Logistic Flow Control System in Green Supply Chains

Nikita Osintsev, Aleksandr Rakhmangulov, Aleksander Sładkowski and Natalja Dyorina

Abstract The effective concept implementation of sustainable development in logistics and supply chain management is based on the use of management decision-making methods for changing the parameters of logistics flows. Decisions should be made based on the measurement and evaluation of the parameters and indicators of these flows. The complexity of managing green supply chains is associated with insufficient knowledge of the system of logistics flows indicators and parameters, as well as in the absence of methods for their comprehensive assessment. In the present work, an original system of indicators (indicators and parameters) of logistic flows in green supply chains is proposed. Managed parameters of logistic flows are identified, the change of which ensures the principles implementation of the sustainable development concept. The use of the fuzzy AHP-TOPSIS method for evaluating the performance of logistics flows in green supply chains is considered. A fuzzy model for managing the parameters of logistics flows has been developed. Changing the parameters of logistic flows in order to achieve the goals of the sustainable development concept is proposed to be carried out using the original system of green logistics instruments. The work presents a calculation implementation example in the logistics flow control system of the procedure for selecting green logistic instruments.

Keywords Sustainable development · Green logistics · Transport systems · Green supply chain management · Logistics flows · Indicators · Fuzzy approach · AHP-TOPSIS · Decision-making

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1 Sustainable Development Problems of the Global Transport System and Supply Chains

The development of international trade in the context of globalization leads to an increase in world trade, the expansion and complication of the commodity nomenclature, and a change in the geographical structure of international trade. The main indicators of foreign economic activity (export and import) of countries that have a significant impact on world trade (USA, China, Germany, etc.) demonstrate a steady upward trend (Fig. 1) [1].

The world trade development is facilitated by the intensive implementation of the One Belt—One Road Initiative [2], based on the economies integration of 65

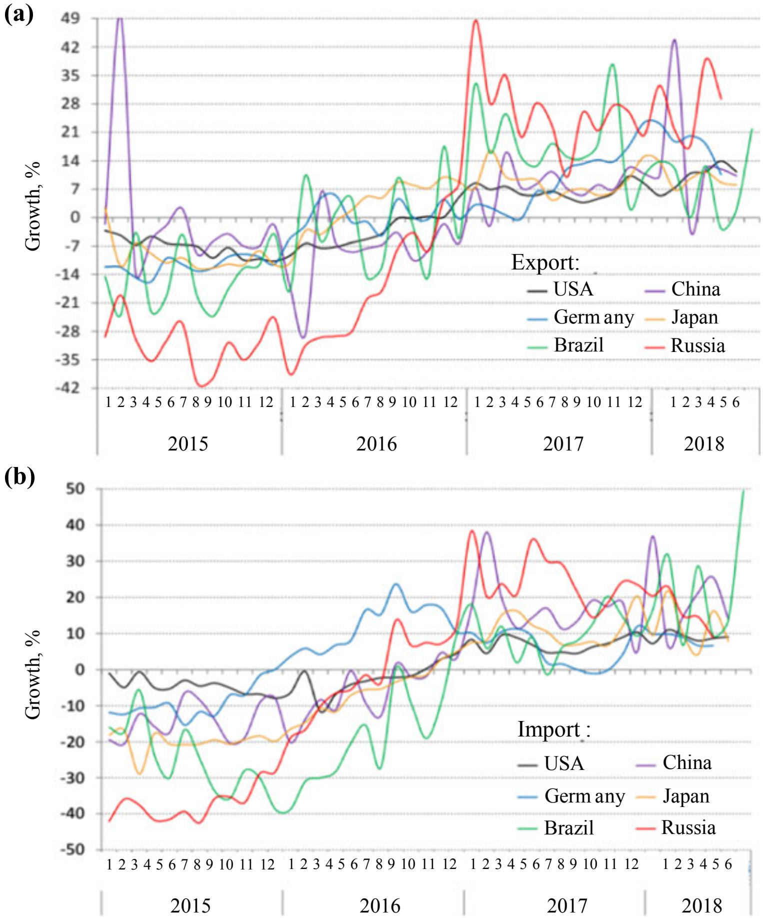


Fig. 1 Monthly dynamics of exports (**a**) and imports (**b**) in the leading countries of the world in current prices in annual terms, 2014–2018

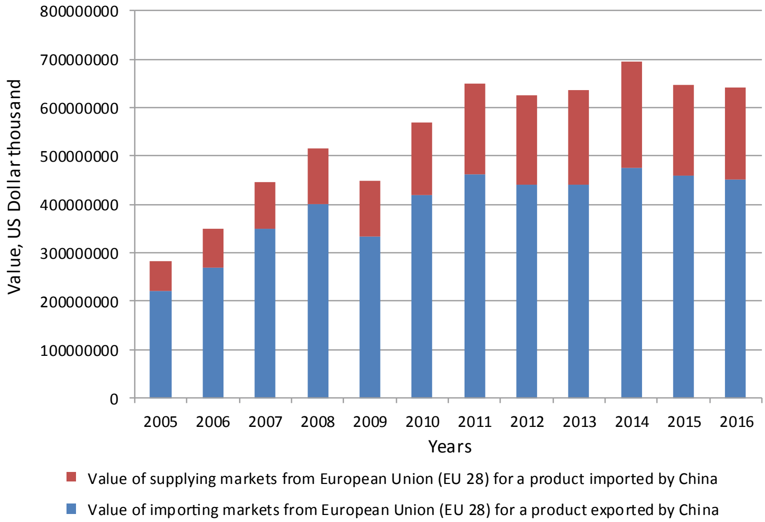


Fig. 2 The dynamics of foreign trade between the European Union and China

countries in the framework of specific transport and economic projects, the Silk Road Economic Belt and the 21st Century Marine Silk Road [3]. The fastest expansion pace of trade and economic ties is observed between the PRC and European countries. EU imports in 2016 amounted to 5218.6 billion US dollars. This amounts to almost 1/3 of the total volume of the global import market. At the same time, China's export to the EU countries has doubled since 2005 and amounts to 452.891 billion US dollars or about 8.7% of the total volume of the European Union import market in 2016 [4] (Fig. 2). Improving the welfare of China population, the active country urbanization makes the Chinese import market more attractive for the sale of products from the European Union [5].

The growth in production and consumption volumes negatively affects the environment—it leads to an increase in carbon dioxide emissions and waste generation. According to the World Resources Institute, only 20 countries managed to reduce the level of greenhouse gas emissions while increasing GDP [6]. This is not enough to achieve the strategic goals of the Paris Agreement to Combat Global Climate Change [7]—to keep the increase in global average temperature by the end of the XXI century within 2 °C.

The relevance of the environmental pollution problem is evidenced by indicators of the environmental capital overuse [8] in the global economy, the facts of uneven use by different countries of renewable energy sources [9], and also such an effective tool as state funding for solving environmental problems.

The main regional differences in climate protection and performance within the 56 evaluated countries and the EU can be proved by the Climate Change Performance Index (CCPI) 2018 results [9]. No country demonstrated well enough to reach the rating "very good", though growth rates in CO_2 emissions decreased a lot (Fig. 3).

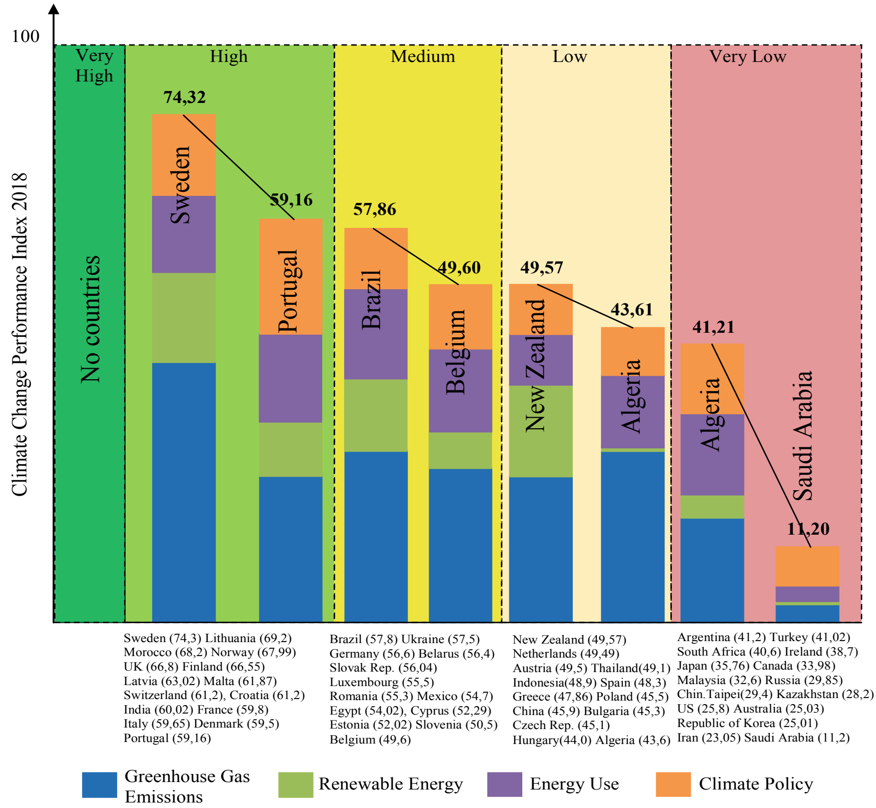


Fig. 3 World energy and natural resource use indicators

The increase in freight traffic in the global transport system contributes to the strengthening of state requirements for environmental aspects of transport and logistics activities. Such requirements become especially relevant for countries through territory of which the routes of international transport corridors pass or are planned [5]. The task of ensuring compliance with environmental requirements is most acute for world leaders in terms of carbon dioxide emissions—China, the USA, India and Russia [5, 10].

The solution to the problems of compliance with environmental requirements for transport is complicated by the presence of specific organizational and technological problems in the global transport system. The main problems in the interaction of the national transport systems that make up the international transport corridors are [5]: insufficient development level of the transport and logistics infrastructure and the lack of its transmission capacity; the use of various technologies for the delivery of goods and methods for organizing the interaction of various modes of transport; poor integration of transport systems of individual countries into the global transport system. In the conditions of uncertainty and dynamism of the external environment, the influence of many economic, social and environmental factors on the processes of promoting cargo flows, the presence of the above problems does not allow for effective mutually beneficial cooperation between countries. Beside these problems lead to an increase in investment and operating costs for the formation and development of transport corridors and transport facilities logistics infrastructure, strengthening the negative impact on the environment, and, as a result, does not ensure the goal achievement of sustainable development concept [11].

The sustainable development concept is based on the idea of achieving a reasonable balance between environmental, economic, social, cultural development and people's needs [11, 12]. The economic component of sustainable development is focused on the effective use of limited resources, saving energy, the use of environmental and material-saving technologies. The socio-cultural component implies maintaining the sustainability of cultural and social systems, an equitable distribution of benefits. The environmental component is focused on maintaining the integrity of natural systems for present and future generations.

Transport plays an important role in ensuring sustainable development, since, on the one hand, it is the most important tool for solving social, economic, and technological problems, and on the other, its functioning has a diverse negative impact on the environment and is an object of increased danger for the life and health of people [13, 14]. In addition, the transport system is the most energy-intensive and least environmentally friendly element of the supply chain. According to The International Energy Agency (IEA) [15], between 1990 and 2011, energy consumption in transport in the world increased by almost 55% to 102 exajoules (EJ), and transport became the fastest growing end-use sector. In 2001, transport accounted for 27% of global final energy consumption. The increase in associated CO_2 emissions generally matched this increase in energy consumption and reached 6.8 billion tons of carbon dioxide (billion tons of CO_2).

The negative impact of international transport corridors and supply chains on the environment is expressed in [13, 16] (Fig. 4):

- consumption of natural resources (energy, water, atmospheric and lithosphere resources);
- environmental pollution with harmful substances (gaseous, liquid and solid);
- energy and visual environmental pollution (noise, vibration, electromagnetic fields, heat emissions, light pollution);
- alienation and land degradation;
- injuries and deaths of people, animals, causing harm to health;
- causing material damage as a result of traffic accidents, accidents, and traffic accidents.

On the other hand, there is a gradual change in the attitude of the business, including transport, towards the idea of sustainable development and environmental problems, in particular. The main reasons determining such changes are [13, 17, 18]:

- state regulation and control of compliance with environmental and social laws by using not only restrictive (fines), but also incentive measures (tax benefits);

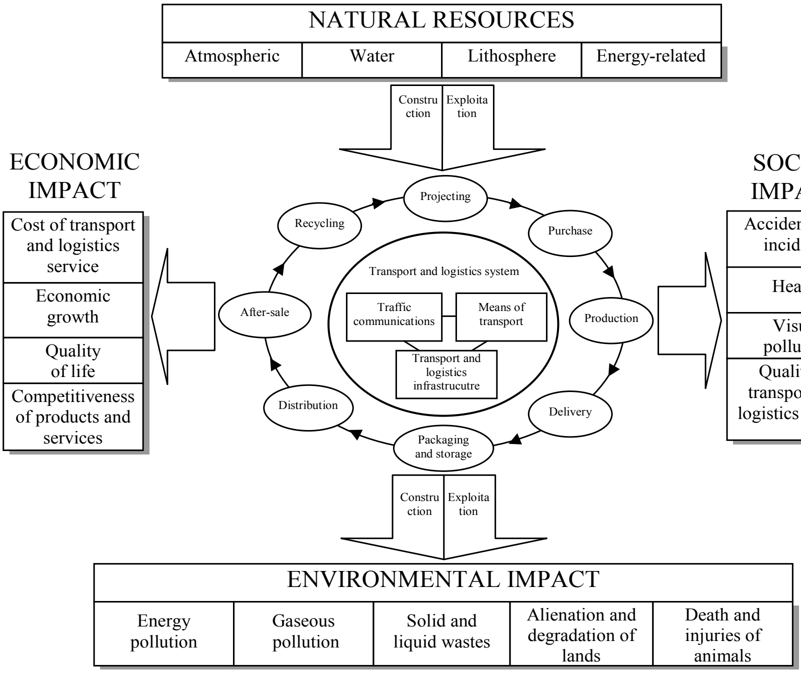


Fig. 4 The environmental impact of the transport and logistics system

- increasing requirements (demand) for the quality of services and products. Organizations that produce technologically advanced, high-quality and environmentally friendly products and services, increase the image of their brand and improve the reputation of their organization in the eyes of consumers;
- improving the reputation created by the public, own employees, consumers, shareholders, other companies (investment, insurance, banking), in turn, helps to increase the capitalization of the company, improve its financial performance in the long-term, as a rule, perspective;
- compliance with the requirements of supply chain partners, enhancing interaction with suppliers and customers, as well as shaping and developing social corporate responsibility;
- reduction of environmental and social risks. Socially and eco-friendly companies usually have lower insurance costs due to the fact that the size of insurance premiums is associated with decreasing environmental risks of enterprises;
- cost reduction and increased profits achieved through the use of modern environmentally friendly and at the same time cost-effective technologies;
- achieving a competitive advantage as a result of positioning products and services as environmentally friendly, which allows attracting profitable partners and conquering new markets.

The grouping of the considered reasons on the aspects of sustainable development allows us to understand the relationship between the features of the functioning of transport in the supply chain and the sustainable development concept [13]:

The environmental aspect. Assessment and consideration of environmental factors, as well as resource constraints, is necessary in the design and investment analysis, with strategic planning for the development of territories, justification of priority directions for the development of transport [19]. Studies [20] suggest dividing environmental factors into two groups: factors that negatively affect the environment during the construction of transport infrastructure, and factors that appear directly during the operation of transport systems. Insufficient consideration of environmental factors in the activities of transport and logistics companies leads to excessive consumption of natural resources; environmental pollution by harmful substances, energy and visual pollution; alienation and land degradation; reduction of biodiversity on earth, the emergence of environmental pathologies.

The social aspect. The consideration and assessment of social factors in the design and operation of transport and logistics systems is aimed at improving living standards as a result of mainly ensuring transport security, increasing accessibility and improving the quality of transport services to the population, protecting health, ensuring social welfare, and developing environmental competence of citizens and the development of a society's "environmental etiquette" in relation to transportation. The solution to the last two of these tasks is based on the formation of a people's systematic view of the human environment and understanding the impact of human activity on nature.

The economic aspect. The economic features of sustainable development of transport and logistics systems consist in harmonizing the sustainable development goals with the goals of transport functioning in supply chains—making a profit, economic growth, and increasing competitiveness. The main hypothesis of this coordination is that the implementation of logistic methods, concepts and functions fundamentally allows you to reduce the cost of resources and minimize costs, which potentially helps to reduce the harmful effects on the environment.

The modern logistic approach to the consideration of transport systems and the implementation of logistic methods and solutions [21–23] makes it possible to ensure that transport corresponds to all aspects of sustainable development at the same time. This is achieved mainly as a result of rational use of resources and improving the quality of transport services. A comprehensive systematization of factors influencing the sustainable development of the supply chain, presented in the form of a logistic system, was made in [13] (Fig. 5) on the basis of the logistic approach.

Presented in Fig. 5 system of factors for the sustainable development of supply chains is used by the authors as the basis for the development of indicators for assessing logistics flows in supply chains, the systematization of green technologies in transport, as well as methods for selecting tools for managing the parameters of logistics flows in green supply chains.

