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DECARBONISATION OF WAREHOUSE PROCESSES BY LOGISTICS SERVICE PROVIDERS

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Purpose: The purpose of the research was to analyse the methods of decarbonising warehouse processes in the activities of logistics service providers and to identify the main barriers on the way to achieving the assumptions of the concept of green warehouse.
Design/methodology/approach: The article consists of two parts: literature research and empirical research using an interview questionnaire among 3PL providers. The literature research included bibliometric analysis using the Scopus database and VOSviewer software focusing on TSL industry and sustainability. The literature review outlined the main assumptions of the green warehouse concept. In empirical part of the research an interview questionnaire was employed. This approach enabled the identification of the main decarbonisation methods and the barriers associated with their implementation in warehouses.
Findings: The article outlines initiatives undertaken by 3PL providers to decarbonize warehouse processes. The measures identified primarily focus on implementing energy-efficient solutions. The research allowed to establish the barriers associated with these methods. Those barriers were categorized into three main areas: organizational, technical, and financial.
Research limitations/implications: A main limitation encountered during the research was the small number of enterprises that agreed to participate. This limitation was primarily due to the extended duration of the interviews. Future research could potentially be expanded to include a broader range of 3PL service providers.
Practical implications: The research findings exemplify practical actions for logistics service providers to implement the green warehouse concept. The decarbonization methods presented offer inspiration for other companies in the TSL sector. It should be emphasized that the surveyed entities were interested in further cooperation in identifying new areas where decarbonization tools could be implemented.
Originality/value: The article presents an analysis of the decarbonisation methods used in warehouse operations by 3PL providers and main barriers concerning achievement of green warehouse assumptions.
Keywords: logistics service provider, sustainable development, green warehouse.
Category of the paper: research paper.

1. Introduction

Due to the growing economic development, the TSL industry is becoming increasingly important. The industry is growing both from the perspective of B2C and B2B relations. However, it should be noted that the development of the logistics industry is also facing numerous challenges, of which one of the most important is currently meeting the requirements for sustainable development. This challenge results both from increasingly stringent legal requirements, but also from changes in the awareness of customers, for whom the choice of a given logistics service is no longer determined only by price and quality, but also by the level of the carbon footprint. Logistics service providers, i.e. companies that offer comprehensive logistics services, while taking over the obligations of their customers in the field of organizing the distribution process, are particularly influenced by the growing requirements of stakeholders. 3PL services are outsourced logistics solutions that handle transportation, warehousing, and distribution for businesses (Qureshi, 2022). Due to the high importance of the topic of sustainable development in scientific research (Cano et al., 2022), it is worth undertaking research on the environmental impact of 3PL. Research on the assumptions of green warehouse has been conducted by many researchers (Indrasiri et al., 2015; Malinowska et al., 2018; Xin et al., 2019; Ren et al., 2023), however, in the literature there is a lack of sufficient qualitative studies that focus directly on the methods of decarbonization of warehouse processes. Based on the identified research gap, two research questions were formulated:

- Q1 - what are the methods of decarbonizing warehouse processes in the activities of logistics service providers?
- Q2 - what are the main barriers to achieving the assumptions of the green warehouse concept in the activities of logistics service providers?

The main aim of the article is to analyse the methods of decarbonising warehouse processes and to identify the main barriers on the way to achieving the assumptions of the concept of green warehouse. To answer the research questions, literature and empirical research was conducted. The literature research included bibliometric analysis using the Scopus database and VOSviewer software, focusing on the TSL industry and sustainable development. The literature review presented the classification and importance of warehouse processes in 3PL services and the main assumptions of the green warehouse concept. The literature review also focused on the sources of carbon dioxide emissions in warehouse processes. Based on the conducted literature research, an interview questionnaire was created. In the empirical part of the research, an interview questionnaire was used, which allowed for determining decarbonization methods and barriers to their implementation in warehouse processes. The conclusions summarize the conducted research and identify their main limitations.

