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EXECUTIVE SUMMARY OF THE THESIS

Towards net-zero warehouses: state-of-art of consumption and emission figures through an international benchmark and longitudinal analysis of best-practices among Italian logistics sites.

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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1. Introduction

Sustainability is becoming a strategic priority for companies and this evolution is driven by two main forces: top-down and bottom-up. With the first is meant the regulatory pressure and the necessity to respect standards imposed by legislators (Rogeli et al., 2016). With the second, the increasing importance that stakeholders associate to sustainability-related topics (Perotti et al., 2022). Companies need to have a clear roadmap towards sustainability, even more the ones pertaining to the Logistics sector: Logistics and transportation activities account for 5.5% of total GHG emissions. Of this percentage, 11% is due to warehouses (World Economic Forum, 2009) and this will be the focus of the Master Thesis. The choice derives come the acknowledgment of the rising importance of logistics buildings, not anymore considered as simple deposit of materials but as active node within supply chain operations. Moreover, current scientific literature pertaining to Green Logistics mostly focused on transportation and, today, very little data is available on GHG emissions from the buildings and terminals in which goods are stored, handled and transshipped (A. McKinnon, 2018). Thus, this Master Thesis aims at filling this gap: not only investigating theoretical models but providing empirical evidence of the impact that the implementation of energy-efficient solutions has on warehouses environmental performance. The scope will be first broader at first, performing an international analysis and then, a longitudinal analysis of Italian warehouses will be done.

2. Methodology

2.1. Context analysis

A context overview was fundamental to understand the environment in which this dissertation would have been inserted and the state-of-art of current research. For doing so, first secondary sources were consulted; then, a Systematic Literature Review (SLR) was done.

2.1.1. Analysis through Secondary sources

Examined secondary sources included, e.g., companies' sustainability reports and international reporting frameworks. Through them, the evolution of the logistics sector was tackled arriving to the definition of Logistics sustainability. To let the Master Thesis being up to date with current external environment, it was also addressed the topic of resilience, being now central after the shock caused by COVID-19 pandemic to supply chains and logistics. To conclude, Logistics 4.0 solutions were discussed, both at a descriptive level – explaining which are and how work the most common Logistics 4.0 implementations – and at operational level, explaining the potential environmental benefits deriving from them.

2.1.2. Systematic Literature Review

After that, the SLR was performed. This approach was chosen because it employs a predefined evaluation procedure that allows to reduce bias and ensure an objectives and scientific output (Denyer and Tranfield, 2009). As first step, it requires the formulation of precise and clearly answerable research questions. Below questions have been addressed:

RQ1: How are companies addressing energy efficiency improvements in warehousing?

RQ2: How companies are improving the resilience and the sustainability of their warehousing strategy as a consequence of recent supply chain disruptions?

RQ3: How are digital tools helping companies improving efficiency and effectiveness of their warehousing processes and, therefore, their environmental performance?

Answers have been formulated looking at scientific papers in electronic databases. The search phase involved the formulation of keywords. From 616 documents, after different screening stages, 31 publications were selected to answer the RQs. This procedure was useful to map current state-of-art about Green Warehousing and identify existing gaps to be addressed in future research. It emerged the absence of a holistic perspective while speaking about environmental sustainability: most of the papers focuses on a single energy-efficient solution or considers limited areas of impact for a technology. Additionally, are missing longitudinal studies that maps and demonstrates over years which benefits can be achieved from the implementation of sustainability strategies.

2.2. Empirical analysis

From the context analysis, objectives and directions of the Master Thesis have been set. Then, in order to clearly define scope and focus of the dissertation, two methodolofical questions were formulated.

- *Which is the state-of-the art in terms of consumption and emission figures at logistics sites in Italy? What benchmark can be performed between Italy and Germany?*
- *Which roadmap have companies undergone to transition towards net-zero warehouses?*

The answers to those two questions have been provided through an empirical analysis that represents the core of this work. Two different investigations have been performed: first, an international analysis and, then, a longitudial study within Italian bounderies. Data collection process was ease by the collaboration with the Observatory Contract Logistics "Gino Marchet" of Politecnico di Milano. Particularly, international analysis was made possible by its participation in the GILA project: a joint project research with Fraunhofer Institute and Universidad de Los Andes. The sample analysed for this Master Thesis, anyhow, comprehends only Italian and German warehouses, respectively: 127 and 66 logistic sites. This data collection process was started by the Observatory in 2017 asking companies to yearly answer the survey. Of course, thanks to technological improvements and the rising interesest on the topic, some aspects were modified or added over time. Beside the usual general information that did not change in time, the biggest portion of the survey - the section about the implementation of Green Warehousing solutions – evolved. Solutions are presented in a 6 clusters framework: *Green Building, Utilities, Lighting, Material Handling and Automation, Materials Management and Operational practices*. Within each of them the most common solutions were indicated, but companies were free to add new ones, in case. *Figure 1* shows the new solutions that this year were added to the survey, in line with recent trends.

