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ENVIRONMENTAL ASPECTS OF TRADE AND LOGISTICS CENTERS

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Abstract. In modern conditions of globalization and environmental challenges, the greening of enterprise activities, in particular in the areas of trade and logistics, is of particular importance. This article reveals the essence of the ecological characteristics of trade and logistics enterprises as important business entities that have a significant impact on the environment. It analyzes the main sources of environmental pressure associated with the operation of logistics centers, including air pollution from vehicle emissions, the generation of packaging waste, high energy consumption, noise pollution, and soil degradation. Special attention is paid to the analysis of the role of transport infrastructure and warehouses as centers of increased anthropogenic load. The necessity of introducing environmentally safe technologies, environmental management systems, energy-efficient solutions, and comprehensive monitoring of enterprise impacts on the environment is emphasized. It is pointed out that successful greening is possible only if technical innovations, organizational changes and improvement of the environmental culture of personnel are combined. The article also examines the experience of individual enterprises in implementing sustainable practices, such as waste sorting and recycling, the use of electric transport, the implementation of a green logistics system, the use of renewable energy sources, the use of eco-labeling of goods and the optimization of transport routes. The main barriers to greening activities are identified: lack of funding, low environmental awareness of management personnel, limited regulatory and legal framework, weak interest of enterprise owners in long-term environmental investments and the absence of a system of state incentives. It is concluded that an integrated approach combining environmental, economic and social aspects is necessary to ensure the sustainable functioning of trade and logistics centers. Environmental modernization of logistics and trade processes should become a key component of national environmental policy and responsible resource management.

Keywords: logistics, trade, sustainable development, environmental management, ecological safety, trade enterprises.

1. Introduction

Modern trends in the global development of mankind increasingly emphasize the need for harmonious coexistence of society and the environment.

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In this context, the problem of greening the activities of enterprises arises, in particular those operating in the field of trade and logistics. Trade and logistics centers play a significant role in the daily life of the population, as well as a key role in the economy. The scope of their activities includes a wide range of services, namely:

- transportation and forwarding of goods within settlements, as well as between cities, countries and continents by road, rail, air and water transport (Shymko, 2011);
- storage of finished goods in open and closed warehouse facilities (Konishcheva et al., 2005);
- preparation of goods for shipment to customers, namely picking and packaging (Korin, 2011);
- procurement management – supplier selection and supply strategy development (Lykholat et al., 2022);
- consulting services providing information on management and optimization of supply chains in logistics operations (McKeown et al., 2014);

Trade and logistics centers handle goods from various industrial sectors – food products, consumer goods, equipment, metals, fuels, etc (Beylot et al., 2020).

Despite the lack of direct environmental impact similar to that of the manufacturing sector, trade and logistics companies still leave a significant environmental footprint. This is evident in emissions to the atmosphere, energy consumption, packaging waste generation, and traffic load on urban infrastructure (Savchuk et al., 2020).

One of the key environmental problems is the large-scale use of road transport, which is accompanied by significant emissions of greenhouse gases, primarily CO_2. In the European Union, transport accounts for about 26 % of total emissions, with freight transport representing the majority. The intensive activity of trade and logistics centers is also accompanied by noise, light and vibration pollution, which creates additional risks for public health and biodiversity. A significant negative factor is secondary environmental pollution due to the formation of a large amount of solid household and industrial waste - in particular, packaging materials, worn tires, batteries, oils and filters (Mashchak, 2011). Table 1 presents a summary of the main environmental characteristics of trade and logistics enterprises.

A comparison of environmental characteristics (Table 1) shows that logistics enterprises have a significantly higher level of energy consumption and environmental impact than trade enterprises. This is primarily due to the use of transport, the operation of warehouses, and the scale of the logistics infrastructure. In trade, the main sources of impact are lighting, heating, and packaging waste. BAt the same time, logistics is characterized by a greater regional and global impact due to CO_2 emissions, noise, and high energy consumption.