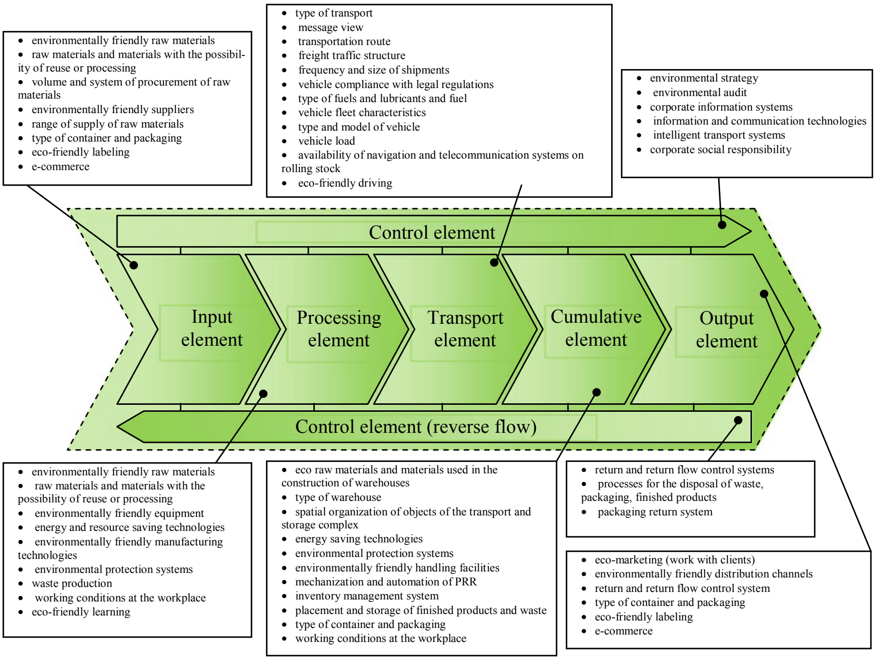


Fig. 5 Factors scheme of the transport and logistics system sustainable development

2 Research Review of Sustainable Development in Transport Systems and Supply Chains

To date, the key guideline for environmental policymaking for most countries is the "Sustainable Development Goals" (SDGs)—a universal set of 17 goals and 169 goals that are included in the global strategic program "Transforming our world: Agenda day in the field of sustainable development for the period until 2030" [12]. The achievement of the SDGs is based on the principle's implementation of sustainable development and largely depends on the activities of international organizations, the coordination of national, regional and international development programs, as well as ongoing activities in the field of ecology, environmental protection and in the economic sphere.

The majority of existing sustainable development models is based on achieving a reasonable balance between environmental, economic, cultural and social development and people's needs. However, the complexity of implementing this approach, as shown by the analysis of well-known models of sustainable development [5, 24], is associated with the following circumstances:

- static and insufficient emphasis on the dynamics of the development process;
- fragmented relations between aspects of sustainable development (ecology, economy and society);

- implementation complexity associated with a variety of constraints and the inconsistency of sustainable development goals.

With regard to transport systems, sustainable development means that meeting transport needs should not contradict the priorities of protecting the environment and human health, and will not lead to irreversible natural changes and the depletion of irreplaceable resources [21]. The work [25] notes the growing interest in the Concepts of Sustainability, Livability, Sustainable Development and Sustainable Transport. Despite the difference in approaches and definitions of the listed concepts, most experts talk about the balance of economic, environmental and social aspects of sustainability.

A logistic approach to solving environmental problems and implementing the principles of sustainable development began to be applied in the 1980s of the XX century [16, 26]. In work [27], four stages of priority research on the problems of the interaction of logistics and the environment are distinguished: economic rationalization of environmental factors in production (until 1990); development of Reverse Logistics (1990–2000); Green Logistics on Enterprise Level (2000–2010); Green Supply Chain Management (from 2010 to the present).

Many scientists note that logistics has significant potential for environmental monitoring of transport systems, product recycling processes, control and minimization of environmental pollution, energy and resource conservation processes [16]. At the same time, a number of scientists [28–30] note the contradiction between the classical logistic approach aimed at maximizing profits, ensuring economic growth and green logistics, which is associated with a decrease in the negative impact on the environment.

In [21, 31] it is shown that the concept implementation of sustainable development and green logistics is currently carried out on the basis of two approaches—state and market. The first is based on public administration and the observance by companies of mandatory requirements and restrictions, both forcibly and on the basis of incentive measures. The market approach is based on obtaining economic benefits, competitive advantages, increasing the image and public popularity of companies using green technologies.

In features studies of managing green supply chains, six main subject areas are distinguished [32, 33]:

- Policy—issues of business ethics and corporate social responsibility, environmental audits, as well as solving problems on environmental issues, compliance with the requirements of the law and the state in the field of ecology;
- Synthesis—literature reviews, studies, and training aids on managing green supply chains at all stages of the goods delivery from purchase to sale;
- Purchasing—environmental problems associated with the relationship between suppliers and customers, environmental solutions, certification and issues of compliance with environmental quality standards;
- Manufacturing—problems of design and construction, development and manufacture of ecologic products in order to reduce harmful emissions and wastes;

- Green logistics—environmental issues related to the sustainable transportation, handling and storage of hazardous materials, inventory management, warehousing, selection of locations for transport and logistics infrastructure, the preservation and use of containers and packaging, aimed to reduce CO_2 emissions;
- Reverse logistics—increasing the efficiency of logistics in the separation of return flows (material flows moving from consumers to the primary sources of these flows) into streams that are subject to secondary processing and utilized streams (waste).

The works [34, 35] give the analysis of existing and promising solutions for the integrated implementation of the state and market approaches to reducing the environmental impact of transport systems, and also the following grouping of these solutions was proposed:

- economic decisions are aimed at increasing the transportation cost, which forces companies, for example, to use cheaper and more environmentally friendly modes of transport, to optimize the workload of rolling stock;
- legal decisions are normative restrictions developed in advance and approved in the established manner. They can be used, for example, to accelerate the technological development of transport systems by gradually tightening the standards and requirements for vehicles, the level of harmful emissions into the environment;
- information and analytical solutions, for example, research, training, dissemination of best practices, benchmarking, consulting, the use of carbon calculators and environmental labeling;
- decisions in the field of social policy are focused on the development of a transport infrastructure that meets environmental requirements, the introduction of urban intelligent transport systems, the rational organization of passenger transportation, etc.

A review of existing and promising green technologies in transport and logistics [34, 36–40] showed a variety of approaches and views on the content of green logistics methods and instruments, which is the reason for the lack of systematic implementation. To date, various types of environmental programs and projects are actively implemented in logistics and transport companies around the world with the support of public and state institutions, the feasibility and effectiveness of green technologies use in practice have been substantiated [41]. At the same time, analysis of research results [16, 33] on the integration of the environmental factor into the practice of logistics management shows that research is still fragmented, in most cases affecting certain areas of logistics.

Approaches and methods for managing green supply chains vary in developed and developing countries [42]. The complex of Vancouver principles of sustainable transport [43], which is based on the idea of taking into account the environmental, social and economic conditions of different countries and regions within countries, had a strong influence on the sustainable development of transport systems.

In [44], eight sustainable development principles of transport systems are presented, which contribute to improving the quality of life and ensure economic viability while observing the requirements of the environment. The authors of [39] classify environmental principles applicable to supply chains in the following areas: product design, packaging, collection and transportation, waste processing and disposal, creation of an eco-business environment, storage, management questions (in the field of marketing and information technology).

The five principles underlying The GHG Protocol Corporate Accounting and Reporting Standard (relevance, completeness, consistency, accuracy and transparency) were used in paper [45] to formulate six principles for reducing carbon emissions from logistics activities. The authors of [36] examine the guidelines for environmental design (engineering) for supply chain sustainability in relation to product life cycle strategies.

The results of the scientific literature analysis presented in [26, 46], allowed to identify 151 logistic principles mentioned by various scientists. We have established that most of the well-known logistic principles implemented in practice ensure the achievement of management goals, assessed according to economic criteria, but poorly take into account the environmental aspects of logistics activities. This does not allow implementing the sustainable development concept in the management of green supply chains.

The complexity of managing green supply chains lies in the insufficiently investigated relationships between indicators and parameters of logistics flows. The scientific literature analysis [47] showed that there is no accepted universal system of parameters and indicators for logistic flows.

The main meters of material [48] and transport [49] flows are considered to be the transport mass, transport route and transport time. As additional parameters characterizing the flow, use [50–52]: initial, intermediate and final points; geometry (trajectory) of the flow; length (measure of the trajectory); speed and time of movement; intensity. In [53], in addition to the volume of traffic and points of origin and redemption of traffic flows, it is proposed to describe the logistic flows as its composition, quality and cost. The study [54] proposes to separate the parameters of logistic flows into three groups, each of which describes both a separate logistic flow and a combination of homogeneous and heterogeneous flows.

In [55], the parameters of logistic flows in supply chains are grouped into four groups: quantity, quality, costs and time. The authors of [22] suggest that the parameters of logistic flows be divided into two groups: a group of physical parameters that reflect the spatiotemporal properties of flows and a group of statistical parameters that characterize patterns of change in physical parameters. The study [56] established patterns of interaction between the flow and structural elements of the transport system. It is proposed that flow estimation be performed taking into account two parameters: average flow size and disorganization of flow. In [57], a characteristic of the parameters of material flow (the flow of goods and vehicles) in the logistics system is presented. The author [58] established the relationship between the quantitative parameters of flows and stocks in logistics. In [59, 60], an assessment of logistic flows by two components is proposed: vector (flow direction) and scalar (volume of resources). In [59], in relation to this approach, a complex of thirty-five indicators for assessing the total costs (financial flows) arising from the formation of innovation flows in the logistics system is proposed. In [61], a “metric” of information flow in logistics was proposed, and in [62] a relationship was established between the parameters of material, information, labor and financial flows in the logistics system.

The drawback of the majority of existing approaches to the assessment of all logistic flows is the consistency lack in the parameters and flow indicators consideration. In logistics practice, the assessment of material flows is carried out mainly by such parameters as mass, speed (time), and the route of advancement. This is due to the fact that these flow parameters are controllable. The traditional mechanism for managing logistics flows is based on decision-making on the results of comparing the actual values of these controlled parameters with the calculated (planned) ones. However, the calculated values of the controlled parameters are the result of stream optimization exclusively according to logistic, mainly economic criteria, known as the “seven right of logistics” [63] and do not take into account the environmental and social aspects of modern logistics activities.

At present, when solving complex multifactorial and multicriteria problems of forming and managing green supply chains, multicriteria decision-making approaches (MCDM) are widely used, which can be used to quantify the trade-offs between economic, social, and environmental criteria of sustainable supply chain development. In the scientific literature, MCDMs are divided into two categories [64]: a small and finite set of solutions called multi-factor decision making (MADM) and a large and infinite set of alternatives called multi-purpose decision making (MODM) or multi-purpose programming (MOP) a small and finite set of solutions, called Multi-Attribute Decision Making (MADM), and a large and infinite set of alternatives, referred to as Multi-Objective Decision Making (MODM) or Multi-Objective Programming (MOP). MADM approaches are aimed at determining the best option based on the known attributes of a limited number of alternatives, while MODM approaches are aimed at finding the best solution that satisfies the wishes of the decision maker.

The variety of parameters, properties and characteristics of logistics flows in supply chains makes it necessary to combine MCDM with various fuzzy approaches and methods. The use of methods of the fuzzy sets theory and methods of making managerial decisions is justified by the need to take into account many factors determined by the specifics of the functioning of transport systems and supply chains, as well as the variety of flow parameters circulating within the framework of the logistics system (supply chains). Unlike traditional mathematical methods that require precise and unambiguous formulations of laws, fuzzy set theory methods allow, based on both accurate quantitative indicators of the functioning of transport systems and approximate qualitative estimates, to generalize data on various factors that have different effects on the sustainability of supply chain development.

The analysis shows that in the practice of managing green supply chains, the authors use various fuzzy approaches and methods, in particular, fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) [65–67], fuzzy Importance and Performance Analysis (FIPA) [68], fuzzy Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [69, 70], fuzzy Analytic Network Process (ANP) and fuzzy Technique for Order Preference by Similarity Ideal Solution (TOPSIS) [66, 71, 72], analytic hierarchy process (AHP) AHP-TOPSIS and fuzzy Grey Relational Analysis (GRA) [73–75], interpretive structural modelling (ISM) [76–78], fuzzy game theory [79, 80] and others.

Applications of fuzzy goal programming has been studied in the supply chain when evaluating and selecting suppliers [81–83], designing a supply chain network [84, 85], supply chain planning [86, 87], evaluations job safety [88, 89] and urban transport systems [90].

The studies [91] proved the effectiveness of using mixed methods for theory in managing green supply chains, allowing taking into account the dynamic nature of green supply chains.

In studies [92], using the fuzzy Multi Criteria Decision Making (MCDM) approach, analyzing the drivers of green manufacturing was performed. In [93], a fuzzy model and methodology for a comprehensive assessment of eco-innovation was proposed. The following work [94] presented a multi-purpose mathematical model for improving economic and environmental performance of a supply chain that works under fuzzy environment and can handle multi-objectives.

An optimization model based on a fuzzy game theory for three players (government, manufacturers and customers) was proposed in [79] with the goal of choosing an optimization model of three-player payoff based on fuzzy game theory in green supply chain). The authors of [80] propose three models of green supply chain management with government interventions under fuzzy uncertainties of both manufacturing cost and consumer demand.

The paper [73] considers group decision making using fuzzy and gray set theories helped to give better results in green supplier selection. The fuzzy green supplier selection model proposed in [95] is based on the 4R principle (recycle, reduce, reuse and replace) and six sigma quality indices. The authors of [96] propose a comprehensive assessment of the cost structure in green supply chains using the process of the fuzzy analytical hierarchy of the entropy weight fuzzy analytic hierarchy process.

The authors of [97] analyzed the use of fuzzy demand to GSCM, proposed two nonlinear integer programming models, a crisp model and a fuzzy model. A genetic algorithm (GA) and hybrid genetic algorithm-pattern search (HGAS) are developed to solve the models.

The works [98, 99] presented a fuzzy programming model for designing a forward network supply chain aiming at minimizing the environment emission and total cost.

The disadvantage of most existing methods and models is the lack of comprehensiveness and systematic assessment of all types of logistics flows to take into account the relationship between indicators and flow parameters to achieve the goals of the concept of sustainable development. Thus, a review of research in the sustainable development field of transport systems and supply chains allows us to draw the following conclusions:

- the conceptual and terminological apparatus of green logics and management of green supply chains has been formed, approaches and principles of sustainable development have been formulated, there are systems of indicators for assessing this activity; a regulatory framework has been created for the practical implementation of the concept of sustainable development, which includes a set of regulatory legal acts of international and national legislation;

- there is no universal system of logistics principles, and most of the well-known and implemented logistics principles are aimed at improving management efficiency and achieving the economic goals of supply chain functioning;
- insufficient systematic implementation of the methods and instruments of green logistics in practice often leads to a decrease in the effectiveness of each of these methods and instruments separately, and does not contribute to the emergence of a green synergistic effect in supply chains;
- generally accepted logistics management criteria poorly take into account environmental and social aspects, which reduces the efficiency of managing logistics flows in accordance with the goals of the concept of sustainable development.

3 Comparative Analysis of Commodity Flows and the Benefits of Green Logistics

The volume analysis of trade flows in the global economic system demonstrates their following dynamics: a smooth increase until the end of the 1990s; sharp growth since the beginning of the 2000s; sharp decline after the 2008 economic crisis. In recent years, there has been a gradual restoration of traffic volumes in the global transport system. World export of commercial services and World merchandise exports increased from 1995 to 2014, respectively, from 1.179 to 4.872 and from 5.168 to $19 billion [100]. The global logistics market is anticipated to register a CAGR of 3.48% from 2016 to 2022 to attain a market size of around $12,256 billion by 2022 [101].

The commodity structure of freight flows in the global transport system in 2017 is presented in Figs. 6 and 7. The largest volume of transportation is accounted for by capital, intermediate and consumer goods, which in the structure of world exports and imports reach up to 45% of the total volume. In addition, in the structure of world trade, there is an increase in traffic between the EU countries and China [5, 102]. At a fast pace, there is an increase in the supply of various food products.

Such positive dynamics in the development of international trade and the organization of new transport links of international traffic contributes to an increase in requirements for existing transport corridors, makes it urgent to convert them into green supply chains [103], and to develop sustainable transport systems that can cater for increasing volumes of traffic internationally and nationally, as efficiently as possible, ensuring a reduction in the environmental load at all stages of the cargo delivery process. At the same time, the analysis of indicators of economic transport growth and development in a number of countries (the USA, the UK, Japan, and Germany) shows that indicators of freight activity stabilize or even decrease when a country reaches a high level of economic development [104]. This is mainly the

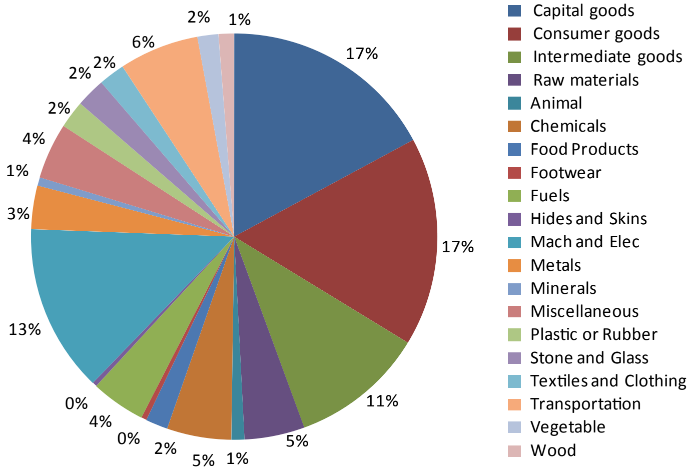


Fig. 6 World merchandise export by major product groups, 2017

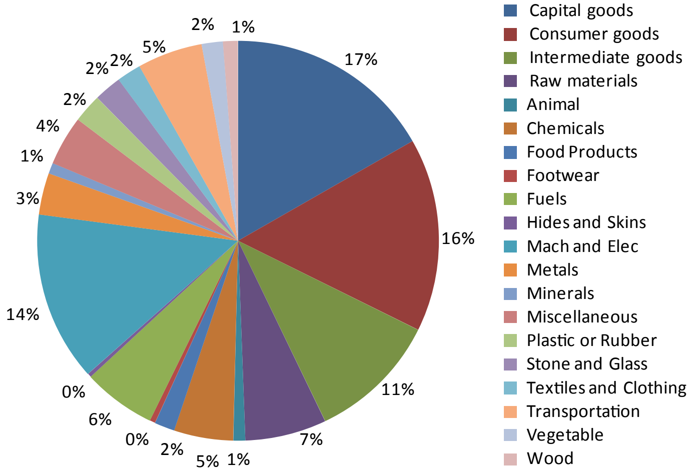


Fig. 7 World merchandise import by major product groups, 2017

result of adopting a low-carbon transport policy, structural changes in the economy and/or improving logistics management in transport and manufacturing.

