Transitioning towards Net-Zero Warehouses: Empirical Insights and Best Practices in Italy

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In recent years, sustainable warehousing has become more and more in focus among researchers and practitioners. On the one hand, practitioners – e.g. Logistics Service Providers (LSPs), manufacturers, and retailers – have been looking for solutions to decrease the environmental impact of their logistics facilities and incorporate practices and solutions towards greener warehousing processes. Still, on the academic side, although an increasing number of papers have been found addressing logistics sustainability, empirical evidence is lacking on sustainable warehousing, i.e. how are logistics facilities transitioning towards net-zero warehouses, what are the solutions and practices in place, and what are the related effects on warehouse environmental performance over time. This contribution aims at addressing this research gap. Based on an extensive longitudinal study in Italy, the paper discusses four best practices and illustrates their roadmap towards net-zero logistics facilities. Some key messages are elaborated, and streams for future investigation are highlighted. The main novelty of the work consists in discussing real business data related to warehouse environmental performance collected over a four-year timeframe and proposing some key findings as a starting point for future developments.

CCS CONCEPTS • Green Warehousing • Best Practices • Environmental Sustainability Roadmap

Additional Keywords and Phrases: Green logistics, Sustainable warehousing, Logistics facilities, CO_2e emissions, Environmental performance

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1 INTRODUCTION

Logistics sustainability and related emission reduction have been receiving increasing attention from both the scientific and business communities ([1], [2]). Multiple factors are behind this trend. On one side, increasing pressures from a variety of stakeholders, such as investors and the entire society, are making sustainability one of the key drivers in logistics decision-making processes ([3], [4]). On the other side, more demanding regulatory pressures and growing recommendations are coming from national governments, as well as international organisations [5].

According to [6], logistics and transport activities account for 13% of the overall GHG emissions worldwide, where logistics sites represent 11%. Traditionally, warehouses have been recognised as key components within supply chains. The complexity of their operations has increased over time, due to their substantial evolution [7] from simple inventory repositories into multi-functional logistics hubs ([8], [9]). This brought along significant challenges and necessary improvements not only in terms of efficiency and service level fulfilment [10], but also concerning their environmental impact, thus entraining an increasing interest in solutions able to reduce consumption figures and, at the same time, decrease the related emissions at logistics sites. Growing investment have recently characterised the logistics real estate industry, with particular reference to green building projects and installation of utilities – such as photovoltaic panels on the rooftop – that could reduce energy consumption while mitigating the environmental performance of the building. Several certifications such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) have become more and more widespread to assess the sustainability of a building since its design phase, also in the logistics domain [3]. Moreover, digital technologies and energy-efficient systems have been progressively widespread, such as LED lighting and light sensors, lithium-ion batteries for material handling equipment, and fast chargers ([11], [12]). Greener operational practices, as well as packaging consumption monitoring and waste reduction, have also increased, and several related solutions have become common [13].

From an academic perspective, the literature dealing with sustainability at logistics sites has recently boosted ([14], [15]). Although papers that qualitatively describe green warehousing solutions are available, very few of them report empirical insights on green warehousing practices, and case studies or best practices showing the transition towards net-zero warehouses, together with the related implications in terms of environmental performance, are currently lacking. This paper aims to fill this gap. Based on an extensive longitudinal study in Italy, it discusses four best practices in the Italian panorama and illustrates their roadmap towards net-zero logistics facilities. Green practice adoption and related consumption and emission performance are examined. The main novelty of the work consists in discussing real business data related to warehouse environmental performance collected over a four-year timeframe and proposing some key findings as a starting point for future developments. From a managerial viewpoint, the work aims at offering a benchmark for practitioners willing to understand the potential of green practices to improve energy efficiency and environmental sustainability of their logistics sites.

The remainder of the paper is as follows. The next section provides an outlook of the literature review, and the methodology is then presented. Findings are discussed in Section IV. Conclusions are finally drawn and streams for future investigation are highlighted.

