the context of the formation of the sustainability concept will help identify interrelationships and justify the gradual transition from a traditional industrial approach to a paradigm balancing economic, social, and environmental interests.

A significant number of works are devoted to the development of innovations in the field of ecology. Leading scientists such as V. M. Kurikov, S. A. Meshkov, E. I. Baldina, I. V. Cheremushkina, O. V. Oseneva, N. Batova, E. S. Mishacheva, K. S. Kabargin, V. O. Markitantov, A. R. Sharipov, L. V. Borisova and others have revealed key aspects of environmental innovations and their significance in combating numerous problems.

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Despite the extensive coverage of innovations in ecology in the works of scientists, some aspects of the topic remain not fully explored. In particular, it remains unclear how environmental innovations developed in light of the formation of the concept (Mishacheva, 2025).

2 MATERIALS AND METHODS

The theoretical and methodological basis of the research consisted of works by leading domestic and foreign scientists, methodology, and systemic principles of conducting comprehensive scientific research. Among the special research methods used in the work are: abstract-logical – for studying the development of the problem and generalizing conclusions; theoretical generalization in the process of defining the concept of "environmental innovation"; observation, comparative advantages – for researching the theoretical basis for developing and adopting the sustainable development concept.

3 RESULTS AND DISCUSSION

The fundamental tenets of the concept of environmental innovation were formulated as a result of ongoing global changes in various spheres of society, including science and economics. It underwent a complex development path: from isolated environmental initiatives to a systemic approach in business management and public policy formation (Kabargin, 2025). The first mentions of the need to consider environmental aspects in production activities appeared as early as the 18th century, before the deployment of the industrial revolution; in particular, A. Smith in his work "An Inquiry into the Nature and Causes of the Wealth of Nations" pointed out the role of environmental innovations in ensuring economic growth (Smith, 2020). In the 19th century, industrialization brought significant economic growth but also led to air and water pollution and depletion of natural resources. During this period, environmental issues were considered exclusively from the standpoint of preventing local pollution and complying with sanitary norms. In the first half of the 20th century, the development of science and technology allowed for a deeper analysis of the relationship between industrial development and the state of the environment (Cheremushkina, 2023). However, at that time, environmental problems were not yet considered a global issue.

The real impetus for rethinking the relationship between industry and nature came in the 1960s-1970s.

It was during this period that the environmental movement rapidly developed, triggered by serious environmental disasters. On January 28, 1969, a blowout occurred at a platform of the Union Oil company, located about 9.7 km off the coast of Santa Barbara, California. This environmental disaster significantly impacted marine life, killing over 3,500 seabirds, as well as numerous dolphins, sea lions, and seals. This event received widespread media coverage and caused public outrage, which contributed to the intensification of the environmental movement and became a catalyst for the creation of the first Earth Day (Stalповskaya, 2020).

In addition to the oil spill, an event that significantly influenced the development of the environmental movement occurred on July 10, 1976, at the ICMESA chemical plant near Seveso, Italy. An accident at the plant resulted in the release of a significant amount of toxic dioxin TCDD into the atmosphere. The dioxin release caused serious health consequences for the local population, with over 200,000 people exposed to toxic substances, many developing severe skin lesions (Centemeri, 2021). The Seveso accident became one of the most serious industrial disasters in Europe and led to the tightening of environmental legislation, particularly the adoption by the European Union of the so-called "Seveso Directive," aimed at preventing similar incidents in the future. These events highlighted the need to revise approaches to industrial production and became catalysts for the development of environmental innovations aimed at minimizing the negative impact of industry on the environment.

Subsequently, in the 1980s, so-called "end-of-pipe technologies" were widely used to reduce the negative impact of industry on the environment. These involved installing equipment for cleaning emissions and effluents at the final stages of production processes to reduce pollution before it entered the environment. The most prominent examples of that time are: installation of flue gas filters, wastewater treatment plants, and waste capture systems. However, the use of end-of-pipe technologies had limited effectiveness, as it did not change the essence of the production processes themselves and did not prevent pollution formation at the initial stages. Furthermore, the implementation of end-of-pipe technologies often required significant financial costs and was not always economically beneficial for enterprises of that time.

