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Green Warehouses - The Future of Sustainable Logistics

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ABSTRACT

As sustainability becomes an increasingly critical priority in logistics and supply chain management, the implementation of green warehousing practices has emerged as a key area of interest for both academic researchers and practitioners. This study aims to examine the feasibility, current level of implementation, and perceived environmental and operational benefits of green warehousing features—such as selective waste collection, energy-efficient lighting systems, the use of renewable energy sources, and green roofs—among companies operating in Győr-Moson-Sopron County, Hungary. Based on a quantitative survey conducted among a diverse sample of companies varying in size and sectoral focus, the research explores the extent to which green warehousing practices are integrated into everyday operations. Data analysis was carried out using SPSS software, applying descriptive statistics and correlation analysis to assess the relationship between company characteristics (e.g., size, ownership structure, industry) and the implementation of specific green solutions. The results indicate a growing awareness of and openness toward environmentally sustainable warehousing. However, they also reveal significant barriers to implementation, primarily related to financial limitations, technological readiness, and lack of institutional incentives. While larger firms appear more capable of adopting advanced green technologies, small and medium-sized enterprises (SMEs) face structural challenges that hinder their transition toward more sustainable warehousing models. This study contributes to the literature on green logistics by providing empirical insights into the regional dynamics of sustainable warehouse management. Furthermore, it offers practical implications for policy-makers, industry actors, and support organizations seeking to foster the wider adoption of green practices in warehousing, especially in the context of SMEs operating in regional economies.

Keywords: decision support systems, economic indicators, artificial intelligence, measuring homogeneity, data-driven economics

INTRODUCTION

The growing urgency of climate change and resource scarcity has brought sustainability to the forefront of global industrial strategies. In this context, green logistics plays a pivotal role in reducing environmental impacts and enhancing resource efficiency across the supply chain. By integrating environmentally conscious practices into procurement, production, warehousing, transportation, and waste management, green logistics supports long-term ecological and economic goals (L. Ping, 2009). Among the components of logistics systems, warehousing deserves special attention. As a central hub for material storage, handling, and distribution, warehouse operations significantly affect energy consumption, emissions, and material use. The transformation towards sustainable warehousing involves the adoption of intelligent automation, renewable energy sources, and eco-friendly construction materials and technologies (Jingzhe Zhao & Xiaolin Zhu, 2023). In parallel, government incentives, voluntary corporate initiatives, and green certification systems such as LEED and BREEAM contribute to the transition by setting environmental standards and promoting best practices (Newsham, 2009; Green et al.). Despite increasing interest in sustainability, the actual implementation of green warehousing solutions varies widely between companies and regions. While multinational corporations often have the resources to invest in complex technologies, smaller firms may struggle with financial and infrastructural constraints (Zhang Guirong et al., 2010). Therefore, it is important to explore how different green warehouse features are perceived in terms of feasibility, environmental benefit, and current implementation. This paper aims to investigate the applicability of green warehouse solutions through an empirical study conducted in Győr-Moson-Sopron County, Hungary. By combining literature-based indicators with survey data from logistics professionals, the research evaluates the degree to which specific green technologies and practices—such as energy-efficient lighting, ergonomic equipment, selective waste collection, and green roofing—can be realistically adopted in existing warehouse operations. In doing so, the study contributes to a better understanding of the relationship between organisational characteristics and the implementation of sustainable logistics solutions. The structure of the paper is as follows. Section 2 presents the literature review, highlighting the characteristics of sustainable warehousing and green technologies. Section 3 outlines the applied methodology. Section 4 presents the results, including comparative analysis, a SWOT evaluation, and statistical correlations. Section 5 discusses the findings in relation to the existing literature and practical challenges. Finally, Section 6 offers conclusions and recommendations for enhancing the adoption of green warehousing practices.

LITERATURE REVIEW

Characteristics of Sustainable Storage

The transformation of warehousing is key to sustainability. Modern warehouses use automated and digitalised systems to optimise logistics processes while reducing environmental impact. Innovative material handling technologies, such as electric forklifts and robotic storage systems, promote energy efficiency and minimise emissions (Veronika Tiupysheva et al., 2023). The integration of sustainable practices in logistics, such as incorporating green transition indicators, further underscores the importance of minimising environmental impacts in warehousing operations (Kálmán et al., 2024c). Integrating green logistics is crucial to achieving sustainable warehouses. Minimising waste, optimising energy use and using renewable energy sources will help achieve sustainability goals. This will not only reduce environmental impacts, but also lower operating costs (N. Reznik et al., 2022). Logistics centres also play a key role in sustainable warehousing. Intermodal centres, which combine several modes of transport, such as water and rail, enable more efficient movement of goods. Regional centres specialise in serving customer needs more quickly, while local centres provide direct supply chain services to domestic firms (Lin Li & Li Yanmin, 2011). The role of geoparks in sustainable development similarly highlights how strategically located centres can support regional growth while promoting sustainability goals (Kálmán et al. 2024d). The corporate logistics system can be divided into three main areas: procurement logistics, production supply logistics and sales logistics. These sub-processes are closely related to the various activities of warehousing. For example, purchasing logistics deals with the management of materials and parts inventory, while production supply is the storage of semi-finished products and work in progress. Sales logistics focuses on the distribution of finished goods (S. Wichaisri & A. Sopadang, 2013).