2. Sustainability in 3PL services

Sustainable development is a widely discussed topic in many scientific publications. It can be defined as a growth that meets present needs without compromising the ability of future generations to meet their own (Chichilnisky, 1999). In the literature, sustainable development is most often divided into three main pillars: environmental, social and organizational (Sachs et al., 2022). Each of the initiatives undertaken in the above pillars can interact with each other and has an impact on the implementation of sustainable development goals of an organization. Sustainable development in logistics activities is the subject of a growing number of studies in both domestic and foreign literature. These studies are conducted in various aspects, but mainly focus on environmental issues. These activities should focus mainly on trying to decarbonise transport and warehouse processes. To meet the requirements of stakeholders, logistics service providers often have separate departments dealing with sustainable development. Departments are directly involved in the formation and supervision of the implementation of the sustainable development strategy. Strategies should take the form of publicly available documents that clearly define the goals of the organization's sustainable development and describe how the organization intends to achieve them (Ji et al., 2023).

To learn more about the relationship between sustainable development and the logistics industry, a bibliometric analysis was conducted using the Scopus database and VOSviewer software. As part of the analysis, 6591 scientific publications in the period from 2006 to 2024were distinguished, which in their keywords had issues related to logistics and sustainable development at the same time. To increase the level of transparency of the relationship map, it was decided to include only keywords that appeared at least 70 times in the entire set. The visualization of the relationship is presented in Figure 1. The issues presented in the visualization show the most frequently discussed topics among scientific publications, but also present the methods for their analysis, among which the most used are survey questionnaires and interview questionnaires.