For the German side, data have been provided by the Fraunhofer institute already anonymized. Questions asked were really similar, with very few exceptions related to Operational practices.

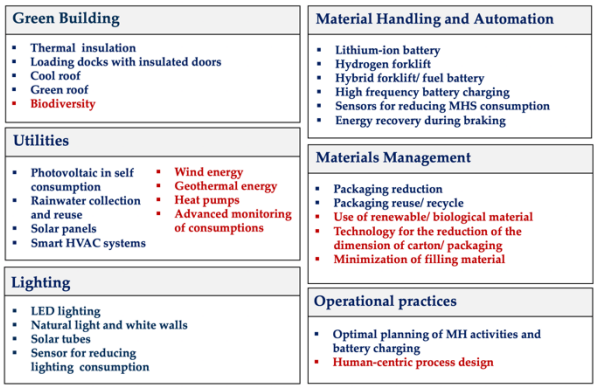

Figure 1. Survey (2021)

3. State-of-art of consumption and emission figures: international benchmark between Germany and Italy

In this section the level of adoption of energy-efficient solutions in German and Italian warehouses has been discussed, both as current adoption and prospective interest. Then, the analysis consisted in highlighting the main differences in terms of consumption and emission figures understanding how exogenous factors influence the choice of solutions to implement. Of course, all the findings will be interpreted looking at samples' characteristics. For sake of simplicity and brevity, only the most relevant findings will be reported below. What emerged is that Lighting represents a priority for companies in both countries: they require low investments but lead to important savings. Using LED bulbs, e.g., entrains energy savings up to 80% and emission reduction up to 20% (Ries et al., 2017). Immediately after Lighting, Italian respondents demonstrate interest for Utilities and Material Handling and Automation, while German towards Green Building. Similar trend in the prospective scenario.

Analyzing implementations pertaining to Utilities is useful to see how exogenous factors influence companies' sustainability strategies. In fact, due to external climate conditions, this cluster is more spread in Italy where the most applied solution is photovoltaic panels. The same does not apply for Germany: the radiation is not strong enough to make it economically sustainable and, thus, they bet on smart HVAC, solar panels and rainwater collection and reuse. In both cases, the prospective scenario confirms the interest to be energetically self-sufficient and to switch towards renewable energy sources, considering the uncertainty related to the current energy procurement situation.

After this first section about the level of adoption of energy-efficient solutions, consumption figures were tackled. The main sources of consumption analyzed were electricity, fuels, refrigerants, waste generation and packaging. Starting from the first, the average yearly electric consumption has been computed. In Italy, the value equals 1,996 MW, (46% coming from sustainable sources). German value is 1,429 MW and even in this case, 20% of respondents affirmed to buy electricity from certified renewable sources. Deepening Italy, the most energy intensive type of warehouses – with no surprises - are frozen ones, with an average electric consumption of 423 kWh/m2 versus 91,47 kWh/m2 of ambient ones. Among them, the highest share of electricity needed is due to cooling (85% of the total), as *Figure 2* shows.

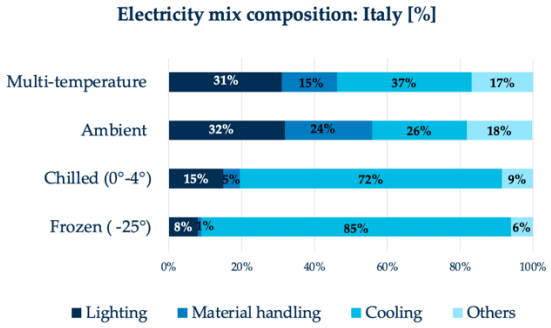

Figure 2. Electricity mix composition: Italy [%]

For what concern fuels, Italy and Germany showed similar trends: 99,9% of total requirements is met by natural gas and remaining by gasoline and LPG.

Different scenario, instead, for refrigerants: in Italy, ammonia represents the most used one with an average of 892 kg/year, while in Germany the most employed are R-717 and R448a with 616 kg/year.