2 LITERATURE REVIEW

Academia has shown a mounting interest towards the topic of green warehousing. As per [15], the number of papers addressing these themes revealed a considerable evolution from 2015 onwards, also symptom of the emerging awareness of the need for transitioning towards more sustainable logistics networks and nodes. The existing literature has tackled two main streams: on the one hand, the available energy-efficient solutions and green practices that can be leveraged [16], and, on the other, the development of KPIs and frameworks in order to monitor sustainability and energy efficiency in the warehouse (e.g. [17], [3]). Specifically, looking at the first research stream on green warehousing solutions and practices, the available studies are still quite limited in number, and only few case studies have been identified. Moreover, they are mostly centred on the application of a specific solution, rather than embracing a more holistic perspective on multiple interventions at the same time, nor offering a longitudinal view of such cases. For instance, as far as green building is concerned, [18] illustrate the benefits of cool roofs in Australia and how those changes according to different climate conditions. Reference [19] focus on the best warehouse configuration, combining solutions of green and bond roof with underground building construction, to minimise energy consumption in a temperature-controlled warehouse in Iran. Another example is provided by [20] who discuss the feasibility of underground warehouses for chilled food products in the Dolomites in Italy. Other case studies have been detected on the possibility to exploit geothermal energy to reduce fuel consumption for heating purposes [21] or related to the implementation of consumption monitoring for cooling systems [22]. As far as material handling, the implementation of lithium-ion battery forklifts and related impacts on operational strategies have also been studied [23].

Overall, the literature analysis revealed that initial insights on how to develop greener warehousing facilities have started to appear. However, no studies have been found so far that perform an in-depth examination of the roadmap that companies have started to define in their warehouses to allow the transition towards net-zero buildings and related operations.

3 METHEDOLOGY

To address the above-highlighted literature gap, an extensive longitudinal study in Italy has been performed. The main source of information has been a database collecting information of logistics facilities located in Italy over a 5-year timeframe (i.e., from 2018 onwards). Such database has been developed starting from a survey-based empirical analysis performed within the Logistics Real Estate and Intralogistics Workgroup, part of the "Contract Logistics" Observatory at Politecnico di Milano, Department of Management, Economics and Industrial Engineering.

The dataset includes detailed data on 125 logistics facilities, resulting in over 3.6 million square metre total floorspace. The sample is heterogeneous in terms of building type (e.g. central warehouses, transit points, distribution centres), tenant (i.e. LSP, retailers, manufacturers), industry sector, year of construction, location and temperature of the warehouse (i.e. ambient, refrigerated – chilled or frozen – or multi-temperature). Data for such warehouses have been collected on a yearly basis with reference to warehouse features, flows, and consumption figures (electric energy, fuels, refrigerants, water, and waste), as well as green warehousing solutions and practices in place. Related emission factors (CO2e) have been also computed, according to the methodology proposed by [3].

3.1 Case selection

For the purposes of the present paper, four business cases have specifically identified, with three main criteria considered in case selection. Primarily, it was important to select companies that have demonstrated a clear roadmap ongoing towards warehousing sustainability; second, data had to be available for at least 3 years to highlight the evolution over time of their strategy; finally, case heterogeneity was taken into account, in terms of tenant (two LSPs and two retailers), warehouse temperature, warehouse size and year of construction. The features of the four business cases are presented in Table I.

Table 1: Overview of the Selected Business Cases

Case No.	Tenant	Warehouse features			
		Type of site	Year of construction	Floor space [m^2]	Temperature
C1	Retailer	Distribution centre	1980	20,000	Ambient
C2	Retailer	Central warehouse	2017	140,000	Ambient
C3	LSP	Transit point	2017	11,000	Ambient
C4	LSP	Distribution centre	2018	30,000	Multi-temperature

3.2 Data collection

The main source for data collection for the four business cases was the above-described database. Data were collected through a survey addressing companies operating in the Italian logistics industry. The unit of analysis was the warehouse. Data collection was updated every year, adjusting the questionnaire e.g., by adding new solutions and refining the questions. In some cases, interviews with company managers were also performed to integrate the data collected.

3.3 Data analysis

According to [24], the approach included a within case analysis, so that each case was analysed independently, and a cross-case analysis, in order to identify potential common patterns, synthesize the information obtained and capture novel findings that may exist in the data. Data computation (i.e., consumption and emission figures) was supported by MS Excel.