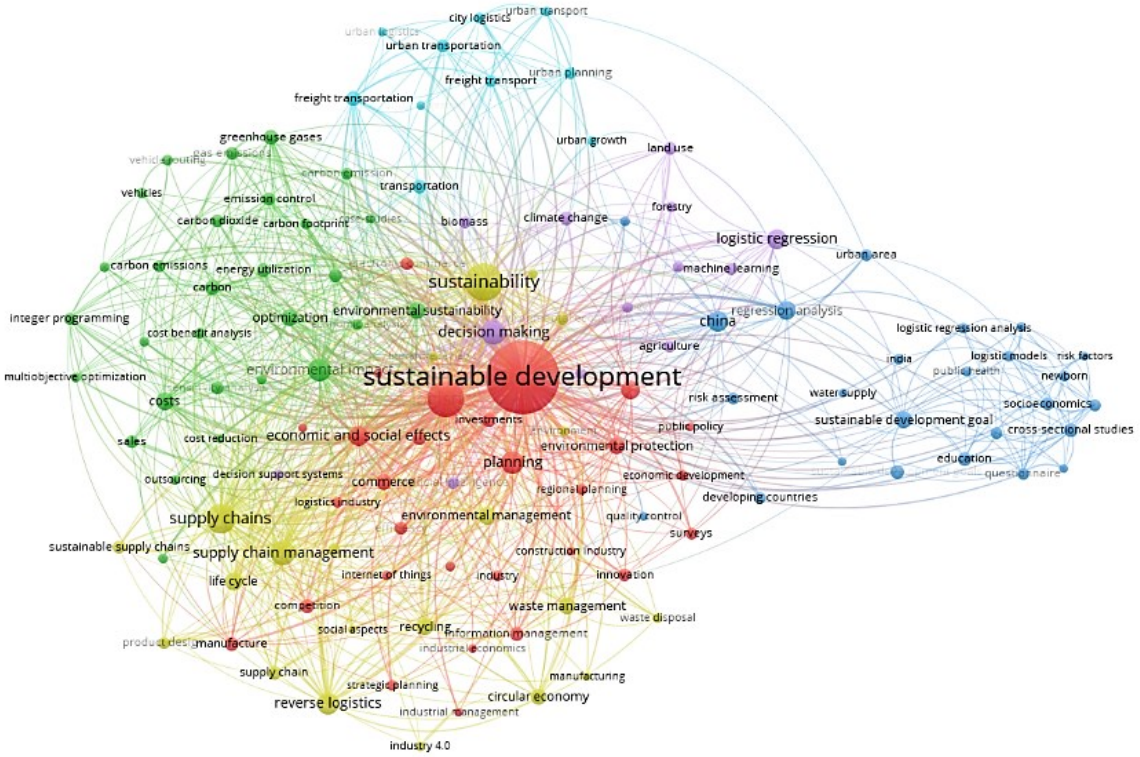

Figure 1. Connections between the main keywords based on Scopus database.

Source: own elaboration with the use of VOSviewer [access: 27.01.2025].

To properly analyse the created map, it was decided to focus on the analysis of the links between two main clusters: sustainable development and supply chains. As part of the analysis, attention should be paid to the most frequently discussed topics in scientific publications, which focus on issues related to the transport of goods and storage, as well as the use of innovations to reduce the carbon footprint in logistics processes. Publications in this aspect often raise issues related to the possibilities of using modern technologies such as the Internet of Things (IoT), but also operational activities and strategies aimed at implementing the assumptions of sustainable development. Many scientific studies are also considering methods and tools that could help decarbonise logistics processes. The issue of process decarbonisation is complex and requires an appropriate literature analysis, but in the first phase the classification of warehouse processes in the activities of a logistics service provider should be analysed.

2.1. Classification and importance of warehouse processes in 3PL services

Warehouse and transport processes and their management are the main source of services provided by 3PL providers. The warehouse can be defined as a facility for storing goods before distribution or sale (Dudziński, Kizyn, 2002). Warehouses play a major role in the functioning of companies. Among other things, they allow for minimizing the company's expenses on transport, through less frequent deliveries with a larger quantity of cargo, which will be stored in the warehouse (Grzybowska, 2010).

It is also worth noting that warehouses are places where there is a risk of various types of disruptions, which may hinder the implementation of the main warehouse functions. These disruptions may appear at different stages of the storage process and have different sources of origin. They may concern inaccurate forecasting of demand for a given stock and difficulties related to the flow of materials within the warehouse. Eliminating these disruptions is one of the challenges faced by warehouse managers (Bendkowski, 2015).

Warehouses can have different purposes and take many forms. Due to the wide range of processes taking place in a warehouse, its classification can be made according to many categories. The main one is the classification according to the purpose of the warehouse, within which it can be distinguish: industrial, distribution and reserve warehouses (Niemczyk, 2008). Warehouses are also classified according to the conditions of storing supplies. There are warehouses in which specialist conditions should be maintained, such as appropriate temperature and humidity, and warehouses for hazardous materials, which should be protected against the penetration of stored loads into the external environment, which could pose a threat to fauna and flora. Warehouses can also be divided according to the form of stored loads: cargo units, bulk materials, liquids and gases (Gubała, Popielas, 2005).

The warehouse process is defined in the literature as the systematic management of activities like receiving, storing, picking, and shipping goods to ensure efficient logistics operations (Polim, Lestari, 2023). The warehousing process begins with the receiving phase. The first aspect of this phase that must be determined is delivery planning and setting the exact time at which the supplier is to arrive with the load. The warehouse manager should determine the most appropriate time at which deliveries should be made, considering available staff resources, the number of shifts, available equipment and the specifics of the warehouse. The IT systems used in warehouses to manage the warehouse, WMS (Warehouse Management System), most often have modules designed for delivery planning (Gwynne, 2016).The storage phase is closely linked to the main function of the warehouse, which is the storage of loads. It consists of the organized arrangement of loads in the warehouse using the existing warehouse infrastructure. Warehouse workers working in the storage zone use available means of transport to transport the delivered loads to the storage zone, where they arrange them according to the adopted method (Adeodu et al., 2023).