To conclude, in Italy the most used packaging type is wood (58% of the total amount), while in Germany is plastic (64%). In both cases, then, the most spread waste is the one deriving from carton.

For the last section on emission figures, data were obtained through the use of Green Router software that, applying a specific characterization model (IPCC GWP100), determines companies' emissions [kg/tonCO_2eq] starting from consumption data.

For both Italy and Germany, electricity was the main source of emissions, respectively 59% of total

emissions in Italy and 56% in Germany. Then, Italian sample was characterized by a higher portion of emissions linked to refrigerants (28%), while in the German one the second position was occupied by emissions linked to fuels (43%).

To conclude the international benchmark some remarks can be done. First, the increasing attention towards sustainability topics is translated into multiple energy-efficient solutions covering various warehouses areas, from building techniques to automation systems or materials management. Secondly, those interventions are not only effective in highly energy-intensive buildings but even in ambient temperature warehouses. The latter, in fact, can have high emission values, not so far from temperature-controlled warehouses' ones.

Another important aspect is the necessity to manage simultaneously different energy carriers and to adopt risk-hedging strategies for energy procurement. Concluding, the different analysis performed on the two samples show how emission and consumption figures are strictly linked with the characteristics of the buildings. In fact, the differences identified among the solutions implemented by the warehouses of Italian and German samples, are the empirical evidence of the importance to adopt sustainability interventions fitting with exogenous variables. Warehouses characteristics (e.g., temperature level, product type, activities and level of automation), have been translated in the choice of solutions applied.

4. Longitudinal analysis of best practices among Italian logistics sites[1]

The second analysis, as said, was performed only on Italian warehouses. It is a longitudinal analysis discussing four best-practices and illustrating their roadmap towards net-zero logistics facilities.

To choose the 4 cases among all the 127 available in the database of the Observatory, three main criteria have been used. Primarily, it was important to select companies demonstrating a clear roadmap towards warehousing sustainability; second, data had to be available for at least 3 years to highlight the strategy evolution over time; finally, cases must be heterogeneous, in terms of tenant (two LSPs and two retailers), temperature, size and year of construction, as shown in *Figure 3*.

Case No.	Tenant	Warehouse features			
		Type of site	*Year of construction*	*Floor space [m²]*	*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

Figure 3. Overview of the selected business cases

According to Eisenhardt (1989) proposed investigation method, the analysis includes a within case analysis - each case analysed independently; and a cross case analysis – to identify common patterns and capture novel findings that may exist in the data.

Within-case analysis

Business case C1 is about a retailer and the analysed years go from 2018 to 2021. It was interesting to analyse how the progressive implementation of Lighting solutions (i.e., LED bulbs and white walls) resulted in a reduction of over 40% of emissions related to this area. Moreover, the introduction of a system for energy recovery while 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 and Automation with respect to 2019. Overall, all the solutions implemented by the company have positively contributed to the environmental performance, thus allowing for a significant reduction of total emissions generated: 29% decrease in 2021.

Business case C2 refers to a central warehouse and years of analysis as before 2018-2021 but, here, 2020 is missing. In 2021 the site achieved the BREEAM certification. The site has various solutions in place pertaining to different areas of intervention: Material Handling and Automation, Lighting, Green Building and Utilities. This strategy helped in continuously reduce the emissions of the site even with an increase in energy consumption (+22%) between 2018 and

[1] This chapter is based on the paper by Sara Perotti, Martina Coslovich and Elena Granata (2022), "*Transitioning towards net-zero warehouses: empirical insights and best practices in Italy*", submitted to the 12th International Conference on Industrial Technology and Management (ICITM 2023), Cambridge (UK), February 16th -18th, 2023

2021. This rise was due to two overlapping effects: an increase in the volumes handled and 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 tonCO_2e to 969.31 tonCO_2e.

Business case C3 concerns a transit point managed by a LSP and years of analysis 2018-2021. In 2020, the site received the BREEAM certification. In the examined timeframe, it is worth mentioning that Green Warehousing solutions are mainly referred to Utilities, Material Handling and Automation, Green Building and Lighting. The solutions helped in achieving a considerable performance in terms of emissions per square metre, i.e., 8.1 kgCO_2e/m^2, being 23.9 kgCO_2e/m^2 the average value of the sample, considering only those the logistics facilities with similar characteristics.