4 FINDINGS AND DISCUSSION

A summary of within-case and cross-case analyses are reported hereinafter. As far as within-case analysis, each business case included a detailed analysis of: (i) consumption figures, with specific reference to electric energy that represents the foremost source of consumption in a warehouse [17]; (ii) share (%) among consumption sources, i.e. lighting, material handling, refrigeration, and other; (iii) types of green warehousing solutions adopted over time, clustered around six main strategic areas of intervention, namely Green Building, Utilities, Lighting, Material Handling and Automation, Materials, and Operational Practices; and, finally, (iv) related implications in terms of warehouse consumption and emission figures.

4.1 Within-Case Analysis

Business case C1 refers to a retailer's distribution centre operating in the grocery industry. Built in 1980 in the north of Italy, it is an ambient-temperature warehouse with floorspace equal to 20,000 m^2 and clear building height of 8.3 m. As far as electric energy consumption breakdown, 42% is referred to lighting, 20% to material handling, 6% to cooling, and 32% to other (e.g., offices). During the period of analysis (2018-2021) several green warehousing solutions have been implemented as per Figure 1. This resulted in 26% reduction of electricity consumption in the considered timeframe, i.e. from 1,349 MWh/year to 1,000 MWh/year.

Specific attention has been paid to Lighting and Material Handling and Automation as strategic areas of intervention. Looking at Lighting, the solutions installed have progressively increased, ranging from sensors for energy consumption reduction, LED bulbs, to natural lighting and white walls. The continuous investment in solutions related to lighting resulted in a reduction of over 40% emissions related to this area in the considered timeframe. Looking at Material Handling and Automation, the introduction of a system for energy recovery while braking (i.e. regenerative braking) within the Automated Storage and Retrieval Systems (AS/RS) in 2020 and high frequency battery charging forklifts have led to a decrease of -27% emissions related to material handling with respect to 2019. Overall, emissions related to material handling and automation decreased from 88 tonCO2e in 2018 to 51 tonCO2e in 2021 (-29%).

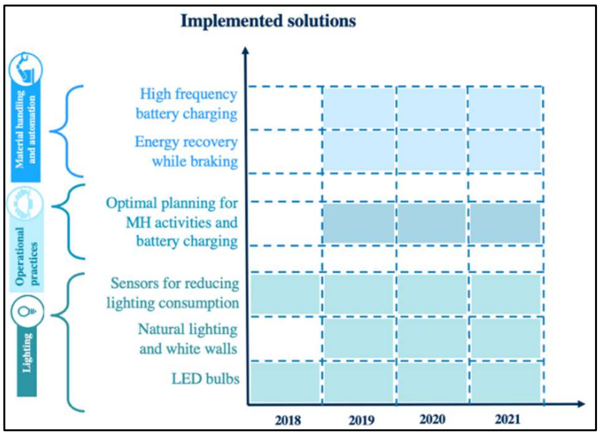

Figure 1: C1 – Solutions implemented over time

All the solutions implemented by the company have positively contributed to the environmental performance of the logistics facility, thus allowing for a significant reduction of total emissions generated, i.e. -29% in the examined timeframe (Figure 2).

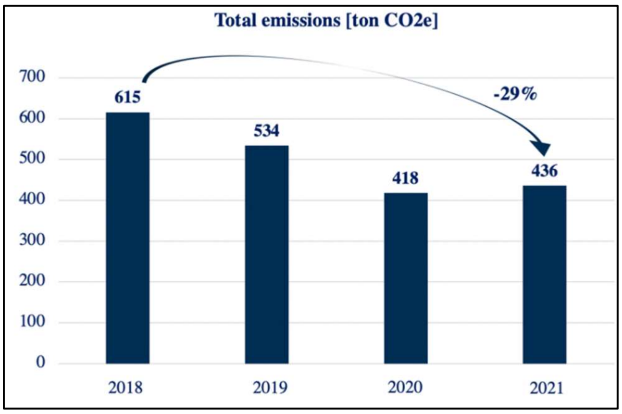

Figure 2: C1 – Total emissions over time [ton CO2e]

