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GREEN WAREHOUSES – STRATEGIES TO REDUCE THE CARBON FOOTPRINT IN LOGISTICS

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Abstract: The warehouse logistics industry faces increasing challenges related to the need to reduce its negative impact on the environment, associated with greenhouse gas emissions and the implementation of sustainable development goals. Today, increasing numbers of companies are investing in environmentally friendly solutions that simultaneously reduce their environmental impact and improve operational efficiency.

This article analyses key strategies that can lead to a reduction in carbon dioxide emissions in the logistics and warehousing sector. These include: the use of renewable energy sources, the implementation of intelligent energy management systems, the optimisation of waste management, including the implementation of the 'zero waste' concept, and the use of modern insulation materials and energy-saving technologies.

The article also presents examples of the implementation of green solutions in warehouses and analyses their economic and environmental benefits. Investing in 'green technologies' allows for environmental protection, financial savings and opportunities for meeting the growing demands of consumers. This article is based on an analysis of available sources, including scientific developments and industry reports.

Keywords: green technologies, Renewable Energy Sources, environmental protection, energy saving, zero waste.

1. INTRODUCTION

At a time when the intensive development of the TSL (Transport, Shipping and Logistics) sector is becoming increasingly important, activities within this sector are increasingly focused on reducing the negative impact of warehousing on the environment. High energy consumption, greenhouse gas emissions, interference with the natural landscape and significant noise pollution mean that warehouses often form a significant source of the carbon footprint. Growing consumer expectations and constantly changing EU standards mean that companies need to

implement innovative technologies and environmentally friendly solutions. All this translates into increased energy and economic efficiency of the logistics facilities.

Logistics companies have responded to growing environmental and social pressure by increasingly turning to solutions aimed at minimising the negative impact of warehouse operations on the environment. The use of renewable energy sources, the implementation of emission reduction concepts and the optimisation of lighting processes are just some of the measures taken, including those in this area. Initiatives of this type not only reduce greenhouse gas emissions, but also have a positive impact on the competitiveness of companies in a dynamically changing market reality. Thanks to a comprehensive approach, it is possible to obtain facilities that are not only environmentally friendly, but also more cost-effective, meeting growing legislative requirements and the expectations of a changing market [Bartolini, Bottani and Grosse 2019; Mensah et al. 2020].

The purpose of this article is to analyse the key strategies for reducing the carbon footprint in warehouse logistics.

2. THE CARBON FOOTPRINT AND STRATEGIES FOR ITS REDUCTION

A carbon footprint is the total amount of greenhouse gas emissions caused directly or indirectly by a given entity. It includes the emissions of carbon dioxide, methane, nitrous oxide and other greenhouse gases, which are expressed in CO₂ equivalents. For companies, the carbon footprint includes the amount of emissions generated by all their activities, including energy consumption by their buildings and means of transport. Available analyses indicate that entities using fossil fuels emit the most CO₂. This refers to the industrial sector (mainly the mining industry), the transport sector and construction [Carbontrust 2025].

Figure 1 shows the factors causing the highest consumption in manufacturing and storage facilities.

The carbon footprint affects not only land but also global water resources. Unlike human activity, and although oceans emit significant amounts of carbon dioxide into the atmosphere, they have a negative carbon balance. This means that they absorb more CO₂ than they emit, and it is estimated that on average they remove almost 30% of the emissions generated by human activity from the atmosphere. Proper management and optimisation of energy consumption not only brings economic benefits, but also supports global trends in sustainable development. Various innovative technological solutions, introduced both on domestic and foreign markets, help to achieve various objectives. One such solution is cogeneration, also known as combined energy management. It is an effective technology that enables the simultaneous generation of electricity (or mechanical energy) and heat in a single technological process, which significantly increases energy efficiency and reduces

greenhouse gas emissions [Institute of Meteorology and Water Management 2023; Olorunfemi et al. 2023; Institute for the Development of Ecological Thought 2025].