The activities of logistics and transport companies, on the one hand, contribute to significant environmental pollution by harmful gaseous, liquid, and solid substances [13]. On the other hand, companies are increasingly using innovative methods and methods of “decarbonizing the economy” [105], implementing green strategies in business processes by considering green business practices in various functions of the business value chain [106]. According to Lise Kingo, Executive Director of the UN Global Compact, "Many companies are already starting to look through the Sustainable Development Goals—imagining how their operations, products and services can support the realities of our planet and better serve markets both today and in the future" [107].

The company on the way to sustainable development goes through three stages [105, 108]:

1. Development (formation) of a sustainable development strategy when senior managers consider climate change issues as strategic issues of their own business, and the measure development and adoption are compatible with their business interests.
2. Localization, which provides for the implementation of strategic plans for sustainable development by using green technologies by companies in practice, involving middle managers in the creation of new structures at the local level, involving all participants in the supply chain (from suppliers to consumers) in the implementation of eco-friendly-initiatives.
3. Normalization, which consists in reaching a compromise between business needs and sustainable initiatives. This stage is the most difficult, because the company faces a choice: to continue implementing sustainable development programs or return to familiar practice. The reasons for this choice may be, for example, financial difficulties, unjustified expectations from the implementation of programs, etc.

Researchers [17, 33] identify seven key benefits of green logistics and green supply chains:

1. Positive impact on financial performance. As a rule, the effectiveness of financial indicators is considered in the long term.
2. Sustainability of resources, i.e. efficient use of the organization's production resources.
3. Lower costs and increase efficiency. Effective resource management (including waste reduction, disposal and reuse) helps reduce operating costs, reduce fines, as well as the use of tax benefits and other economic instruments.
4. Product differentiation and competitive advantage. Positioning services and products as environmentally friendly allows attracting profitable customers (partners), strengthens the image of the company and its reputation on the market.
5. Regulation and risk reduction. The introduction of green technologies reduces the risk of being held accountable for violating environmental standards and using unethical business practices.
6. Improving the quality of services and products. Organizations that produce technologically advanced and environmentally friendly products increase the brand image and reputation of customers.
7. Involvement of the company, supply chain partners, employees, suppliers and customers in the development and implementation of long-term green solutions. This helps to strengthen relations with customers, forms and develops corporate citizenship and social corporate responsibility.

The best practices review for implementing green technologies in various business areas [109, 110] and in supply chain management in the countries of South [105, 111] and North [17, 112, 113] America, Western Europe [17, 37, 114–116], Eastern Europe [116, 117], Northern Europe [35], Southern Europe [115, 118], India [118–120], Asia [74, 121, 122], Australia [105], as well as in the work of logistics operators around the world [17, 109, 112, 121, 123, 124], showed a variety of approaches and views on the content of the methods and instruments of green logistics [33, 41].

In the practical activities of companies, such diversity leads to a decrease in the effectiveness of each of these methods and instruments separately, and does not contribute to the systematic reduction of harmful environmental impacts, provided that the supply chains are more economically efficient. As an example of insufficient systematic use of green logistics methods, Tables 1 and 2 [41] provide brief characteristics of large transport and logistics companies that use green technologies and the principles of the concept of sustainable development. The green technologies (solutions) used by companies were grouped according to the elements of the logistics system and the functions of these elements [22]. In distinguishing the logical elements and their functions, the approach proposed in [31, 40] was used.

In order to assess the prevalence of certain green technologies and green logistics methods, the authors analyzed the number of references in the scientific literature, as well as the number of green technologies implemented in practice. Figure 8 presents the results of the decomposition of the number of references and identified cases of the implementation of green technologies according to the elements of the logistics system and the functions of these elements. The detailed description of the structural and functional approach to the presentation of transport systems and supply chains in the form of logistics systems with the allocation of logistics functions and elements is presented in Sect. 4. In accordance with this approach, the following logistics elements are distinguished: input; output; processing; transport; cumulative. The selection of these elements is justified by the set of supporting logistic functions performed by them. A complete list of the supporting functions of the logistic elements is presented in Table 4 (Sect. 4).

Figure 8 uses the following notation for the columns of a chart:

- height of blue columns—the number of references in the scientific literature of green technologies with distributions by elements of the logistics system;
- the height of the green columns—the number of references in the scientific literature to green technologies with the distribution of the supporting functions of the elements of the logistics system;
- the number of brown columns—the number of identified green logistics methods that implement the corresponding function of the logistic element;
- height of brown columns—the number of references in the scientific literature to green logistics methods, with a distribution by function of the elements of the logistics system;
- the height of the yellow columns—the number of companies that implement green technologies in practice, with the distribution of the elements of the logistics system by function;

Table 1 Characteristics of transport and logistics companies implementing green programs (projects) [41]

No.	Name of company (country)	Main activity	Name of the implemented program (project)
1.	Schenker AG (Germany)	International logistics provider	"Climate Protection Program 2020"; "Eco Plus", "Eco Ocean Lane", "Eco Charter", "Eco Warehouse", "Eco Neutral"
2.	Green Cargo (Sweden)	Railway Logistics Operator	"Environmental Impact Calculation"
3.	DHL (Germany)	International logistics company	"Go-Green"
4.	FedEx (USA)	Freight company	"EarthSmart"
5.	Kuehne Nagel (Germany)	Leading global provider of logistics services	"Go Clean-Go Green","Global Transport Carbon Calculator", "Climate Neutral Services"
6.	UPS (USA)	International Supply Chain Management Company	"Eco Responsible Packaging"
7.	K Line Logistics (Japan)	International logistics company	"Drive Green Network"
8.	COSCO Group (China)	International container operator	"Wind Wing Ship", "Green Trip"
9.	Ekol (Turkey)	Transport and logistics operator	"Virtual Server"; Participation in the program "WWF Green Office"
10.	JSCo "Russian Railways" (Russia)	State Railway Company	The environmental strategy of Russian Railways for the period until 2017 and the future until 2030
11.	PJSC "TransContainer" (Russia)	Container operator	Separate projects
12.	UCL Holding (Russia)	International Transport Group	Separate projects

- the number of yellow columns—the number of green technologies implemented in practice that correspond to a certain method of green logistics and the function of the logistic element.

The results of the analysis allow us to conclude that at present no methodological base has been formed for the practical implementation of the sustainable development concept in relation to transport systems and supply chains. There is still a process of accumulation and selection of private solutions (technologies and methods) to reduce the harmful effects of transport on the environment. Research is needed to

Table 2 Systematization of green technologies used by transport and logistics companies [41]

Logistic system element	Logistics system function supported by green technology	Implemented green technologies (Company No., in accordance with Table 1)
Input element	Supply quality analysis	The use of environmentally friendly fuels and lubricants and fuels (1–4, 6–9, 12)
Processing element	Production and product quality management	Organization of a waste management system (10, 11, 12)
	Personnel management	Eco-friendly staff training (1, 9, 10)
	Improving technical and technological support	Designing energy-efficient rooms (3, 4, 5, 10); The use of environmentally acceptable engineering and technology in the production process (10); Alternative energy sources (1, 4, 6, 8, 9, 10, 11)
Cumulative element	Inventory level optimization	Reduction of stocks and consumption of materials and spare parts (8)
	Improvement of technical equipment and storage technology	Environmental design of warehouse complexes (1, 5); Use of energy and resource saving equipment (1, 4, 6, 7)
Output element	Selection and organization of product distribution channels	Application of technologies for managing reverse and return material flows (3, 5, 6, 9); Packing and packaging management (reverse logistics methods) (4, 5, 9)
	Service flow formation	Stimulating consumers to use green services (2, 3, 4, 5, 12); The use of eco-packaging and returnable packaging (3, 4); Weight and volume optimization of packaging material (4, 5)
Transport element	Selection of optimal transportation schemes	The use of intermodal technologies and multimodal transport (1, 2, 6, 9, 10); Optimization of driving routes according to the criterion of minimum harmful effects on the environment (1, 2, 3, 5, 8, 10); Analysis and optimization of emissions (2, 3, 4, 5)

(continued)

Table 2 (continued)

Logistic system element	Logistics system function supported by green technology	Implemented green technologies (Company No., in accordance with Table 1)
	The choice of a system for organizing the promotion of material flows	Formation of long trains (1); Consolidation of Supplies (6)
	Operational management of material flow parameters	Vehicle speed optimization (8)
	Improving the technical support of the transportation process	Use of environmentally friendly vehicles (1, 2, 3, 4, 6, 9); Use of energy-saving equipment (1, 2, 8, 10); Modernization of the fleet of vehicles, modification of transport equipment (1, 3, 4, 7, 8, 10, 12)
Control element	Logistic strategy development	The inclusion of environmental aspects in the company's strategy (1–12); Implementation of a transparency policy (1–12)
	Organization of interaction and coordination of the work of LS elements	Implementation of integrated environmental protection systems (10, 11)
	Coordination and regulation of LS elements	Electronic (paperless) workflow (1, 4, 8, 10); Use of intelligent transport systems (1, 7, 8); The use of modern information systems (6)
	Formation of a favorable socio-economic environment of LS	Dissemination of information on environmental achievements (1–12); Formation of corporate social responsibility in the field of sustainable development (1–12)

systematize the found effective solutions (green technologies, green methods) and to create a general theory of sustainable transport development. The author's version of such systematization is presented in [40, 125]. The proposed system of methods and instruments (technologies) of green logistics is based on the factors study of sustainable development of transport and logistics systems, as well as on the use of a structurally functional approach to the description of logistics and transport systems, involving the identification of the basic and supporting functions of the elements of these systems [22].

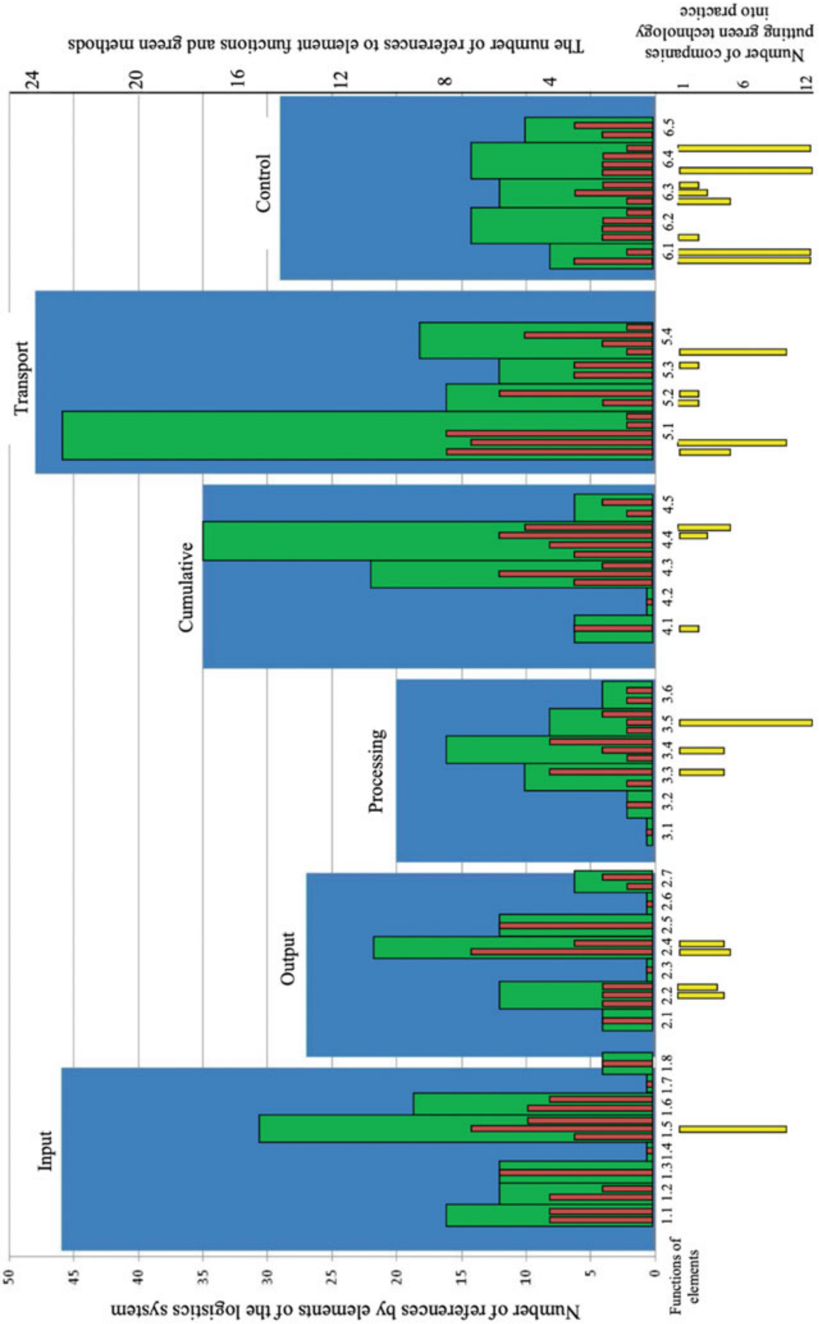


Fig. 8 The number of references and cases of using green technologies in logistics activities

4 The Concept of a Logistics Flow Management System in Green Supply Chains

The analysis of the goals, objectives, advantages and disadvantages of the implementation of a particular conceptual approach in logistics shows that the issues of reducing the negative impact on the environment and achieving sustainable development goals are indirect and, as a rule, are focused on compliance with current regulatory and legal restrictions and requirements in environmental areas to be performed by companies operating in the logistics services market. At the same time, many scientists note that logistics has a significant potential for solving environmental problems. Table 3 presents the qualitative assessment results of the environmental

Table 3 Qualitative assessment of the environmental potential of logistics concepts

Environmental impact	Concept[a]
Positive	
Selecting nearby suppliers of material resources	JIT, LP
Reduction of the transport component due to effective feedback on orders	RP, DDT, SCM
Choosing the optimal mode of transport and driving route	RP, SCM
Minimization of defects (defects) in the production process and, as a result, waste reduction	JIT, LP
Minimization of the level of stocks of material resources, work in progress, finished products, waste	RP, JIT, DDT, LP, SCM
Reduced need for storage space by reducing inventory levels	RP, JIT, DDT, LP, SCM
Reduced energy intensity and rational use of storage facilities, rational land use	JIT, LP
Formation of corporate social responsibility as a necessary condition and result of the implementation of logistic concepts and the creation of green supply chains	JIT, LP, SCM
Returnable material management (reverse logistics)	DDT, SCM
Negative	
The increase in the intensity of use of transport in the transition to production in small volumes with a high frequency of departure	RP, JIT, DDT, LP
An increase in the volume of loading and unloading operations due to a decrease in the size of consignments	RP, JIT, DDT, LP
Increased environmental load at the locations of transport corridors and nodes	RP, SCM
The use of buffer depots for storing stocks of raw materials, finished products and waste	RP, DDT
The increase in the number of failures in the system due to its large dimension and complexity	RP, DDT

[a]*Note* RP—Resource Planning, JIT—Just in Time, LP—Lean Production; DDT—Demand-Driven Techniques, SCM—Supply Chain Management

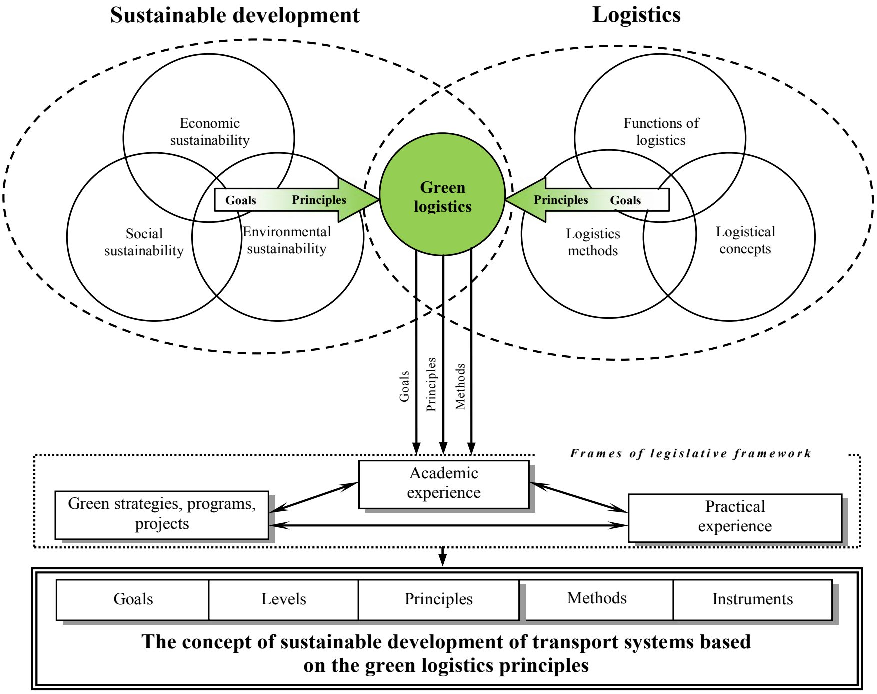


Fig. 9 The scheme of the proposed approach to achieving the sustainable development goals in the functioning of transport systems and supply chains

potential of existing logistics concepts. The number of references and cases of using green technologies in logistics activities are shown on Fig. 8.