Sustainable storage systems are based on technologies and processes that reduce environmental impact while improving operational efficiency. Automated systems, such as electric forklifts, minimise emissions and increase energy efficiency, which is a key element in achieving sustainability in warehousing (Reznik et al). Kálmán et al.

(2024b) highlight the importance of integrating sustainability and financial inclusion, emphasizing how practices that reduce operational inefficiencies can lead to broader economic benefits. Green certification schemes, such as LEED (Leadership in Energy and Environmental Design) and BREEAM (British Research Establishment Environmental Assessment Method), are key to the design of sustainable warehouses.) LEED assesses buildings in various categories, such as energy efficiency, water use and sustainability of materials, and assigns certified, silver, gold or platinum levels (Newsham, 2009). BREEAM assesses buildings in a similar way, emphasising the integration of environmental considerations into the construction process (Green et al). Németh et al. (2024) suggest that incorporating such systems into broader frameworks of financial and environmental security can promote not only sustainability but also economic resilience. Linking corporate logistics systems and sustainable warehousing is key to reducing environmental impacts and increasing operational efficiency. The use of green logistics, automated technologies and green certification schemes can help companies meet sustainability requirements while improving business performance.

Activities in the Logistics System

Warehouse processes can be divided into two main groups: operational and planning and management processes. Both groups are integral to the efficient operation of the warehouse and the optimisation of the logistics system.

Operational processes

The operational processes can be divided into three basic functions: movement, storage and information transfer. These activities are fundamental to the day-to-day operation of a warehouse (Reznik et al., 2022).

Warehouse material movements involve a wide range of operations that can be grouped into three major categories:

- Receipt of goods: the receipt of goods involves the unloading of goods, checking the quantity and quality of incoming goods, and examining the documents accompanying the shipment (Bowersox, 2002).
- Intra-warehouse stock movement: the placement of goods in the right place in the warehouse in order to identify them and prepare them according to customer needs (Tiupysheva et al., 2023).
- Delivery: preparing goods for order and preparing them for final delivery.

The primary consideration in the design of the storage space is to maximise the space available. The characteristics of the goods, such as weight and volume, are decisive factors in choosing the right storage method. A distinction should be made between random and fixed placement, taking into account the compatibility and characteristics of the products (Mohan Kumar et al., 2015).

Planning and management processes

Warehouse management processes include the following activities:

- Master data management: this includes keeping records of suppliers, customers and stocks. These data have a major impact on the efficiency of inventory management (Novák, 2010).
- Relationship management: managing data on the warehouse's external partners, such as suppliers and freight forwarders, is essential for smooth operations.
- Monitoring stock levels: continuous monitoring of stocks ensures that supplies arrive on time and helps to avoid possible inventory shortages (Shuai, 2020).

To increase the efficiency of warehouse processes, it is crucial to coordinate operational and management activities. The use of automated systems and modern technologies not only reduces costs but also helps to achieve sustainability goals.

Mechanical warehousing equipment

Material handling systems play a vital role in corporate logistics, as they allow raw materials, semi-finished and finished products to flow efficiently within the company. The purpose of material handling is to move goods without any external modifications, thus optimizing warehousing and transportation processes (Satish, 2023). Warehouse logistics systems can generally be divided into four main types: production serving systems, warehouse material handling systems, dock material handling systems, and other systems such as bank or library material handling. Warehouse material handling systems can be divided into two main functions: material handling in storage areas and material handling in goods preparation areas (Reznik et al., 2022). Storage area systems are designed to ensure the proper storage and movement of goods within the warehouse, including picking, loading and unloading. These types of systems require different types of equipment, such as conveyor tracks, loading forklifts, conventional forklifts, rack handling machines and pusher forklifts, all of which contribute to increasing logistics efficiency (Tissayakorn & Akagi, 2014). Material handling systems in goods preparation areas mainly perform the tasks of delivery and preparation for storage of newly received goods. These machines can be, for example, conveyor belts, stacking trucks or transport trucks, which ensure the fast and safe movement of materials within the warehouse (Tiupysheva et al., 2023). The efficiency of warehousing and material handling is significantly affected by the different storage systems. Dynamic rack storage systems allow for the continuous movement and reuse of products while maximising the utilisation of storage space. Storage systems in goods preparation areas use well-structured shelving systems, while static storage systems are ideal mainly when goods are exchanged in large quantities but with slow rotation, such as in libraries or archives (Lakatos, 2018). Rack and tray storage systems are particularly suitable for storing larger unit loads that cannot be stacked, such as fragile goods or products in special packaging. Such systems are operated by stacking machines that ensure easy access and rapid movement of products (Benkő, 2013). Material handling machines come in several types, all of which contribute to the optimisation of logistics processes. Forklift trucks are the most common material handling machines in warehouses, used to move goods between different storage facilities. Cranes are heavy-duty conveyors that can move loads in both horizontal and vertical directions, while rack handling machines are systems specifically used in high-bay warehouses to move goods between racks (Frazelle, 2001).