Fig. 1. Diagram of the largest emissions sources of a single plant

Source: own study based on [Photon Energy].

Table 1 presents examples of combined heat and power systems which, when used appropriately, enable the production of both energy and heat using the same amount of fuel and other power sources.

Table 1. Table showing the composition of combined heat and power systems

Gas turbines	The heat from the exhaust gases of a gas turbine is used here. Natural gas is the most common fuel used in this system
Gas engines	Natural gas is the most common fuel burned in this type of engine
Biofuel engines	These engines use specially adapted piston gas engines or diesel engines. The choice depends on the type of biofuel. This has the advantage of reducing the consumption of hydrocarbon fuels
Gas/steam systems	A system used in combined heat and power plants

cont. Table 1

Nuclear power plants	It is possible to obtain heat in this way, but it is not used for municipal purposes due to the large distance between the power plant and the place of residence, which entails high costs
Molten carbonate or solid oxide fuel cells	These systems have very hot exhaust gases, which are therefore suitable for heating
Small-scale combined heat and power systems	These can be equipped with piston engines or Stirling engines. In these systems, heat is collected from the radiator and at the outlet. They are popular in small systems
Recovery boilers (a type of steam boiler)	Uses heat from exhaust gases or an engine to heat water and generate steam. Steam is used in industrial processes or to drive a steam turbine

Source: own study based on: [Cummins Inc. 2021; Polish Climate Congress 2025].

The most important strategic elements that can be implemented in warehouses to achieve the lowest possible environmental impact include: cogeneration, passive and low-carbon construction, optimisation of logistics processes, and reverse logistics. Cogeneration is a technology that enables the simultaneous production of electricity and heat in a single process. This makes it possible to significantly reduce energy losses and CO₂ emissions, compared to traditional energy production methods. Solutions of this type are increasingly used in modern logistics facilities, especially in facilities with high energy demand [Institute of Meteorology and Water Management 2023; Institute for the Development of Ecological Thought 2025].

In accordance with passive and low-carbon building standards, constructing warehouses including this system is one of the most effective ways of reducing the carbon footprint. Facilities of this type use modern insulation materials, windows with low heat transfer coefficients and heat recovery systems. Increasingly, modern warehouse buildings combine passive design solutions with renewable energy sources, such as photovoltaic systems and energy storage facilities. For example, the use of green roofs and façades helps to reduce the temperature inside buildings during the summer and also to improve rainwater retention [Anand, Kadiri and Putcha 2023; Polish Green Building Council 2024].

Not only do warehouse buildings themselves have an impact on the environment, but so does the rational management of the flow of goods and energy within them. This includes minimising empty runs, shortening internal transport routes and optimising the use of storage space. The implementation of modern warehouse management systems, which enable precise planning and monitoring of operations, plays a key role here. Thanks to such solutions, it is possible to reduce fossil fuel consumption and greenhouse gas emissions [Krechowicz and Krechowicz 2024].

3. THE ENVIRONMENTAL IMPACT OF WAREHOUSES

The demand for warehouse space worldwide is growing by an average of 7.2% per year. The dynamic development of the sector necessitates the implementation of new practices. The construction of new warehouses continues to grow rapidly, especially in cities and suburban areas, driven by the development of e-commerce, exports and population growth. The location of warehouses affects their size, construction time and operational efficiency, while their proximity to local markets, ports and intermodal terminals increases their importance. At the same time, warehouse development has a significant impact on the environment, including through energy consumption, emissions and waste generation, which requires the implementation of strategies to reduce the carbon footprint and the use of recyclable materials [Oloruntobi et al. 2023].