Another serious challenge is the high energy intensity of logistics processes. Trade and logistics centers consume a significant amount of energy, mainly from traditional, non-renewable sources, which further exacerbates ecological risks. At the same time, there is an irrational use of resources, a low level of waste recycling and insufficient implementation of the circular economy. Additionally, the development of trade and logistics centers is accompanied by large-scale construction, which requires significant land resources and often leads to the destruction of natural ecosystems, loss of biodiversity, deforestation and landscape degradation (Hryniv et al., 2023).

Table 1

Main Environmental Characteristics of Enterprises

Characteristics	Trade	Logistics
Energy consumption	Moderate	High
Emission sources	Heating, Lighing	Transport, warehouses
Waste volumes	Packaging, products	Pallets, tare
Application of environmental techmologies	LED-lighting, sorting	Eco-transport, automation
Environmental impact	Local	Regional/Global

These problems are exacerbated by the weakness of the logistics infrastructure, which does not provide an effective combination of different modes of transport, in particular rail and water, which could significantly reduce the environmental load. Furthermore, a number of legal, organizational, and financial barriers exist – complex permitting procedures, the absence of a unified regulatory framework, insufficient coordination among market

participants, and limited investment opportunities (Hurzhiy et al., 2017). Thus, while trade and logistics centers are an integral part of the modern economy and ensure the smooth movement of goods, they also pose a significant threat to the environment. Fig. 1 shows the results of a comparison of the level of environmental impact of trade and logistics enterprises on the environment.

Analysis of the graphs in Fig. 2 confirms that logistics prevails in all environmental impact criteria - particularly CO_2 emissions, noise and energy consumption. This highlights the need to prioritize the greening of logistics processes.

The situation calls for the introduction of innovative technologies, increased environmental responsibility of logistics entities, improved regulatory frameworks, and government support for the sustainable development of logistics infrastructure. Without appropriate responses, these centers may become sources of chronic environmental burden, incompatible with the principles of sustainable management.

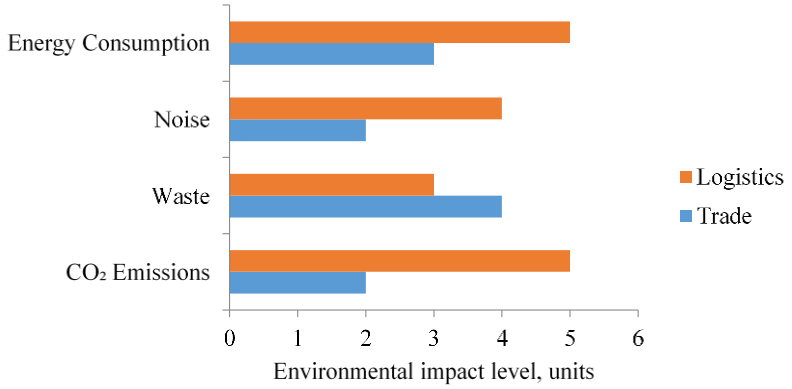

Fig. 1. Comparison of environmental impact levels on a five-point scale, where 5 is the highest impact

2. Theoretical part

The implementation of environmental technologies and a responsible attitude toward the environment is an important stage in the operations of trade and logistics centers to reduce their negative environmental impact.

Since the operation of shopping and logistics centers generates a large amount of environmental pollutants, they contribute to an increase in carbon emissions and loss of biodiversity (Blakley et al., 2020). Therefore, it is necessary to introduce environmental "green technologies" to reduce the negative impact on the environment.

One of the solutions is the collection and sorting of waste for its further processing or disposal (Salo, 2023). Waste collection and sorting in the operations of trade and logistics centers are of critical environmental importance: they reduce the burden on landfills, prevent contamination of soils and water bodies, and lower greenhouse gas emissions by enabling greater use of recycled materials. Proper management of packaging, wood, metal, electronic waste, and hazardous waste supports the circular economy and preserves primary resources. Beyond the direct environmental benefits, a systematic approach to sorting enhances a company's environmental responsibility, reduces operational risks, and improves relations with the local community and regulators.