From a sustainability perspective, green logistics solutions such as energy-efficient material handling systems and environmentally friendly storage technologies are a priority. Properly designed material handling systems not only save costs, but also help minimise environmental impacts. The use of green logistics strategies in warehouse operations contributes significantly to sustainable operations while also improving the competitiveness of companies (Chang, 2016). Waste management is a key aspect of sustainable business operations, which includes energy efficiency, emission reduction and recycling practices. These practices are not only important for environmental protection, but also contribute to increasing the financial efficiency of the company and improving customer satisfaction (Bhushan, 1992; Shanklin et al., 1991). To improve energy efficiency, companies are increasingly relying on renewable energy sources such as solar and wind power. Intelligent lighting systems such as LED technology and motion-sensing lamps can further reduce energy consumption. The use of photovoltaic systems not only reduces energy costs but also contributes to minimising greenhouse gas emissions in the long term (Noviyanti et al., 2015; Carli et al., 2020). As part of their emission reduction strategies, companies are using materials with lower GWP (Global Warming Potential) and switching to electric or hybrid technologies in transport and warehousing processes. Such measures support green logistics goals and reduce fossil fuel use (Timofei, 2022; Torres Velásquez & Pérez Pulido, 2023). The three basic elements of waste management are waste minimisation, reuse and recycling (3Rs), which are the cornerstones of sustainability. Industrial sectors such as manufacturing and catering are increasingly recycling, reducing the burden on landfills and promoting a circular economy (Shanklin et al., 1991; Dastur, 2014). Recycling organic waste, for example, allows its use as biogas for energy purposes. Companies often transform waste into raw materials or use it to generate heat and electricity, contributing to the sustainable use of resources (Braga et al., 2016; Soares et al., 2019). Innovative technologies such as RFID systems can significantly improve supply chain transparency, allowing the tracking of goods and the optimal use of resources. Such systems reduce labour costs and increase process accuracy through automation (Lipsmeier & Ghabel, 1999; Neto & Pinto, 2020)

METHODOLOGY

The empirical part of this study was based on a quantitative survey, aimed at exploring the feasibility, environmental benefits, and implementation status of green warehouse features in Győr-Moson-Sopron County, Hungary. The research design followed a non-probability, purposive sampling method, targeting logistics professionals and employees with relevant experience in warehouse operations. The study sought to identify how different green features—such as energy-efficient lighting, green roofing, ergonomic equipment, and selective waste collection—are perceived across organisations of various sizes. The questionnaire was developed based on a comprehensive review of the literature and international sustainability standards (e.g., LEED, BREEAM). It comprised two main parts:

- Demographic and organisational background, including age, gender, education, job position, company size, sector, and years of experience.
- Professional assessment, consisting of three matrix-style sections using a six-point Likert scale (1 = not at all, 6 = fully applicable) to measure:
    - the feasibility of each green warehouse feature in the respondent's organisational context,
    - the perceived environmental usefulness of each feature,
    - and the current level of implementation at the respondent's workplace.

The survey was administered online via Google Forms and disseminated through social media platforms and professional networks between 1 March and 1 May 2024. Participation was voluntary and anonymous. A total of 326 valid responses were collected, all from residents of Győr-Moson-Sopron County who were actively employed at the time of the survey.

Collected data were exported and analysed using Microsoft Excel and IBM SPSS Statistics. Basic descriptive statistics were calculated for demographic variables, while deeper inferential analyses were conducted to explore potential relationships between organisational size and attitudes toward green warehouse features.
In particular, Spearman's rank-order correlation was used to examine the strength and direction of associations between:

- the size of the employer organisation (micro, small, medium, large),
- and the feasibility, environmental usefulness, and implementation levels of individual green warehouse features.

Additional analysis included:

- percentage-based feasibility evaluations, calculated using the product of feasibility, usefulness, and implementation level for each item,
- and a comparative analysis between features considered easily adoptable versus those requiring major investment or structural change.

While the relatively high sample size allowed for meaningful statistical analysis, the findings should be interpreted with caution due to the non-representative nature of the sample and the regional focus. The self-reported nature of responses may also introduce a degree of subjectivity or bias, particularly in the perception-based questions. However, the consistency of results across multiple features and the alignment with international literature lend credibility to the overall findings.

Analysis

Comparison of Conventional and Green Warehouses

Traditional warehouses face a number of challenges, such as outdated architecture and technology, lack of energy efficiency, and poor waste management and recycling. These problems often result in a lack of space for workers and suboptimal optimisation of warehouse processes (Timofei, 2022). Lighting systems are still often based on neon tubes and air conditioning is not automated but simply by opening and closing doors. Outdated systems require constant maintenance, which increases operating costs (Braga et al., 2016). In traditional warehouses, the lack of IT systems means that inventory is often paper-based, which increases the possibility of errors such as shortages or surpluses. Lack of appropriate software can lead to inaccurate data and manual tracking of expiry dates, which requires additional resources (Shanklin et al., 1991). Energy efficiency and lack of sustainability are also common in these facilities. Automation, such as smart lighting systems and energy efficient equipment, is generally lacking, resulting in significant energy consumption (Soares et al., 2019). When designing green warehouses, it is important to consider energy efficiency, resource optimisation and the use of environmentally friendly technologies. These infrastructures are based on new technologies and software that not only help to accurately track and manage stocks, but also support sustainability goals. Energy-efficient lighting, renewable energy sources and optimised waste management are essential elements of green warehouse operations (Timofei, 2022; Carli et al., 2020). Modern warehouse software not only simplifies inventory and documentation work, but also helps optimise the storage and movement of products. Automated systems, such as RFID-based tracking solutions, minimise the possibility of errors and improve supply chain efficiency (Lipsmeier & Ghabel, 1999).