At this stage, the concept of sustainable development emerged, and a landmark event of that period is considered to be the report "Our Common Future" prepared by the UN World Commission on Environment and Development under the leadership of G. H. Brundtland in 1987. The main theses of the report defined a new development paradigm that formed the basis for the further formation of environmental policy, the concept of environmental innovations, and the global environmental agenda (Gontar, 2024). The report presents the official concept of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The proposed definition laid the foundation for global environmental policy and brought to the forefront responsible attitude towards natural resources, long-term planning, and the integration of the environmental factor into all areas of social development.

In the analyzed report, despite the absence of direct use of the term "environmental innovation," its conceptual features are clearly traced, which later became the basis for the formation of modern approaches to technological transformation in the context of sustainable development (Fig. 1).

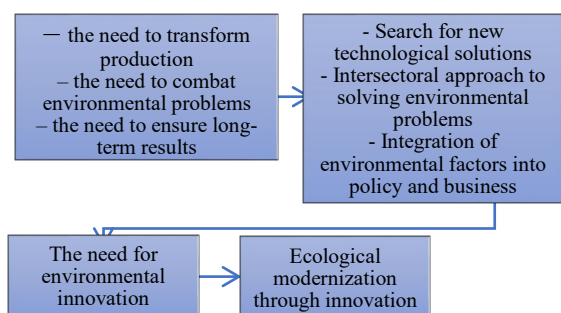


Figure 1: Conceptual features of environmental innovations in the context of the formation of the sustainable development paradigm.

First and foremost, the document emphasizes the need for transformation of production and consumption systems, which implies modernization of industrial processes to minimize negative environmental impact and optimize the use of natural resources. Such modernization is impossible without the implementation of the latest technological solutions, which are now outlined by the concept of "environmental innovations." Furthermore, the report emphasized the importance of integrating

environmental factors into political governance and economic activities, which effectively created the groundwork for the further development of ESG approaches in business and the investment system. The need arose to consider the environmental component not only as a constraint or standard, but as an integral part of strategic planning, forming a demand for innovations in clean technologies, energy efficiency, waste management, etc.

Scientists emphasize a cross-sectoral approach based on comprehensive solutions to various environmental problems. These solutions can be applied across key sectors of the country's economy: agriculture, transport, energy, and construction. The vision of that time is analogous to the modern understanding of environmental innovations as an interdisciplinary field focused on reducing human impact and increasing the environmental efficiency of economic activities. At the same time, the report notes the priority of the long-term effect of innovation implementation, which in the modern context correlates with one of the key principles of environmental innovations – a focus on sustainable results, the ability to provide positive impact in the long term.

The provisions presented in the report were ahead of their time. They also became the ideological basis for the development of scientific fields in environmental innovation. These scientific principles form the foundation of the global sustainable development strategy.

Over time, it became evident that to achieve more sustainable results, it was necessary to move from responding to pollution to preventing it through the implementation of clean technologies and optimization of production processes. An analysis of the concept of eco-innovation over the past 35 years has revealed global changes that include technical solutions and new integrated management methods. The concept considers the "cleaner production" model, which is based on reducing waste and increasing resource efficiency in manufacturing.

It was in the 1990s that the concept of "industrial ecology" began to be applied in manufacturing. This concept advocates for waste reduction through the reuse of resources and the creation of closed production cycles. This approach focuses on using waste from one production stage as resources for another. These measures ultimately helped reduce the environmental impact of environmental pollution. (Dudareva, 2021).

Also, to develop the "industrial ecology" direction, the UN organized the "Earth Summit" (Rio de Janeiro, Brazil, 1992), which made a significant

contribution to the formation of global environmental policy and the beginning of a systemic approach to sustainable development. The Summit established the foundation for transforming the production and economic model toward reducing the anthropogenic burden on the environment through new technological solutions (Marin, 2022). The Summit resulted in the public presentation of a document entitled "Agenda 21." This document outlined a comprehensive framework for action aimed at supporting sustainable development.