In the warehouse departments, it is advisable to use innovative approaches to packaging, which include aspects such as the secondary use of recycled packaging materials, the use of packaging materials that can decompose naturally, as well as reducing the amount of packaging materials to the necessary minimum, which will ultimately reduce the amount of waste (Zharska et al., 2022). The application of innovative warehouse management systems such as Manhattan can shorten the time required for warehouse operations (Jefimovaite et al., 2022). In conjunction with intelligent warehouse management systems, the use of autonomous vehicles and robotic systems for moving objects in warehouses can increase the efficiency of warehouse departments, accelerate their operations, and reduce the amount of equipment needed to illuminate large warehouse areas, while reducing electricity consumption (Sun et al., 2021).

For the transport department, electrification of transport, as well as the introduction of hydrogen technologies, will lead to a reduction in greenhouse gas

emissions (Reznik et al., 2024). Liquefied natural gas and compressed natural gas are also alternative economical and more environmentally friendly fuels (Mutie et al., 2020). Environmental benefits of alternative fuels include a significant reduction in local emissions of harmful pollutants, a smaller greenhouse-gas footprint (provided low-carbon energy sources are used), reduced noise, and improved air quality around warehouses and along delivery routes. Electrification delivers zero tailpipe emissions and high energy efficiency, making it especially effective for urban and short-haul routes. Hydrogen fuel cells also produce zero on-site emissions and are suitable for heavy-duty and long-distance transport, but their environmental performance depends heavily on how the hydrogen is produced. CNG/LNG reduce CO_2 , NOx, and particulate emissions compared with diesel, but they remain fossil fuels and carry risks of methane leakage that can undermine their climate benefits. Together, these technologies can substantially decarbonize transport logistics; however, the real environmental outcome is determined by the energy sources used, leak control, and high-quality integration into infrastructure.

Innovative route planning and transport management systems, such as Paragon, reduce vehicle mileage and delivery time (Jefimovaite et al., 2022). In addition to optimizing transport routes, it can increase transportation efficiency by reducing the number of trips through cargo consolidation – using vehicles as efficiently as possible (Ren et al., 2020). The use of autonomous vehicles and unmanned aerial vehicles for cargo transportation, coupled with intelligent route management systems, will reduce the burden on transport infrastructure and reduce greenhouse gas emissions (Sun et al., 2021). In addition, it is important to modernize production processes aimed at reducing the use of energy, water and materials (Chigrin et al., 2011).

Overall, the use of renewable energy sources such as solar and wind significantly reduces the environmental impact of trade and logistics centers (Sotnyk, 2023). Since trade and logistics centers occupy significant areas, during construction it is necessary to take into account such an aspect as the use of modern materials that will reduce heat loss in the cold season, and on the other hand, to improve the microclimate and reduce thermal loads, green areas should be created on the roofs and walls of buildings (Liu et al., 2024). The digitization of document management in companies also reduces paper consumption (Schmid et al., 2024).

Examples of successful implementations are the cases of various companies around the world that have already implemented technologies to reduce their environmental impact.

The German "Kässbohrer" and the Polish "Erontrans" closely cooperate in the field of transportation and have introduced environmentally friendly vehicles. Particularly," Erotrans" has added 45 Kässbohrer SCS M Mega Curtainsider trucks to its fleet. These vehicles are designed with improved aerodynamics and reduced weight, due to the use of lightweight structural materials. As a result of such engineering solutions, it was possible to achieve a reduction in fuel consumption. Also, these trucks are specially designed for intermodal transportation, equipped with fasteners for loading onto a train, which ultimately allows the use of different modes of transport without the need to reload goods and increasing the speed and efficiency of operations (Zharska et al., 2022).