SWOT analysis in warehouse logistics

To plan warehouse processes effectively, it is essential to use a SWOT analysis to identify strengths, weaknesses, opportunities and threats. Strengths include the use of logistics expertise and effective communication, while weaknesses include the difficulty of meeting deadlines and the use of outdated software. Opportunities include the introduction of training programmes and automation technologies, while threats include the unreliability of suppliers and inappropriate management decisions (Bhushan, 1992; Timofei, 2022). One of the major advantages of traditional warehouses is the existing infrastructure, which is already established and operational, allowing for a quick start-up (Timofei, 2022). In addition, workers can follow familiar processes, which results in high efficiency in performing their routine tasks (Bhushan, 1992). Furthermore, due to the low degree of automation, decisions and problem solving are human-based, which allows for quick reactions and flexible solutions in certain situations. A major weakness of traditional warehouses is their outdated technology, which often relies on manual systems such as paper records, increasing the potential for errors (Shanklin et al., 1991). In addition, outdated lighting and heating systems result in low energy efficiency, which is not only costly but also polluting (Carli et al., 2020). Another disadvantage is that ad hoc communication methods such as phone calls and emails often slow down processes, hindering effective collaboration. Technological improvements, such as the introduction of new software and hardware, can significantly improve the efficiency of inventory and tracking (Lipsmeier & Ghabel, 1999). Training programmes for employees can contribute to the successful introduction of new technologies and to overall labour efficiency. In addition, the application of sustainability guidelines can not only bring environmental benefits, but can also lead to long-term cost savings in warehouse operations. Supplier delays are a serious risk, as a lack of timely delivery can disrupt the supply chain. The emergence of new automated warehouses is increasing competition in the market, putting pressure on traditional warehouses. Furthermore, outdated infrastructure requires regular maintenance, which becomes more costly over time, placing an additional financial burden on the business (Figure 1).

Figure 1. Traditional warehouses SWOT analysis

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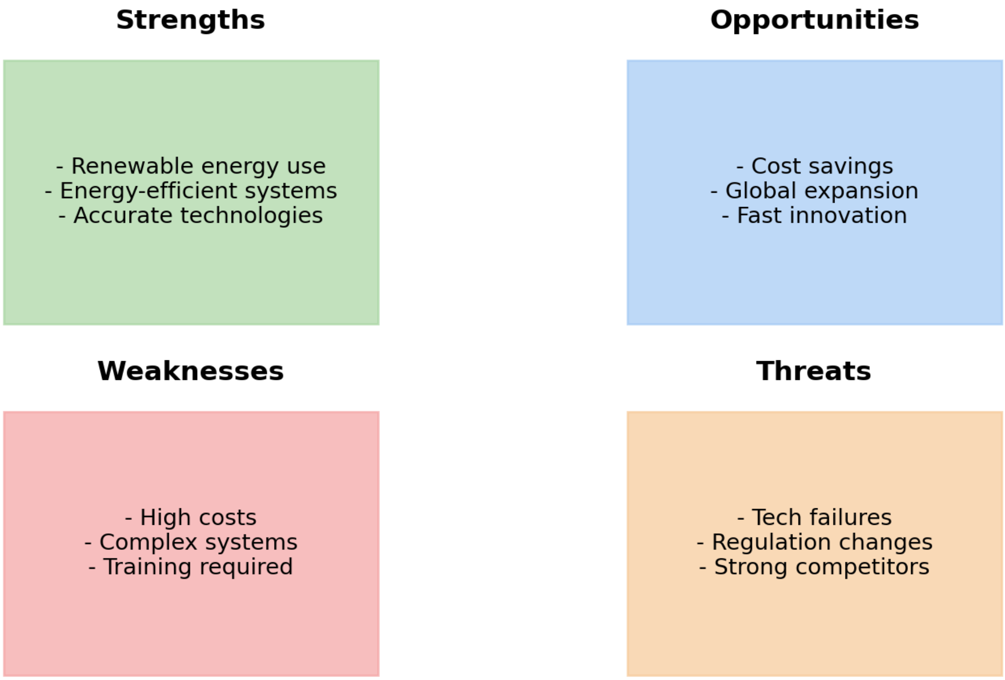
Green warehouses excel in environmental sustainability as they use renewable energy sources such as solar and wind power, which significantly reduce the ecological footprint while supporting global sustainability goals (Braga et al., 2016). Energy efficiency is also a key benefit, as automated lighting and heating systems not only reduce operating costs but also improve the quality of the working environment. Moreover, modern technologies such as RFID and other automated systems minimise the possibility of human error, increasing supply chain accuracy and efficiency (Carli et al., 2020). Green warehouses also face significant challenges. One of the biggest drawbacks is the high initial investment costs required to implement automated systems and green technologies, which can be a barrier, especially for smaller companies (Timofei, 2022). Furthermore, the technological complexity of new systems requires specialised expertise and regular maintenance, which increases the cost of operation. In addition, the need to retrain staff is also time-consuming and costly, as employees need to keep up to date with the demands of new technologies. The use of green technologies can lead to significant cost savings in the long term, as energy-efficient and sustainable solutions reduce operating costs and environmental impact. The use of sustainable solutions also increases the company's competitiveness in international markets, creating opportunities for global expansion. Furthermore, the rapid integration of innovative technologies allows further increasing plant efficiency and rapid adaptation to industry innovations. In the application of sustainable technologies, technological failures can pose a significant threat and can have a serious impact on the entire supply chain. Regulatory changes, such as rapid changes to sustainability requirements, can increase compliance costs and place a burden on companies. In addition, competitors that are quicker to adapt to new sustainability trends can gain a significant market advantage, which can reduce the competitiveness of slower responding companies (Figure 2).