The picking phase refers to all activities related to receiving goods from the storage location and combining them, thus creating an order. Picking activities can take place in a designated picking zone or directly in the product storage zone. During this phase, one of fixe principles of issuing is applied: FIFO (First In, First Out), LIFO (Last In, First Out), FEFO (First Expired, First Out), LOFO (Lowest In, First Out), HIFO (Highest In, First Out). The duration of the picking process depends on many factors: the arrangement of loads and the size of the order and the route the warehouse worker takes to pick the order has a great impact on the picking time. Therefore, it is very important to correctly determine the way in which the employees involved in picking move (Gwynne, 2016).

In the picking phase, two solutions can be distinguished in terms of the degree of automation: PTG and GTP. "Person-to-goods" (PTG) is the way in which the warehouse worker who picks products in the warehouse aisles moves. The person responsible for picking walks between the shelves, picking subsequent products, then goes to the main picking point where he gives the order. Another method of picking is the "goods to person" (GTP) method, which is an automatic system that allows for picking by means of a machine (Krnjaic et al., 2024).

The last phase of the storage process is the issuing phase, in which several activities related to the issuing of previously completed orders occur. At the beginning, loads intended for issuing are transported to the appropriate storage fields in the issuing zone. The next step is to organize the loads in such a way as to facilitate loading when the semi-trailer is attached to the dock. Then, an inspection is carried out, during which the quantity of loads is checked for compliance with the order. When the inspection is completed, the loads are additionally secured with foil or mat. When the semi-trailer is provided, they are loaded using available means of warehouse transport. The loads are secured in such a way that they do not move during transport to the recipient. Special tapes are often used for this purpose, which are attached to the semi-trailer and loading units. The final stage of this phase is filling in the documentation, containing data such as the date and time of collection, the number of loads issued and the data of the receiving driver and company. An important element supporting the warehousing process is the efficient flow of information. This flow should cover the supply chain of a given company, and all logistics processes should be properly integrated in it (Maryadi et al., 2024).

In the implementation of warehouse processes, the use of appropriate IT software plays an extremely important role. Researchers emphasize that ERP systems play a significant role in optimizing warehouse processes (Tonq et al., 2023). They integrate and automate key operations, improving efficiency, accuracy, and inventory management. WMS systems support the process and allow for efficient management of the flow of loads in the warehouse. WMS programs are compatible with other programs for managing processes in companies, which will enable efficient data exchange between the warehouse and other departments of the company. These systems deal with, among other things, checking the quantity of loads during deliveries and deliveries, managing available warehouse space, dividing work between warehouse workers and supervising many other warehouse activities (Minashkina, Happonen, 2023).

2.2. Decarbonisation of logistic processes

Despite the significant importance of warehouse processes in the activities of a logistics service providers, it is worth emphasizing, that those processes are the source of the carbon footprint. In the literature, the concept of carbon footprint is defined as total amount of greenhouse gases emitted directly or indirectly by an individual, organization, or activity (Wiedmann, Minx, 2008).

The carbon footprint is created in mainly due to energy consumption, fuel usage in transportation, and emissions from warehouse operations. The list of the main factors that cause the carbon footprint in the activities of a logistics service providers is presented in Table 1. This comparison focuses on two main processes performed by 3PL providers: transportation and warehousing (Wang, Cho, 2014). The factors that determine the level of CO2 emissions in transport processes are mainly focused on fuel consumption, transport distance and delivery frequency. Inefficient route planning and empty runs additionally increase these emissions. Warehouse processes contribute to emissions mainly through energy consumption for lighting, heating and cooling (Ersoy, 2018).