In particular, the need for deep technological modernization of industry, energy, transport, and the agricultural sector was outlined, aimed at reducing pollution levels, rational use of resources, development of renewable energy sources, and implementation of innovations that comply with the principles of environmental safety. Thus, the document "Agenda 21" laid down key ideas that complemented previous judgments and formed the modern concept of environmental innovations: greening technological development, supporting innovative activities aimed at reducing negative environmental impact, and integrating scientific and technological achievements into sustainable development strategies.

Additionally, within the framework of the Earth Summit, the "UN Framework Convention on Climate Change" was signed, establishing the commitments of world countries to prevent dangerous climate change and adapt to its consequences. This document initiated the process of forming an international legal regime for climate policy, within which environmental innovations were recognized as a key tool for achieving carbon neutrality, improving energy efficiency, and developing climate-safe technologies. The "UN Framework Convention on Climate Change" became the foundation for the further development of "green" financing instruments, stimulating investments in the latest environmental technologies, and creating a favorable innovation environment.

Thus, the Earth Summit of 1992 initiated international cooperation in the field of environmental protection and outlined environmental innovations as a key vector for implementing the Sustainable Development Concept. The adopted documents formed the basis for the further normative, political, and economic formalization of innovative activities focused on environmental safety and conservation of natural capital, assigning environmental innovations the role of a strategic factor in transforming the global economy.

In 1996, researchers C. Fussler and P. James first introduced the concept of "eco-innovation" in their book "Driving Eco-Innovation: a Breakthrough Discipline for Innovation and Sustainability". They defined eco-innovation as new products and processes that provide value to customers and businesses while significantly reducing negative environmental impact. In 1997, P. James developed these ideas, emphasizing the importance of integrating environmental aspects into innovation processes to achieve sustainable development (Dmitrieva, 2021).

Researching the formation of environmental innovations, it is extremely important to pay attention to an outstanding international event that defined strategic guidelines for the entire world. Also in 2015, all UN member states adopted the "2030 Agenda for Sustainable Development," which includes 17 Sustainable Development Goals (SDGs). All goals are a call to action for all countries to eradicate poverty, protect the planet, and ensure prosperity for all. In particular, the list includes goals related to environmental innovations, such as Goal 7 - ensuring access to affordable, reliable, sustainable, and modern energy for all, Goal 9 - promoting sustainable industrialization and innovation, and Goal 15 - preserving ecosystems and biodiversity (Wang, 2025). In our opinion, it is advisable to thoroughly investigate the SDGs related to the implementation of environmental innovations.

Sustainable Development Goal 7 – "access to affordable, reliable, sustainable, and modern energy" envisages ensuring access to sustainable energy sources, which is a fundamental prerequisite for reducing the negative impact of industry on the environment. Research (Kurikov, 2024) allowed substantiating the contribution of environmental innovations to achieving SDG 7, in particular:

- development of renewable energy sources, particularly the use of solar, wind, geothermal, and bioenergy, significantly reduces greenhouse gas emissions and contributes to the transition to a low-carbon economy;
- improving energy efficiency through modernization of production capacities, implementation of "smart" grids and energy-saving technologies, allowing optimization of energy resource use;
- expanding access to energy in developing regions through the popularization of microgrids and autonomous solar stations, ensuring electrification of remote settlements and improving the population's standard of living.

Sustainable Development Goal 9 "promoting sustainable industrialization and innovation" envisages industrial production without harm to the environment, contributes to the development of a low-carbon economy, and creates prerequisites for further environmental transformation of enterprises. Research (Batova, 2024) showed that through environmental innovations it is possible to achieve environmentally responsible industrialization through:

- development of the circular economy, particularly through the integration of closed production cycles, material reuse, waste minimization, and implementation of eco-design of goods;

- implementation of clean technologies in production processes, particularly the use of hydrogen technologies, biotechnologies, environmentally friendly chemical processes and materials, reducing the impact of industry on the environment;

- development of "green" transport and logistics, particularly through the transition to electric vehicles, use of biofuels, and optimization of transport routes, allowing significant reduction of CO₂ emissions and air pollution;

- Industry 4.0 and digitalization of production processes, particularly through automation, use of artificial intelligence and the Internet of Things, contributing to increased production efficiency and reduced resource consumption.