The use of green technologies in Slovak enterprises was studied by researchers Klaudia Hubová and Patrik Ríchnak, who found that "green logistics" is used by both large (49.5 %) and small (7.4 %) enterprises. In their sample, 72.3 % were manufacturing firms, 17.7 % service providers, and 10 % were trade organizations. It is important to note that 36.5 % use voluntary instruments of the enterprise's economic policy, while legislative instruments – 32.8 %. The most popular among the voluntary ones is corporate social responsibility – in 29.8 % of companies, which is most manifested in short delivery times, minimal waste and recycling of secondary packaging. Also, many enterprises (24.6 %) are guided by a legislative instrument – the ISO 14001 environmental management system (Richnak et al., 2021). Overall, there is a trend among companies to gain competitive advantage by offering environmentally friendly products or services. In particular, the founding of "ŠvihajŠuhaj" a Slovak bicycle delivery service, is a good example of an environmental offer in the courier service sector (Skvarcekova et al., 2019).

In Lithuania, the transport and logistics sector contributes over 12 % of the national gross domestic product, according to the analytical company "Scorify", as a result, the government promotes continuous development by investing in roads, ports, state logistics centers, and modern infrastructure. Green technologies in Lithuanian transport and logistics companies were studied by researchers Milita Vienažindienė, Tamulienė Vilma, and Jurgita Zaleckienė. They note that the companies are focused on minimizing the use of transport, maximizing the use of warehouse space and optimizing storage space, reducing the use of transport containers, improving and

implementing innovative loading systems, using recyclable materials for packaging, and further recycling them. The implementation of "green technologies" in companies is most stimulated by the desire to receive subsidies and other benefits, as well as demands from society (Vienazindiene et al., 2021). An example of the Lithuanian company "Vingėslogistikas", which implements "green technologies" in the field of warehousing. The company's warehouses occupy an area of 28 thousand m^2 and since 2017 they have started using solar energy to generate electricity, so a power plant has been installed on the roof of the warehouse building (Zharska et al., 2022).

In Ukraine, good examples of companies implementing "green technologies" are "Nova Post" and "ZAMMLER Ukraine". Particularly, "ZAMMLER Ukraine" has certified its environmental management system according to the international standard ISO 14001:2015, in addition, they try to minimize the impact on the environment by saving resources, double-sided printing and electronic document management, replacing transport with more environmentally friendly ones. The largest operator in Ukraine "Nova Post" is investing in energy-efficient, environmentally friendly delivery methods and constructing postal terminals that reduce courier mileage – and thus CO_2 emissions – by shortening delivery routes (Zharska et al., 2022).

The "Euroterminal" company with its initiative of the railway route "Dry Port" – "Odesa-Peresyp" allows transporting cargo in excess of one million tons per year, thereby reducing the amount of freight on the roads and reducing the load on the city's infrastructure. This also helps reduce CO_2 emissions into the atmosphere (Reznik et al., 2024).

Logistics company "GEFCO" is actively working to achieve carbon neutrality in its business. One way is to launch a carbon neutral train, consisting of 41 carriages. The train is equipped with Internet of Things (IoT) devices to monitor and control the movement, as well as the temperature and integrity of the cargo (Reznik et al., 2024).

"Volvo Trucks" is developing electric trucks to reduce CO_2 emissions into the atmosphere and has six fully electric trucks in its model range, designed for various transport tasks. In addition to developing electric vehicles, the company is working to improve their efficiency, and after conducting a major test of its electric trucks in extreme cold conditions near the Arctic Circle in northern Sweden, they proved that their vehicles demonstrated very high efficiency (Reznik et al., 2024). The American company "EVIATION" has developed an electric cargo plane, the "Alice" model, with zero carbon emissions, lower noise pollution and reduced operating costs. This model is being ordered by large logistics companies such as "DHL", as the demand for environmentally friendly solutions is only growing (Reznik et al., 2024).

The world's first zero-emission container ship is designed and built by "KONGSBERG" in partnership with "VARD". "Yara Birkeland" is a container ship with the ability to be fully autonomous. Using this ship, carbon emissions can be reduced by at least 1000 tons per year (Reznik et al., 2024).