The proposed concept of managing logistics flows in green supply chains (Fig. 9) is based on the idea of achieving a balance between the economic, environmental and social sustainability of the logistics system. The formation of such a system should be subject to the following conditions:

- consistency of logistic principles with the principles of the sustainable development concept;
- achieving and maintaining a balance between the economic, environmental and socio-cultural sustainability of the logistics system within the framework of the regulatory framework of international and national legislations;
- development of a system of methods and instruments for green logistics based on the best practices for the environmental programs and projects implementation in the activities of public and state institutions, business structures, research organizations and international associations.

The basis of the proposed concept is the following provisions:

1. *Achievement of sustainable development goals in the operation of transport systems and supply chains is achieved by bringing the goals, methods and principles of green logistics into line with the goals and objectives of the organization's business.*

The goals comparison of sustainable development and the goals of the functioning of transport systems show the presence of contradictions between them. If the transport system work is focused on achieving economic goals (improving the quality of services, making a profit, reducing costs), then the main goal of sustainable development is to achieve a balance between the economic, social and environmental needs of society. From the perspective of green logistics, it is necessary to look for the ways to coordinate the goals of sustainable development and logistics. The main hypothesis of such coordination is that the implementation of logistic methods, concepts and functions fundamentally reduces the cost of resources as a result of optimizing the parameters of logistic flows, which potentially helps to reduce the harmful effects on the environment. Effective, using logistics solutions, the use of resources allows us to improve the logistics processes, and as a result, realize the social and environmental needs of society. However, this requires the development of a system of functions, methods and concepts of logistics for the development of "synthetic" principles of green logistics, the observance of which will ensure the achievement of both logistics goals and sustainable development goals.

We systematized the functions, methods and concepts of logistics for the logistics system, which is considered as a model of transport systems. The authors of this work understand the logistic system as a complex, organizationally-completed economic system consisting of functionally separate elements interconnected in a single process of promoting material and related service flows, information and financial flows [26]. Each of the logistic elements performs certain functions of influencing the logistic flows (Table 4). The performance of these functions is necessary to achieve the goals of the logistics elements for the passage and processing of logistics flows (Fig. 10). In relation to logistics systems, it is necessary to distinguish the following functions, the implementation of which is carried out depending on the level of logistic tasks to be solved [22]:

- key functions are management functions of logistic elements and the logistics system as a whole;
- basic functions are generalized functions of influence on logistic flows. These include: supply (input flows into the system); production (qualitative changes in flows); transportation (flow promotion); storage (accumulation or deceleration of flows); sales, distribution (the withdrawal of flows from the system with the conversion of material flows and service flows into financial flows);
- supporting functions are specific functions of each element of the logistics system, which, in turn, are a set of specific operations (actions) to change the parameters of logistic flows. As a result of the implementation of logistics operations and supporting functions, the basic logistics functions of the logistics system are implemented.

Table 4 Basic and supporting logistic functions

Logistic element (basic function of the element)	Supporting logistic functions
1. Input (receipt of logistics flows in the logistics system)	1.1. Research of the supply marketplace
	1.2. Flows requirement identification
	1.3 Delivering methods identification
	1.4. Supplies costs analysis
	1.5. Supplies quality analysis
	1.6. Supply planning
	1.7. Supply controlling
	1.8. Parameters correction (quality) flows or flow requirements
2. Output (disposal of logistics flows from the logistics system)	2.1. Marketing researching of sales area and market requirement determining in LS products
	2.2. Market requirement deter-mining in LS products
	2.3. Pricing
	2.4. Flow services formation
	2.5. Deliveries and services traffic planning
	2.6. Supply and service control
	2.7. Parameters of supplies and services controlling
3. Processing (processing, changing the quality properties of logistics flows)	3.1. Production planning
	3.2. Coordination of work of structural units
	3.3. Production and product quality management
	3.4. Personnel management
	3.5. Improvement of technical and technological support
	3.6. Production cost management
4. Cumulative (deceleration, accumulation and storage of logistics flows, inventory management)	4.1. Inventory level optimization
	4.2. Control and regulation of stock levels
	4.3. Material flows management, their distribution in LS
	4.4. Improvement of technical equipment and storage technology
	4.5. Flow processing quality management
5. Transport (promotion, acceleration of logistics flows)	5.1. Selection of optimal transportation schemes

(continued)

Table 4 (continued)

Logistic element (basic function of the element)	Supporting logistic functions
	5.2. The choice of a system for organizing the promotion of material flows
	5.3. Operational management of material flow parameters
	5.4. Improving the technical support of the transportation process
6. Manager (coordination of the functioning of logistics elements for processing and promotion of material flows and service flows using information and financial flows)	6.1. Logistic strategy development
	6.2. Organization of interaction and coordination of the work of LS elements
	6.3. Coordination and regulation of LS elements
	6.4. Formation of a favorable socio-economic environment of LS
	6.5. Monitoring the sustainable functioning of LS

The determination of logistic functions based on a structurally functional approach makes it possible to systematize the logistic principle and methods for achieving sustainable development goals. In addition, this will allow you to group well-known green methods and instruments according to two main characteristics—belonging to a logistics element that implements one of the basic logistics functions, and according to the effect of the method on logistics flows based on the implementation of key management functions of logistics elements. This will exclude duplication of green methods at various stages of the logistic process; will allow identifying and using promising green methods and instruments.

2. *The formation and development of transport systems and supply chains is based on the system use of green logistics principles, which is a synthesis of the principles of sustainable development with logistic principles.*

The results of the analysis [26, 31, 33, 46] of the principles of sustainable development and logistics show that at present there is no universal system of logistics principles, and most of the well-known and implemented in practice logistics principles are aimed at achieving the economic goals of the functioning of logistics systems. Such an approach contradicts the concept of sustainable development, the purpose of which is to create a balance between the economic, socio-cultural and environmental needs of society. Table 5 presents the analysis results of the shortcomings of the known sustainable development principles and logistics principles.

For the effective implementation of the sustainable development concept of transport systems and supply chains, the authors have synthesized the existing principles of logistics and principles of sustainable development. The new synthesized system

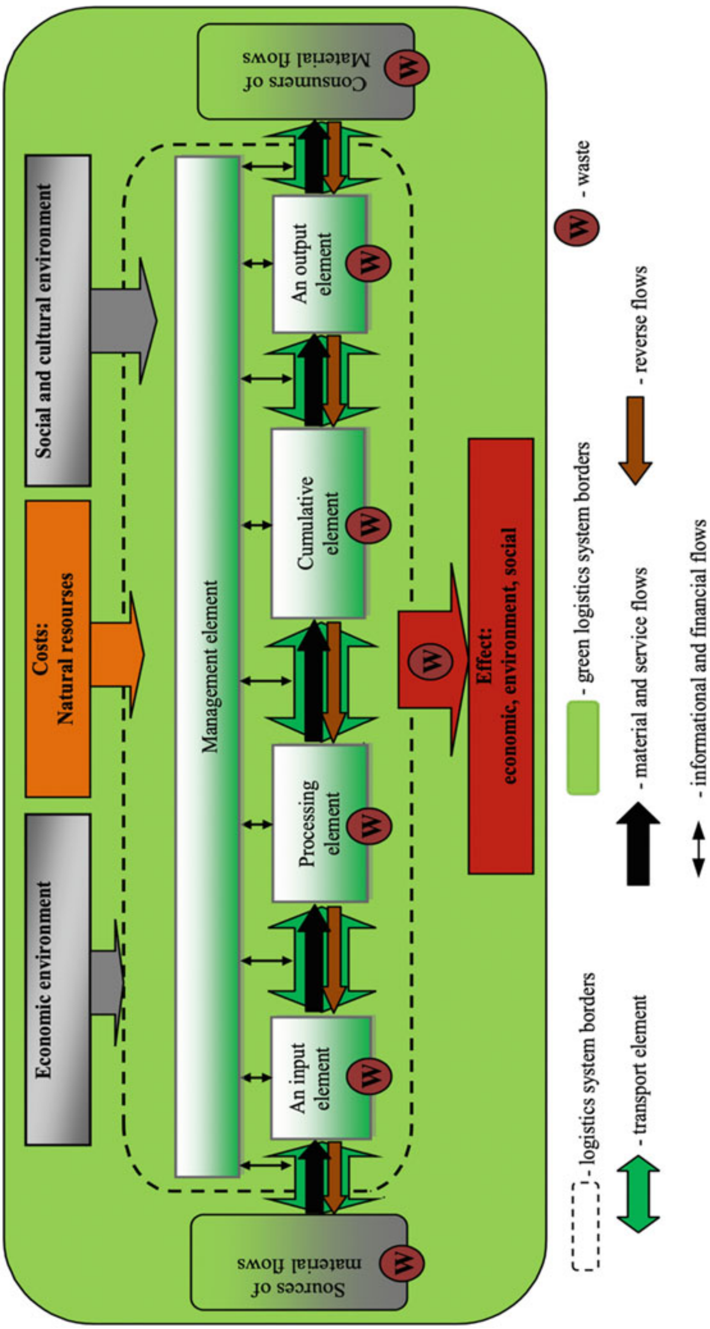


Fig. 10 Green logistic system diagram

Table 5 The results of the analysis of the shortcomings of the known principles of sustainable development and logistics principles

Principles of sustainable development	Logistics principles
1. **The lack of consistency** of generally accepted principles of sustainable development, expressed in the absence of their separation into environmental, economic and social aspects 2. **Differences in the interpretation** of the principles of sustainable development in the environmental legislation of different countries, leading to legal conflicts when transporting in international traffic 3. **The lack of concreteness** of the principles of sustainable development, which is the reason for the variety of methods and instruments for their implementation both at the state level and in the economic activities of companies	1. In scientific works there is a description of the set of logistic principles, but there is **no universal** accepted set (system) of logistic principles 2. A significant part of the logistics principles **is aimed at improving management efficiency** and achieving the economic goals of the functioning of the logistics system. This contradicts the principles of the concept of sustainable development, the purpose of which is to create a balance between the economic, socio-cultural and environmental needs of society 3. There is **no comprehensive and systematic** approach to the implementation of logistics principles in relation to the elements of the logistics system and their functions, logistics flows and levels of organization of logistics systems 4. **Numerous discrepancies in the applied terminology** and understanding of the essence of logistic principles, uneven use of these principles to regulate various types of logistics activities have been identified

of principles of green logistics is based on the idea of achieving a balance between the economic, environmental and socio-cultural sustainability of the logistics system.

Using the proposed system of principles in the practical activities of logistics and transport companies (in supply chain management) will allow us to efficiently develop and implement methods and instruments of green logistics, to ensure closer integration of supply chain elements, and as a result, to achieve the goals of the logistics system considering the requirements to reduce the harmful effects on the environment (Table 6).

3. *Achieving and maintaining a balance between the economic, environmental and social sustainability of the transport system is ensured by the implementation of the developed system of green logistics methods and instruments that affect the elements of the logistics system and logistics flows.*

The analysis [16, 33, 40] shows, currently found effective environmental solutions, including resource-saving and environmental-friendly solutions in the field of green logistics, are implemented haphazardly. Research is needed to develop a general theory of sustainable transport development and a system of methods and instruments for green logistics, in particular. The author's version of such a system is presented in [40, 125]. The proposed system of methods and instruments of green logistics is based on the study of factors of sustainable development of transport and logistics systems

Table 6 The system of green logistics principles [26]

Sustainability aspect	Principle name	The essence of the principle
Systematic sustainability	Principle of system	considering environmental, economic and socio-cultural aspects of the sustainable development of the logistics system and the relationships between them as a single system
	Adaptability principle	adaptation to the influence of external factors on the logistics system (to environmental changes) to maintain market sustainability and the effective use of advanced technologies
	Development principle	continuous and focused qualitative improvement of the structure and functions of the logistics system, methods, methods and instruments of green logistics
	Principle of self-organization	creation of conditions for the constant search and implementation of the found optimal environmental, economic and social solutions
Economic sustainability	Principle "polluter pays"	Compensation for environmental damage associated with the provision of logistics services at all stages of the promotion of material flow
	Justice principle	Proportional distribution between producers, sellers and carriers of the total benefits of meeting consumer demand
	The principle of efficiency and safety	Assessment of decisions in the field of the development of the logistics system in terms of economic efficiency, safety and the negative impact of the system on the environment

(continued)

Table 6 (continued)

Sustainability aspect	Principle name	The essence of the principle
	Optimality principle	The development of optimal solutions in the management of the logistics system is carried out on the basis of environmental costs as part of the total logistics costs
	The principle of non-waste and resource conservation	The maximum use of production waste, packaging and packaging as secondary raw materials or their environmentally friendly disposal, as well as the minimum use of raw materials and packaging not subject to reuse or safe disposal
Environmental sustainability	Principle of minimal impact	Reduction of negative environmental impact throughout the entire production, transportation, direct use and processing of material flows
	Principle of innovation	Introduction of innovative technologies in order to reduce the negative impact on the environment
	Rationality principle	Rational use of natural resources and all enterprise resources
	Sequence principle	The sequence of implementation of decisions on sustainable development of supply chains should correspond to the hierarchy of aspects of sustainable development: ecology -> economy -> society -> culture
	The principle "from particular to general"	The formation and development of a green logistics system is carried out sequentially—from a separate logistics element to the logistics chain or the logistics network as a whole

(continued)

Table 6 (continued)

Sustainability aspect	Principle name	The essence of the principle
Socio-cultural sustainability	Principle of responsibility	Increasing environmental responsibility of personnel and the formation of corporate environmental culture
	Transparency principle	Building relationships with customers and stakeholders based on interactivity, information and financial transparency
	Principle of reasonable consumption	The desire to reduce the transport needs of society and the state, not violating the rights and freedoms of movement and trade
	Competency principle	The formation and availability of competencies for all participants in the supply chain necessary for the sustainable development of these systems
	The principle of humanization	Compliance of logistic functions and operations with ergonomic, social, ethical requirements of staff

[13], as well as on the use of a structurally functional approach to the description of logistics and transport systems, involving the identification of the main (basic) and supporting functions of the elements of these systems [22].

The structural and functional approach used by the authors to systematize the well-known methods of green logistics is fundamentally different from the common way of distinguishing the functional areas of logistics: transport, marketing, production logistics, and supply and storage logistics. The disadvantage of this functional approach is the "linking" of logistics functions and operations to the infrastructure elements of the supply chain—warehouses, industrial enterprises, supply and sales departments, and transport. When using the functional approach to solving the problem of systematizing logistic methods, a situation arises when the same method of managing logistics flows is implemented in different functional areas of logistics. This is one of the main reasons for the inconsistent use of green logistics methods and instruments, when essentially the same methods and instruments are implemented on a different methodological basis, supported by various, often conflicting, and regulatory documents.

A typical example is the allocation in green logistics of a separate functional area—the so-called reverse logistics. In our opinion, such a separation is excessive, since the object of managing reverse logistics is also a material flow, consisting of production waste, packaging, secondary raw materials, but differing from the main material flow only in the direction of movement—it moves towards the main. In fact, the green methods of reverse flow control are implemented by the same logistic elements, the control object of which is the material flow.

The application of the structural-functional approach as the basis of the system of methods and instruments of green logistics allowed us to group the majority of well-known decisions in the field of ecology and resource conservation. Figure 11 presents the systems of methods of green logistics with the allocation of green logistics instruments in relation to the transport element of the logistics system.

The proposed method of systematizing the methods and instruments of green logistics is proposed to be used as a basis for assessing the effectiveness of the best practices in implementing environmental programs and projects in the activities of public and state institutions, business structures, research organizations and international associations. It is assumed that the result of such an assessment will be the expansion and improvement of this system of methods and instruments, which will ensure their coordinated practical application at various stages of the logistics process and at various levels of transport system and supply chain management.

5 Parameters and Indicators System of Logistic Flows in Green Supply Chains

The object of logistics research and management is a system of flows: material, information, financial and service flows. The traditional main goal of the logistic system is the promotion (processing) of flows with minimal costs, subject to timely satisfaction of consumer demand for high-quality goods and services. However, in the context of increasing anthropogenic impact on nature and the requirements of the world community to reduce the negative impact of transport on the environment, the "classic" goals of minimizing costs in the logistics system, without taking into account the environmental aspects of the functioning of logistics systems, are no longer relevant in modern world.