Table 1.
List of factors causing carbon footprint in logistics processes

Transportation	Warehousing
- Fuel consumption in vehicles	- Energy consumption for lighting and heating
- Emissions from trucks, ships, and planes	- HVAC system operations
- Type of fuel used (diesel, gasoline)	- Refrigeration for temperature-sensitive goods
- Distance travelled	- Warehouse equipment (e.g., forklifts) fuel usage
- Frequency of transportation trips	- Packaging materials used
- Empty vehicle returns	- Waste generation and disposal
- Vehicle maintenance and efficiency	- Storage system efficiency
- Traffic congestion delays	- Energy source for warehouse operations
- Poor route planning	- Frequency of inventory restocking
- Use of non-renewable energy for operations	- Transportation of goods between warehouses

Source: own elaboration based on: Wang, Cho, 2014, pp. 14-22; Ersoy, 2018, pp. 21-44.

Considering the above factors, it is worth focusing on tools and methods for reducing carbon footprint emissions. Particular attention in this area should be paid to the concept of decarbonisation, which is defined in the literature as a process aimed at reducing or eliminating carbon dioxide emissions (Jankowska, 2016). Researchers point out that this concept can be applied both in the energy policy of a given country or region, but can also refer to processes occurring in enterprises (Kotyński, 2007). The level of carbon dioxide emissions is most often expressed in tCO2e (tonne of CO2 equivalent), which is a unit measuring the global warming impact of greenhouse gases, standardized to the effect of one tonne of CO2. One of the first steps that a logistics service provider should take in this aspect is to define realistic goals that it intends to achieve in reducing emissions in its operations. However, to reduce emissions, enterprise should know direct and indirect greenhouse gas emissions. Direct greenhouse gas emissions of an organization come from sources owned or controlled by the organization. Indirect greenhouse gas emissions result from the organization's activities but occur at sources it does not own or control (La Notte et al., 2018).

Understanding the difference between Scope 1, 2, and 3 of CO2 emissions is essential for logistics service providers to accurately measure their total carbon footprint. Differentiating these scopes ensures compliance with environmental regulations and corporate sustainability reporting standards. The difference between the scopes is explained in Figure 2. Scope 1 covers direct emissions from sources owned or controlled by a company, such as fuel combustion in

company vehicles or factories. Scope 2 includes indirect emissions from purchased electricity, heat, or steam, while Scope 3 encompasses all other indirect emissions across the value chain, including supply chain activities, product use, and business travel (Bacas, Dylla, 2024).

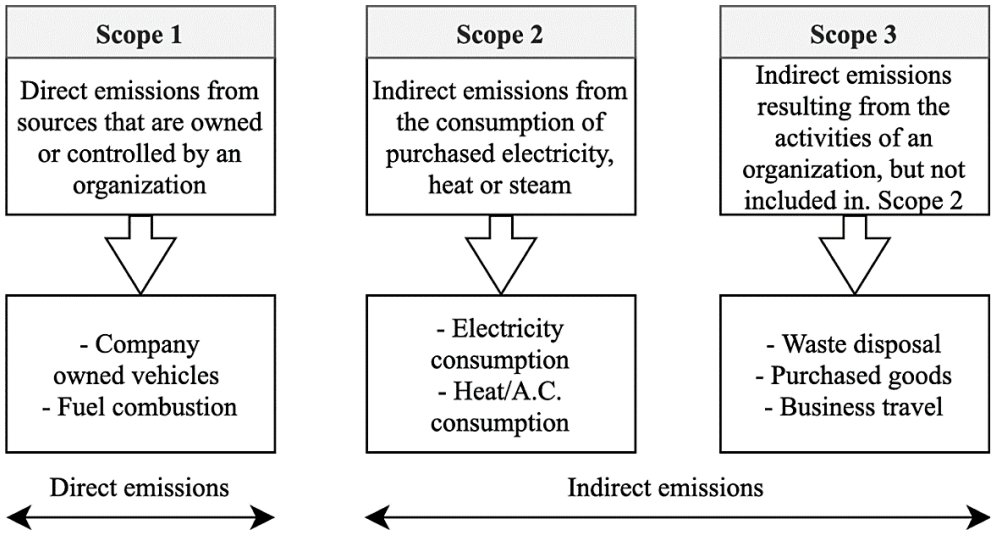

Figure 2. Scopes of carbon emissions.