In Greece, companies are actively implementing transport management systems to optimize delivery routes, and also use GPS technology to adjust routes in real time. This leads to reduced fuel consumption and lower CO_2 emissions. In addition, reusable packaging solutions are used, and recyclable and biodegradable packaging materials are used, which reduces waste (Chatzoudes et al., 2024).

The use of reverse logistics, which means moving waste materials from their destination to their place of origin for recycling, is an example of how Kenyan companies are reducing their environmental impact. They also prefer to use liquefied natural gas and compressed natural gas in transport, which is more cost-effective and environmentally friendly (Mutie et al., 2020). To reduce their environmental impact, the Group of Seven countries are actively developing the use of natural gas as a fuel (Sahoo et al., 2024).

Due to investments in the development of clean technologies, Denmark is a leader in the Global Cleantech Innovation Index. In particular, the development of wind energy technologies, investments in the research and development of wind turbines, as well as the introduction of onshore and offshore wind farms have led the country to the status of a leader in this area. It should be noted that the Danish government stimulates the development of innovations in the field of clean technologies by providing development subsidies (Chychkalo-Kondratska et al., 2019).

Energy-recovery technologies, such as the Organic Rankine Cycle and flue-gas heat recovery, have delivered positive results in Austria, Slovenia, Lithuania, Croatia, and Slovakia. These systems reuse excess waste heat to generate electricity or store heat for facility heating (Sebo et al., 2023). The essence of such technologies is the reuse of waste heat to produce additional electricity or accumulate thermal energy for heating premises.

"Cisco Systems" has implemented a Supplier Code of Conduct, which requires suppliers to disclose

information about their environmental impact, including greenhouse gas emissions, and to implement measures to reduce their environmental impact. The Code focuses on environmental sustainability, including transparency and accountability of suppliers (Haar et al., 2023).

"PepsiCo" implements risk assessments to identify potential problems and conducts audits to verify compliance with sustainability standards as part of its Sustainable Supply Program, which aims to reduce environmental impact and improve resource efficiency (Haar et al., 2023).

Canadian company "Visual Defence" has developed an AI-based online road condition monitoring solution. Using algorithms that analyze information collected from sensors installed on vehicles and infrastructure, the system automatically alerts services to problems that require repair or maintenance, thereby improving road safety and reducing congestion (Science and Economic Development Canada, 2023).

In France, software is also used to estimate and optimize traffic. For example, "Simetab-Freturb" is used to estimate the number of deliveries per week and to construct Origin-Destination matrices, then "TransCAD" is used to calculate the equilibrium of the traffic destination for different periods of time, also taking into account the capacity of the transport network. Using this information, "Copcete" is used to calculate the amount of pollutant emissions (Koning et al., 2021).

The activities of automotive companies such as "Toyota" and "Volkswagen" have a significant impact on the environment, and 15 % of total CO_2 emissions are caused by transport, in particular cars. However, due to the large-scale implementation of the policy to ensure sustainable development goals, there has been a gradual decrease in CO_2 emissions per unit of production during the years 2009–2018 (Kasich, 2024).

In general, the logistics sector is a source of significant CO_2 emissions, causing environmental impacts and climate change. However, compared to road transport, the amount of CO_2 emissions from rail and water transport is significantly lower (Cepinskis et al., 2011). Good practice is to stimulate local production to shorten the length of transport chains, which in turn reduces emissions (Pilz. 2023).

Undoubtedly, the implementation of "green technologies" in trade and logistics centers brings a range of important environmental benefits. Above all, it helps achieve significant reductions in greenhouse gas emissions, thereby lessening the logistics sector's impact on climate change. Energy-efficient solutions, renewable energy sources, and heat-recovery systems reduce electricity and heat consumption and, consequently, the strain on energy resources and the environment. Electrifying transport, adopting hydrogen technologies, and using low-carbon fuels deliver cleaner transportation, improving air quality and reducing noise levels in cities and around logistics hubs.