It is proposed that the goal of green logistics is to consider the quality maximization of the products and services provided by the logistics system, subject to the observance of economically justified costs of resources. The satisfaction of the social and environmental needs of society is also understood under the quality. For green supply chains, meeting these needs means increasing the timeliness and safety of transport, as well as reducing the flow of harmful environmental impacts. Achieving the goal of green logistics is limited by the consumed resources. The green technologies discussed in the third section make it possible the rational consumption of resources in green supply chains. Thus, a feature of managing logistics flows in green supply chains is the consideration of quality indicators of transport services (service flow), as well as the following material flows:

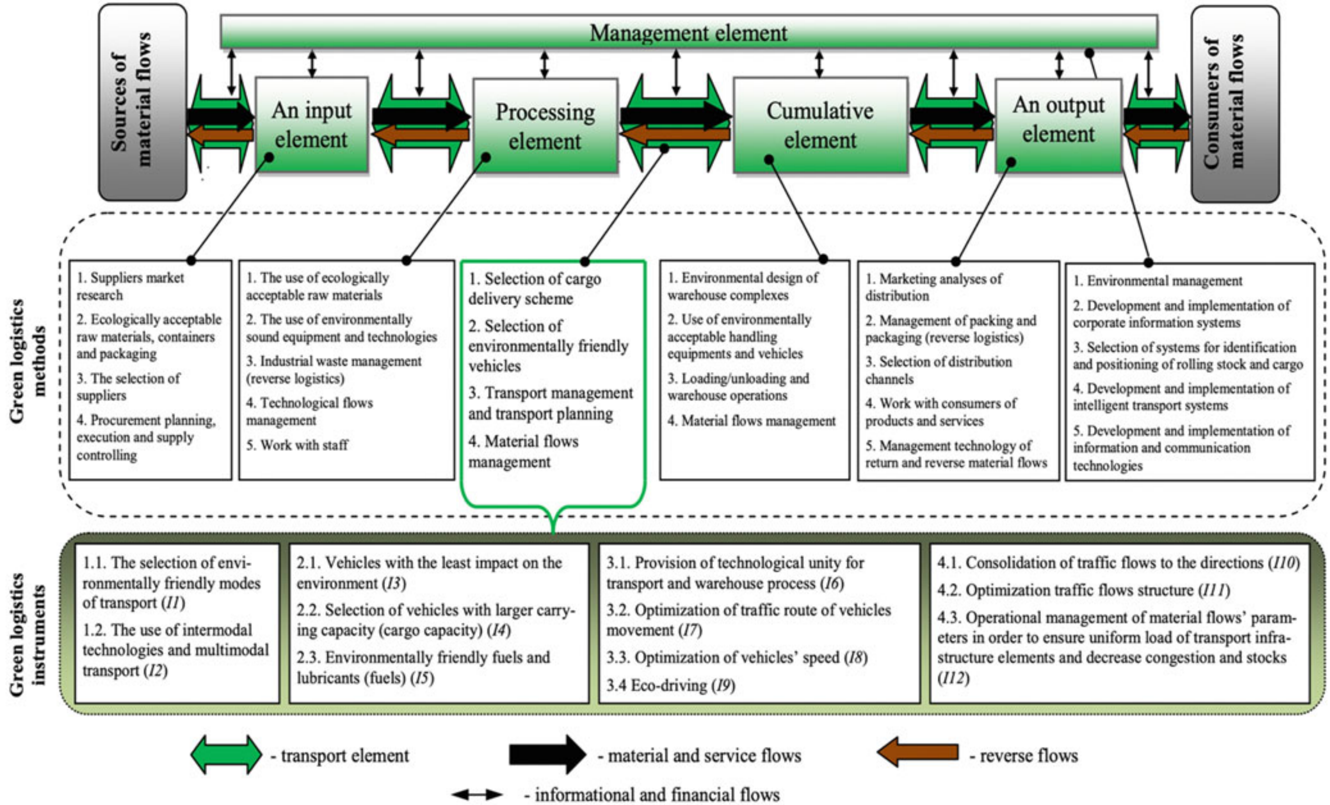


Fig. 11 Systematization scheme of green logistics methods and instruments (with the allocation of a system of green logistics instruments for the transport logistics element)

1. The flow of consumed primary and secondary energy resources. Without exception, all elements of the logistics system are consumers of non-renewable resources (fossil fuels) necessary for the implementation of logistics operations related to the generation, transformation, accumulation, storage, transportation and absorption of material and related information, financial and service flows. These resources directly (in the form of fuel for vehicles) or through energy conversion, transmission and distribution systems (power stations) in the form of electricity and heat are necessary to ensure the main and auxiliary technological processes.
2. The flow of polluting harmful substances. In the process of burning fuel, substances are released that have a negative effect on the biosphere. The main pollutants released into the atmosphere are sulfur dioxide (SO_2), nitric oxide (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter.
3. The flow of thermal energy into the surrounding space from the facilities of the logistics infrastructure, buildings and structures, vehicles. This effect contributes to the greenhouse effect and is one of the main causes of global warming.

The indicator "greenhouse gas emissions" is used in this work as the main parameter for assessing the flows of polluting pollutants and thermal energy. The calculation of this indicator is based on the guidelines of the IPCC (Intergovernmental Panel on Climate Change, IPCC) and the International Energy Agency (IEA) [126].

When developing a parameters and indicators system of logistic flows in green supply chains, the authors proceeded from the assumption that these flows, depending on the level of detail and at different levels of the control system, appear to be either discrete or continuous.

Discrete logistic flows are presented as a set of separate objects (elements or jets), for example, in the form of separate consignments or vehicles as part of a material flow or various logistic operations in a service flow. Such a presentation of logistics flows is necessary for the selection and implementation of logistics technologies at lower levels of management.

The presentation of logistic flows as continuous is used at the highest levels of management, for example, strategic, when the parameters of individual elements of the flow are not important, but it is necessary to operate with generalized (averaged) indicators, such as, for example, the intensity or average flow rate.

Given this approach, the authors propose using the following universal concepts on which the proposed parameters and indicators system of logistic flows in green supply chains is based (Fig. 12):

- logistic flow element—an elementary indivisible flow object that has certain properties;
- stream of the logistic flow—a part of the flow, which is a collection of elements that have the same (similar) properties;
- logistic flow—a set of jets perceived as a single whole and existing as a process at a certain time interval.

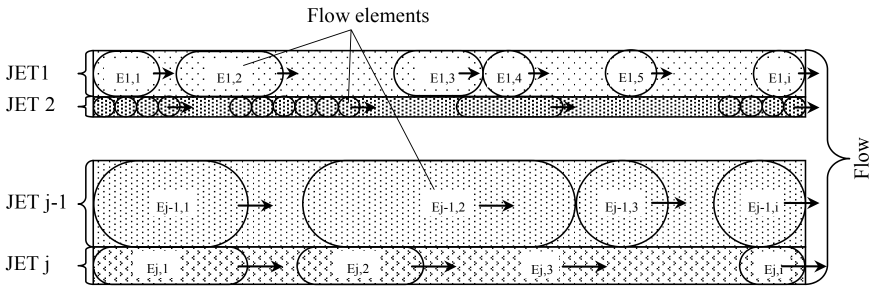


Fig. 12 Schematic diagram of the logistics flow structure

As an example, explaining Fig. 12, let us consider the movement of a material stream, consisting of the *j*th number of jets of various owners of rolling stock, delivering products of various nomenclatures and the *i*th number of E elements (trains, cars, marine vessels) involved in the carriage.

The difficulty of managing green supply chains lies in the insufficiently studied interrelations of indicators and parameters of logistics flows, in the absence of comprehensive assessment methods for many parameters and indicators of logistics flows. For example, making decisions to ensure timely delivery can lead to an increase in uneven flow of goods, which will negatively affect the energy intensity of the entire logistics process and the volume of greenhouse gas emissions. On the other hand, the desire to increase the coefficient of discreteness of the flow (to reduce the size of the transport-cargo parties) allows achieving a more uniform advancement of the flow, but leads to an increase in transport costs.

The authors propose a new approach to the management of green supply chains, based on the use of the original system of parameters and indicators to evaluate the parameters of logistics flows for compliance with the principles of sustainable development (Table 7). Five groups of parameters and indicators of logistics flows in green supply chains have been identified:

- the group of controlled (physical) parameters of logistic flows, characterizing the intensity of flows and the properties of changes in flows in space and time;
- the group of economic parameters of logistic flows characterizing the efficiency of use of all types of resources of the logistics system, as well as the degree of economic viability of the logistics system;
- the group of energy and environmental parameters characterizing the efficiency of energy use in the process of promoting flows and the impact of logistics flows on the environment;
- the group of parameters for quality assessment, characterizing the safety and timeliness of the promotion and processing of flows, as well as the quality of duct management;
- the group of statistical parameters, reflecting the patterns of change in the controlled parameters of flows.

Table 7 System of parameters and indicators of logistic flows in green supply chains

Group of parameters or indicators	Name of parameter or indicator	Characteristic
Group of controlled (physical) flow parameters	The mass (quantity) of flow	The total mass (number) of flow elements in motion along the flow route
	The length of the route	The total distance (the sum of the lengths of the $n - 1$ vectors that make up the route) that the flow element travels along the route
	The speed of flow	The ratio of the length of the route to the time of movement of the stream along the route (averaged characteristic of the speed of the jets of flow)
Group of economic indicators	Profit	The difference between total revenue and operating expenses
	Operating expenses	The sum of all types of expenses associated with the conversion of investments into profits
	Fixed investment	The amount of cash spent on the formation of fixed assets
The group of energy and environmental parameters	The energy intensity	The amount of energy spent on promoting the flow along the route
	Greenhouse gas emissions of CO_2	Total greenhouse gas emissions from all sources involved in promoting flow
The group of parameters for quality assessment	Safety of cargo transportation	Indicators characterizing transportation without damage, without pollution, without loss
	Timeliness of cargo transportation	Indicators characterizing the transportation of goods by the deadline, the frequency of arrival of goods and the urgency of transportation

(continued)

Table 7 (continued)

Group of parameters or indicators	Name of parameter or indicator	Characteristic
	The coefficient of flow controllability	The ratio of the mass of the information flow, the elements of which are messages on the indicators observance of transportation safety and timeliness, to the mass of the control information flow (the number of information-control messages)
The group of statistical parameters	The coefficient of flows irregularity	The deviation of the values of the physical parameters of the flows (jets, elements) from their average values
	The coefficient of flow structure complexity	It characterizes the number of jets that make up the logistic flow
	The coefficient of flow discreteness	It characterizes the number of elements that the flow consists of. It is calculated as the ratio of the time interval between flow elements to the minimum non-zero value of the interval at which the flow is considered continuous
	The coefficient of flow differentiability	It characterizes the change in the complexity of the flow structure in the process of its movement along the route. It is calculated as the ratio of the number of jets of the stream at the final point of the route of advancement of the flow to the number of jets at the starting point

The developed system of parameters and indicators of logistic flows in green supply chains is used in the proposed management system to evaluate flows and develop management decisions to change these parameters in order to achieve the goal of functioning of the green supply chain and the goals of the sustainable development concept as a whole.

6 Evaluation of Parameters and Indicators of Logistic Flows Using the Fuzzy AHP-TOPSIS Method

The values assessment of parameters and indicators of logistic flows in green supply chains is carried out in order to increase the efficiency of using green logistics instruments (green technologies) to ensure the sustainability of supply chains. In the present, the fuzzy AHP-TOPSIS combined method was used to perform this assessment.

The first use of fuzzy AHP based on triangular fuzzy numbers and the extent analysis method was described in [127] fuzzy AHP approach was presented by Chang [127], triangular fuzzy number (TFN) are preferred for pair wise comparison scale of fuzzy AHP and extent analysis method was used for the synthetic extent value of pair wise comparison. Later, the application of the fuzzy AHP approach is justified for solving the problems of sustainable transportation systems [128, 129], supply chain management [130, 131] and reverse logistics [132].

Using fuzzy AHP, unlike the basic method of hierarchy analysis (AHP) proposed by Tomas L. Saaty [133], eliminates such disadvantages as [134, 135]: unbalanced judgment scales, uncertainty, inaccuracy and subjectivity expert judgment, and ensure accuracy of ranking.

Since the authors have identified a lot of unsystematically applied instruments of green logistics, the problem arises of assessing the effectiveness of each instrument, that is, determining how the parameters and indicators of logistics flows change as a result of using one or another instrument. In fact, this task boils down to ranking the instruments in terms of efficiency. According to the authors, the best solution to this problem is achieved by using the fuzzy TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution)—a fuzzy method for determining the sequence number (or rank) of a solution depending on its proximity to the ideal solution. The TOPSIS approach chooses alternative that is closest to the positive ideal solution and farthest from the negative ideal solution. The "decision" in this study refers to the choice of a particular green logistics instrument.

For the first time, the use of the TOPSIS method was proposed in [136] with the goal of selecting the best alternative with a finite number of criteria. In [137, 138] presented a review of scientific publications in the field of using the TOPSIS method for solving various problems, among which the largest share falls on supply chain management and logistics and design, engineering and manufacturing systems. A number of works [131, 139–141] substantiate the use of fuzzy TOPSIS to solve multi criteria decision making problems under fuzzy environment and to manage with uncertainty in the judgments and evaluations of the decision makers.

The combination of AHP-TOPSIS methods allows you to improve the quality of assessment of decision makers in the selection and implementation of green logistics instruments. fuzzy AHP is used to determine the weight of parameters and indicators of logistic flows, and fuzzy TOPSIS is used to rank green logistics instruments, considering the influence of each instrument on these parameters and indicators.

Table 8 The system of parameters and indicators of logistics flows

Group of flow parameters (I hierarchy level)		Flow indicators (II level of hierarchy)	
Group of economic flow parameters	E	Profit	EI1
		Operating expenses	EI2
		Fixed investment	EI3
The group of energy and environmental parameters	EE	The energy intensity	EEI1
		Greenhouse gas emissions of CO_2	EEI2
The group of parameters for quality assessment	S	Safety of cargo transportation	SI1
		Timeliness of cargo transportation	SI2
		The coefficient of flow controllability	SI2
The group of statistical parameters	ST	The coefficient of flows irregularity	ST1
		The coefficient of complexity structure of flow	ST2
		The coefficient of flows discreteness	ST3
		The coefficient of differentiability of flow	ST4
Group of controlled (physical) flow parameters	M	The mass (quantity) of flow	MI1
		The speed of flow	MI2
		The length of the route	MI3

In order to use fuzzy AHP, it is necessary to present a system of parameters and indicators of logistic flows in the form of a multi-level hierarchical model. The components of the first level of the hierarchy are groups of parameters of logistics flows that correspond to the main aspects of the concept of sustainable development. The components of the second level of the hierarchy are 15 parameters and indicators of logistic flows (Table 8), the description of which is presented in paragraph 6 of this work.

The use of a triangular function, which is given by the relation:

$$\mu_M(x) = \begin{cases} 0, 0 \leq x \leq a \\ \frac{x-a}{b-a}, a \leq x \leq b \\ \frac{c-x}{c-b}, b \leq x \leq c \\ 0, c \leq x. \end{cases}, \tag{1}$$

where a is the left zero; b is the point at which the value of the membership function is 1; c is the right zero (Fig. 13).

Based on a summary of the studies [129, 131, 141] in this work, linguistic variables and triangular fuzzy numbers are accepted for evaluating the parameters and indicators of logistic flows (Table 9).

The construction of matrices for pair wise comparisons $\tilde{A}(\tilde{u}_{ij})$ is performed for all parameters and indicators of logistics flows in order to determine the relative importance of each pair of parameters (indicators) among themselves.

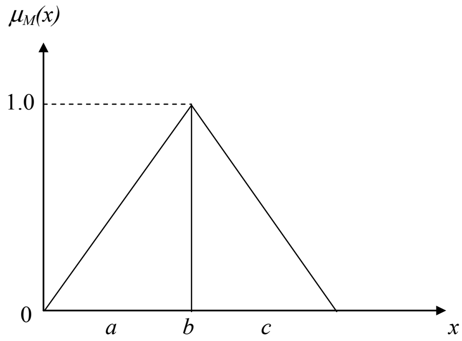


Fig. 13 Triangular membership function

Table 9 Fuzzy and linguistic variables for evaluating parameters and indicators of logistic flows

Fuzzy number	Linguistic term	Scale of fuzzy number
1	Equal importance	(1, 1, 3)
2	Moderate superiority	(1, 3, 5)
3	Significant superiority	(3, 5, 7)
4	Strong superiority	(5, 7,9)
5	Absolute superiority	(7, 9, 10)

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{u}_{12} & \tilde{u}_{13} & \cdots & \tilde{u}_{1(n-1)} & \tilde{u}_{1n} \\ \tilde{u}_{21} & 1 & \tilde{u}_{23} & \cdots & \tilde{u}_{2(n-1)} & \tilde{u}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \tilde{u}_{(n-1)1} & \tilde{u}_{(n-1)2} & \tilde{u}_{(n-1)3} & \cdots & 1 & \tilde{u}_{(n-1)n} \\ \tilde{u}_{n1} & \tilde{u}_{n2} & \tilde{u}_{n3} & \cdots & \tilde{u}_{n(n-1)} & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{u}_{12} & \tilde{u}_{13} & \cdots & \tilde{u}_{1(n-1)} & \tilde{u}_{1n} \\ 1\big/\tilde{u}_{12} & 1 & \tilde{u}_{23} & \cdots & \tilde{u}_{2(n-1)} & \tilde{u}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1/\tilde{u}_{1(n-1)} & 1/\tilde{u}_{2(n-1)} & 1/\tilde{u}_{3(n-1)} & \cdots & 1 & \tilde{u}_{(n-1)n} \\ 1/\tilde{u}_{1n} & 1/\tilde{u}_{2n} & 1/\tilde{u}_{3n} & \cdots & 1/\tilde{u}_{(n-1)n} & 1 \end{bmatrix}, \quad (2)$$

where

$$\tilde{u}_{ij} = \begin{cases} 1, i = j \\ 9^{-1}, 8^{-1}, 7^{-1}, 6^{-1}, 5^{-1}, 4^{-1}, 3^{-1}, 2^{-1}, 1^{-1}, 1, 2, 3, 4, 5, 6, 7, 8, 9, i \neq j \end{cases} \quad (3)$$

The values of fuzzy synthetic extent with respect to ith criterion is defined as

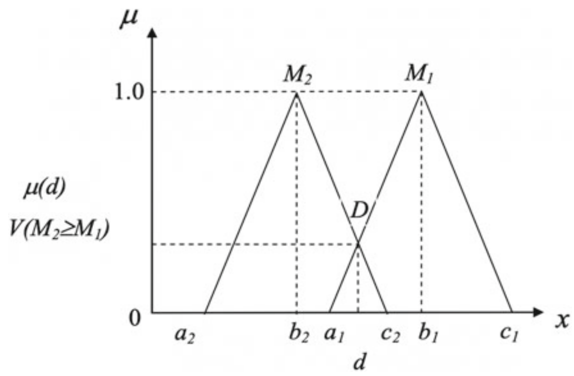


Fig. 14 The intersection between two fuzzy numbers M_1 and M_2

$$S_i = \sum_{j=1}^{m} \tilde{u}_{ij} \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{u}_{ij} \right]^{-1}, \tag{4}$$

where

$$\sum_{j=1}^{m} \tilde{u}_{ij} = \left(\sum_{j=1}^{m} a_j, \sum_{j=1}^{m} b_j, \sum_{j=1}^{m} c_j \right), \tag{5}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{u}_{ij} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} c_i}, \frac{1}{\sum_{i=1}^{n} b_i}, \frac{1}{\sum_{i=1}^{n} a_i} \right) \tag{6}$$

To obtain the estimates for the vectors of weights under each criterion, we need to consider a principle of comparison for fuzzy numbers (Fig. 14).