Warehouses are an integral part of logistics in the broad sense and thus have a significant impact on the environment. Warehouse operations generate greenhouse gas emissions and noise. Starting with emissions related to operation, i.e. the carbon footprint, understood as the amount of greenhouse gases manufactured by a given company, the energy consumption used throughout the entire supply chain can be taken into account. Although Poland does not carry out precise measurements of the amount of carbon dioxide produced, in 2022 the country exceeded the so-called planetary resources almost three months earlier than the rest of the world, at the beginning of May. Companies monitor their carbon footprint during deliveries using the method specified in the PN-EN 16258:2013 standard. The solution to this problem is to implement sustainable development measures in warehouses, i.e. green logistics. Green logistics means conducting business in such a way as to minimise consumption of electricity, reduce greenhouse gas emissions and save water. It is well known that pro-environmental activities involve numerous implementation costs, but there are subsidies available specifically for this purpose [Griela and Ożadowicz 2016; *Magazyn a środowisko...* 2025].

Nowadays, there are many ways to reduce your carbon footprint. For companies, this should be of key importance not only because of the desire to protect the environment, but also because of the growing demands of customers who want to buy products that are manufactured, stored and transported in an environmentally friendly way.

Figure 2 shows the basic ways of reducing the carbon footprint throughout the entire chain related to the production and transport of products to the customer, taking into account their requirements.

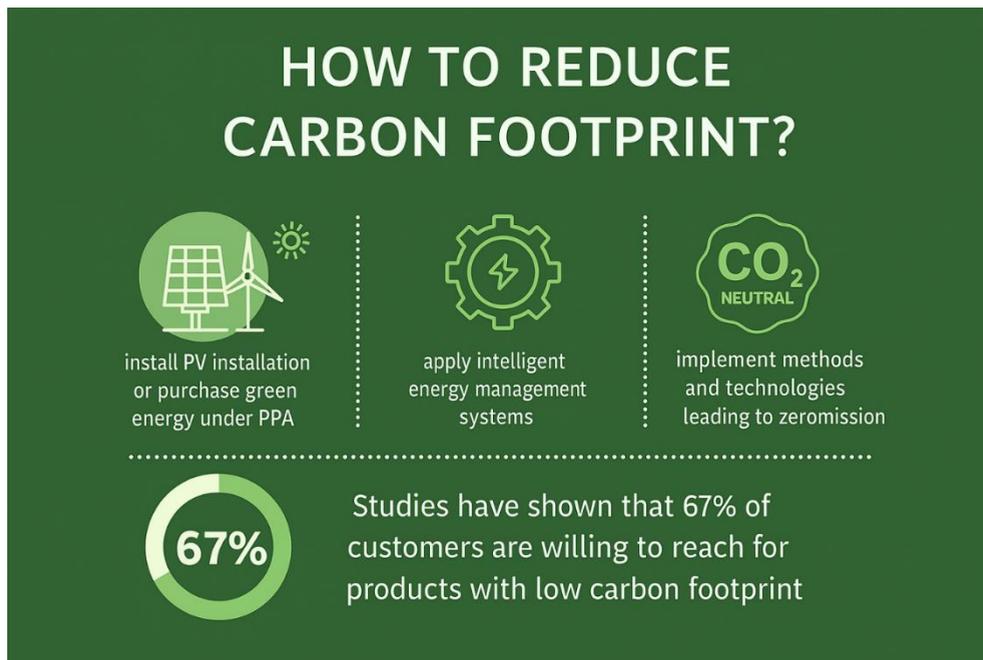


Fig. 2. Diagram showing ways to reduce the carbon footprint

Source: own study based on [Photon Energy].

Other important elements through which warehouses affect the environment are interference with the natural landscape and noise generation. Warehouses built on large areas occupy vast tracts of land, which are often obtained by converting green or agricultural areas. Such interference with the existing green landscape has a negative impact on the biodiversity of natural systems and disrupts animal migration routes. The operation of warehouses itself generates significant noise and exhaust emissions, especially during construction, operation, and cargo handling [Samborski et al. 2025].

A study published on the Nature Communications website indicates that in the immediate vicinity of e-commerce warehouses, the nitrogen dioxide (NO₂) content in the air increases by almost 20%, which in the future can result in numerous health problems, such as asthma, acute lower respiratory tract infections in children, and even diabetes affecting 1.8% of the adult population. Nitrogen dioxide itself, when present in large quantities, has a pungent odour and absorbs visible sunlight, thereby reducing air transparency and contributing to global warming [Bałamut 2024; Polish Green Building Council 2024].