The second business case (C2) refers to a central warehouse located in the north of Italy. It is a large-sized site with 140,000 m^2 floorspace and 12.5 m clear building height. The warehouse is quite recent, i.e. built in 2017, and achieved the BREEAM certification (Very Good). Looking at the breakdown of electric energy consumption, 60% is referred to material handling, 20% to lighting, and 20% to other sources, and these figures seem overall aligned to the average values for ambient logistics facilities [17]. The warehouse has various solutions in place pertaining to different strategic areas of intervention. Specifically, as far as Material management is concerned, the use of renewable or biological material and packaging reduction have been adopted. This is accompanied by lithium-ion battery forklifts (Material handling and automation), sensors for energy consumption reduction, white walls and LED bulbs (Lighting), and building thermal insultation and insulated doors (Green building). Besides, advanced monitoring for energy consumption, geothermal energy, wind energy, photovoltaic systems for self-consumption (Utilities) have been also implemented. This strategy helped the company continuously reduce the emissions of the site even with an increase in energy consumption (+22%) between 2018 and 2021. This rise was due to two overlapping effects: on the one hand, an increase in the volumes handled, and, on the other, the implementation of a new highly automated material handling solution for storage and picking. As such, despite energy consumption has risen from 3.083 MWh/year to 3,752 MWh/year, total emissions have decreased over time, from 1,003.98 tonCO2e in 2018 to 969.31 tonCO2e in 2021 (-3%).

Business case C3 refers to an ambient-temperature transit point located in the north of Italy and managed by a LSP. Built in 2017, it has 11,000 m^2 floorspace and 12 m clear building hight. In 2020, the site received the BREEAM certification, (Very Good). As far as electric energy consumption breakdown, 80% is related to material handling, whereas 20% to lighting. In the examined timeframe, it is worth mentioning that green warehouse solutions (Figure 3) are mainly referred to Utilities, Material handling and automation (e.g. regenerative braking), Green building (e.g. thermal insultation) and Lighting (e.g. LED bulbs, natural light, white walls and sensors for consumption reduction).

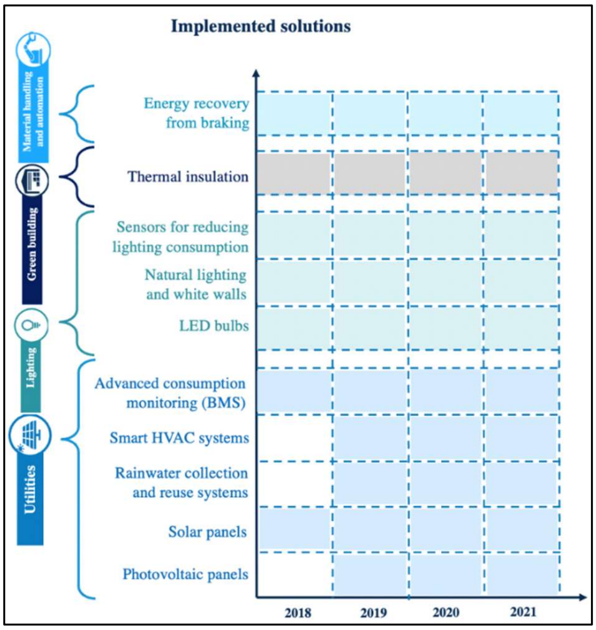

Figure 3: C3 – Solutions implemented over time

The solutions in place have helped this warehouse achieve a considerable performance in terms of emissions per square metre, i.e. 8.1 kgCO2e/m^2, being 23.9 kgCO2e/m^2 the average value of the sample, considering only those the logistics facilities with similar characteristics. Focusing on Utilities, beside solar panels and advanced monitoring consumption

(Building Management System, BMS) already present in 2018, in 2019 additional solutions have been implemented, such as smart air conditioning systems, rainwater collection systems and photovoltaic panels. Being almost stable the number and type of solutions related to other strategic areas of intervention in that year, presumably practices related to utilities can be considered as major responsible of halving emissions in 2019. As shown in Figure 4, total emissions shifted from 456 tonCO2e in 2018 to 226 tonCO2e in 2019, with a progressive reduction up to 2021 (200 tonCO2e, i.e. -56% with respect to 2018).