The degree of possibility of $M_2 = (a_2, b_2, c_2) > M_1 = (a_1, b_1, c_1)$ is defined as

$$V(M_2 \geq M_1) = \sup\left[\min\left(\mu_{M1(x)}, \mu_{M2(y)}\right)\right] = hgt(M_1 \cap M_2) = \mu_{M2(d)}, \tag{7}$$

$$\mu_M(d) = \begin{cases} 1, & if \quad b_2 \geq b_1 \\ 0, & if \quad a_1 \geq c_2 \\ \frac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)} & otherwise \end{cases}, \tag{8}$$

where d is the ordinate of the highest intersection point D between $\mu_{M1(x)}$ and $\mu_{M2(y)}$.

To compare M_1 and M_2, both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are needed.

The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i (i = 1, 2, 3, \ldots, k)$ can be defined by

$$V(M \geq M_1, M_2, \ldots, M_k) = V\big[(M \geq M_1)\ and\ (M \geq M_2)\ and \ldots and\ (M \geq M_k)\big] \\ = \min V(M \geq M_i), i = 1, 2, \ldots, k. \tag{9}$$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k), \quad for \quad k = 1, 2, \ldots, n; \quad k \neq i. \tag{10}$$

Then the weight vector is given by

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T, \tag{11}$$

where $A_i (i = 1, 2, 3, \ldots, n)$ vector of estimated parameters consisting of n elements.

Via normalization, the normalized weight vectors are

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T, \tag{12}$$

where W is a nonfuzzy number.

Thus, the result of applying the fuzzy AHP method is the weight of parameters and indicators of logistics flows in supply chains. These results are further used in the construction of a fuzzy model of logistics flows in supply chains (Sect. 7).

The fuzzy TOPSIS method is used to rank green logistics instruments by the degree of their influence on the performance of logistics flows in supply chains. In general, the sequence of stages of the execution of fuzzy TOPSIS includes the following actions [138, 141]:

1. Formation of decision matrix and rating criteria and alternatives.
2. Determination of criteria weight using various methods.
3. Normalization of the fuzzy solutions matrix.
4. Calculation of a weighted normalized matrix of fuzzy solutions.
5. Calculation of the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS).
6. Determining the distances from each alternative to FPIS and FNIS.
7. Calculation of the proximity coefficient CC_i for each alternative.
8. Ranking alternatives and choosing the best alternative.

The developed methodology for implementing the fuzzy TOPSIS method for solving the problem of ranking green logistics instruments includes the following steps.

1. Assigning ratings to criteria and alternatives. Suppose that there are m possible alternatives, called $I = \{I_1, I_2, I_3, \ldots, I_m\}$ alternatives, which are evaluated according to criteria $C = \{C_1, C_2, C_3, \ldots, C_n\}$ by a group of k decision makers $D = \{D_1, D_2, D_3, \ldots, D_k\}$.

Table 10 Green logistics instruments (for example, a transport element)

Instrument name	Designation
The selection of environmentally friendly modes of transport	I_1
The use of intermodal technologies and multimodal transport	I_2
Vehicles with the least impact on the environment	I_3
Selection of vehicles with larger carrying capacity (cargo capacity)	I_4
Environmentally friendly fuels and lubricants (fuels)	I_5
Provision of technological unity for transport and warehouse process	I_6
Optimization of traffic route of vehicles movement	I_7
Optimization of vehicles' speed	I_8
Eco-driving	I_9
Consolidation of traffic flows to the directions	I_{10}
Optimization of traffic flows structure	I_{11}
Operational management of material flows' parameters in order to ensure uniform load of transport infrastructure elements and decrease congestion and stocks	I_{12}

$$D = \begin{array}{c} \\ I_1 \\ I_2 \\ \vdots \\ I_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_1 & \cdots & C_1 \end{array} \\ \begin{pmatrix} r_{11} & r2 & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix} \end{array}, \tag{13}$$

where r_{mn} is the rating of alternatives I_m according to the criterion C_n, estimated by the k-th decision maker.

The green logistics instruments act as alternatives (Table 10).

2. Calculation of cumulative fuzzy scores for criteria and alternatives. If fuzzy estimates of all decision-makers are described as a triangular fuzzy number (Table 11), then the assessment of each criterion is determined by the formulas

Table 11 Linguistic variables and triangular fuzzy numbers for green instrument rating

Fuzzy number	Linguistic term	Triangular fuzzy number
1	Very poor	(1, 1, 3)
2	Poor	(1, 3, 5)
3	Fair	(3, 5, 7)
4	Good	(5, 7, 9)
5	Very good	(7, 9, 10)

$$a_{mnk} = \min_k\{a_{mnk}\},$$

$$b_{mnk} = \frac{1}{K}\sum_{K}^{1} b_{mnk}, \tag{14}$$

$$c_{mnk} = \max_k\{c_{mnk}\}.$$

3. Normalization of the fuzzy solutions matrix. The normalized matrix of fuzzy solutions will take the following form $R = \left[r_{ij}\right]_{m\times n}, \quad i = 1, 2, 3 \ldots, m; \quad j = 1, 2, 3 \ldots, n$

$$\text{benefit criteria} : r_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right) \quad u \quad c_j^+ = \max_i\left\{c_{ij}\right\}, \tag{15}$$

$$\text{cost criteria} : r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{c_{ij}}\right) \quad u \quad a_j^- = \min_i\left\{a_{ij}\right\}. \tag{16}$$

4. Calculation of a weighted normalized matrix. The weighted normalized matrix V is determined by the product of the weights of the evaluation criteria (w_j) by the normalized matrix of fuzzy solutions (r_{ij})

$$\begin{aligned} &V = \left[v_{ij}\right]_{m\times n}, \quad i = 1, 2, 3 \ldots, m; \quad j = 1, 2, 3 \ldots, n, \\ &V = r_{ij} \times w_j, \\ &\sum\nolimits_{i=1}^{n} w_j = 1. \end{aligned} \tag{17}$$

5. Calculation of a fuzzy positive ideal solution (FPIS) and a fuzzy negative ideal solution (FNIS)

$$A^+ = \left(v_1^+, v_2^+, \ldots, v_n^+\right), \quad v_j^+ = \max_i\left\{v_{ij}\right\}1, 2, 3 \ldots, m; \quad j = 1, 2, 3 \ldots, n, \tag{18}$$

$$A^- = \left(v_1^-, v_2^-, \ldots, v_n^-\right), \quad v_j^- = \min_i\left\{v_{ij}\right\}1, 2, 3 \ldots, m; \quad j = 1, 2, 3 \ldots, n. \tag{19}$$

6. Calculation of the distance of each alternative from FPIS and FNIS. The calculation of the distance (d_i^+,d_i^-) of each alternative A^+ and A^- is carried out according to the formulas

$$d_i^+ = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2 \right\}^{\frac{1}{2}}, \quad i = 1, 2, 3 \ldots, m, \tag{20}$$

$$d_i^- = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2 \right\}^{\frac{1}{2}}, \quad i = 1, 2, 3 \ldots, m. \tag{21}$$

7. Calculation of the closeness coefficient CC_i of each alternative. The proximity coefficient CC_i represents the distances to a fuzzy positive ideal solution (A^+) and a fuzzy negative ideal solution (A^-) at the same time

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+}, \quad i = 1, 2, 3 \ldots, m \tag{22}$$

8. Ranking alternatives. Alternatives are ranked according to proximity coefficient (CC_i) in descending order. The best alternative is the one closest to FPIS and the farthest from FNIS.

7 Fuzzy Model of Logistics Flows in Green Supply Chains

The fuzzy model of logistic flows in green supply chains described in this section is used for an integrated assessment of the supply chain's compliance with the goals of the concept of sustainable development. The value of the integral indicator of the sustainability of the supply chain is determined on the basis of a fuzzy assessment of the performance of logistics flows, taking into account the weight of these indicators calculated by the fuzzy AHP method.

The developed fuzzy model of logistics flows in green supply chains consists of the following elements: a diagram of the relationship of parameters and indicators of logistics flows; basic values of parameters and indicators for various modes of transport and transport system type; a set of membership functions for terms of linguistic variables that describe the parameters and indicators of logistics flows; a set of logical control rules.

A relationship diagram of parameters and indicators in the developed fuzzy model of logistics flows in green supply chains is presented in Fig. 15.

The proposed model contains three fuzzy input variables that correspond to the physical parameters of the flow—mass, flow velocity and length of its route. The values of the input variables are introduced into the model taking into account statistical data obtained on the basis of the analysis of the supply chain. Three intermediate

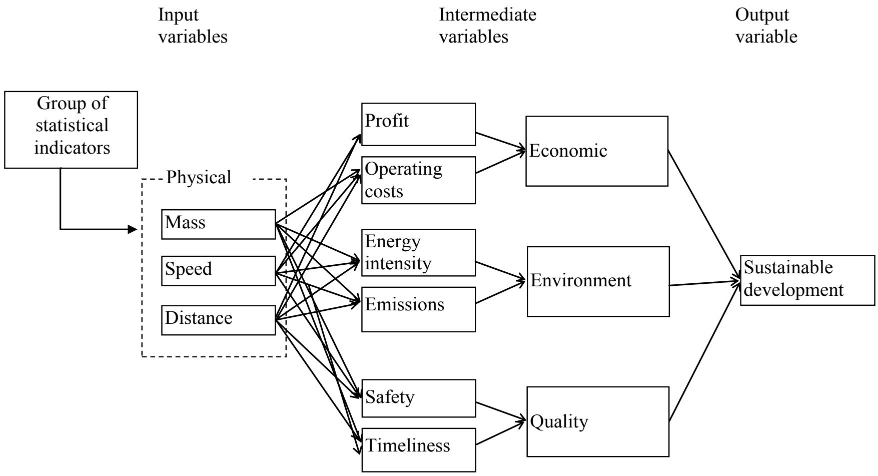


Fig. 15 Diagram of a fuzzy model for evaluating the parameters of logistics flows in green supply chains

groups of indicators are used as intermediate fuzzy linguistic variables—economic ("Economic"), energy-ecological ("Environment"), and quality indicators ("Quality"). Each group of indicators consists of two indicators, in accordance with Table 8. The output variable is the sustainability of the logistics flow.

The basic values of the parameters and indicators of logistic flows included in the fuzzy model depend on the transport type and the transport system type for which a specific fuzzy model is built. Basic values (ranges of values) of parameters and indicators of logistics flows for various modes of transport are presented in Tables 12, 13 and 14.

In the present study the national transport system was chosen as an example, within which the supply chain operates in inter-regional communication. The basic value of the "route length" parameter for such supply chains is presented in Table 15.

Table 12 The indicator value of logistics flows for various modes of transport[a]

Indicator	Truck	Railroad	Inland vessel	Aircraft
Profit (profitability), %	0–100			
Operating expenses	Average	Low	Low	High
Greenhouse gas emissions of CO_2, g/tkm	104	31	35	2030
The energy intensity, liter/100 tkm (at the rate of 1 L of gasoline—8.78 kW h of electricity)	5.1–9.2	0.7–1.0	0.6–1.4	51–73
Cargo transportation safety factor	0–1.0			
The coefficient of timeliness of transportation of goods	0–1.0			

[a]Based on [22, 36, 142, 143]

Table 13 The value of the parameter "mass of the logistic flow" for various modes of transport

Type of dispatch	Modes of transport			
	Truck	Railroad	Inland vessel	Aircraft
Small (small part)	10 kg < m < 5 t (or qγ/2)	20 kg < m < 20 t	m < 20 t	10–45 kg
Light tonnage	–	10-20 t	–	–
Large part	q auto (to 44 t)	–	–	–
Combined delivery	–	–	20 t	–
Carriage	–	q railway carriage		–
Ship	–	–	21,412 containers	–
Charter	–	–	–	to 130 t
Group	–	q wagon < m < Q route	–	–
Route	–	Q route (to 8050 t)	–	–

Table 14 The value of the parameter "logistic flow rate" for various modes of transport

Indicator	Modes of transport			
	Truck	Railroad	Inland vessel	Aircraft
Technical speed, km/h	15–60	35–45	25–35	450
The average speed of cargo delivery, km/day	450	260–370	280–300	10,000

Table 15 The value of the parameter "length of the route of the logistic flow" for various modes of transport

Indicator	Short	Average	Farther
Distance, km	10–200	200–800	800–2000

The type and parameters (definition domain) of membership functions for terms of linguistic variables [144, 145], describing the parameters and indicators of the developed fuzzy model, were determined by experts with knowledge in this field. In the process of debugging the model, as well as when changing the appearance of the transport system or supply chain, the type and parameters of membership functions can change.

In order to form a set of logical rules for the management of "if … then" the authors used the following rule, most often used in fuzzy choice systems

$$\text{Rule} < \# >: \text{IF} \ll \beta_1 \text{ is } a' \gg, \text{THEN} \ll \beta_2 \text{ is } a'' \gg .$$

The fuzzy saying «β_1 *is* a'» is a condition of this rule, and the fuzzy saying «β_2 *is* a''» is a fuzzy conclusion of this rule. A set of fuzzy inference rules is intended to formally represent empirical knowledge or expert knowledge. Such a set is usually presented in structured text form:

RULE_1: IF «*Condition_1*» THEN «*Conclusion_1*» (F_1);
RULE_2: IF «*Condition_2*» THEN «*Conclusion_2*» (F_2);
RULE_n: IF «*Condition_n*» THEN «*Conclusion_n*» (F_n).

Minimization of the deviation of the results of the logistic conclusion from the experimental data, that is, an increase in the accuracy of the results of the fuzzy model is ensured by its training, that is, an iterative change in the form and parameters of the membership functions of the fuzzy terms.

The fuzzyTECH program [145, 146] was chosen as an instrument for implementing the developed fuzzy model of parameters and indicators of logistic flows in green supply chains. This program is focused on solving the problems of modeling various objects and processes using the methods of the theory of fuzzy sets and fuzzy logic. The choice of the fuzzyTECH program is due to the presence in it, in addition to the standard for such a group of programs, fuzzy inference functions, and additional functions for generating program code for implementing the fuzzy inference system in one of the programming languages. The resulting software listings can when compiled in other computing platforms. This function is important for the development of the developed system for managing logistics flows in green supply chains by integrating a fuzzy inference system into a simulation model of logistics flows. It is assumed that such integration will automate the process of training and adjusting the fuzzy model with changes in the managed transport system or supply chain, and will also improve the accuracy of the fuzzy inference system.

8 Formation of a Logistics Flow Management System in Transport and Logistics Companies

The green logistics instruments presented in the previous sections, the selected parameters and indicators of logistics flows in the green supply chains, the method of estimating the weight of parameters and indicators of logistics flows—fuzzy-AHP and the ranking method of these parameters and indicators—fuzzy TOPSIS, a fuzzy model of the relationship of parameters and indicators—are the elements of a developed logistics flow management system.

The management process consists in monitoring the actual values of the parameters and indicators of logistics flows with the subsequent selection and implementation of green logistics instruments [40] in order to ensure the sustainability of the supply chain, that is, the compliance of its indicators with the goals of the concept of sustainable development. It is assumed that the result of the implementation of each instrument is a change in a certain combination of controlled parameters of logistics flows [47].

The presence of a wide variety of types of transport systems and supply chains makes it necessary to build a logistics flow management system that considers the specifics of these objects. The authors have developed a universal technique for the formation of a system for managing logistics flows, which includes the following steps (Fig. 16):

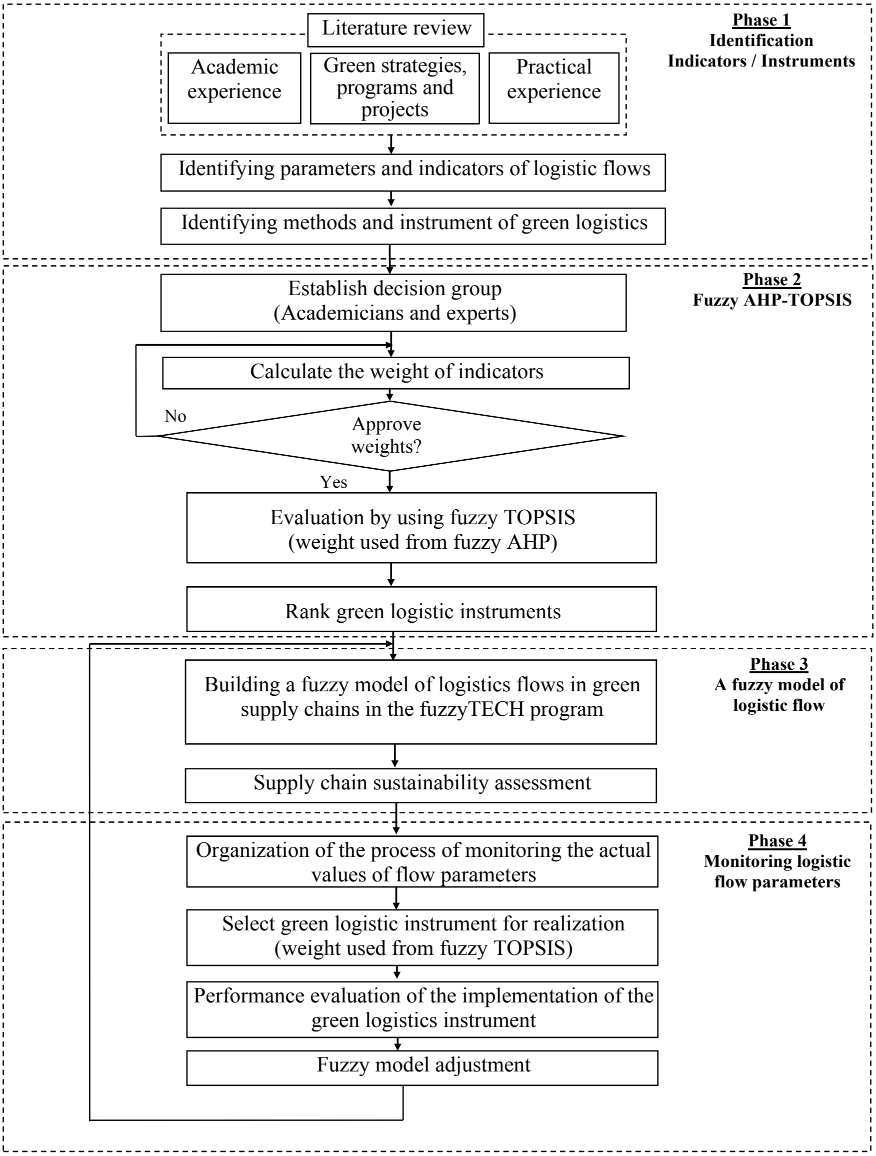


Fig. 16 Formation methodology for the system of managing the parameters of logistics flows in green supply chains

Stage 1. Refinement of parameters and indicators of logistic flows for a particular transport system or supply chain and selection of specific green logistics instruments. In most cases, it is recommended to use the system of green logistics instruments presented in Sect. 3 (Table 2) and the system of parameters and indicators of logistics flows presented in Sect. 5 (Table 7).