4. USE OF RES

In recent years, the use of renewable energy sources has become increasingly important. This is significant not only for companies, which can save money, but also for consumers who care about making conscious choices about products that are manufactured and delivered in an environmentally friendly manner. Corporations also place increasing emphasis on this issue, with climate and environmental certifications becoming increasingly important [Edwarczyk and Stachowiak 2009]. Photovoltaic panel systems can be seen in both newly built warehouses and those that have been in operation for a long time. Although companies regularly strive to reduce their energy consumption, energy will always be needed for the proper functioning of warehouses. Photovoltaic panels are a solution for producing energy in an environmentally friendly and economical way [Magazyn a środowisko... 2025].

Photovoltaic systems operate in special configurations, and an example of such a configuration is shown in Figure 3.

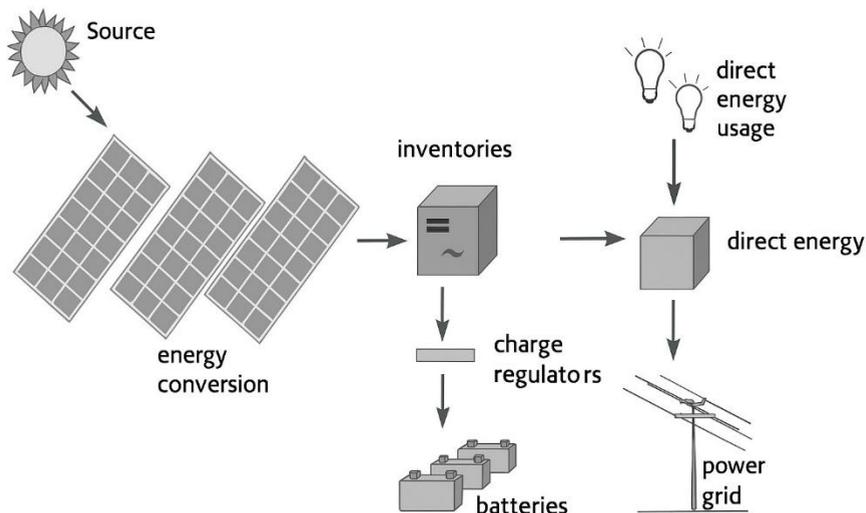


Fig. 3. Photovoltaic system operation diagram

Source: own study based on [Szpręglewska and Zięba 2013].

Currently, there are two types of photovoltaic systems [Szpręglewska and Zięba 2013]:

- Fixed – consisting of immovable collectors, positioned at an appropriate angle to the sun to capture as much sunlight as possible;

- Autonomous – equipped with small motors that allow the collectors to rotate so that the sun's rays fall on them at a right angle at all times, allowing for the maximum amount of energy to be obtained, which can then be used in storage.

Photovoltaic systems allow for a reduction in the amount of energy consumed from the grid, or even complete disconnection from it.

5. OPTIMISATION OF ENERGY CONSUMPTION

One of the most important issues affecting the environment in warehousing processes is energy consumption. Optimising its use helps to reduce the facility's maintenance costs and has a positive impact on the environment. Companies implement solutions that significantly reduce energy consumption, focusing on areas where its use does not adversely affect the efficiency of the warehousing processes. The requirements for the establishment, implementation, maintenance and improvement of energy management systems are described in the PN-EN ISO 50001:2018-09 standard [Füchtenhans et al. 2023].

One of the increasingly popular solutions are motion sensors that turn on the lighting only when they detect movement. This means that the lights in the individual sectors or rooms of the warehouse are turned on only when employees enter. The use of these sensors allows for a significant reduction in energy consumption, as the equipment only operates when it is actually needed. Warehouses that have implemented this solution have reported savings of up to 20% in kilowatt-hour consumption, and the sensors automatically switch off after a specified time since the last movement was detected [Füchtenhans et al. 2023].