Sustainable Development Goal 15 "preserving ecosystems and biodiversity" includes the protection, restoration, and promotion of sustainable use of terrestrial ecosystems, sustainable forest management, combating desertification, halting and reversing land degradation, and halting biodiversity loss. In a world where human activity continues to pressure natural systems, environmental innovations serve as an important means of achieving this SDG. Environmental innovations in the field of ecosystem conservation encompass a wide range of solutions that enable not only minimizing harm to the environment but also actively restoring natural resources, in particular:

- use of ecosystem monitoring technologies (remote sensing, geographic information systems, satellite observation), which allow tracking changes in the state of forests, soils, water resources, habitats of rare species of animals and plants, enabling responses to threats of deforestation, pollution, erosion, and illegal hunting;

- application of sustainable land use practices (green manure, organic farming, agroforestry,

minimal tillage), allowing preservation of soil fertility and purity of water resources;

- use of biotechnologies for reclamation of disturbed lands, soil remediation, afforestation, and restoration of natural landscapes, enabling restoration of biodiversity and ecosystems;

- ensuring genetic diversity in agriculture, creation of ecological corridors, conservation of endangered species using biobanks and DNA archives, creation of digital databases for managing natural territories.

Therefore, it is reasonable to conclude that in the context of achieving the Sustainable Development Goals, environmental innovations generally contribute to harmonizing economic growth, social progress, and environmental protection. Separately, environmental innovations significantly reduce the impact of industry on the environment by ensuring access to clean energy (Goal 7), promoting innovative industrialization (Goal 9), and preserving ecosystems and biodiversity (Goal 15).

Further, in 2023, the G20 countries, which collectively account for over 75% of global greenhouse gas emissions and over 80% of global GDP, took a strategic step towards global climate leadership by approving the Sustainable Energy Transition Strategy (Nevmerzhietskaya, 2025). This document became an important stage in the international movement for decarbonization of the world's energy sector, outlining key principles and commitments for achieving a carbon-neutral economy by 2040, in particular: large-scale expansion of renewable energy (solar, wind, hydro, and geothermal), with an emphasis on decentralized energy systems, green hydrogen, and energy storage; gradual reduction of dependence on fossil fuels through decommissioning of coal-fired power plants, modernization of power grids, implementation of carbon capture and storage technologies, cessation of fossil fuel subsidies; development of investment platforms for financing climate-neutral technologies, environmental innovations, startups in energy efficiency, smart infrastructure, and the circular economy; improving energy efficiency in all sectors through the transition to zero-energy in new buildings, expansion of electric transport, intelligent energy consumption management systems, and modernization of the technological fleet; a fair and inclusive transition, guaranteeing protection of workers' rights in the coal and oil and gas sectors, development of new "green" jobs, gender equality, and support for vulnerable communities.

The approval of the G20 strategy became an important signal for business, governments, and the

scientific community about the need to accelerate the implementation of environmental innovations.

The document created the basis for forming a favorable innovation environment through tax incentives, targeted financing, public-private partnerships, and interstate technology exchange programs. In turn, the G20 participating countries agreed to ensure technological cooperation, expand access to "green" financing for developing countries, and create joint institutions for monitoring carbon footprints, data exchange, and knowledge transfer.

A study of scientific literature revealed that modern sustainable development depends directly on environmental innovation. Environmental innovation enables the economy to reach new levels by conserving natural resources and generating clean energy. The implementation of these measures will ensure the global community's security, economic, and environmental stability in the future.

4 CONCLUSIONS

The formation of environmental innovations occurred in close interrelation with the concept of sustainable development established at the end of the 20th century. From isolated reactions to environmental disasters and end-of-pipe technologies to the comprehensive transformation of production and economic systems, environmental innovations have followed an evolutionary path as a response to the escalation of global environmental challenges. The gradual integration of the environmental component into political governance, business models, and international law became possible due to the growing awareness of the inseparability of environmental security from sustainable socio-economic development. Environmental innovation is a technological and strategic tool that helps achieve a balance between economic growth, quality of life, and environmental protection.

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