The implementation of "green technologies" significantly reduces the number of emissions. Globalization allows countries to stimulate through legislative initiatives and allocate more resources to implement "green innovations" and improve the environmental situation (Wan et al., 2022). However, in some countries, such as China, India, Brazil, due to insufficient implementation of "green policies", globalization can lead to the opposite effect – a decrease in environmental quality, due to an increase in production and trade (Aydin et al., 2022).

It should be noted that, for example, in China, the introduction of "green technologies" occurs through regulatory pressure – the introduction of standards and laws, as well as sanctions and fines for non-compliance with such requirements. While in India, pressure is exerted by stakeholders, including customers, partners and investors, and it is they who, by giving preference to companies that reduce their environmental impact, stimulate others to also introduce "green technologies" (Benmamoun et al., 2018).

Also, environmental regulations in developed countries can become barriers to exports from developing countries, but stimulate the introduction of "green technologies" (Wang et al., 2018). In general, there is an understanding in the world that companies that reduce their environmental impact improve their image and level of organizational efficiency (Rahman et al., 2022).

Import-export trade operations provoke greenhouse gas emissions, mainly carbon dioxide CO_2 and methane CH_4, emissions of acid gases SO_X, NO_X, NH_3, acid rain, pollution of soils and water bodies (Beylot et al., 2020).

Analyzing the publication of articles on the topic of "green logistics" on one of the scientific resources "Web of Science", 3 periods can be distinguished – the initial stage (1993–2003), when this topic was very poorly covered, later a period of weak development (2004–2014) – publications became more numerous and the topic began to gain popularity, and then a period of rapid development, which began in 2015, and is accompanied by very active discussions and research on the topics of "green logistics" and environmental protection in general (Atance et al., 2024).

Comparative studies of environmental law in different countries help to better understand the peculiarities of their own legal systems and global trends, as well as the development of best practices (Vinuales, 2024). Among the global trends, one can single out the transition to a low-carbon economy, which Canada is striving for and is supported at the government level (Financial Times, 2023). Such studies are divided into three main categories: incidental references to other systems, such as brief mentions of how similar problems are solved in other countries; analysis of political and social aspects, such as a comparison of approaches to chemical regulation with an emphasis on the social consequences of policy decisions; specialized comparative studies, such as a comparison of environmental impact assessment systems in different countries and an analysis of effectiveness, methodology and results (Vinuales, 2024). For example, environmental impact assessment in Canada has been developing since the 1970s and was introduced at the federal level, then the goal was to ensure that attention was paid to environmental consequences in new projects. In the 1980s, a wider range of projects was included and socio-economic factors were taken into account. The next decade (1990s) was accompanied by the introduction of legislative regulation of the environmental impact assessment process, namely the Canadian Environmental Impact Assessment Act. And from the 2000s to the present, there has been a continuous improvement of the assessment process and the inclusion of new methodologies and approaches Doelle et al., 2020).

The use of technologies that reduce emissions of harmful substances will have a positive impact on human health and ecosystems as a whole, will slow down the pace of climate change, and, thanks to the efficient use of natural resources, for example, for electricity generation, will help extend the life of exhaustible resources (Canadian Climate Institute, 2023).

The integration of "green technologies" is a key aspect in the process of ecological modernization of trade and logistics centers in view of the issue of reducing the negative impact on the environmen.

The experience of companies around the world shows that green technologies contribute to competitive advantages and economic growth. Striking examples include optimization of logistics processes, energy-efficient construction, innovations in packaging materials and their recycling, and the use of environmentally friendly transport (Malovanyy, et al., 2022). All these technologies offer high potential for sustainable development. Ecological initiatives of trade and logistics enterprises are summarized in Table 2.