Figure 2. Traditional warehouses SWOT analysis



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The SWOT analysis shows that while the advantages of traditional warehouses are based on existing infrastructure and low start-up costs, green warehouses offer long-term sustainability and efficiency. However, the high upfront costs of sustainability technologies can be a major barrier that needs to be addressed through careful planning and strategic investments.

Quantitative Research

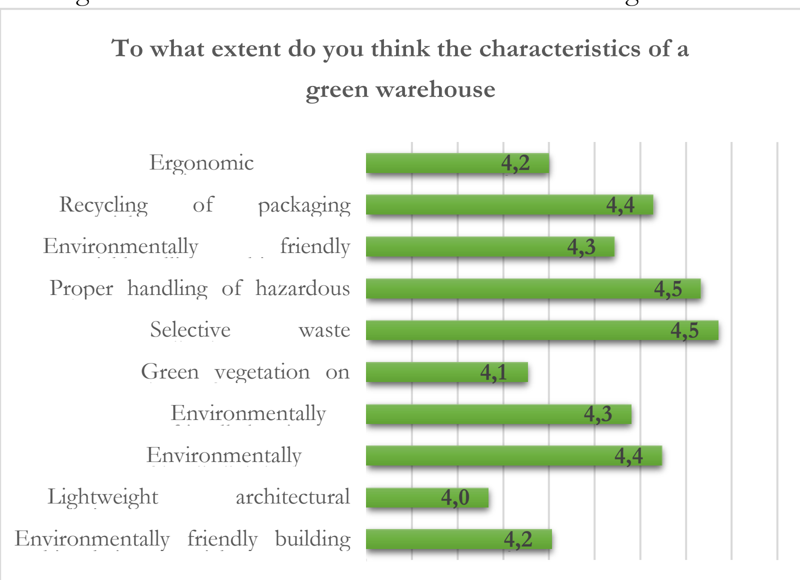
The research was conducted using a questionnaire method, which consisted of two main phases. The first part collected demographic and company data, while the second part focused on professional opinions. The demographic section aimed at obtaining basic information such as the gender, age, education and occupation of the respondents. The questions on companies looked at the size of the organisations and their areas of activity, complemented by a professional thematic block focusing on the characteristics of green warehouses.

The professional block consisted of three tabular questions, which respondents rated on a six-point Likert scale. These questions examined the extent to which green warehousing features are feasible for the employer, the extent to which they benefit the environment and the stakeholders concerned. The questionnaire was administered using Google Forms and disseminated mainly through social media, where contacts were also involved in promoting the completion of the questionnaire. Data collection took place between 1 March and 1 May 2024, during which time 326 responses were received. Respondents were selected exclusively from Győr-Moson-Sopron county residents and the sampling criteria included the existence of a residential attachment and an income-earning legal status. Although the large sample size allowed for inferential statistical analyses, it is important to stress that the sample is not representative. SPSS and Microsoft Excel were used to process the data. The graphs generated by the Google form were not used in the analyses, as the aim of the research was to perform a deeper statistical analysis. Based on the demographic data of the respondents, we found that the logistics sector is significantly dominated by men, which was also reflected in our research. The respondents included 167 men, 151 women and 4 participants classified in other categories, with a further 4 respondents who did not declare their gender. Overall, the multistage sampling procedure and the structured nature of the data collection allowed us to draw relevant conclusions about the feasibility and environmental benefits of green warehouses and the interests of stakeholders.

The average age of survey respondents is 38.8 years, with a standard deviation of 11.13 years. The youngest respondent was 18 years old and the oldest 69 years old. In terms of age distribution, the 30-39 and 40-49 age groups were the most populous, with 94 and 99 respondents respectively. Those under 20 years of age accounted for 8, those aged 20-29 for 64, those aged 50-59 for 36 and those aged 60 and over for 25. In terms of education, the respondents were dominated by secondary education, with 114 having a school-leaving certificate, 67 having a vocational qualification and only a few (8) having only a bachelor's degree. The number of tertiary educated respondents is significant, 125, of whom 71 hold a BSc/BA, 54 hold an MSc/MA, while 2 hold an academic degree. In terms of occupational distribution, the number of manual workers was 92, while the number of clerical workers was 94. The number of lower-level managers was 32, while middle managers numbered 63. The number of people in senior management positions was 10 and 31 respondents identified themselves as entrepreneurs. In terms of length of employment, most people (138) have been in their current job for less than five years. Those with 5-9 years of experience numbered 107, while those with longer experience (10-14 years: 35, 15-19 years: 25, over 20 years: 17) were less represented. The breakdown of respondents by company size was as follows: 44 respondents from micro, 66 from small, 74 from medium and 128 from large. Several (21) were unable to specify the size of their company and 3 did not wish to respond.