Source: own elaboration based on: Feist, 2018, pp. 24-26.

In warehouse processes, Scope 1 emissions come from on-site fuel combustion. This scope is particularly relevant for gas heating systems and diesel forklifts. To reduce or eliminate Scope 1 emissions, researchers emphasize the role of switching to renewable electricity-based alternatives. Scope 2 emissions in warehouses most often result from purchased electricity used for lighting, heating, and cooling. Scope 3 emissions result from supply chain activities, including freight transport, waste disposal, and employee commuting. Implementing real-time energy monitoring can further reduce overall carbon dioxide emissions. Information about the company's emission reduction goals in each scope should be communicated to external stakeholders of the organization, so that the solution meets not only the environmental but also the social goals of sustainable development (Rüdiger et al., 2016). To reduce Scope 2 and 3 emissions in warehouse processes, some researchers emphasize the role of offsetting and carbon credits. A carbon credit is defined in this aspect as measurable, verifiable reductions in carbon dioxide emissions from certified climate projects. These projects reduce, avoid, or remove greenhouse gas (GHG) emissions. However, it should be emphasized that the use of offsetting should only take place after the reduction of Scope 1 emissions (Tan et al., 2009).

2.3. Green warehouse assumptions

One of the goals of ecologically conscious logistics service providers should be to strive to implement the assumptions of a green warehouse. A green warehouse is a relatively new concept and can be understood as a warehouse that meets environmental requirements and considers ecological solutions in operational processes (Xin et al., 2019). According to the

definition presented, the main assumptions of this concept include (Knez et al., 2010; Malinowska et al., 2018; Ren et al., 2023):

- Conducting regular environmental audits.
- Conducting employee training.
- Designing warehouse layouts to reduce unnecessary movement and fuel use.
- Encouraging paperless operations through digital documentation.
- Environmental friendly plot area.
- High level of warehouse automation.
- Implementing of modern IT systems (ERP, WMS, SCM).
- Implementing smart ventilation systems.
- Installing green roofs to improve insulation and reduce heat absorption.
- Installing of roof skylights.
- Introducing low-emission means of transport, such as electric forklifts.
- Monitoring CO2 emissions in real time to effectively reduce them.
- Optimizing warehouse insulation to reduce energy consumption.
- Using ecological packaging and recycling systems.
- Using energy-efficient LED lighting and intelligent energy management systems.
- Using motion sensors and timers to optimize lighting and energy consumption.
- Using of rainwater for irrigation.
- Using renewable energy sources, such as solar panels and heat pumps.
- Utilizing biodegradable or compostable packaging materials.

Ren et al. emphasize that to fully meet the green warehouse assumptions, external factors (architecture, space, lighting, heating) and internal factors (logistics processes, warehouse layout, inventory management) must be considered. Indrasiri et al., based on a study of 1200 warehouses, distinguished 11 factors that have the greatest impact on the implementation of the green warehouse assumptions, among which they mentioned, among others, emission reduction resulting from heating, green lighting practices, but also green practices in HR and IT, which indicates that these activities can also have a social character (Indrasiri et al., 2015). According to the cited results, the green warehouse assumptions are strongly related to decarbonisation methods. To learn about the currently implemented initiatives and barriers regarding the decarbonisation of warehouse processes in the activities of logistics service providers in Poland, it is necessary to conduct appropriate research.