Table 2

Ecological initiatives of enterprises

Type of initiative	Examples of implementation
Energy saving	Use of energy-saving equipment
Waste minimization	Waste sorting, packaging reduction
Transport greening	Use of electric vehicles
Certification and standards	ISO 14001, eco-passports
Public relations	Information campaigns, reporting

The data in Table 2 demonstrate a wide range of environmental initiatives: from energy saving to certification and interaction with the public. This indicates a growing awareness of the environmental responsibility of enterprises.

Of course, in addition to their own initiatives, state regulation of the processes of introducing clean technologies in enterprises is important; it can be both restrictive – through the introduction of sanctions and fines for non-compliance with legislation and established standards, and stimulating – through subsidies and privileges for companies that introduce "green technologies" into their processes. Fig. 2 illustrates the frequency of implementation of environmental measures at trade and logistics enterprises.

Analysis of the information in Fig. 2 shows that energy saving and waste sorting are most often implemented. System certification and the use of eco-packaging remain less common, which indicates the unevenness of environmental efforts.

Environmental modernization of enterprises not only reduces pressure on the environment, but also supports sustainable economic development.

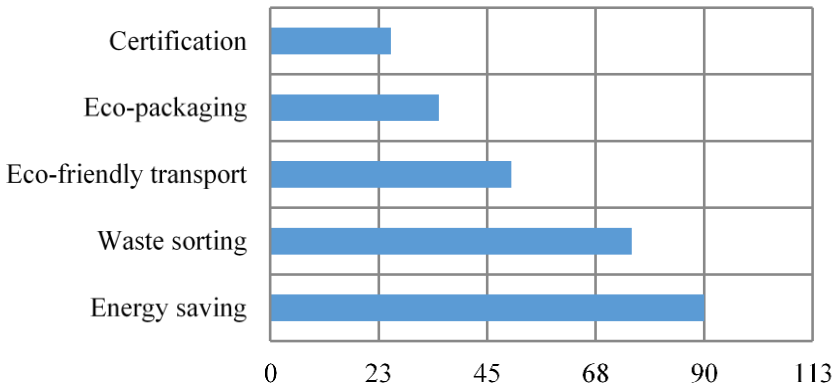

Fig. 2. Frequency of implementation of environmental measures

Thus, the environmental characteristics of trade and logistics services enterprises are an important component of a modern economic model focused on sustainable development. Effective greening requires not only investments in the latest technologies, but also the transformation of corporate culture, the involvement of personnel in environmental initiatives and the creation of an effective motivation system. The integration of environmental approaches into everyday activities allows you to form a positive image, reduce costs and achieve long-term competitive advantage in a globalized economy (Chorna, 2023).

The integration of "green technologies" is a key aspect in the process of ecological modernization of trade and logistics centers in view of the issue of reducing the negative impact on the environment.

Ecological modernization of enterprises not only reduces pressure on the environment, but also supports sustainable economic development.

3. Conclusions

Trade and logistics companies, although not direct polluters, leave a significant environmental footprint due to the intensive use of transport, energy consumption, waste generation and impact on urban infrastructure. The environmental burden from logistics centers is particularly high, which is associated with CO_2, emissions, noise and vibration pollution, the use of fossil fuels and a large territorial presence.

Analysis of environmental characteristics indicates the need for a comprehensive approach to reducing environmental impact. Among the main areas are the introduction of energy-saving equipment, environmentally friendly transport, waste recycling and minimization, automation of warehouse processes, digitalization of document flow and the use of alternative energy. Practical experience of Ukrainian and foreign companies proves the effectiveness of such measures both in reducing environmental risks and in increasing economic efficiency.

Ecological modernization should be accompanied by changes in the management culture of enterprises, increasing the environmental awareness of personnel, as well as the active participation of the state in the formation of incentives – financial, tax and regulatory. Sustainable development in the field of trade and logistics is possible only under the conditions of coordination of technical, organizational and social changes.

Thus, the greening of the activities of trade and logistics enterprises is a key element of the modern economic model, which contributes not only to preserving the environment, but also to increasing the competitiveness of business in a globalized market.

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