The industrial sector dominated in terms of area of activity with 128 employees, while the service sector employed 102 people. Agriculture and forestry accounted for 34 respondents and 62 respondents did not give a clear answer. The results of the research showed that the feasibility characteristics of green warehouses presented challenges of varying difficulty. Among the easiest elements to implement are hazardous materials management, which already meets the tightening legislation for many warehouses, and selective waste collection, which is widely used due to legal requirements. These features scored highly, indicating that their integration into existing systems can be implemented as a workable solution. Medium feasible features include environmentally friendly lighting, supported by the availability of modern technologies, although the initial purchase of equipment can be costly. The use of ergonomic equipment is hampered by space constraints, while the efficiency of green heating systems is often reduced by open windows. These features score medium, reflecting that they are feasible under certain conditions. Lower scoring features, such as the recycling of packaging materials, showed mixed results. Solutions are simpler for single-component materials, but multi-component packaging is a significant barrier to sustainable solutions. Environmentally friendly material handling machines are difficult to procure due to their high costs, making them less feasible. The most challenging features, such as green roof vegetation, lightweight construction and the use of environmentally friendly building and insulation materials, require major retrofitting of existing buildings. This process is not only costly but also complex, making these features some of the most difficult to implement. The results show that criteria scoring above 3.5 can be easily integrated into existing storage and logistics systems, while elements scoring below 3.5 are most hampered by cost, technological access and infrastructure constraints. The recommendations suggest that emphasis should be placed on further encouraging and increasing the uptake of higher scoring features. For those elements that are more difficult to implement, targeted support programmes such as public funding or tendering opportunities can help to reduce the costs of integration and promote the uptake of sustainable solutions (Figure 3).

Figure 3: How useful are the characteristics of the green warehouse in the sample.



Source: own editing

Table 1 assesses the correlations between each item and organisational size, paying particular attention to the strength and significance of the relationships. The study found that green vegetation on the roof showed the strongest relationship with organisational size, with the highest correlation coefficient (0.291). This suggests that this element is significantly correlated with organisational size. The use of lightweight construction showed a similarly strong correlation, with a correlation coefficient (0.247) also indicating a strong relationship. Moderately strong correlations include environmentally friendly building and insulation materials, with a correlation coefficient (0.221) suggesting that these elements are also moderately correlated with organisational size. Environmentally friendly material handling machinery showed a similar degree of correlation, with a value of (0.210) also indicating a medium-strength correlation. Weaker but still significant relationship items include selective waste collection (0.139) and proper handling of hazardous materials (0.138). Although these values are lower, their significance indicates that these items may also influence the association with organisational size. Environmental lighting and ergonomic equipment showed a non-significant correlation. For these items, the p-values were above the 0.05 level, so no statistically significant relationship with organisational size could be established for these items. Overall, based on the interpretation of the correlation coefficients, items with stronger correlations are more significant depending on the organisational size, as they have a greater impact on feasibility. The results of the study suggest that organisational size may play a key role in the successful implementation of certain green warehouse solutions.

Table 1. Inferential statistics

Questions		Size of employer's organisation
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.221
	Sig. (2-tailed)	0.000
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.247
	Sig. (2-tailed)	0.000
How far do you think the green warehouse features are feasible at your employer?	Correlation Coefficient	0.087
	Sig. (2-tailed)	0.127
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.192
	Sig. (2-tailed)	0.001
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.291
	Sig. (2-tailed)	0.000
How far do you think the green warehouse features are feasible at your employer?	Correlation Coefficient	0.139
	Sig. (2-tailed)	0.014
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.138
	Sig. (2-tailed)	0.015
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.210
	Sig. (2-tailed)	0.000
To what extent do you think the green warehouse features are implemented by your employer?	Correlation Coefficient	0.144
	Sig. (2-tailed)	0.011
How far do you think the green warehouse features are feasible at your employer?	Correlation Coefficient	0.099
	Sig. (2-tailed)	0.080

Source: own editing

The analysis highlighted the relationship between organisational size and the different green warehouse elements, which were evaluated using correlation coefficients (Table 2). The strongest relationship was shown by the green vegetation on the roof, which had the highest correlation value (0.291), indicating that this element is closely related to the size of the organization. Similarly, the use of lightweight construction showed a significant correlation, with a correlation value (0.247) also indicating a strong relationship. Moderate correlations can be found for the results for environmentally friendly building and insulation materials (0.221) and environmentally friendly material handling equipment (0.210). These items show moderate relationships with organisational size, suggesting that they may also be important factors in some circumstances. A weaker, but still significant, association was found for selective waste collection (0.139) and proper handling of hazardous materials (0.138). Although these relationships are less strong, they are statistically significant and affect feasibility to some extent. The results showed a non-significant correlation between green lighting and ergonomic equipment, with p-values above the 0.05 level. This suggests that these items are not strongly related to organisational size. We also assessed feasibility on a percentage basis, calculated using the average scores given by respondents. This percentage indicates the extent to which each feature is considered feasible in the current environment. Stronger correlations suggest greater importance, as these elements have a greater impact on feasibility depending on the size of the organisation. The results highlight that the implementation of green warehouse elements depends to varying degrees on organisational capabilities and available resources.