Stage 2. Ranking using fuzzy AHP-TOPSIS green logistics instruments according to the degree of influence on the performance of logistic flows.

Stage 3. Building a fuzzy model of logistics flows in green supply chains in a fuzzyTECH environment.

Stage 4. Organization of the process of monitoring the actual values of flow parameters with the subsequent selection using a fuzzy model of a specific instrument for green logistics. Implementation of the selected instrument, evaluation of the results and the actual effectiveness of the implemented instrument. Adjustment of the fuzzy inference model is repetition of the 3rd stage.

Since the methodology for performing the first and second stages is described in detail in Sect. 6, and the description of the fuzzy model (the third stage) for managing the parameters of logistics flows in green supply chains is described in Sect. 7, in more detail we will consider the contents of the fourth stage of the formation of a system for managing the parameters of logistics flows in green supply chains.

1. Based on the monitoring of supply chain logistics flows, the actual values of their indicators I_k are determined, where $k = 1,2, \ldots, K$, is the number of analyzed parameters and indicators of logistics flows.
2. The numerical actual values of the parameters and indicators of flows I_k are used as input in a fuzzy model of logistics flows to assess the sustainability of the supply chain. Figure 17 shows an example of a fuzzy model for estimating the parameters of logistic flows in fuzzyTECH for the selected supply chain at the level of the national transport system.
3. The results of modeling the relationship of parameters and flow indicators in a fuzzy model of logistic flows in green supply chains in fuzzyTECH are:
   - the value of the integral indicator of supply chain sustainability;
   - a surface describing the dependence of the integral indicator of the sustainability of the supply chain on changes in the values of physical parameters of material flows (mass, speed and route length), which are manageable in the developed control system.
4. Improving the sustainability of the supply chain is ensured by the implementation of green logistics instrument. The choice of an instrument is based on their rank, obtained by using the fuzzy AHP-TOPSIS methods.
5. As a result of applying the selected instrument, the values of the controlled parameters of the logistic flows change. The obtained value of these parameters is introduced into the model in order to assess the effectiveness of the selected instrument and its actual impact on the sustainability of the supply chain. Based on the results of evaluating the effectiveness of the implemented instrument, the model of the fuzzy choice is adjusted.

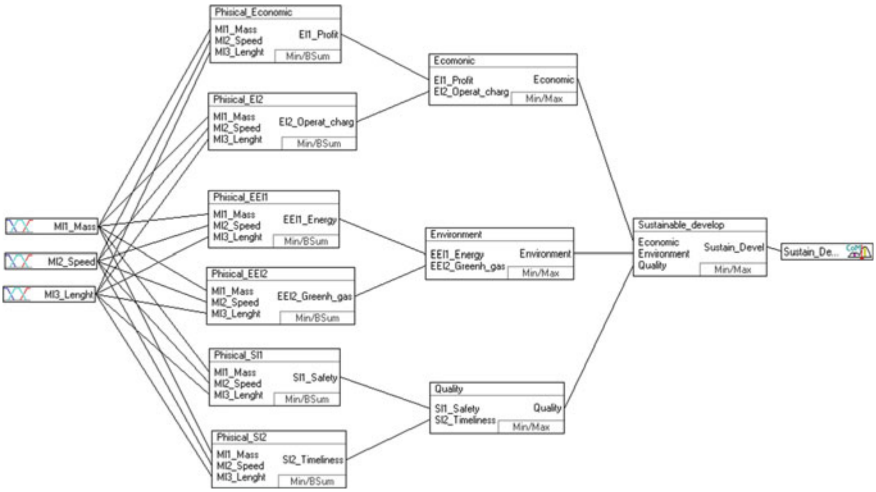


Fig. 17 Presentation of a fuzzy model for evaluating the parameters of logistics flows in the fuzzyTECH program

In the process of creating a system for managing logistics flows in green supply chains, the 5th stage of the presented methodology for implementing the fuzzy inference model can be implemented using a simulation model of the supply chain. Using the simulation model in the formation of the flow management system allows you to effectively train a fuzzy model of logistics flows, and in the process of operating the formed control system, you can predict changes in the parameters and indicators of logistics flows and plan, based on forecasts, the optimal sequence of implementation of green logistics instruments.

9 An Example of Using the Methodology for Managing the Parameters of Logistics Flows in Green Supply Chains

In the presented example, the supply chain operating within the national transport system is used as the control object.

1. Based on the literature review and practice of implementing green logistics instruments in supply chain management, 12 green logistics instruments were selected (Table 10). Assessment of logistics flows was carried out according to 5 groups of parameters and 15 indicators in accordance with aspects of the concept of sustainable development (Table 8).
2. As academic decision makers, 7 academic experts were selected. The experts evaluated the parameters and indicators of logistic flows using linguistic variables

and triangular fuzzy numbers. The final results of fuzzy AHP in the form of the fuzzy aggregated decision matrix for evaluating the parameters and indicators of logistic flows with weighting coefficients are presented in Tables 16, 17, 18, 19, 20 and 21. Designations of parameters and indicators of logistics flows are adopted in accordance with Table 8.

As an example, the calculation of the value of the fuzzy synthetic extent (The extent) according to the Formulas (4–6) for the groups of parameters of the logistics flows (Table 22).

The results of calculated degree of possibility of criteria (V-values) using Formulas 7–8 for groups of logistic parameters are presented in Table 23.

The degree of possibility for each parameter is calculated by Formula (9).

Table 16 Calculated fuzzy aggregated decision matrix of logistic flow parameters

Parameters	E	EE	S	ST	M	Weight	Rank
E	(1, 1, 1)	(1.12, 1.85, 2.69)	(0.19, 0.27, 0.43)	(3.97, 6.20, 8.27)	(0.19, 0.29, 0.46)	0.2538	2
EE	(0.37, 0.54, 0.89)	(1, 1, 1)	(1.37, 2.09, 4.11)	(2.44, 3.51, 5.92)	(0.21, 0.32, 0.58)	0.2219	4
S	(2.17, 3.47, 5.05)	(0.24, 0.43, 0.73)	(1, 1, 1)	(2.17, 2.76, 5.23)	(0.85, 1.26, 2.47)	0.2474	3
ST	(0.12, 0.16, 0.25)	(0.17, 0.28, 0.41)	(0.19, 0.36, 0.46)	(1, 1, 1)	(0.32, 0.39, 0.86)	0.0005	5
M	(2.17, 3.48, 5.05)	(1.72, 3.08, 4.64)	(0.40, 0.79, 1.17)	(1.15, 2.56, 3.11)	(1, 1, 1)	0.2764	1

Table 17 Calculated fuzzy aggregated decision matrix of economic indicators of logistics flows

Indicators	EI1	EI2	EI3	Weight	Rank
EI1	(1, 1, 1)	(2.27, 3.64, 4.96)	(1.58, 2.86, 4.11)	0.7572	1
EI2	(0.20, 0.27, 0.44)	(1, 1, 1)	(0.43, 0.69, 1.16)	0.0151	3
EI3	(0.24, 0.35, 0.63)	(0.86, 1.46, 2.30)	(1, 1, 1)	0.2277	2

Table 18 Calculated fuzzy aggregated decision matrix of energy and environmental indicators of logistics flows

Indicators	EEI1	EEI2	Weight	Rank
EEI1	(1, 1, 1)	(1.87, 3.31, 5.24)	0.9862	1
EEI2	(0.19, 0.30, 0.53)	(1, 1, 1)	0.0138	2

Table 19 Calculated fuzzy aggregated decision matrix of quality indicators of logistics flows

Indicators	SI1	SI2	SI3	Weight	Rank
SI1	(1, 1, 1)	(1.27, 1.70, 2.30)	(0.85, 1.72, 2.86)	0.4478	1
SI2	(0.43, 0.59, 0.79)	(1, 1, 1)	(0.72, 1.40, 2.09)	0.0349	3
SI3	(0.35, 0.58, 1.17)	(0.48, 0.71, 1.39)	(1, 1, 1)	0.2473	2

Table 20 Calculated fuzzy aggregated decision matrix of statistical indicators of logistics flows

Indicators	STI1	STI2	STI3	STI4	Weight	Rank
STI1	(1, 1, 1)	(1.47, 2.02, 2.43)	(1.04, 1.72, 2.36)	(1.26, 1.81, 2.17)	0.4116	1
STI2	(0.41, 0.49, 0.68)	(1, 1, 1)	(0.87, 1.54, 2.45)	(1.37, 2.17, 2.76)	0.3290	2
STI3	(0.42, 0.58, 0.96)	(0.41, 0.65, 1.13)	(1, 1, 1)	(0.96, 1.17, 1.51)	0.1747	3
STI4	(0.46, 0.55, 0.79)	(0.36, 0.46, 0.73)	(0.66, 0.85, 1.04)	(1, 1, 1)	0.0846	4

Table 21 Calculated fuzzy aggregated decision matrix of managed logistics flow parameters

Indicators	MI1	MI2	MI3	Weight	Rank
MI1	(1, 1, 1)	(0.95, 1.29, 1.90)	(1.70, 2.57, 3.96)	0.4507	2
MI2	(0.53, 0.78, 1.05)	(1, 1, 1)	(2.36, 4.53, 6.59)	0.5447	1
MI3	(0.25, 0.39, 0.59)	(0.15, 0.22, 0.42)	(1, 1, 1)	0.0046	3

Table 22 Values of fuzzy synthetic extent

Parameters	$\sum_{j=1}^{m} \tilde{u}_{ij} = \left(\sum_{j=1}^{m} a_j, \sum_{j=1}^{m} b_j, \sum_{j=1}^{m} c_j\right)$	$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{u}_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} c_i}, \frac{1}{\sum_{i=1}^{n} b_i}, \frac{1}{\sum_{i=1}^{n} a_i}\right)$	S_i
E	(6.4773, 9.6169, 12.8589)	(1/57.8058, 1/39.1306, 1/26.5671)	(0.11205, 0.24576, 0.48402)
EE	(5.4023, 7.4697, 12.5095)	(1/57.8058, 1/39.1306, 1/26.5671)	(0.09346, 0.19089, 0.47086)
S	(6.4337, 8.9299, 14.4818)	(1/57.8058, 1/39.1306, 1/26.5671)	(0.1113, 0.22821, 0.5451)
ST	(1.8021, 2.1975, 2.9859)	(1/57.8058, 1/39.1306, 1/26.5671)	(0.03118, 0.05616, 0.11239)
M	(6.4518, 10.9166, 14.9697)	(1/57.8058, 1/39.1306, 1/26.5671)	(0.11161, 0.27898, 0.56347)

Table 23 Calculated degree of possibility of criteria (V-values)

Parameters	E	EE	S	ST	M
E	–	1	1	1	0.91811
EE	0.86736	–	0.90598	1	0.80309
S	0.96104	1	–	1	0.89516
ST	0.00177	0.12322	0.00631	–	0.00349
M	1	1	1	1	–

$$d'(E) = \min V(S_i = S_k) = \min(1,\ 1,\ 1,\ 0.91811) = 0.91811.$$

For other parameters, the values will be equal $d'(EE) = 0.80309$, $d'(S) = 0.89516$, $d'(ST) = 0.00349$, $d'(M) = 1$.

The weight vector of each criteria is given by

$$W' = 0.91811, 0.80309, 0.89516, 0.00177, 1.$$

Via normalization of weight vector, the final weight vector obtained as

$$W = 0.25375, 0.22196, 0.24741, 0.00049, 0.27639$$

Similar calculations are carried out for each group of parameters of logistics flows. The final results of calculating the weighting coefficients of the parameters and indicators of logistics flows are presented in Table 24.

3. In order to rank the green logistics instruments using fuzzy TOPSIS, experts evaluated the instruments using triangular fuzzy numbers (Table 11).

In order to calculate the total matrix of fuzzy decisions, Formula (14) is used. The results of calculating the total fuzzy score for indicators of logistics flows and green logistics instruments are presented in Table 25.

Taking into account the criteria of benefit or cost, in accordance with Formulas (15) and (16), normalization of fuzzy decisions was performed (Table 26).

In order to calculate the weighted normalized matrix, we use the weight coefficients of the logistic flow indicators obtained as a result of applying the fuzzy AHP method (Table 24). The calculation results are presented in Table 27.

After determining the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS) using Formulas (18) and (19), the distance (d_i^+, d_i^-) for each alternative from FPIS and FNIS is calculated using the Formulas (20) and (21). Using the proximity coefficient (CC_i) calculated by Formula (22), the ranking of green logistics instruments is performed (Table 28).

The ranking results of green logistics instruments by their degree of impact on the parameters and indicators of logistics flows are used when choosing an instrument to adjust the actual values of the indicators of logistics flows in accordance with the requirements of the sustainable development concept.

Table 24 Final ranking parameters and indicators of logistics flows

Criterion	Weight	Sub-criteria	Weight	Finalized weight	Global Rank
Group of economic flow parameters (E)	0.2538	EI1	0.75726	0.19216	2
		EI2	0.01508	0.00383	9
		EI3	0.22766	0.05777	8
The group of energy and environmental parameters (EE)	0.2220	EEI1	0.98622	0.21890	1
		EEI2	0.01378	0.00306	10
The group of parameters for quality assessment (S)	0.2474	SI1	0.44784	0.11080	5
		SI2	0.30491	0.07544	6
		SI3	0.24725	0.06117	7
The group of statistical parameters (ST)	0.0005	ST1	0.41160	0.00020	12
		ST2	0.32903	0.00016	13
		ST3	0.17474	0.00009	14
		ST4	0.08463	0.00004	15
Group of controlled (physical) flow parameters (M)	0.2764	MI1	0.45068	0.12456	4
		MI2	0.54476	0.15056	3
		MI3	0.00456	0.00126	11

We try to consider, as an example, the implementation of the proposed methodology for managing the parameters of logistics flows in green supply chains. Transportation of goods in the supply chain between the cities of Moscow and Yekaterinburg (the Russian Federation) is carried out using road transport. Actual supply chain metrics are presented in Table 29.

By substituting the actual flow indicators into the developed fuzzy inference model, we obtained surfaces describing the influence of fuzzy values of the controlled parameters of logistic flows on the value of supply chain sustainability (Fig. 18).

Based on the analysis of the actual values of the flow indicators, indicators are selected that do not meet the environmental requirements: increased energy intensity; high greenhouse gas emissions. In order to bring the indicators of logistics flows in line with the required values, a green logistics instrument is selected.

The analysis of the possibilities of implementing green logistics instruments, as applied to the supply chain under consideration, allowed us to identify 4 instrument: optimization of speed (I_8); route optimization (I_7); use of vehicles with a higher carrying capacity (I_4); the use of environmentally friendly modes of transport (I_1). The implementation of the remaining green logistics instruments for the analyzed conditions is not advisable.

As a result of the possible implementation of each instrument, new values of the controlled parameters were determined (Table 30).

As an example Fig. 19 demonstrates surfaces that describe the effect of fuzzy values of the controlled parameters of logistics flows on the sustainability of the supply chain when implementing the instruments "Optimization of the route of movement"

Table 25 Calculated aggregate fuzzy decisions matrix of green logistics instruments

Green logistics instruments	Logistics flow indicators						
	EI1	EI2	EI3	…	MI1	MI2	MI3
I_1	(3, 5.67, 9)	(5, 7.67, 10)	(5, 8.33, 10)	…	(1, 5, 9)	(1, 5, 9)	(3, 5.67, 9)
I_2	(5, 7.67, 10)	(3, 6.33, 10)	(5, 7, 9)	…	(1, 4.33, 9)	(3, 6.33, 9)	(3, 7, 10)
I_3	(1, 4.33, 9)	(1, 5.67, 9)	(3, 6.33, 10)	…	(1, 3.66, 7)	(1, 3.67, 7)	(1, 3.67, 7)
I_4	(3, 5.67, 9)	(3, 7, 10)	(1, 6.33, 10)	…	(5, 7, 9)	(1, 3.67, 9)	(1, 1.67, 5)
I_5	(3, 5.67, 9)	(3, 6.33, 9)	(1, 3, 7)	…	(1, 1, 3)	(1, 2.33, 5)	(1, 1, 3)
I_6	(1, 5.67, 10)	(3, 7, 10)	(1, 5, 9)	…	(1, 3.67, 9)	(1, 5, 9)	(1, 3.67, 7)
I_7	(1, 5, 9)	(3, 5.67, 9)	(1, 3, 7)	…	(1, 2.33, 7)	(1, 5, 9)	(1, 5.67, 10)
I_8	(1, 5, 10)	(1, 5, 9)	(1, 1.67, 5)	…	(1, 2.33, 5)	(7, 9, 10)	(1, 3, 7)
I_9	(1, 2.33, 5)	(1, 3.67, 7)	(1, 1, 3)	…	(1, 1.67, 5)	(1, 5, 9)	(1, 2.33, 7)
I_{10}	(1, 4.33, 7)	(1, 5.67, 9)	(1, 1.67, 5)	…	(5, 7.66, 10)	(1, 5, 9)	(1, 5.67, 9)
I_{11}	(1, 5.67, 9	(1, 5, 9)	(1, 2.33, 5)	…	(3, 5, 7)	(1, 6.33, 10)	(1, 3.67, 7)
I_{12}	(1, 4.33, 9)	(1, 5, 9)	(1, 2.33, 5)	…	(1, 5, 9)	(3, 6.33, 9)	(3, 5.67, 9)

(the least sustainability is 0.1357) and "Use of environmentally friendly modes of transport" (the highest sustainability is 0.4027).