3. Methods

To achieve the aim of the article, which is to analyse the methods of decarbonisation of warehouse processes in the activities of logistics service providers and to identify the main barriers to achieving the assumptions of green warehouses, it was decided to get to know the perspective of 7 3PL providers operating in the Silesian Voivodeship using interview questionnaires. The research involved enterprises that were characterised by at least European scope of providing logistics services. Their selection was made based on their position in the rankings of logistics operators in Poland and the number of environmental certificates received. The interviews were conducted both remotely and in person, and were answered by people representing the management staff. 3PL providers participating in the study wished to remain anonymous. The research was carried out from July to November 2024.The average time it took to conduct an interview using the questionnaire was 30 to 50 minutes. Based on the conducted literature research, an interview questionnaire was created. The questionnaire was divided into three main parts. The first part concerned aspects related to the type and nature of services provided by a given company and the general assumptions of the sustainable development strategy (Q.1-Q.5). This part of the research raised the question of the goals set by the 3PL providers in particular GHG scopes. The second part focused on the analysis of warehouse processes and identification of methods of their decarbonisation (Q.6-Q.12). The third part of the questionnaire aimed to get to know the main barriers to the implementation of green warehouse assumptions in the activities of logistics operators (Q.13-Q.15). The interview questionnaire is presented in the Table 2.

Table 2.
Interview Questionnaire

Id.	Interview questions:
Q.1	What range of logistics services does the company provide?
Q.2	Has the company set sustainability goals for its operations?
Q.3	Are the company's sustainability goals adequately communicated to stakeholders?
Q.4	Does the organization use green warehouse principles?
Q.5	What carbon reduction targets has your company set in each of GHG scopes?
Q.6	What energy sources are used in the warehouse?
Q.7	Does the warehouse use energy-saving technologies? If so, which ones?
Q.8	What actions is the warehouse taking to decarbonise its processes?
Q.9	Have recycling and waste reduction systems been implemented in warehouses?
Q.10	What automation technologies help reduce the carbon footprint in warehouse processes?
Q.11	Does the warehouse use eco-friendly packaging materials?
Q.12	What actions are being taken to reduce water consumption in the warehouse?
Q.13	What are the main barriers to implementing decarbonisation of warehouse processes in an organization?
Q.14	What support would be needed to facilitate the transformation towards a green warehouse concept?
Q.15	Which stakeholders should cooperation take place to achieve the objectives of a green warehouse?

Source: own elaboration.

4. Results

The results of the questionnaire surveys were used to analyze the methods of decarbonisation of the warehouse processes. The type and properties of the stored goods among 3PL providers differed, which allowed for learning different perspectives on the warehouse processes. Two of the surveyed entities specialized in storing FMCG products, while the others had a much wider range of stored stocks, including electronics and consumer products. Surveyed managers were aware of the importance of the green warehouse assumptions and had appropriately communicated strategies for sustainable development in their organisations. Surveyed 3PL providers set specific time frames for achieving their carbon reduction goals. One of the entities set a goal of achieving complete carbon neutrality in Scope 1 & 2 by 2030.

The second phase of the study focused on implemented initiatives concerning the decarbonisation of warehouse processes. All of the surveyed entities implemented solutions in this aspect to a varying extent. The solutions most often focused on reducing energy consumption. The most common solution in warehouses was the installation of energy-saving lighting and motion sensors, but companies were also increasingly installing photovoltaic panels on the roofs of warehouses. In addition to these solutions, companies implemented initiatives that were included in Chapter 2.3. The organisations emphasised that the changes introduced are not only influenced by legal regulations, but also by the growing requirements of customers in terms of the sustainability of logistics services. The third part of the research focused on identifying the main barriers to achieving the assumptions of the green warehouse concept. The answers obtained from representatives of 3PL providers in this aspect were most often very similar, and the barriers could be related to one of three categories: organizational, technical or financial, which was shown in Figure 3.