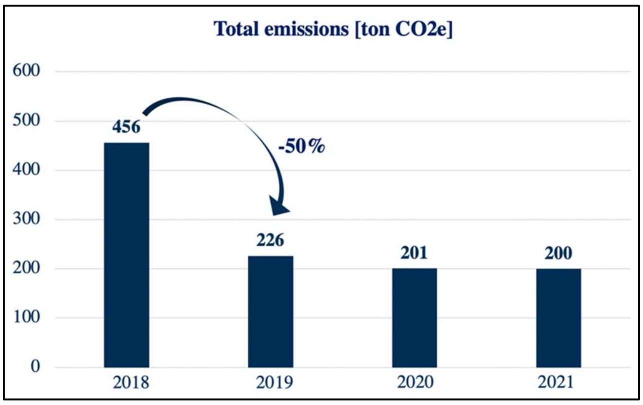

Figure 4: C3 – Total emissions over time [ton CO2e]

Business case C4 refers to a distribution centre located in the north of Italy, built in 2018 and operated by a LSP. The warehouse has 30,000 m^2 floorspace and clear building height equal to 13 m. The building received the LEED Gold certification right after construction (2019). It is a multi-temperature building. The 60% of the total floorspace is devoted to chilled goods, with a temperature range between 0°C and +18°C. The remaining 40% of the total floorspace is occupied by frozen goods, with a temperature up to -25°C. This has obviously substantial implications in terms of energy consumption: looking at the electric energy consumption breakdown, 85% is due to refrigeration, 10% to lighting and 5% to material handling.

What is particularly interesting to analyse here are the solutions implemented at the site in order to reduce the impact coming from refrigeration. In this sense, the selection of refrigerants to be used is fundamental. Here, NH3, CO2 and CH4 have been used as refrigerants. Specifically, NH3 is carbon neutral, and the other two refrigerants have also good environmental performance and low Global Warming Potential (GWP) values, with conversion factors well below the average of common refrigerants such as R134a, R404A, R407A or R507A. The low operating temperatures within the warehouse have an impact also on Material handling and automation practices. However, besides the limitations in performance that electric forklifts can have in frozen and chill areas, as far as loading and unloading areas the company has decided to adopt lithium-ion battery vehicles. Looking at Material handling and automation, hybrid forklifts, regenerative braking and high frequency battery charging have been also adopted. Those solutions, already implemented in 2018, positively contributed to the environmental performance in the considered timeframe. Indeed, -8% of emissions related to Material handling and automation has been registered between 2018 and 2020.

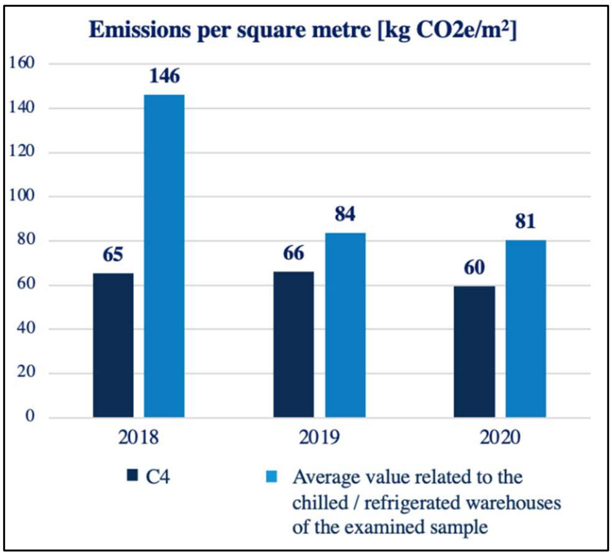

Figure 5: C4 – Emissions per square metre over time [kg CO2e/m^2]

In case of warehouses handling chilled or refrigerated goods it is also fundamental to combine solutions related to the "Utilities" areas of intervention with Green building practices, e.g. thermal insulation. This latter might help reduce energy required by HVAC systems of 6-15% [15], while improving the overall environmental performance. As far as Utilities, here smart HVAC systems, solar and photovoltaic panels were already adopted since 2018. Looking at Green building, thermal insulation, cool roof and flaps with insulated doors have been detected as the main solutions in place. Even in this case, the high number of green warehouse solutions implemented helped the warehouse achieve a good environmental performance if compared to the other logistics sites of the sample with similar characteristics. The results are displayed in Figure 5. Overall, the solutions implemented in the examined timeframe have concurred to a reduction of - 9% total emissions, shifting from 1,920 tonCO2e in 2018 to 1,750 tonCO2e in 2020.