A solution that allows for even greater energy savings is the Smart Lighting system. It analyses data on the presence of employees in rooms using sensors and, on this basis, decides whether to turn the lights on or off, thus offering functionality similar to traditional motion sensors. However, the system stands out for its ability to control lighting intensity, which is made possible by light intensity sensors. When there is insufficient natural light in the warehouse, the system automatically illuminates the space, and when it is sufficiently bright, it turns off the artificial lighting [Liang, Junrui and Yile 2021; Füchtenhans et al. 2023].

The use of Smart Lighting systems enables significant reductions in energy consumption. Figure 4 shows a graph illustrating how energy consumption changed after these systems were implemented in one company. It shows a clear decrease after the system was implemented, confirming its effectiveness. Before its implementation, energy consumption remained at a constant level in each month. After the system was implemented, a clear decrease can be seen, especially in the period from spring to autumn. Although consumption is still higher in winter, the systems still significantly reduce unnecessary energy losses, resulting in lower

overall consumption. This solution not only contributes to significant financial savings for the company, but also to environmental protection.

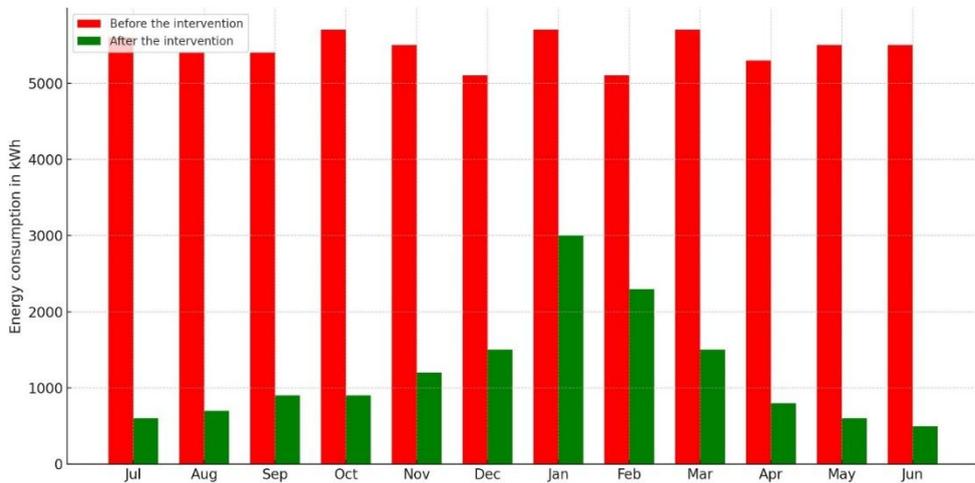


Fig. 4. Energy consumption before and after the introduction of Smart Lighting

Source: own study based on [Füchtenhans et al. 2023].

Another popular solution for optimising energy consumption is replacing traditional lighting with energy-efficient LEDs. Replacing fluorescent lamps with LEDs can save up to 60% of the energy consumed for lighting, which is why the vast majority of new warehouses are equipped exclusively with such solutions [Füchtenhans et al. 2023].

The use of photovoltaic panels also contributes to significant energy consumption optimisation. A study conducted in [Zawiasa 2024] showed that the use of a 41.78 kW photovoltaic system in a grain warehouse allows for an annual energy production of 48,847.01 kWh, which exceeds the annual energy consumption of the warehouse's ventilation system, amounting to 45,158.4 kWh. The surplus energy, amounting to 3,688.61 kWh, can be used to power other equipment in the company. These results suggest that the integration of renewable energy sources with grain warehouse air conditioning systems is an effective solution for sustainable energy management in the agricultural sector. Significant energy savings in warehouses are also possible thanks to recuperation systems, which allow the heat removed during the ventilation process to be recovered. These solutions are particularly effective in warehouses, including those with rooms that require intensive cooling. In such cases, warm air is directed to areas where the temperature needs to be raised. This system generates significant savings, as it eliminates the need for additional air heating; all that is required is to redirect the recovered heat to the places that need it [Zborowski and Koziół 2014; Zawiasa 2024].