Table 2. Demographic data

Questions	No	Age	Position	Education
To what extent do you consider environmentally friendly building and insulation materials beneficial for the environment in green warehouses?	-0.021	0.005	0.272	0.108
	0.715	0.933	0.000	0.064
How environmentally beneficial do you find the use of lightweight architectural solutions in green warehouses?	-0.074	-0.074	0.196	0.123
	0.187	0.182	0.000	0.035
In your opinion. how much do eco-friendly lighting systems contribute to the environmental sustainability of a green warehouse?	-0.084	-0.038	0.287	0.155
	0.137	0.490	0.000	0.008
How effective do you think green heating systems are in reducing the environmental impact of warehouse operations?	-0.014	-0.082	0.231	0.069
	0.808	0.138	0.000	0.234
To what extent do you believe rooftop vegetation enhances the environmental performance of a green warehouse?	-0.037	-0.030	0.171	0.155
	0.514	0.585	0.002	0.008
How important do you find selective waste collection in promoting environmental responsibility within a green warehouse?	-0.021	-0.018	0.252	0.188
	0.706	0.753	0.000	0.001
How environmentally valuable do you find the proper handling of hazardous materials in warehouse operations?	0.059	0.021	0.207	0.116
	0.292	0.705	0.000	0.047
How do you evaluate the environmental benefits of using eco-friendly material handling equipment in a green warehouse setting?	-0.031	0.021	0.282	0.194
	0.586	0.709	0.000	0.001
To what degree do you consider the recycling of packaging materials as an effective environmental practice in green warehouses?	-0.057	-0.100	0.231	0.165
	0.311	0.071	0.000	0.005
How much do you think ergonomic equipment contributes to sustainability and environmental well-being in warehouse environments?	-0.049	0.098	0.227	0.226
	0.384	0.077	0.000	0.000

Source: own editing

Warehouse Percentage Characteristics

The feasibility of green warehouses is determined by a formula with three variables, taking into account the feasibility (m), the environmental benefit (h) and the degree of completion (k). Feasibility and environmental utility were assessed by a team of experts who scored the elements according to predefined criteria. The degree of preparedness, in turn, was determined by the auditors on the basis of a detailed examination of the warehouse. The evaluation process was supported by two separate tables, one for the analysis of new warehouses and the other for the analysis of converted warehouses. The percentage of feasibility for each element was calculated based on the average scores given by respondents and statistical analysis. This percentage value accurately reflects the extent to which a given feature is feasible in the current environment. In the calculation, the degree of completeness was scored on a scale of 0 to 100 percent, which provides an objective measure of the condition of the warehouse. Detailed calculations for the converted warehouses are shown in Table 3. These calculations are based on data from a real warehouse that is intended to remain incognito and give an accurate picture of the different aspects of feasibility. The results will help to identify which elements require further improvements and where faster progress can be made to achieve sustainability goals.

Table 3. Sample table for the scoring procedure.

Criteria	**m (%) feasible**	**h (%) usefulness**	**k (%) degree of alert**	**m*h**	m*h*k
Environmentally friendly builder and insulator materials	56%	68%	0%	0,38	0,00
Lightweight architectural solution	10%	45%	0%	0,05	0,00
Environmentally friendly lighting	95%	90%	20%	0,86	0,17
Environmentally friendly heating	90%	95%	40%	0,86	0,34
Green vegetation on the roof					

	75%	85%	0%	0,64	0,00
Selective waste collection	98%	78%	10%	0,76	0,08
Proper handling of hazardous substances	100%	98%	80%	0,98	0,78
Environmentally friendly material handling machines	70%	92%	40%	0,64	0,26
Recycling of packaging materials	65%	85%	90%	0,55	0,50
Ergonomic equipment	94%	87%	70%	0,82	0,57
Total				6,53	2,70

Source: own editing

DISCUSSION

The results of the research show that the feasibility of green warehouses is closely related to the size of the organisation and its technological development. The highest correlation coefficient was found for "Green vegetation on the roof", indicating a strong correlation between organizational size and implementation. This result is supported by Zhao and Zhu (2023), who argue that sustainable logistics infrastructures, such as green roofs, have a significant impact on the environmental sustainability of companies (Zhao & Zhu, 2023). Environmentally friendly lighting and heating systems also achieved high feasibility scores, which is in line with Newsham's (2009) research that emphasized the use of energy efficient lighting technologies in sustainable construction projects (Newsham, 2009). Such systems not only reduce environmental impact, but also result in cost savings in the long run. At the same time, the results highlighted the challenges of hard-to-implement elements such as environmentally friendly building materials and lightweight construction solutions. This is in line with Tiverovsky's (2023) findings that the introduction of sustainable building materials requires significant investment, which is a barrier for many companies (Tiverovsky, 2023). The results of the research also highlight the importance of waste management, such as selective waste collection, which is a cornerstone of sustainability guidelines. This is supported by a study by Braga et al. (2016), which found that waste minimisation and recycling contribute significantly to environmental sustainability (Braga et al., 2016). The results provide useful guidance to encourage the implementation of green warehouses, particularly those that are easy to implement and have high utility. Further research is needed to develop implementation strategies for hard-to-implement elements that can contribute to the wider adoption of sustainable logistics practices