4.2 Cross-Case Analysis

The cross-case analysis allowed us to synthesize the information obtained from the business cases and capture interesting findings. The cases have highlighted significant reductions in terms of emissions over the considered timeframe, ranging from -3% to -56% depending on the examined logistics facility and related green warehousing solutions implemented. In particular, it should be noted that the implementation of energy-efficient solutions has generally led to long-term benefits and a steady consumption reduction also in the subsequent years. Some final elements seem to emerge.

First, when transitioning towards net-zero logistics facilities companies generally adopt a multidimensional approach, with manifold solutions being implemented and multiple strategic areas impacted. In the examined timeframe, the solutions identified and implemented have increased and diversified significantly over time, covering all aspects of the warehouse (i.e. from construction techniques to the management of materials and refrigerants), thus highlighting growing logistics awareness of the need for a more sustainable behaviour. This seems in line with [25] and becomes even more important if related with the current lack of academic papers and empirical studies that embrace such a holistic approach in addressing warehouse sustainability.

Second, being sustainable does not necessarily mean new buildings from greenfield. Building from brownfield, material recovery while (re)building, and retrofitting of existing buildings seem valuable ways for achieving good environmental performance. Particularly, to obtain important emission reductions – and related cost-savings opportunities – the study revealed how retrofitting of existing buildings can bring significant benefits, not only for the most energy-intensive buildings, but also for ambient-temperature warehouses. This is in line with [18], discussing the potential of cool roof and green building solutions in retrofitting.

Third, logistics nodes need to be progressively seen also as "energy nodes", with self-production (and storage) systems, and new fuels such as hydrogen for the future. Therefore, the warehouse must be more and more flexible, given the need for managing even multiple energy sources, and achieve an active role to act as a key component of the grid [26].

Finally, a key aspect in the transition towards net-zero warehouses entails the need for developing a comprehensive view that couples strategic planning with advance monitoring systems. Indeed, the implementation of sustainable solutions at logistics sites must be designed within a structured holistic strategy and needs to be supported by the development of adequate KPIs and monitoring systems in order to promote control, intervention and improvement actions, and this seems in line with [4]. Finally, a structured action plan, in terms of which solutions to implement and when, can not only lead to the achievement of predetermined targets but also allow the company to obtain certifications (e.g. LEED, BREEAM) that can contribute to substantiate the communication of its commitment towards environmental sustainability.

5 CONCLUSIONS AND FURTHER DEVELOPMENTS

The objective of the paper was to shed light on how logistics facilities are progressively transitioning towards net-zero warehouses, what solutions and practices are in place, and what are the related effects on warehouse environmental performance over time. To this extent, based on an extensive longitudinal study in Italy, the paper discussed four best practices and illustrated their roadmap towards environmental sustainability. Detailed within-case investigation as well as cross-case discussion were offered, with interesting elements emerged from the analysis.

The main limitation of the research is related to the small number of business cases and best practices being in-depth discussed, that prevent the results from being fully generalisable. Additionally, the study focuses on a specific country, i.e., Italy, and results may differ for other countries.

Despite the above-highlighted limitations, this study opens promising streams for future investigation in the arena of sustainable logistics and warehousing. On the one hand, empirical investigation can be further developed by means of enlarging the sample from a geographical (i.e., including additional logistics facilities in Italy and on an international scale) and a temporal (i.e., longer timespan under examination) perspectives. On the other hand, as also highlighted by [17], future research is recommended on the impact assessment and evaluation of specific sustainability measures along the full life cycle of hubs, so that logistics hubs owners and operators can be given decision-making support in the selection and implementation of sustainability measures.

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