6. SMART METERING IN REDUCING ENERGY CONSUMPTION

Smart metering systems are also used to track media consumption in real time. They allow for quick detection of energy losses, such as those caused by open docks, by monitoring current water, electricity and gas consumption. Smart metering also allows for the collection of environmental information on temperature, pressure, humidity, CO₂ concentration and light intensity. This data, its appropriate analysis and the information entered into the system regarding the method of notification or automatic responses allow for quick problem solving, which enables savings in energy consumption [Piotrowicz 2025].

Figure 5 shows a diagram illustrating how Smart Metering systems work and how information is transmitted within them.

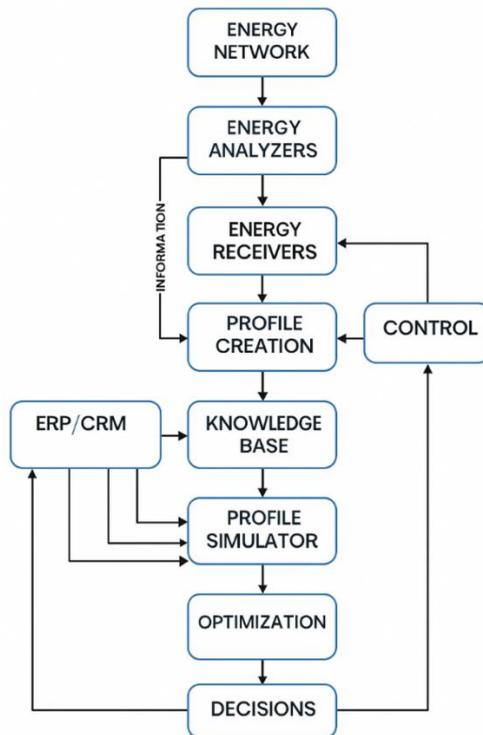


Fig. 5. Smart Metering operation diagram

Source: own study based on [Piotrowicz 2025].

In the electricity consumption monitoring and optimisation system, energy receivers are connected to meters and analysers that record data on their operation. Based on the collected information and data from control systems, energy

consumption characteristics are created for both individual devices and entire buildings. All collected data is stored in a central knowledge base. The system analyses this information, also taking into account data from external sources, such as ERP (Enterprise Resource Planning) and CRM (Customer Relationship Management) systems, the energy exchange and supplier tariff databases. This makes it possible to simulate various media consumption scenarios and assess their impact on costs. Optimisation algorithms then propose the best solutions, such as changing equipment control parameters or adjusting tariffs. The final optimisation decisions are forwarded to the appropriate control systems, which then implement them [Ożadowicz 2014].

The proper design of the warehouse is also important. Proper thermal insulation allows you to create a facility that does not overheat in summer and does not cool down in winter, which is crucial for maintaining the optimal temperature of products. The requirements for proper thermal insulation are described in the PN-B-20105:2024-04 standard. Maintaining a constant temperature or its slow change translates into energy savings, which would otherwise have to be used to heat or cool the warehouse [Edwarczyk and Stachowiak 2009].

7. CONCLUSIONS

This article presents the problem of the carbon footprint and gives examples of how to reduce it. It also describes specific strategies for reducing the impact of warehouses on the natural landscape, such as through cogeneration, renewable energy sources and the adequate thermal insulation of buildings. Although warehouses are perceived solely as infrastructures integral to logistics, they play an important role in shaping the entire TSL sector's impact on the environment. They face challenges, such as numerous pollutants, noise, consumption of natural resources and integration into the natural landscape, all of which require a fully conscious approach. It is therefore important to change public awareness towards green logistics so that it does not become a temporary trend, but an element of responsibility for the future of the planet in terms of the next generations.

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