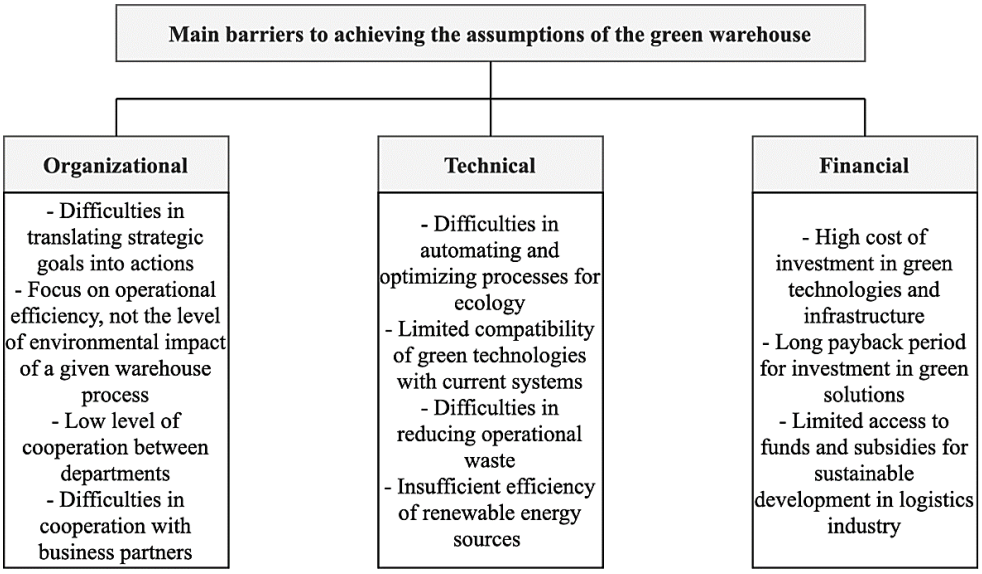

Figure 3. Main barriers to achieving the assumptions of the green warehouse.

Source: own elaboration.

5. Discussion and Conclusion

The presented results of the questionnaire surveys are the basis for formulating conclusions regarding methods of decarbonisation of warehouse processes in the activities of 3PL providers. The main limitation in conducting the research was the limited number of organisations that were willing and had time to be interviewed. Nevertheless, the answers obtained allowed to learn about the perspective of companies on the issue of decarbonisation of warehouse processes and to identify the main barriers in this area. All of the organisations surveyed were aware of the need for changes that should be undertaken in warehousing and were familiar with the green warehouse concept. Companies had set goals for reducing greenhouse gas emissions. It should be emphasised that the answers obtained from logistics operators mostly coincided with the initiatives that were identified during the literature research (Knez et al., 2010; Malinowska et al., 2018; Ren et al., 2023) in Chapter 2.3. Companies mainly try to focus on eliminating emissions in Scope 1. The most common solution in this area were energy saving activities and the use of energy-efficient lighting and motion sensors. These results are consistent with the factors identified by Indrasiri et al. in their study on a sample of 1200 warehouses (Indrasiri et al., 2015). In addition, an increasing number of entities tried to use recycled packaging in their processes. During the interview, company representatives also emphasized that not only the environmental aspect is important to them, but also the social aspect in accordance with the CSR assumptions. As part of the conducted research, the main barriers regarding the decarbonisation of warehouse processes were identified, which were divided into three main categories: organizational, technical and financial. As part of the organizational barriers, the surveyed organizations omitted factors related to the difficulty of translating strategic goals regarding emission reduction into specific actions and the difficulties in cooperation with partners in the case of Scope 3. The technical barriers of companies included difficulties in ensuring compatibility with solutions currently functioning in the company. The financial barriers of representatives of logistics operators included high costs of investment in sustainable technologies and a long payback period. As emphasized by the organization's representatives, these barriers are significant, but with the development of technology and the gradual reduction of their costs, it is possible to overcome them.

The presented research findings are highly relevant for 3PL providers. The results highlight potential activities for reducing environmental impact and serve as a foundation for further scientific exploration. The conclusions are important in the face of sustainable development of the logistics industry. The decarbonization methods presented also offer inspiration for other enterprises in the logistics sector. The study underscores the necessity of continued efforts to overcome existing challenges and implement more sustainable and efficient practices. Expanding future research to a broader range of 3PL organisations could provide a more in-depth understanding of the issue and support the industry's transition toward greener operations.

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