The results of the research provide significant insights into the feasibility and usefulness of different features of green warehouses. The results show that the high correlation values of "Green vegetation on the roof" and "Lightweight architecture" show that these characteristics are closely related to the size and technological capabilities of companies. Similar findings were reported by Jingzhe Zhao and Xiaolin Zhu (2023), who investigated green logistics development strategies and emphasized the importance of organizational size (Zhao & Zhu, 2023). This research supports that the implementation of sustainable warehouses can be achieved through the application of technological innovations. For example, lighting systems based on LED technology can lead to significant energy savings, as highlighted by Newsham (2009) in his study (Newsham, 2009). Another important aspect is the integration of waste management and recycling, which is essential to achieve sustainability goals. According to research by Braga and colleagues (2016), the proper management and recycling of waste not only brings environmental benefits but also economic benefits (Braga et al., 2016).

The implementation of green warehouses is not only environmentally essential, but can also bring economic and social benefits. The benefits and challenges identified in this research have shown that the implementation of sustainable logistics systems requires strategic planning and targeted allocation of resources. Green warehouses, such as green roof vegetation, energy-efficient lighting systems and selective waste collection, have significant potential to reduce environmental impacts and lower operating costs. The high cost of green warehouse technologies, such as integrating renewable energy sources or purchasing environmentally friendly material handling equipment, can be a barrier for small and medium-sized enterprises. These costs are often coupled with long payback periods, making resource-constrained firms particularly vulnerable. As highlighted by Tiverovsky (2023), public support schemes or tax incentives are needed to reduce investment risks (Tiverovsky, 2023). The introduction of new technologies involves complexity, especially for firms that do not have an adequate pool of experts or experience in managing automated systems.

Constantly changing regulations, such as energy efficiency requirements and waste management standards, can create uncertainty for companies, making long-term planning difficult. Converting outdated warehouses into green warehouses can be a significant challenge, especially where the existing infrastructure does not support the integration of modern technologies. Energy-efficient solutions such as LED lighting and the use of renewable energy sources can lead to significant operational cost reductions. These solutions are not only economically sustainable, but also support environmental objectives. The implementation of sustainable warehouses enhances a company's market image and credibility, especially in industries where environmental performance is important. This is particularly true in international markets where sustainability can be a key factor in building business relationships. The introduction of green technologies can generate further innovation in warehousing and logistics processes, helping to increase efficiency and optimise the supply chain. As noted by Zhang and Mu (2010), the rapid diffusion of new technologies can contribute to the overall sustainability of the industry (Zhang & Mu, 2010). The availability of government subsidies, tax incentives and tendering resources can also facilitate the adoption of sustainable technologies by smaller companies. In addition, cooperation between companies, such as joint warehouse projects, can reduce individual costs. The results of the research suggest a number of areas for further investigation. A detailed analysis of the cost-effectiveness of green technologies is essential, especially for smaller companies. In addition, it would be important to explore strategies to transform existing warehouse infrastructures into green warehouses. Finally, the impact of measures to reduce regulatory barriers and encourage industry cooperation should also be examined in detail. In order to support the implementation of green warehouses, it is critical to create synergies between technological development and government regulations, which is a key condition for achieving sustainability goals.

CONCLUSION

This study set out to explore the feasibility, environmental utility, and current implementation of green warehouse features within the regional context of Győr-Moson-Sopron County, Hungary. By combining insights from the literature with data collected from logistics professionals, the research provided a comprehensive analysis of how sustainable warehousing solutions are perceived and adopted in practice. The results indicate that while certain green features—such as selective waste collection, hazardous material handling, and environmentally friendly lighting—are relatively easy to implement and already widely adopted, other elements like green roofing, lightweight structures, and eco-certified building materials present substantial challenges, particularly for smaller companies. The statistical analyses revealed a significant correlation between organizational size and the feasibility of implementing these more complex features, suggesting that access to financial and infrastructural resources remains a key determinant of sustainable innovation in logistics. The research contributes to the growing body of knowledge on green logistics by identifying which warehouse features offer the most realistic opportunities for transition and where support is most needed. In addition to environmental benefits, many green solutions also contribute to operational efficiency and long-term cost reduction, highlighting the potential for aligning sustainability with business performance. For practitioners, the findings offer concrete guidance for prioritizing investments in green technologies and identifying areas where external support—such as government incentives, funding schemes, or collaborative infrastructure projects—can enhance adoption. For policymakers, the study underscores the need for tailored support mechanisms that address the distinct barriers faced by small and medium-sized enterprises in the green transition. Future research should further investigate the cost-benefit ratio of individual green warehouse features, explore industry-specific implementation strategies, and examine the role of digital technologies in enabling sustainable logistics. Expanding the geographical scope of the study and conducting cross-country comparisons could also enrich our understanding of contextual factors influencing green warehouse adoption. In conclusion, green warehouses represent not only a technological innovation but a strategic imperative for sustainable logistics, bridging the gap between environmental responsibility and operational competitiveness. Their successful implementation depends on informed decision-making, targeted support, and continued collaboration between industry stakeholders, researchers, and public authorities.

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