Thus, in order to bring the indicators of logistics flows in line with the required values, the most effective instrument is the "Use of environmentally friendly modes of transport" (transition from road to rail). The least effective is the "Vehicle route optimization" instrument.

10 Conclusion

For the effective implementation of the sustainable development concept in logistics and supply chain management, methods are needed to develop managerial decisions to change the parameters of logistics flows based on the measurement and evaluation

Table 26 Normalized fuzzy decisions matrix of green logistics instruments

Green logistics instruments	Logistics flow indicators				
	EI1	EI2	EI3	…	MI3
I_1	(0.3, 0.567, 0.9)	(0.2, 0.130, 0.1)	(0.5, 0.833, 1)	…	(0.333, 0.177, 0.111)
I_2	(0.5, 0.767, 1)	(0.333, 0.158, 0.1)	(0.5, 0.7, 0.9)	…	(0.333, 0.143, 0.1)
I_3	(0.1, 0,433, 0.9)	(1, 0.177, 0.111)	(0.3, 0.633, 1)	…	(1, 0.273, 0.143)
I_4	(0.3, 0.567, 0.9)	(0.333, 0.143, 0.1)	(0.1, 0.633, 1)	…	(1, 0.6, 0.2)
I_5	(0.3, 0.567, 0.9)	(0.333, 0.158, 0.111)	(0.1, 0.3, 0.7)	…	(1, 1, 0.333)
I_6	(0.1, 0.567, 1)	(0,333, 0.143, 0.1)	(0.1, 0.5, 0.9)	…	(1, 0.273, 0.143)
I_7	(0.1, 0.5, 0.9)	(0.333, 0.176, 0.111)	(0.1, 0.3, 0.7)	…	(1, 0.177, 0.1)
I_8	(0.1, 0.5, 1)	(1, 0.2, 0.111)	(0.1, 0.167, 0.5)	…	(1, 0.333, 0.143)
I_9	(0.1, 0.233, 0.5)	(1, 0.273, 0.143)	(0.1, 0.1, 0.3)	…	(1, 0429, 0.143)
I_{10}	(0.1, 0.433, 0.7)	(1, 0.176, 0.111)	(0.1, 0.167, 0.5)	…	(1, 0.177, 0.111)
I_{11}	(0.1, 0.567, 0.9)	(1, 0.2, 0.111)	(0.1, 0.233, 0.5)	…	(1, 0.273, 0.143)
I_{12}	(0.1, 0.433, 0.9)	(1, 0.2, 0.111)	(0.1, 0.233, 0.5)	…	(0.333, 0.177, 0.111)

of their indicators. As the analysis of scientific literature shows, the difficulty of managing green supply chains perform:

1. The lack of a universal system of logistics principles that ensure the formation of a balance between the economic, social and environmental sustainability of the logistics system;
2. A variety of approaches and views on the content of the methods and instruments of green logistics, which is the reason for the lack of systematic implementation in practical activities;
3. Lack of an integrated and systematic approach to the assessment of all types of logistics flows, based on taking into account the relationship between indicators and flow parameters from the perspective of the sustainable development concept.

The study presents the concept of managing logistics flows in green supply chains. The concept is based on the idea of achieving a balance between the economic, environmental and social sustainability of the logistics system or supply chain. The formation of such a system should be based on the following provisions:

Table 27 Weighted normalized fuzzy decisions matrix of green logistics instruments

Green logistics instruments	Logistics flow indicators				
	EI1	EI2	EI3	…	MI3
I_1	(0.0576, 0.1089, 0.1729)	(0.0008, 0.0005, 0.0004)	(0.0289, 0.0481, 0.0578)	…	(0.0004, 0.0002, 0.0001)
I_2	(0.0961, 0.1473, 0.1922)	(0.0013, 0.0006, 0.0004)	(0.0289, 0.0404, 0.052)	…	(0.0004, 0.0002, 0.0001)
I_3	(0.0192, 0.0833, 0.1729)	(0.0038, 0.0007, 0.0004)	(0.0173, 0.0366, 0.0578)	…	(0.0013, 0.0003, 0.0002)
I_4	(0.0576, 0.1089, 0.1729)	(0.0013, 0.0005, 0.0004)	(0.0058, 0.0366, 0.0578)	…	(0.0013, 0.0008, 0.0003)
I_5	(0.0576, 0.1089, 0.1729)	(0.0013, 0.0006, 0.0004)	(0.0058, 0.0173, 0.0404)	…	(0.0013, 0.0013, 0.0004)
I_6	(0.0192, 0.1089, 0.1922)	(0.0013, 0.0005, 0.0004)	(0.0058, 0.0289, 0.052)	…	(0.0013, 0.0003, 0.0002)
I_7	(0.0192, 0.0961, 0.1729)	(0.0013, 0.0007, 0.0004)	(0.0058, 0.0173, 0.0404)	…	(0.0013, 0.0002, 0.0001)
I_8	(0.0192, 0.0961, 0.1922)	(0.0038, 0.0008, 0.0004)	(0.0058, 0.0096, 0.0289)	…	(0.0013, 0.0004, 0.0002)
I_9	(0.0192, 0.0448, 0.0961	(0.0038, 0.001, 0.0005)	(0.0058, 0.0058, 0.0173)	…	(0.0013, 0.0005, 0.0002)
I_{10}	(0.0192, 0.0833, 0.1345)	(0.0038, 0.0007, 0.0004)	(0.0058, 0.0096, 0.0289)	…	(0.0013, 0.0002, 0.0001)
I_{11}	(0.0192, 0.1089, 0.1729)	(0.0038, 0.0008, 0.0004)	(0.0058, 0.0135, 0.0289)	…	(0.0013, 0.0003, 0.0002)
I_{12}	(0.0192, 0.0833, 0.1729)	(0.0038, 0.0008, 0.0004)	(0.0058, 0.0135, 0.0289)	…	(0.0004, 0.0002, 0.0001)

- the achievement of sustainable development goals in the operation of transport systems and supply chains is achieved by bringing the goals, methods and principles of green logistics into conformity with the goals and objectives of the organization's economic activity;

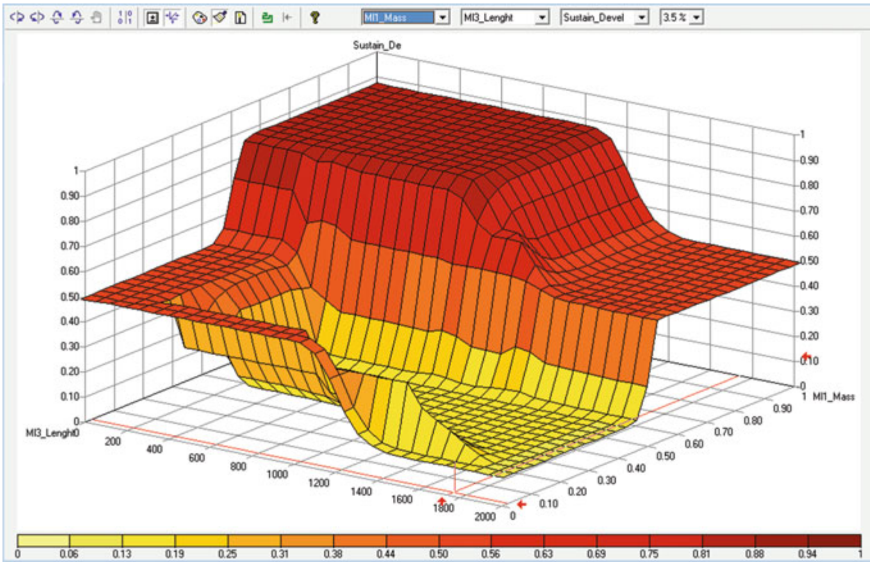
Table 28 Closeness coefficient (CC_i) and final ranking of green logistics instruments

Instrument name	d*	d−	*CCi*	Rank
Use of environmentally friendly modes of transport (I_1)	0.33340	0.24577	0.42435	9
Use of intermodal technologies and multimodal transport (I_2)	0.21181	0.35647	0.62728	2
Use of vehicles with the least environmental impact (I_3)	0.35483	0.23381	0.39721	10
Choosing a vehicle with a higher carrying capacity (cargo capacity) (I_4)	0.30776	0.28637	0.48199	7
The use of environmentally friendly fuels and lubricants (fuels) (I_5)	0.45339	0.09608	0.17487	12
Ensuring technological unity of the transport and storage process (I_6)	0.19521	0.41659	0.68092	1
Vehicle route optimization (I_7)	0.26767	0.33436	0.55539	5
Vehicle speed optimization (I_8)	0.23209	0.35363	0.60375	3
Eco driving (I_9)	0.37680	0.19040	0.33568	11
Consolidation of cargo flows in the directions (I_{10})	0.31117	0.26853	0.46321	8
Optimization of cargo flow structure (I_{11})	0.24126	0.36324	0.60089	4
Operational management of material flow parameters to ensure uniform loading of transport infrastructure elements, reduce congestion and inventory (I_{12})	0.28198	0.30005	0.51553	6

Table 29 Input data for modeling green supply chain flows

Indicators and parameters of logistics flows	Actual values of indicators and parameters (I_k)
Flow controllability coefficient	0.8
Flow irregularity coefficient	1.1
The complexity factor of the flow structure	0.9
Discrete flow rate	0.9
Flow differentiability coefficient	1.0
Flow mass, t	200
The flow rate, km/day	400
The length of the flow route, km	1850
Integral indicator of supply chain sustainability	0.125 (low)

(a) Mass – Route length –Sustainability



(b) Speed – Route Length – Sustainability

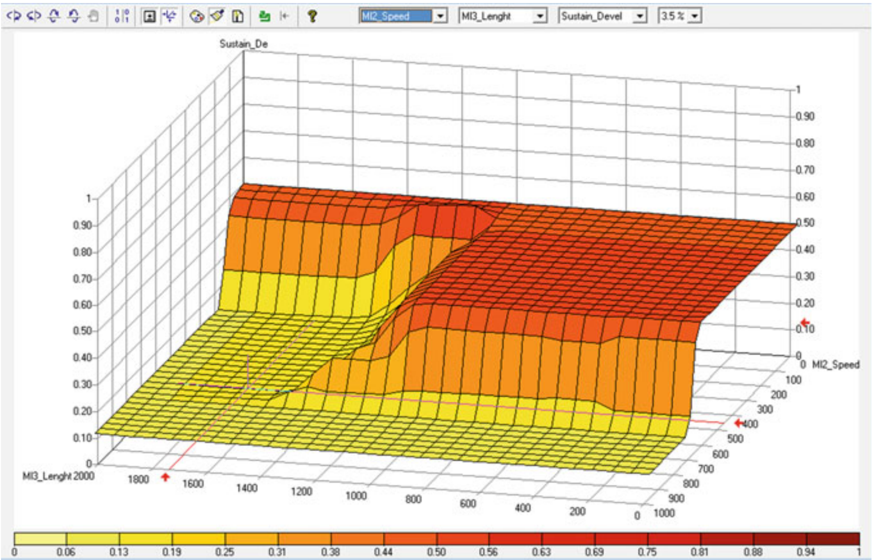


Fig. 18 Supply chain sustainability assessment results (on the example of the carriage of goods by road along the route Moscow-Yekaterinburg)

(c) Mass – Speed – Sustainability

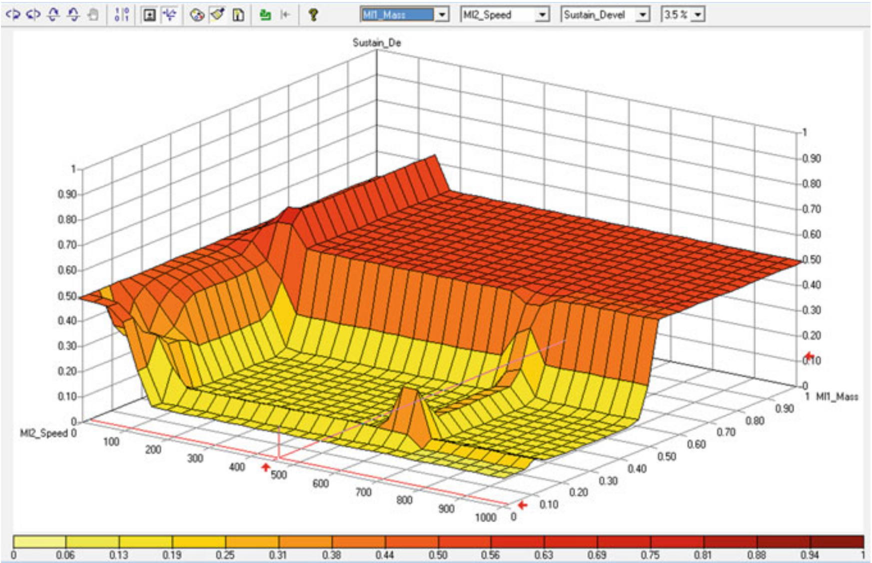


Fig. 18 (continued)

Table 30 Green supply chain flow simulation results

Fuzzy inference model variable	Actual values (I_k)	Simulation options using green logistics instrument			
		Speed optimization (I_8)	Route optimization (I_7)	Use of a vehicle with a higher carrying capacity (I_4)	The use of environmentally friendly modes of transport (I_1)
Instrument rank	–	3	5	7	9
Discrete flow rate	0.1	0.1	0.1	0.4	0.9
Flow mass, t	200	200	200	200	200
The flow rate, km/day	400	550	450	400	270
The length of the flow route, km	1850	1850	1793	1850	1764
Supply chain sustainability	0.125	0.307	0.1357	0.1391	0.4027

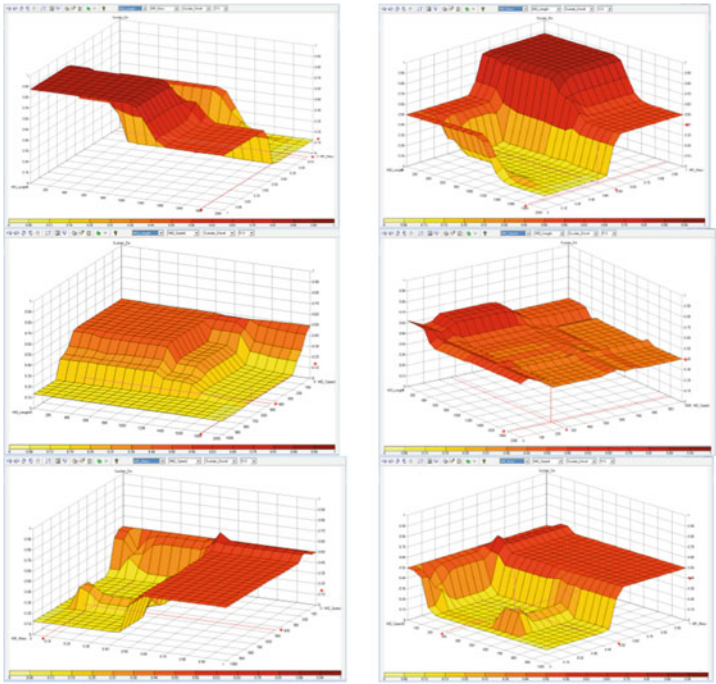


Fig. 19 Supply chain sustainability assessment results using green logistics instruments I_7 and I_1

- the formation and development of transport systems and supply chains is based on the use of the system of principles of green logistics, which is a synthesis of the principles of sustainable development with logistic principles;
- achieving and maintaining a balance between the economic, environmental and social sustainability of the transport system is ensured by the implementation of the developed system of methods and instruments of green logistics, affecting elements of the logistics system and logistics flows.

Assessment of logistic flows in green supply chains is carried out using the original system of parameters and indicators of logistic flows, which includes the following groups of indicators: economic indicators, energy and environmental indicators, quality indicators, statistical indicators. The main controlled flow parameters are: mass flow; flow rate; length of the flow route.

The proposed methodology for managing flow parameters in green supply chains includes the following main steps:

1. Identification of parameters and indicators of logistics flows. The choice of green logistics instruments and the ranking of selected instruments by the degree of

influence on the performance of logistics flows using the fuzzy AHP-TOPSIS method.
2. Building a fuzzy model of logistics flows in green supply chains using the fuzzyTECH program. The inclusion in the fuzzy model of the actual values of the parameters and indicators to assess the sustainability of the supply chain.
3. The selection and implementation of a green logistics instrument to increase the sustainability of the supply chain and bring the parameters of logistics flows in line with sustainable development goals.

Using the proposed approach to managing the parameters of logistics flows in green supply chains will improve: the quality of the assessment of the status of logistics flows according to the criterion of compliance with the goals of the concept of sustainable development; the effectiveness of decision-making on flow management in the logistics system based on the use of a system of methods and instruments of green logistics.

Further development of the developed methodology will be carried out in the following areas:

- clarification of the developed fuzzy rules and the interdependence of indicators and parameters of logistics flows based on simulation of supply chains;
- development of a method for checking the correctness of the choice of an instrument for influencing the parameters of logistic flows (green logistic instrument) and evaluating the effectiveness of its implementation;
- development of a method for teaching the model of fuzzy inference by combining it with a simulation model of supply chains;
- development of a method for choosing the optimal sequence of implementation of green logistics instruments based on forecasts of changes in parameters and indicators of logistics flows obtained using simulation of supply chains.

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