Business case C4 is about a distribution centre operated by a LSP and the years of analysis are 2018, 2019 and 2020. In 2019 The building received the LEED Gold certification. It is multi-temperature and this, clearly, has substantial implications: looking at the electric energy consumption breakdown, 85% of the total is due to refrigeration. The choice of the refrigerants is fundamental: the site, in fact, used NH3, CO2 and CH4. Specifically, NH3 is carbon neutral and the other two also have a good environmental performance with conversion factors well below the average of common refrigerants such as R134a, R404A, R407A or R507A. 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, in fact, might reduce energy required by HVAC systems of 6-15% (Ries et al., 2017). Those considerations helped the warehouse achieving a good environmental performance if compared to the other logistics sites of the sample with similar characteristics.

Cross-case analysis and conclusions

Some of the findings have already been discussed in the international benchmark; others, clearly emerged from the cases. Among the new acknowledgement is that being sustainable does not necessarily mean new buildings from greenfield: building from brownfield, material recovery while (re)building and retrofitting seem valuable ways for achieving good environmental performance. Then, the perspective over years let deduce that the implementation of energy-efficient solutions can bring long-term benefits and a steady consumption reduction also in the subsequent years. Additionally, what emerged is the need to have a structurer and strategic plan towards sustainability, covering different functional areas and a pluri-annual planning. Then, all the benefits arriving need to be monitored and measured with ad-hoc KPIs to activate, eventually, corrective actions. Finally, a structured action plan can allow the company to obtain certifications (e.g., LEED, BREEAM) demonstrating companies commitment. This Master Thesis, of course, is intended to be a starting point for further developing this kind of investigation, both enlarging the geographical scope and the temporal perspective.

5. Conclusions

Besides the conclusions previously drown, other remarks can be highlighted. Below will be reported the theoretical implications deriving from this Master Thesis, managerial implications and some limitations and future studies.

5.1. Theoretical implications

From a theoretical perspective, the goal of this Master Thesis was to provide empirical evidence validating current academic statements, rather than developing other purely theoretical research. The first important contribution is having highlighted the level of adoption of energy-efficient solutions in Italy and Germany, creating the base for further international benchmarks and development of reference values for the sector. Besides, it was created a connection between exogenous factors and the choice of solutions implemented.

The second contribution is the longitudinal analysis performed on Italian warehouses. As emerged from the SLR, there was an important gap in literature concerning the impact that the implementation of energy efficient solutions has on warehouses over time. The goal was to narrow down this gap clearly highlighting the sustainability strategy followed by companies and the consequent results obtained. The

recognition that benefits need to be monitored over time is something that was missing in previous research, even if justified by the novelty of the topic of Green Warehousing. Another missing aspect in literature was the holistic approach which considers the simultaneous implementation of Green Warehousing solutions, present in this dissertation. Academic papers tackling single implementations are not enough to set the base for the roadmap towards decarbonization of logistics.

5.2. Managerial implications

Having a more practical approach, the objective is understanding how this dissertation can help managers in their strategy definition and daily operations for achieving net-zero warehouses.

First, the results presented in terms of consumption and emission figures in Chapter 4 can be used as benchmark values. Companies could look at them for understanding how they are performing in comparison to warehouses having similar characteristics. Additionally, by looking at which are the most performing solutions, depending on the various exogenous factors, companies can avoid implementing ineffective solutions. This last point needs to be read as a cost saving opportunity: is not enough to implement energy-efficient solutions randomly, a clear strategy needs to guide all the choices. Secondly, the longitudinal analysis can constitute a model for managers in approaching sustainability strategies. The roadmap for achieving environmental improvements needs to be set over years. To conclude, a constant monitoring process through measurements and KPIs definition is needed in order to understand if the direction that has been set is right or needs to be adjusted.

5.3. Limitations and future studies

The first immediate limitation is the geographical scope: both for the benchmark and the longitudinal analysis. It could be interesting to enlarge the investigation to other countries, maybe with different climate conditions or economic maturity, examining which type of energy efficient solutions are implemented and their level of adoption. The same could be replicated for longitudinal analysis: having access to more data, it could be useful to perform a pluriannual investigation on foreign warehouses. Always focusing on the longitudinal analysis, it would be effective to enrich the data coming from the survey with interviews directly run to managers to give a clearer and more defined picture. Moreover, it would be value adding to have data availability for more than 4/5 years to have the possibility to see the evolution over time. However, it is important to have in mind that the analysis has been run under unusual conditions: logistic sector has been strongly impacted by the disruption of COVID-19. As a consequence, the authors of this Master Thesis suggest, for the future, to continue investigating those topics with the aim to collect as much data as possible from companies to counterbalance possible biased results emerged from those last years of research.

6. References

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